INTERNATIONAL ATHLETIC FOUNDATION

SCIENTIFIC REPORT ON THE II WORLD CHAMPIONSHIPS IN ATHLETICS ROME 1987

SECOND EDITION

SCIENTIFIC REPORT
ON
THE SECOND IAAF WORLD CHAMPIONSHIPS IN ATHLETICS
Rome, 1987

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Produced for the IAAF by a Scientific Project Team on behalf of the International Athletic Foundation

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NOTES ON THE SECOND EDITION

The intention of the first edition of the International Athletic Foundation Scientific Report on the II World Championships in Athletics, published in 1988, was to provide information which would assist athletes, and their coaches, to analyse performances in Rome and prepare for future competitions. All IAAF Member Federations which had finalists at the World Championships received a copy of the report plus the accompanying video. It soon became apparent, however, that this material was valuable as a general teaching tool and the extra stock of reports was quickly sold out to coaches and instructors around the world.

The decision to reprint the report was based on the numerous requests for the material by both Federations which did not originally receive a copy and other coaches. In addition, it was determined that the demand for copies of the material would increase with the staging of the International Athletic Foundation's "Techniques in Athletics Conference" in Cologne in June 1990. This international Conference was called to analyse and evaluate biomechanical research done in athletics during the 1980s, particularly that undertaken by the IAAF and sponsored by International Athletic Foundation, and to determine the needs and future directions for this type of work. Naturally, additional copies would be needed by the Conference participants.

This second edition includes a special extra section. The report, "Time Analysis of the 100m" was prepared as an article for "New Studies in Athletics" from the original material in the report on the sprints with the addition of a number of new tables and a special commentary by the 1960 Olympic bronze medallist Professor Peter Radford. Some information on the 100m events, therefore, will be repeated but it was felt that the extra tables and insights provided more than justified this.

PRESIDENT'S FORWARD

Following its principles of supporting activities in aspects of Athletics which cannot be directly funded by the IAAF, the International Athletic Foundation is proud to present this Scientific Report on the the II World Championships in Athletics. This report is part of a Scientific Project which was carried out by an international team of experts during the Championships in Rome.

The Foundation recognises that, while the increase and distribution of scientific and technical information are necessary for the development of Athletics, top level research is beyond the financial capabilities of most countries. By carrying out a programme of scientific research and sharing it with as many IAAF Member Federations as possible, the Foundation is demonstrating the seriousness of its commitment to support the development of Athletics in all its aspects.

I sincerely hope that this report will receive the widest possible distribution and that coaches and athletes will find it useful for improvement of their teaching and their performance.

Dr Primo Nebiolo
President
International Athletic Foundation

INTRODUCTION

What coach or aspiring athlete would not profit by being present at a major athletics meeting such as the II World Championships in Athletics, held in Rome in 1987? The chance to observe the world's finest athletes in action and learn from their technique would surely be an invaluable aid to improving performance and the development of new champions.

Though much can be learned simply by being present and watching the events at such a meeting, an increase in practical knowledge is not automatic. The nature of a championship meeting including the numbers of athletes, the speed at which complex movements take place, the drama and emotion which accompany the competition as well as the distance that spectators are located from the action can make detailed and useful observations difficult. A systematic approach and "knowing what to look for" are essential in order to get maximum benefit from such an experience.

Even then, observers may only have an impression of what they have witnessed. Did the winning long jumper have a faster run-up than the second placer or did it just seem that way? What were the differences in the angles of release for the javelin throwers? Which of the hurdlers actually had the best clearance of the barriers? On these types of question even the trained eye can only make guesses, with no practical way of confirming the answers.

The function of the International Athletic Foundation Scientific Project was to be at the World Championships for the coach and athlete who could not be there and to show them not only what they would have witnessed, but also things they could not have seen. By using video and film to repeat and slow the action down, by performing complex analyses with computers and by confirming or dispelling impressions through precise measurements, the information gained from the Championships is the most accurate possible which is vital for improving performance.

Improvement of perfomance is a basic, and quite natural, demand in competitive sport. It does however present a challenge, one which some coaches and athletes have been tempted to meet through means that are, in fact, damaging to young sportsmen and women i.e. the misuse of drugs. The I. A. F. has instituted a number of measures designed to combat this problem directly. In addition, the I.A.F. has supported this and other projects as ways of harnessing the power of science to give alternative means for the improvement of performance, means which are natural and correct.

The technical equipment required for this type of project, such as high speed and video cameras, photocells, film editing and analysis equipment and computers with advanced software programs, would be beyond the financial reach of all but a very small handful of countries. Likewise, the highly qualified technical and organisational staff required represent an enormous cost. Only an international body, such as the I. A. F. is in a position to undertake such a project and make the results available to athletes and coaches in all countries. In addition, as no single labratory, or country even, has the human resources and potential to use the all latest knowledge and equipment for such a large undertaking, this project was a joint international effort, involving a team of scientists, technicians and support staff representing six countries.

The project included a "Fast Information" and Video Service available to all athletes and coaches in the Athletes Village during the Championships. Camera operators and other technicians filmed and collected readings during each day's events. A second group, working through the night, edited the video material and produced the "Fast Information" data for presentation the next morning. Positive comments were received from coaches and athletes from a large number of countries and most expressed the hope that this valuable service would become a standard feature at all future championships.

All the material gathered at Rome was taken back to labratories in Czechoslovakia and F. R. Germany where it was further analysed in conjunction with the high speed film that was shot. This report and the accompanying video are the results of this work. Because of the international nature of the project team, as well as the different nature of the events covered, the reader will notice some differences in style and approach between the chapters in this report. Each chapter, however, is designed to stand on its own as a record of the event it covers, giving complete information on the finalists. The chapters have been divided into event groups and there is an Appendix which includes information from many of the events on athletes who did not make the final.

The ultimate aim of this project was to provide a record and analysis of the II World Championships in Athletics for use by coaches and athletes, without discrimination, in all IAAF Member countries. This information was to be presented in a readily understandable form, without any unnecessary scientific formulae or jargon, so that it could be applied immediately to practice. In other words, the project is an attempt to increase the channels of communication between scientists and coaches, in order to improve the performance of athletes. Communication, however, requires a flow of information in both directions. The International Athletic Foundation is sincerely interested both in comments regarding this report and video as well as suggestions to improve any future projects from coaches and athletes. These comments should be addressed to the The Scientific Project Coordinator c/o IAAF Bureau, 3 Hans Crescent, Knightsbridge, London SW1X OLN, England.

Scientific Project Team
Scientific Report - II World Championships in Athletics, 1987

A

TIME ANALYSIS OF THE 100m

Moravec, P.; Růžička, J.; Dostál, E.; Sušanka, P.;
Kodejš, M.; Nosek, M.; Glad, W; Radford, P.

1. Introduction

The improving performance trends in the 100 Metres events, as shown in the graphs in Fig. 1-2, are to some extent the result of improvements in training methods, starting and running techniques and track surfaces. The curve of the best performances in any year will be extremely uneven as it can be markedly influenced by exceptional performances or athletes. A more telling indication of the changes in world performance levels is a curve of the mean best performances of the world's best athletes in a given event. In the graphs, the solid line shows the course of each year's top performance for the period 1960-1987 while the other two lines indicate the course of the mean of the maximum performances of the top three and top ten athletes respectively. Fully automatic electronic timing was introduced for record purposes in 1972 and that point is indicated in the graphs by a vertical line.

The finals of the 100 Metres events were among the most eagerly awaited at the II World Championships in Athletics in Rome as the match-ups, including the Men's 100 Metres, where 1986 World Number 1 Ben Johnson (CAN) would meet defending World and Olympic Champion Carl Lewis (USA), promised excellent competitive races. Although fast times and even

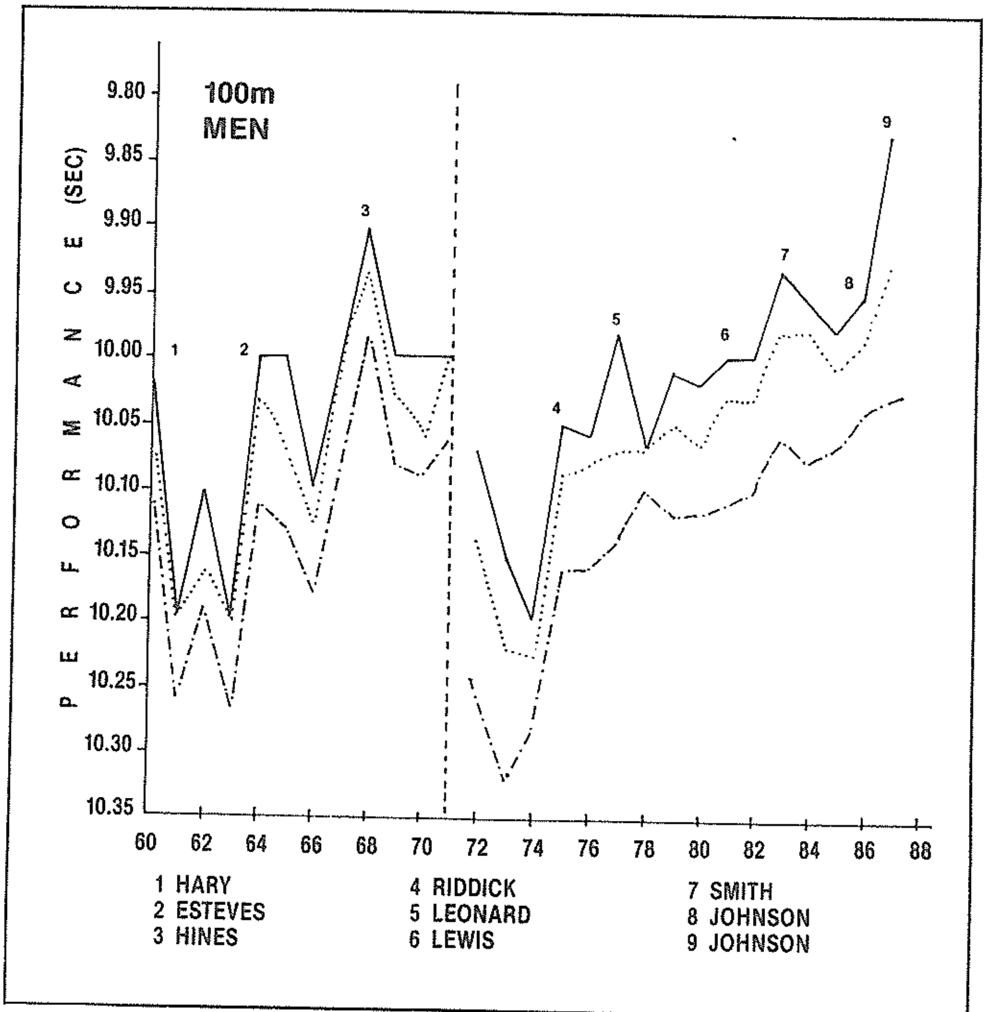

Fig. 1

Championship Records were expected, World Records were not anticipated, as in recent years most World Records in the sprints have been achieved with the aid of the reduced air resistance at high altitude, while Rome is at sea level. However, in the Men's 100 Metres, Lewis tied the World Record of 9.93 only to find himself a full tenth of a second behind the spectacular performance of 9.83 by Johnson. A graphic representation of the course of this historic race is presented in the video which accompanies the International Athletic Foundation/IAAF Scientific Project Report on the Championships.

The final results of the 100 Metres events at the II World Championships in Athletics are given in Tables 1-2. Complete individual time analysis for the medallists in each event are given at the end of this report. Individual time analyses for all finalists and semifinalists are available in the International Athletic Foundation/IAAF Scientific Project Report.

2. Methods and Procedures

2.1 Cameras and Siting

The sprint events at the II World Championships in Athletics were analysed on the basis of recordings made by five SONY video cameras. Time synchronization was ensured by a video recording of the starter's gun. In addition, seven synchronized PHOTOSONICS 500 high-speed cameras were used to film the semifinals and finals of each event. The siting of the cameras is shown in Fig. 3. Information and find-

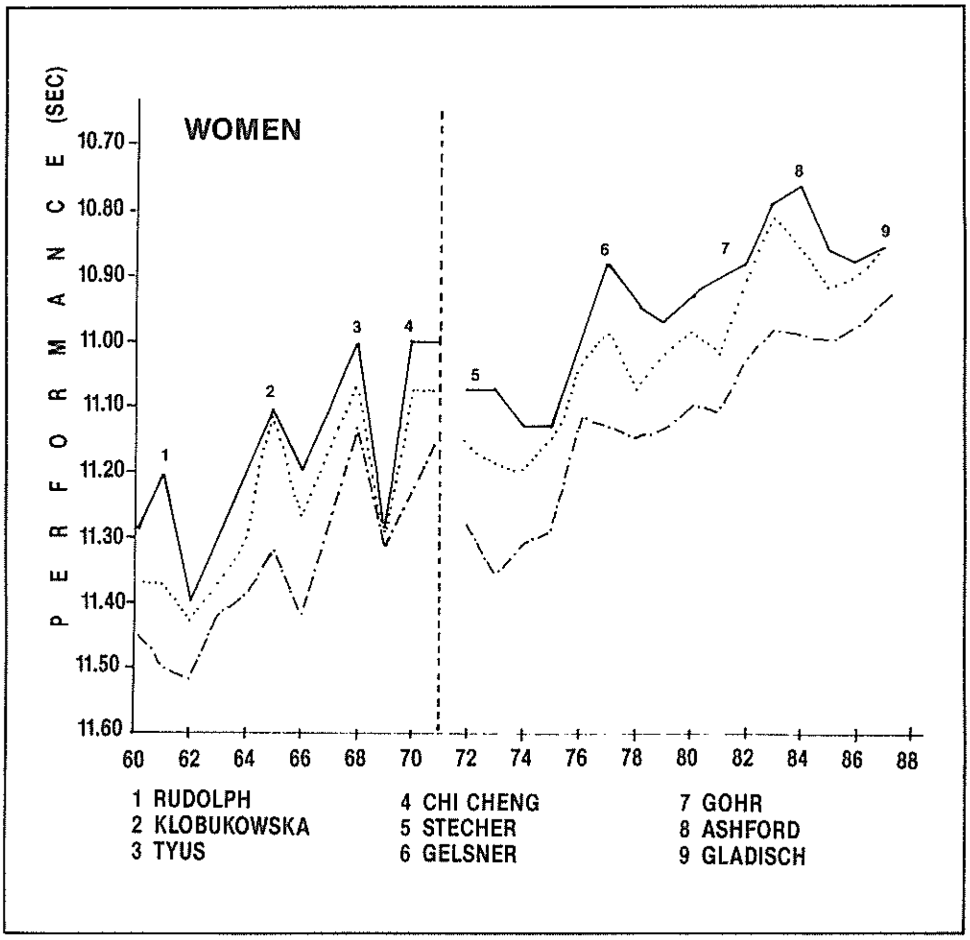

Fig. 2

Table 1 - Results of the 100 metres men - II World Championships in Athletics

HEATS

29/8 - 9.30

1. (+ 1.79 m/s)

1.	624 Stewart Raymond	JAM	10.23 Q
2.	61 Desruelles Ronald	BEL	10.39 Q
3.	438 Mc Farlane Mike	GBR	10.39 Q
4.	917 Cheng Hsin Fu	TPE	10.41 Q
5.	1088 Witherspoon Mark	USA	10.65
6.	214 Penalver Leandro	CUB	10.65
7.	813 Hazel Earl	STK	10.96
8.	517 Loua Robert	GUI	11.09

Time 09:30 — Temp.: +20 °C
Press.: 1015 mBar — Humidity: 78%

2. (+ 1.22 m/s)

1.	337 Moriniere Max	FRA	10.29 Q
2.	950 Yevghenyev Aleksandr	URS	10.33 Q
3.	218 Simon Andres	CUB	10.34 Q
4.	1062 Mc Rae Lee	USA	10.34 Q
5.	364 Haas Christian	FRG	10.39
6.	69 Allassane Issa	BEN	10.68
7.	679 Ziad Hanna	LIB	11.04
8.	741 Amawi Mohd Eid I.	PAL	11.56

Time 09:38 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 77%

3. (+ 0.38 m/s)

1.	86 Da Silva Robson C.	BRA	10.42 Q
2.	524 De Kom Achmed	HOL	10.68 Q
3.	981 Muravyev Vladimir	URS	10.53 Q
4.	71 Pale Harouna	VOL	10.68 Q
5.	166 Nkounkou Theophile	CGO	10.89
	197 Ali Youssouf	COM	DNS
	567 Barnes Greg	ISV	DNS
	457 Wells Allan	GBR	DNS

Time 09:43 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 69%

4. (+ 1.58 m/s)

1.	601 Pavoni Pierfrancesco	ITA	10.24 Q
2.	947 Bryzgin Viktor	URS	10.25 Q
3.	421 Christie Linford	GBR	10.29 Q
4.	630 Fuwa Hiroki	JPN	10.43 Q
5.	177 Li Tao	PRC	10.52
6.	1 Thode Julien	AHO	10.69
7.	746 Fernandez Oscar	PER	11.04
8.	704 Zammit Alan	MLT	11.32

Time 09:46 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 66%

5. (+ 0.52 m/s)

1.	145 Johnson Ben	CAN	10.24 Q
2.	623 Smith Andrew	JAM	10.39 Q
3.	249 Arques Javier	ESP	10.41 Q
4.	803 Seck Charles Louis	SEN	10.43 Q
5.	721 Nwankwo Patrick	NGR	10.43
6.	3 Selmi Mwstapha K.	ALG	10.48
7.	913 Cox Rodney	TKS	11.10
8.	706 Bessi Gilbert	MON	11.77

Time 09:53 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 66%

6. (+ 1.43 m/s)

1.	1053 Lewis Carl	USA	10.05 Q CR
2.	541 Kovacs Attila	HUN	10.26 Q
3.	103 Atanasov Valentin	BUL	10.39 Q
4.	200 Chacon Ricardo	CUB	10.43 Q
5.	392 Schweisfurth Dirk	FRG	10.50
6.	766 Abrantes Arnaldo	POR	10.64
7.	710 Hiram Rick	NAU	11.37
	8 Davis Trevor	ANG	DNS

Time 09:58 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 72%

7. (+ 2.48 m/s)

1.	719 Imoh Chidi	NGR	10.22 Q
2.	39 Berger Andreas	AUT	10.22 Q
3.	163 Williams Desai	CAN	10.30 Q
4.	494 Akwogyikam Eric	GHA	10.37 Q
5.	80 Bonfim Jailto Santos	BRA	10.41
6.	1090 Jeremiah Jerry	VAN	10.81
7.	792 Mohamed-Waheed I.	MLD	11.48
	726 Tuna Takale	NGU	DNS

Time 10:04 — Temp.: +21 °C
Press.: 1015 mBar — Humidity: 65%

° QUAlified: 4 first + 4 best times

QUARTER-FINALS 29/8 - 18.10

1. (−2.97 m/s)

1. 1053 Lewis Carl	USA	10.38 Q	
2. 421 Christie Linford	GBR	10.40 Q	
3. 541 Kovacs Attila	HUN	10.52 Q	
4. 86 Da Silva Robson Ca.	BRA	10.53	
5. 364 Haas Christian	FRG	10.65	
6. 61 Desruelles Ronald	BEL	10.65	
7. 200 Chacon Ricardo	CUB	10.70	
8. 981 Muravyev Vladimir	URS	10.80	

Time 18:10 — Temp.: +26 °C
Press.: 1017 mBar — Humidity: 66%

2. (−1.53 m/s)

1. 947 Bryzgin Viktor	URS	10.29 Q
2. 39 Berger Andreas	AUT	10.35 Q
3. 438 Mc Farlane Mike	GBR	10.35 Q
4. 337 Moriniere Max	FRA	10.39
5. 803 Seck Charles Louis	SEN	10.43
6. 163 Williams Desai	CAN	10.43
7. 917 Cheng Hsin Fu	TPE	10.53
8. 71 Pale Harouna	VOL	10.67

Time 18:16 — Temp.: +26 °C
Press.: 1017 mBar — Humidity: 66%

3. (−0.19 m/s)

1. 719 Imoh Chidi	NGR	10.20 Q
2. 1062 Mc Rae Lee	USA	10.21 Q
3. 601 Pavoni Pierfrancesco	ITA	10.28 Q
4. 494 Akwogyikam Eric	GHA	10.31
5. 103 Atanasov Valentin	BUL	10.37
6. 630 Fuwa Hiroki	JPN	10.38
7. 524 De Kom Achmed	HOL	10.45
8. 80 Bonfim Jailto Santos	BRA	10.46

Time 18:24 — Temp.: +26 °C
Press.: 1016 mBar — Humidity: 66%

4. (− 0.44 m/s)

1. 624 Stewart Raymond	JAM	10.14 Q
2. 145 Johnson Ben	CAN	10.14 Q
3. 218 Simon Andreas	CUB	10.23 Q
4. 950 Yevghenyev Aleksandr	URS	10.37
5. 623 Smith Andrew	JAM	10.37
6. 249 Arques Javier	ESP	10.46
7. 3 Selmi Mwstapha Kamel	ALG	10.48
8. 721 Nwankwo Patrick	NGR	10.49

Time 18:27 — Temp.: +26 °C
Press.: 1016 mBar — Humidity: 66%

Qualified: 4 first + 4 best times

SEMIFINALS 30/8 - 16.30

1. (− 0.38 m/s)

1. 145 Johnson Ben	CAN	10.15 Q
2. 421 Christie Linford	GBR	10.25 Q
3. 601 Pavoni Pierfrancesco	ITA	10.33 Q
4. 1062 Mc Rae Lee	USA	10.37 Q
5. 39 Berger Andress	AUT	10.37
6. 494 Akwogyikam Eric	GHA	10.40
7. 623 Smith Andrew	JAM	10.41
8. 950 Yevghenyev Aleksandr	URS	10.51

Time 16:30 — Temp.: +30 °C
Press.: 1017 mBar — Humidity: 54%

2. (− 1.35 m/s)

1. 1053 Lewis Carl	USA	10.03 Q CR
2. 624 Stewart Raymond	JAM	10.12 Q
3. 541 Kovacs Attila	HUN	10.22 Q
4. 947 Bryzgin Viktor	URS	10.23 Q
5. 218 Simon Andres	CUB	10.24
6. 719 Imoh Chidi	NGR	10.29
7. 438 Mc Farlane Mike	GBR	10.38
8. 103 Atanasov Valentin	BUL	10.53

Time 16:39 — Temp.: +30 °C
Press.: 1017 mBar — Humidity: 54%

/ Qualified: 4 first/

FINAL 30/8 - 18.40

(+ 0.95 m/s)

1. 145 Johnson Ben	61	CAN	9.83	WR CR
2. 1053 Lewis Carl	61	USA	9.93	
3. 624 Stewart Raymond	65	JAM	10.08	
4. 421 Christie Linford	60	GBR	10.14	
5. 541 Kovacs Attila	60	HUN	10.20	
6. 947 Bryzgin Viktor	62	URS	10.25	
7. 1062 Mc Rae Lee	66	USA	10.34	
8. 601 Pavoni Pierfrancesco	63	ITA	16.23	

Time 18:40 — Temp.: +26 °C — Press.: 1017 mBar — Humidity: 61% 61%

Table 2 - Results of the 100 metres women - II World Championships in Athletics

HEATS

29/8 - 10.20

1. (+ 2.28 m/s)

1.	287 Drechsler Heike	GDR	11.02 Q
2.	60 Georgieva Nadejda	BUL	11.27 Q
3.	598 Slyusar Irina	URS	11.34 Q
4	387 Masullo Marisa	ITA	11.71 Q
5.	34 Bada Felicite	BEN	12.22
6.	678 Caulker Alyson	SLE	12.33
7.	496 Rossini Sara	SMR	12.86
8.	128 Tierney Erin	CKI	13.12

Time 10:20 — Temp.: +21 °C
Press.: 1015 mBar — Umidità/Humidity: 59%

2. (+ 1.22 m/s)

1.	403 Ottey Merlene	JAM	11.26 Q
2.	193 Bily Laurence	FRA	11.32 Q
3.	592 Pomoshchnikova Nat.	URS	11.39 Q
4.	12 Holden Diane	AUS	11.53 Q
5.	47 Dos Santos Sheila	BRA	11.82
6.	3 Browne Rosanna	ANG	12.80
7.	439 Nanton Lorraine	MNT	13.30
8.	503 Karim A.	SUD	14.07

Time 10:29 — Temp.: +22 °C
Press.: 1015 mBar — Umidità/Humidity: 56%

3. (+ 0.99 m/s)

1.	616 Brown Alice	USA	11.42 Q
2.	78 Bailey Angela	CAN	11.52 Q
3.	262 Jacobs Simone	GBR	11.77 Q
4.	207 Leroux Philippe F.	FRA	11.92 Q
5.	498 Mangalika Tot. Gan.	SRI	12.34
6.	38 Barrow Sherlete	BIZ	13.21
7.	442 Ephraim Denise	NAU	13.69
	75 Inamahoro Fydia	BUR	DNS

Time 10:27 — Temp.: +22 °C
Press.: 1015 mBar — Umidità/Humidity: 56%

4. (- 0.68 m/s)

1.	70 Nouneva Anelia	BUL	11.37 Q
2.	606 Zolotareva Olga	URS	11.52 Q
3.	136 Allen Lilliana	CUB	11.57 Q
4.	679 Davis Pauline	BAH	11.59 Q
5.	165 Diaz Yolanda	ESP	12.00
6.	330 Haba Lea	GUI	12.78
	450 Launa Jammo	NGU	DNS
	438 Diarra Aminata	MLI	DNS

Time 10:35 — Temp.: +22 °C
Press.: 1016 mBar — Umidità/Humidity: 58%

5. (+ 0.15 m/s)

1.	238 Sarvari Ulrike	FRG	11.37 Q	
2.	292 Gladisch Silke	GDR	11.40 Q	
3.	645 Marshall Pam	USA	11.44 Q	
4.	97 Phipps Angela	CAN	11.62 Q	
5.	333 Ng Ka Yi	HKG	12.26	
6.	352 Nurani Budi	INA	12.34	
7.	407 Sudani Intisar	JOR	12.91	NR
	134 Faouzia Djaffar	COM	DNS	

Time 10:41 — Temp.: +23 °C
Press.: 1016 mBar — Umidità/Humidity: 59%

6. (+ 0.67 m/s)

1.	334 Cooman Nelli	HOL	11.18 Q
2.	88 Issajenko Angella	CAN	11.42 Q
3.	58 Demireva Valya	BUL	11.61 Q
4.	248 Ongolo Gisele	GAB	11.89 Q NR
5.	494 Wirtz Marie Ange	SEY	12.64
6.	541 Robinson Judith	TKS	13.15
7.	542 Comlan Abla	TOG	13.21
	444 Iheagwam Tina	NGR	DNS

Time 10:47 — Temp.: +23 °C
Press.: 1016 mBar — Umidità/Humidity: 59%

7. (- 0,61 m/s)

1.	669 Williams Diane	USA	11.22 Q
2.	293 Goehr Marlies	GDR	11.47 Q
3.	254 Dunn Paula	GBR	11.52 Q
4.	33 Verbruggen Ingrid	BEL	11.62 Q
5.	131 Caicedo Amparo	COL	11.88
6.	108 Diankolela Miss. J.	CGO	12.84
7.	1 Martha Soraima	AHO	12.87
8.	437 Hassan-Didi Jyhan	MLD	15.05

Time 10:50 — Temp.: +23 °C
Press.: 1016 mBar — Umidità/Humidity: 58%

• Qualified: 4 first + best times s

QUARTER-FINALS

29/8 - 17.40

1. QUARTO (– 0.38 m/s)

1.	287 Drechsler Heike	GDR	11.08 Q
2.	70 Nouneva Anelia	BUL	11.29 Q
3.	238 Sarvari Ulrike	FRG	11.32 Q
4.	606 Zolotareva Olga	URS	11.59
5.	97 Phipps Angela	CAN	11.67
6.	12 Holden Diane	AUS	11.68
7.	33 Varbruggen Ingrid	BEL	11.78
	34 Bada Felice	BEN	DNS

Time 17:41 — Temp.: +27 °C
Press.: 1016 mBar — Umidità/Humidity: 64%

2. QUARTO (+ 1.58 m/s)

1.	88 Issajenko Angella	CAN	10.99 Q
2.	334 Cooman Nelli	HOL	11.14 Q
3.	645 Marshall Pam	USA	11.21 Q
4.	598 Slyusar Irina	URS	11.39
5.	254 Dunn Paula	GBR	11.47
6.	387 Masullo Marisa	ITA	11.62
7.	207 Leroux Philippe Fra.	FRA	11.63
8.	47 Don Santos Sheila	BRA	11.76

Time 17:41 — Temp.: +27 °C
Press.: 1016 mBar — Umidità/Humidity: 64%

3. QUARTO (– 1.65 m/s)

1.	669 Willians Diane	USA	11.21 Q
2.	78 Bailey Angela	CAN	11.31 Q
3.	592 Pomoshchnikova Nat.	URS	11.33 Q
4.	293 Goehr Marlies	GDR	11.40
5.	193 Bily Laurance	FRA	11.49
6.	58 Demireva Valya	BUL	11.73
7.	262 Jacobs Simone	GBR	11.83
8.	165 Diaz Yolanda	ESP	12.05

Time 17:50 — Temp.: +27 °C
Press.: 1016 mBar — Umidità/Humidity: 64%

4. QUARTO (– 1.19 m/s)

1.	403 Ottey Merlene	JAM	11.27 Q
2.	292 Gladisch Silke	GDR	11.29 Q
3.	616 Brown Alice	USA	11.34 Q
4.	60 Georgieva Nadejda	BUL	11.47
5.	136 Allen Lilliana	CUB	11.60
6.	679 Davis Pauline	BAH	11.64
7.	131 Caicedo Amparo	COL	12.08
8.	248 Ongolo Gisele	GAB	12.21

Time 17:55 — Temp.: +26 °C
Press.: 1017 mBar — Umidità/Humidity: 65%

/• Qualified: 3 first + 4 best times/•

SEMIFINALS

30/8 - 16.50

1. (+ 2.12 m/s)

1.	292 Gladisch Silke	GDR	10.82 Q
2.	403 Ottey Merlene	JAM	10.89 Q
3.	88 Issajenko Angella	CAN	10.99 Q
4.	645 Marshall Pam	USA	11.06 Q
5.	616 Brown Alice	USA	11.07
6.	60 Georgieva Nadejda	BUL	11.10
7.	238 Sarvari Ulrike	FRG	11.15
8.	598 Slyusar Irina	URS	11.44

Time 16:50 — Temp.: +29 °C
Press.: 1017 mBar — Umidità/Humidity: 56%

2. (+ 0.70 m/s)

1.	287 Drechsler Heike	GDR	10.95 Q CR
2.	70 Nouneva Anelia	BUL	11.01 Q
3.	669 Willians Diane	USA	11.07 Q
4.	78 Bailey Angela	CAN	11.07 Q
5.	592 Pomoshnikova Natalia	URS	11.15
6.	334 Cooman Nelli	HOL	11.21
7.	293 Goehr Marlies	GDR	11.33
8.	254 Dunn Paula	GBR	11.59

Time 16:55 — Temp.: +29 °C
Press.: 1017 mBar — Umidità/Humidity: 56%

• • Qualified: 4 first •

FINAL

30/8 - 19.00

(– 0.58 m/s)

1.	292 Gladisch Silke	64	GDR	10.90 CR
2.	287 Drechsler Heike	64	GDR	11.00
3.	403 Ottey Merlene	60	JAM	11.04
4.	669 Williams Diane	60	USA	11.07
5.	88 Issajenko Angella	58	CAN	11.09
6.	70 Nouneva Anelia	62	BUL	11.09
7.	78 Bailey Angela	62	CAN	11.18
8.	645 Marshall Pam	60	USA	11.19

Time 19:00 — Temp.: +26 °C
Press.: 1017 mBar — Umidità/Humidity: 64%

ings from the video recordings were published as FAST INFORMATION REPORTS and were available to the press and to the athletes and coaches in the Athletes Village in Rome. The recordings from each round were shown the following day as part of a video presentation given to the athletes in the Village.

The location of the high speed cameras enabled 3-D analysis of the athletes. The cameras worked at a frequency of 200 frames per second. One of the cameras photographed the smoke from the starter's gun. The film from this camera was used for both the visual assessment and comparison with the official measurements of the athletes' reaction times. The films were also used for comparing with the material obtained from the video recordings in the preparation of this report.

2.2 Reaction Time Measurement

In addition to the above mentioned visual assessment of reaction times, the "official" reaction times were taken from the print out of the automatic recordings from the false start detection equipment supplied by SEIKO.

3. Factors of performance in the sprint events

For the purpose of this report, we have identified and evaluated the following factors which are likely to be decisive for the final performance in

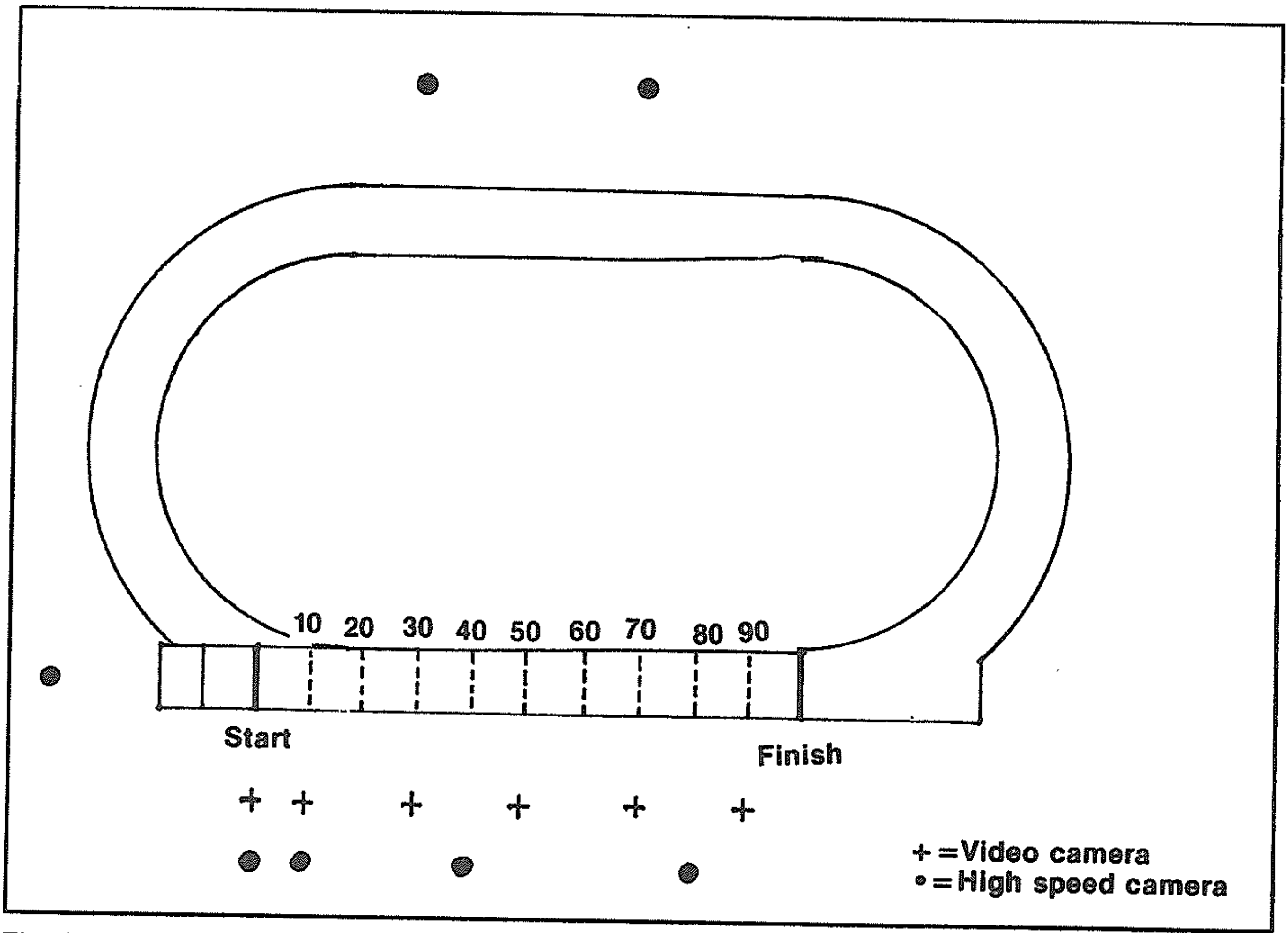

Fig. 3 - Camera positions

the sprint events: reaction time, acceleration speed, maximum speed and speed endurance.

3.1 Reaction time

The term "reaction time" is used here only for the sake of simplicity. In fact, it is the time that elapses between the sound of the starter's gun and the moment the athlete is able to exert a certain amount of pressure on the starting blocks. Therefore, the current method of reaction time measurement includes the duration of the time it takes for the sound of the gun to reach the athlete, the time it takes the athlete to react to the sound and the mechanical delay of measurement inherent in the starting blocks.

Measurement of reaction time has proven an intractable problem in athletics. Information from these measurements can have a considerable influence on the development of starting technique in all sprint and hurdle events. Reaction times should be watched and analysed not only in races but in training as well. However, if reaction times are to be used as comparable quantities, uniform conditions for measuring must be laid down and should be obligatory for companies producing starting blocks with devices for false start detection and the automatic recording of reaction time. This is not the case at present.

Long term investigations have confirmed that measurements made at the World Junior Championships in Athletics in Athens 1986, and at the II World Championships in Athletics were significantly longer in all the sprint events than reaction times recorded at other major championships held between 1978 and 1986 (Table 3). As it is unlikely that such a large variance would show up in a large sample of top level athletes, it suggests a difference in methods of measurement.

In addition to this problem there is the question of what is the minimum time required for a fair start? In theory, if the athlete makes his first move any time after the gun, it is a fair start. However, since it is known that the sound takes some amount of time to reach the athlete and that there must be a maximum speed at which a human being can react to a sound, it is assumed that there is specific minimum reaction time. If the athlete moves before that time has elapsed since the firing of the gun he must have anticipated the gun and therefore false started.

In fact, no definite study exists which could be used as a basis for establishing a minimum time which would define a false start. There is no objective reason for laying down 120 milliseconds, which was used in Rome, (or any other value) as the limit. It is for this reason that the false start detection system is only for the information of the starter, with the starter being the sole judge of a fair start.

A case in point was the final of the Men's 100 Metres. Many observers were of the opinion that Johnson false started and the "official" reaction time of 109ms (Table 4) seemed to confirm this.

Analysis of the films made by the high speed cameras and interpolation of the frames were used to calculate the time that passed between the recorded gun shot smoke and the first noticeable motion of the athlete. Our conclusion is that Johnson was not guilty of a false start. The starter did not and could not have noticed any motion or a false start. It was a very fast start, no doubt,

Table 3 - Reaction times measured at major championships

MEN	100 metres			200 metres			400 metres		
	n	x	SD	n	x	SD	n	x	SD
EC78	51	.151	.20	43	.179	.41	48	.247	.67
OG80	118	.154	.17	112	.159	.21	106	.172	.41
EC82	52	.147	.19	47	.171	.29	50	.226	.67
WC83	121	.157	.25	107	.189	.34	105	.220	.41
WJC86	138	.174	.21	131	.191	.37	71	.238	.65
WC87	103	.185	.31	94	.219	.52	56	.261	.75
AVERAGE		.164	.23		.186	.35		.220	.55

WOMEN	100 metres			200 metres			400 metres		
	n	x	SD	n	x	SD	n	x	SD
EC78	46	.159	.20	48	.180	.37	42	.248	.56
OG80	84	.152	.27	83	.164	.24	62	.195	.45
EC82	42	.155	.15	24	.177	.32	24	.271	.65
WC83	103	.173	.23	96	.201	.37	83	.235	.59
WJC86	80	.185	.41	83	.205	.41	21	.272	.75
WC87	107	.211	.52	53	.234	.68	57	.269	.67
AVERAGE		.177	.33		.194	.39		.244	.65

n = number of readings x = mean SD = standard deviation

Table 4 - Reaction times - Men's 100 Metres - Final

Name	Johnson	Bryzgin	Christie	Pavoni	Lewis	Kovacs	McRae	Stewart
Performance	9.93	10.25	10.14	16.23	9.93	10.20	10.34	10.08
Ranking by Reaction times	1.	2.	3.	4.	5.	6.	7.	8.
Lane	5	1	8	2	6	4	7	3
A	0.143	0.158	0.163	0.173	0.199	0.214	0.224	0.230
B	0.109	0.139	0.135	0.163	0.196	0.201	0.225	0.235
C	0.034	0.018	0.008	0.010	0.003	0.013	-0.001	-0.005

A) Reaction times from film analysis
B) Official Seiko reaction times
C) Difference between A and B

but it was completely legal and the starter was correct to allow it.

The rest of our conclusions on reaction times can be briefly expressed in the following points, formulated in an earlier study (Dostál, 1982):

1. In all sprint events (including heats, semi-finals and finals), the reaction times of the best athletes are shorter than 200ms. This conclusion was confirmed in more than 95% of the results from the II World Championships in Athletics. However, reaction time in Rome were, despite the times recorded by Johnson, generally longer than at other recent championship meetings, a fact probably caused by a lack of uniformity in the methods of measurements. This makes Johnson's reaction time all the more impressive.

2. In identical events, the average reaction times of women are longer than those of men. This conclusion was confirmed in 75% of the results from Rome.

3. Reaction times grow in proportion to the length of the race distance. This conclusion was confirmed, without exception, by the results from Rome.

4. The variance in the range of reaction increased in proportion to the race distance. This was confirmed, with rare exceptions, by the results from Rome.

5. For the best runners, the stability of reaction times is greater. This conclusion, however, was not confirmed by the results from Rome.

6. Reaction time does not correlate with the performance level. This was fully confirmed by the results from Rome.

Table 5 gives an evaluation of reaction times, valid generally and valid for the special case of the II World Championships in Athletics.

3.2 Acceleration

The ability to accelerate is one of the factors that markedly influences performance. For this study acceleration speed is measured by the time achieved for the first 30m in the 100 Metres. Most sprinters, regardless of performance level, achieve maximum speed between 30m and 60m, but the quality of the acceleration (the steepness of the speed increase and the maximum level of speed achieved) correlates directly to both the performance and the quality of the sprinter. However, our findings from Rome are that, while it is usually necessary to run the first 30m below

Table 5 - Evaluation of reaction times

	Valid generally		Valid only for II WC	
100 metres	Men (x=.160)	Women (x=.177)	Men (x=.185)	Women (x=.211)
1. Outstanding	<.130	<.135	<.140	<.140
2. Above average	(.130; .150)	(.135; .160)	(.140; .170)	(.140; .185)
3. Average	(.150; .170)	(.160; .195)	(.170; .200)	(.185; .235)
4. Bellow Average	(.170; .190)	(.195; .230)	(.200; .230)	(.235; .285)
5. Substandard	>.190	>.230	>.230	>.285

4.0s for a performance of 10.40 or better in the 100 Metres, achieving a certain level of final time is not so strictly conditioned by acceleration capacity in men as it is in women.

3.3 Maximum Speed

Maximum speed is clearly important in the sprint events. However, while there was a direct correlation in the Women's 100 Metres, it was shown, again in the analysis of the Men's 100 Metres, that maximum speed is not always directly correlated with the final performance. Maximum speed was measured as a mean in separate 10m sections. While all the male finalists were able to achieve speeds of 11 m/s (the fastest were Johnson and Lewis at 11.76 m/s), there were a number of men who reached this speed but did not better 10.50. Nevertheless, an outstanding performance in the sprints can be said to be conditioned by a high maximum running speed. In other words, a high level of maximum speed is not a guarantee but a precondition of an excellent performance.

3.4 Speed Endurance

Even in the 100 Metres, performance is markedly influenced by the ability to maintain running speed for as long as possibile. Neither reaction time, acceleration speed nor maximum speed correlated in all cases with the final result. However, the correlation between speed endurance and performance was confirmed unequivocally. Speed endurance can be measured by the time achieved for a flying 30m section, by the difference in the times between the first and second halves of the race and by the curve of the functional course of maximum speed (expressed by mean times over 10m sections of the race).

The time for the section between 30m and 60m is an indication of how well the athletes maintain the speed they have reached in the acceleration phase. The stability of speed endurance ability can also be shown by the 30m - 60m time in different races, indicating how close the athletes are to maximum effort in a given round.

The difference between the first and second halves of the race is good for showing the level of speed endurance. Any analysis of a sprint race in which the athlete has run the whole distance at full effort, without a relaxation in the final metres due to clear qualification for the next round, will show that the difference between the first and second halves of the distance increases with improved speed endurance. In other words, it is to be expected that the second half of the race is faster, due to the flying start, but an increase of this difference is an indication of increased speed endurance.

This does not mean that the athletes are running faster in the second half of the race. In fact, the curve of the functional course of maximum speed, which is the most important indicator of speed endurance, shows that there is usually a decrease of velocity in the second half of the race. Inferior sprinters reach a peak of maximum speed which decreases fairly steeply, while elite sprinters lose speed very gently or, in some cases, have a two peak course of the speed curve. Account should also be taken of the individual peculiarities of the athletes (i.e particularly high levels of acceleration or maximum speed will tend to exagerate the loss of velocity yet can still be consistent with good performances).

4. Analyses of the competitions at the II World Championships in Athletics

4.1 Time Analysis of the Women's 100 Metres

REACTION TIME

At the II World Championships in Athletics it was again confirmed that reaction time does not significantly influence the performance level at the 100 metres distance. The reaction times of female sprinters with times over 12.00 were comparable with the reaction times of the female sprinters who recorded times under 12.00 and with the semi-finalists. Above average or excellent reaction times were found only in some of the finalists but, even here, no correlation between reaction time and final performance could be found.

Comparing the reaction times of the finalists (Table 6) we find that the winner Gladisch (GDR) had the fastest (0.141s) while eigth placer Marshall (USA) had the slowest (0.242s). This fully corresponds to the results of the race. However, second placer Drechsler (GDR) had a below average reaction time (0.210s) as did fourth placer Williams (USA) (0.240s) while sixth placer Nouneva (BUL) was above average (0.196s).

ACCELERATION

No athlete who failed to advance from the heats (times over 12.00) was able to achieve a time better than 4.40s for the first 30m while none of those who failed to advance from the quarterfinals (times over 11.50s) timed better than 4.30s. A comparison of times at 30m by the finalists in all four rounds of the competition (Table 7) shows a high degree of stability of acceleration speed. Outstanding acceleration was demonstrated by Gladisch, Issajenko (CAN), Ottey (JAM) and Nouneva; inferior acceleration by Marshall and Drechsler.

MAXIMUM SPEED

Maximum speed, measured as a mean of separate 10m sections, clearly corresponds to the performance achieved in the case of the Women's 100 Metres. Velocities of 9.00 m/s - 9.50 m/s correspond to final times over 12.00 while a velocity of about 10 m/s corresponds to final times between 11.50 and 12.00. Table 8 shows that all the finalists were able to produce speeds higher than 10.40 m/s. The highest measured speeds were for Drechsler (10.87 m/s) and Gladisch (10.75 m/s).

Table 6 - Reaction Times - Women's 100 metres final

Place	Reaction Time	Ranking by reaction time
1. Gladisch	.141	1
2. Drechsler	.210	6
3. Ottey	.172	3
4. Williams	.240	7
5. Issajenko	.203	5
6. Nouneva	.169	2
7. Baily	.191	4
8. Marshall	.242	8

Table 7 - Times at 30 metres - Women's 100 Metres finalists

Final place	Heat	Quarter-Final	Semi-Final	Final
1. Gladisch	4.31	4.22	4.14	4.15
2. Drechsler	4.31	4.29	4.28	4.25
3. Ottey	4.25	4.22	4.18	4.17
4. Williams	4.23	4.17	4.26	4.24
5. Issajenko	4.27	4.15	4.18	4.17
6. Nouneva	4.20	4.23	4.18	4.15
7. Baily	4.38	4.25	4.20	4.22
8. Marshall	4.28	4.29	4.28	4.28

SPEED ENDURANCE

Athletes with final times between 11.50 and 12.00 were not able to clock less than 3.30 for the section 30m - 60m while the semi-finalists and finalists were capable of maintaining their speed on a level that makes this time possible. This is confirmed by a com-

Table 8 - Maximum speed - Women's 100 Metres final

Place	Fastest 10m section(s)	Time	Maximum speed
1. Gladisch	50-60m 60-70m	0.93	10.75 m/s
2. Drechsler	50-60m	0.92	10.87 m/s
3. Ottey	50-60m 60-70m	0.95	10.52 m/s
4. Williams	50-60m	0.94	10.63 m/s
5. Issajenko	40-50m 50-60m 60-70m	0.96	10.41 m/s
6. Nouneva	60-70m	0.95	10.52 m/s
7. Baily	50-60m	0.95	10.52 m/s
8. Marshall	50-60m	0.94	10.63 m/s

Table 9 - Times for 30-60m segment - Women's 100 Metres finalists

Final place	Heat	Quarter-Final	Semi-Final	Final
1. Gladisch	3.00	2.94	2.85	2.85
2. Drechsler	2.85	2.89	2.84	2.85
3. Ottey	2.99	2.95	2.86	2.90
4. Williams	2.98	2.97	2.92	2.91
5. Issajenko	2.99	2.87	2.87	2.91
6. Nouneva	2.98	3.00	2.87	2.91
7. Baily	3.03	2.97	2.92	2.94
8. Marshall	3.05	2.90	2.90	2.93

parison of the data from the four rounds for the finalists (Table 9). The fastest women over this section were again Drechsler (2.84s) and Gladisch (2.85s).

As stated above, inferior athletes lose speed fairly steeply while elite sprinters have a more gradual loss of speed, or, as in the cases of Ottey and Baily (CAN), a two peak course of the speed

Table 10 - 50 meter times - Women's 100 Metres final

Place	First 50m	Second 50m	Difference
1. Gladisch	6.07	4.83	1.24
2. Drechsler	6.18	4.82	1.36
3. Ottey	6.12	4.92	1.20
4. Williams	6.21	4.86	1.35
5. Issajenko	6.12	4.97	1.15
6. Nouneva	6.10	4.99	1.11
7. Baily	6.21	4.97	1.24
8. Marshall	6.27	5.17	1.10

curve. The speed curves of the medallists are presented in graphic form in the individual analyses.

None of the finalists achieved a better performance in the final than in the semi-final although acceleration and maximum speed were in most cases better. This again highlights the importance of speed endurance. In this case, though, the results of the final were affected by several factors: head wind, undue output of energy in the first half of the race (despite the head wind, identical or better intermediate times were achieved) and, probably, accumulation of fatigue from the preliminary rounds.

The individual time analysis of the medallists is shown on pages 84-89

4.2 Time Analysis of the Men's 100 Metres

REACTION TIME

Just as in the women's event, no significant correlation between reaction time and final performance was revealed in the Men's 100 Metres. Very often, athletes achieved poor times and did not qualify for the next round from the heats despite reaction times comparable with the finalists and other sprinters who achieved good performances. As stated above, the reaction times for participants in Rome were generally poorer than for other recent major championships. Among the finalists, Johnson demonstrated not only the fastest reaction time but the highest stability of reaction times. In the final (see Table 4) above average reaction times can be observed in Bryzgin (URS) and Christie (GBR) with below average times recorded by Lewis (USA) and Stewart (JAM).

ACCELERATION

Remarkable differences between athletes could be observed in acceleration capacity. Much like the women, most of the men achieved maximum speed in the section 30m - 60m, although some of the finalists did so even later in the race.

As stated above, acceleration capaci-

Table 11 - Times at 30 metres - Men's 100 Metres finalists

Place	Heat	Quarter-Final	Semi-Final	Final
1. Johnson	3.87	3.82	3.83	3.80
2. Lewis	3.93	4.05	3.98	3.91
3. Stewart	4.00	3.92	3.96	3.98
4. Christie	4.02	4.01	3.96	3.97
5. Kovacs	3.97	4.02	3.95	3.98
6. Bryzgin	3.96	3.92	3.95	3.97
7. McRae	3.92	3.89	3.95	3.94
8. Pavoni	4.01	3.90	3.95	4.33

ty did not condition the final time for the men as it did for the women in Rome. The best level of acceleration ability was demonstrated by Johnson whose 30m times in all rounds were better than 3.90s. It was clearly a combination of reaction time and acceleration ability which decided the final of the 100 Metres as Johnson established a lead of .11s by 30m which Lewis, despite the fact that he was in the process of equalling the World Record was not able to even out. However, in addition to Johnson and Lewis, McRae (USA) also showed high acceleration ability in all rounds yet he had the slowest average of final marks among the finalists. In the final, excluding the injured Pavoni (ITA), the slowest acceleration (3.98s) was demonstrated by both Kovacs (HUN) and third placer Stewart.

Note that while it is usually necessary to run the first 30m below 4.00 in order to achieve a performance of 10.40 or better, Stewart, Christie and Pavoni were all able to beat 10.30 in the earlier rounds despite 30m clockings of 4.00s or slower.

MAXIMUM SPEED

All the finalists, as well as semi-finalist, were able to achieve, in the fastest 10m section of their races, times corresponding to an average velocity of 11 m/s or better. However, there were a number of athletes who were able to reach this speed yet unable to clock better than 10.50 for their final time, showing that, while it is necessary to be able to achieve high levels of maximum speed, it is not a guarantee of an excellent performance. The highest speeds measured were for Johnson and Lewis as both reached 11.76 m/s. Note that Lewis reached his highest speed in the 80m - 90m segment while both Stewart and Kovacs reached their highest speed in the 90m - 100m segment.

Table 12 - Maximum speed - Men's 100 Metres final

Place	Fastest 10m section(s)	Time	Maximum speed
1. Johnson	50-60m 60-70m	0.85	11.76 m/s
2. Lewis	80-90m	0.85	11.76 m/s
3. Stewart	50-60m 70-80m 90-100	0.86	11.62 m/s
4. Christie	50-60m	0.86	11.62 m/s
5. Kovacs	90-100m	0.87	11.49 m/s
6. Bryzgin	50-60m 20-80	0.89	11.23 m/s
7. McRae	50-60m	0.89	11.23 m/s
8. Pavoni	30-40m	1.14	8.77 m/s

Table 13 - Times for 30-60m segment Men's 100 Metres finalists

Final place	Heat	Quarter-Final	Semi-Final	Final
1. Johnson	2.68	2.66	2.68	2.58
2. Lewis	2.64	2.78	2.61	2.59
3. Stewart	2.65	2.67	2.64	2.64
4. Christie	2.65	2.75	2.70	2.65
5. Kovacs	2.68	2.76	2.67	2.69
6. Bryzgin	2.65	2.72	2.74	2.69
7. McRae	2.75	2.70	2.74	2.72
8. Pavoni	2.66	2.70	2.74	*

SPEED ENDURANCE

All the athletes, who bettered 10.40, with the exception of McRae, were able to cover the flying 30m segment between 30m and 60m in 2.70s or less. In the final, Johnson's time was 2.58s while Lewis clocked 2.59s. The difference between the first 50m and second 50m for the finalists ranged from 1.20s for McRae to 1.44s for Stewart.

As with the women, the functional course of the maximum speed, shown graphically in the individual analyses, is considered the most important indicator of speed endurance. Athletes of a lower level usually have a one peak

Table 14 - 50 metres times - Men's 100 Metres final

Place	First 50m	Second 50m	Difference
1. Johnson	5.53	4.30	1.23
2. Lewis	5.64	4.29	1.35
3. Stewart	5.76	4.32	1.44
4. Christie	5.76	4.38	1.38
5. Kovacs	5.77	4.43	1.34
6. Bryzgin	5.77	4.48	1.29
7. McRae	5.77	4.57	1.20

course which drops steeply in the final stages of the race. The elite sprinters are able to maintain high running speeds, with only a gradual loss, even in the later stages of the race. In the final, all the sprinters, with the exception of Pavoni, were able to achieve a two peak course of speed, confirming their ability to maintain high running speed in the second half of the race.

Identical conclusions can be reached by the comparison of the final 20m sections of the halves of the race (30m - 50m and 80m - 100m). Except for McRae and Pavoni, all finalists had equal or faster times in the later segment. Excluding the finalists, this was observed only four times (twice in the semifinals and twice in the quarterfinals).

5. Interpretation from the point of view of coaching practice by Peter F. Radford

From the coach's point of view the value of a detailed study such as this, lies in the practical information it provides about the world's great sprinters, the qualities they bring to their event, and how they use these qualities to construct a world-class performance.

Sprint coaches are, however, aware of two factors in particular that they must consider before generalizing from one championship meeting to sprinting in general. These are that (a) sprinters are strongly affected by their environment, and that wind and temperature, in particular, influence not only the time of a race, but also its internal dynamics, and (b) sprinters are seldom able to run in training as fast as they do in competition, and so the "standards" achieved in the World Championships can only legitimately be compared with other similar races, and not with performances achieved in training.

Conditions

The range of temperatures at Rome, from 20° to 30°, is not likely to influence performance significantly, but

Table 15 - Times for 30-50m and 80-100m segments - Men's 100 Metres final

Place	30-50m	80-100m
1. Johnson	1.73	1.73
2. Lewis	1.73	1.71
3. Stewart	1.78	1.73
4. Christie	1.79	1.77
5. Kovacs	1.79	1.76
6. Bryzgin	1.80	1.80
7. McRae	1.83	1.84

Table 16 - Mean times of the 100 Metres finalists

	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	metres
Men	1.749	1.046	0.956	0.900	0.882	0.876	0.880	0.883	0.886	0.884	sec.
Women	1.869	1.111	1.034	0.989	0.967	0.994	0.950	0.976	1.019	1.021	sec.

the differences in wind force and direction are, I believe, quite serious.

For the men, the report gives details of twelve 100 metres races, none of which had an assisting wind above the permitted limit (2.0 m/s); but for the women, of the fourteen races reported, 2 were above the limit: Ht 1 and SF 1. Although most of the races were below the permitted limit, the variation in wind force and direction was nevertheless too large to permit coaches to draw simple comparisons between one race and another. For the men the range was +1.79 m/s (Ht 1) to —2.97 m/s (QF 1), and for the women +2.28 m/s (Ht 1) to —1.65 m/s (Qf 3).

Sprinters are very sensitive to wind, and because even elite sprinters differ to some degree in their body size, strength, power and endurance, and in the mechanics of their running (body angle, foot strike, etc.), they are not all uniformly helped by an assisting wind, nor uniformly hindered by a head-wind (Davies, 1980).

The 100 metres races

The report breaks the race into 4 parts: Reaction Time, Acceleration, Maximum Speed and Speed Endurance, but of more value than these arbitrary divisions are the times that are reported for each 10m section of the race, for each sprinter.

There is considerable variation between sprinters and between different races by the same sprinter, so to simplify things, I have calculated the mean time taken by all finalists to cover each 10m section of the finals (N.B. Pavoni's times have been taken from the mean of his Ht and SF), see Table 16.

Conclusions

1. TOP SPEED RUNNING AND LOSS OF SPEED

As Table 16 shows, the men in the final, taken as a whole, accelerated to 50m and then maintained their speed without loss (to 0.01 secs) to the end of the race. This is a surprising finding as most earlier work has shown a loss of speed over the last 20m or so (Ikai, 1968, Murase et al., 1976, Morton, 1981). Conditions in this race were close to ideal with a temperature of 26° and an assisting wind of 0.95m/sec., nevertheless it is interesting to find that two of the men were at their fastest in the final 10m of the race. This ability of the best male sprinters to maintain their top speed is probably the single most important factor in reducing sprint times over the past 20 years, and speed endurance is probably a more important aspect of training for 100 metres runners than coaches of the last generation realised. In the 100 Metres finals the men took from 44.6 to 47.0 strides at a mean rate of 4.6 strides/sec., and the women took from 45.4 to 53 strides at a mean rate of 4.5 strides/sec. One of the key objectives of sprint training is to train the anaerobic energy systems so that after adaptation more energy is available to continue the high-intensity muscle contractions that are needed to maintain a high rate of striding at the end of the race. Associated with this, recent evidence shows that sprint coaches must in future be as aware as coaches of longer events of the possibility of glycogen depletion which could be a contributory cause to the loss of top speed in their sprinters at the end of even the 100 metres race (Boobis, et al., 1987; Cheetham et al., 1986; Jacobs, 1987).

For the women sprinters the picture appears to be quite different. As Table 16 shows the women, on average, lose speed progressively over the last 40m. In comparison with the men's final the women on average ran at nearly 94% of the speed of the men over the first 20m, but over the last 20m this dropped to less than 87% and no woman in the final achieved her fastest speed over the last 30m (although half the men did). It is not possible to say to what extent this was a consequence of the conditions (the men had a tail wind of 0.95, and the women a head wind of 0.58), as the report does not give the full details of earlier rounds. In normal conditions it has been calculated that 16% of the sprinter's energy requirements are to overcome air resistance (Pugh, 1970), however, it must be remembered that a woman's 100 metres race lasts 10% longer than a man's and the problems of energy supply to their muscles lasts, therefore, that much longer. For this reason alone it seems reasonable from these results to support those coaches who claim that speed endurance should play an even greater role in the training of women sprinters, than it does of men.

2) ACCELERATION

As Table 16 shows, the mean acceleration continued for both men and women until somewhere between 50m and 60m, when top speed was usually reached. For the men this is where most races are won or lost. In the men's final the athletes were already in their finishing order (to within 0.01 sec.) at 50m. For the women, however, there is a much greater chance of recovering from an average acceleration, because of the greater contribution that speed endurance plays. Nevertheless, coaches are reminded by these results that a good, long acceleration phase is the foundation on which all good 100 metres races are built.

3) REACTION TIME

The results from Rome confirm earlier results already known to coaches, namely that the ability to produce a fast reaction to the gun, is not necessarily associated with sprinting ability. Coaches will therefore continue as before to work with their sprinters to develop their muscular strength, power and skill and so improve their velocity at the time of leaving the blocks. There is no direct data in the study on this important aspect of sprinting but the times to 10m give the coach some useful new information.

4) STRIDE LENGTH AND RATE

In the final analysis sprint performances are about stride length and rate and how these are combined to achieve the best results (Ballreich, 1976). Coaches already know, of course, that stride length and rate are related to leg length, standing height and running speed (Hoffman, 1971), and they also know that for their height and leg length women sprinters run with a lower rate than the equivalent men (Hoffman, 1972). This study, however fails to add any new information as only the total numer of strides for the whole race is reported; this is then expressed as an average length and rate for the whole race including reaction time. A gold mine of information would have been available if sprinters' height and weight had been included and strides for each 10m section had been calculated.

Far too little is known about the ways that men and women sprinters manipulate stride length and rate during acceleration, top speed and when speed is lost, and this could be an important theme of any future research.

The results of this study have provided the coach with some intriguing insights into how the sprinters performed in Rome, but further analysis of other events is necessary to see to what extent these performances were influenced by the specific conditions in Rome. When coaches have other detailed analyses with which to compare these data the information will be much more useful to them.

Editor's note
The following section was received subsequent to the preceeding interpretation having been written.

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6. Comparison of the mean values of further parameters for Johnson and Lewis

The spectacular results achieved in the Men's 100 Metres by both Johnson and Lewis warrant an even closer examination of their performances. It is interesting to note that the two best 100 Metres performances of all time were achieved with considerably different technical styles. As stated above, the race was won in the start and acceleration phases. Johnson was able to gain 87ms of the .10 sec. winning margin in the reaction time alone. However, if we ignore this, we find that he covered the distance of the race only 13ms faster than Lewis, yet the kinematic parameters for the two sprinters were markedly different (See Table 16).

For the 100 metres distance, which they covered in practically the same time, Johnson had a higer mean stride frequency while Lewis had a longer mean stride length. A considerable difference can also be seen in the duration of the support phases of the strides of the first 20m (Johnson - 115ms and 91ms, Lewis - 134ms and 100ms) while the duration of the support phases for the rest of the race are practically identical. For the entire distance Johnson's flight phases were also shorter in comparison to Lewis: (range 4ms-24ms).

The index of running activity I = A SP / A FP (relation of the time duration of the support phase to the duration of the flight phase) is normally a meaningful value for evaluating athletes intra-individually or for estimating the performance level of an athlete. The lower the level I_A the shorter the time for observed section of the race or the higher the mean velocity. However, in the case of the minimum time differences for the observed sections of this race, this particular index is not sensible (note the values for 30m-40m).

Another and, in this case, more significant indicator, is the relationship between stride length and stride frequency. Johnson achieved his highest mean velocity of 11.76 m/s between 50m and 60m while Lewis achieved the same velocity between 80m and 90m. In both cases the athletes were 7-8% below their maximum values for their dominant parameter, Johnson - stride frequency, Lewis stride length.

Table 17

COMPARISON OF MEAN VALUES FOR SELECTED PARAMETERS OF 10 METRE SECTION FOR JOHNSON AND LEWIS

PARAMETERS	NAME	0-10 - RD	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Intermediate times (s)	Johnson	1.73	2.86	3.80	4.67	5.53	6.38	7.23	8.10	8.96	9.83
	Lewis	1.74	2.96	3.91	4.78	5.64	6.50	7.36	8.22	9.07	9.93
Times for 10 m sections (s)	Johnson	1.73	1.02	0.94	0.87	0.86	0.85	0.85	0.87	0.86	0.87
	Lewis	1.74	1.02	0.95	0.87	0.86	0.86	0.86	0.86	0.85	0.86
Mean Velocity (m/s)	Johnson	5.78	9.80	10.64	11.49	11.63	11.76	11.76	11.49	11.63	11.49
	Lewis	5.75	9.80	10.53	11.49	11.63	11.63	11.63	11.63	11.76	11.63
Number of strides (n)	Johnson	7.30	5.30	4.50	4.40	4.30	4.10	4.10	4.05	4.05	4.10
	Lewis	6.95	4.80	4.35	4.20	4.10	3.90	3.90	3.90	3.95	3.65
Stride length (m)	Johnson	1.37	1.89	2.10	2.27	2.32	2.44	2.44	2.47	2.47	2.44
	Lewis	1.44	2.08	2.30	2.38	2.44	2.56	2.56	2.56	2.53	2.74
Stride frequency (m/s)	Johnson	4.22	5.19	4.77	5.05	5.00	4.82	4.82	4.65	4.70	4.71
	Lewis	3.99	4.70	4.58	4.82	4.77	4.53	4.53	4.53	4.65	4.24
Duration of support phases (ms)	Johnson	115	91	85	87	80	80	85	85	83	88
	Lewis	134	100	87	85	83	82	85	82	83	88
Duration of flight phases (ms)	Johnson	86	99	111	113	122	127	122	122	128	138
	Lewis	90	113	121	124	124	133	134	138	135	162
Index of activity (support/flight phase)	Johnson	1.34	0.92	0.76	0.77	0.65	0.63	0.70	0.70	0.65	0.64
	Lewis	1.49	0.88	0.72	0.68	0.67	0.62	0.63	0.59	0.61	0.54

Note: - RD (without reaction time)

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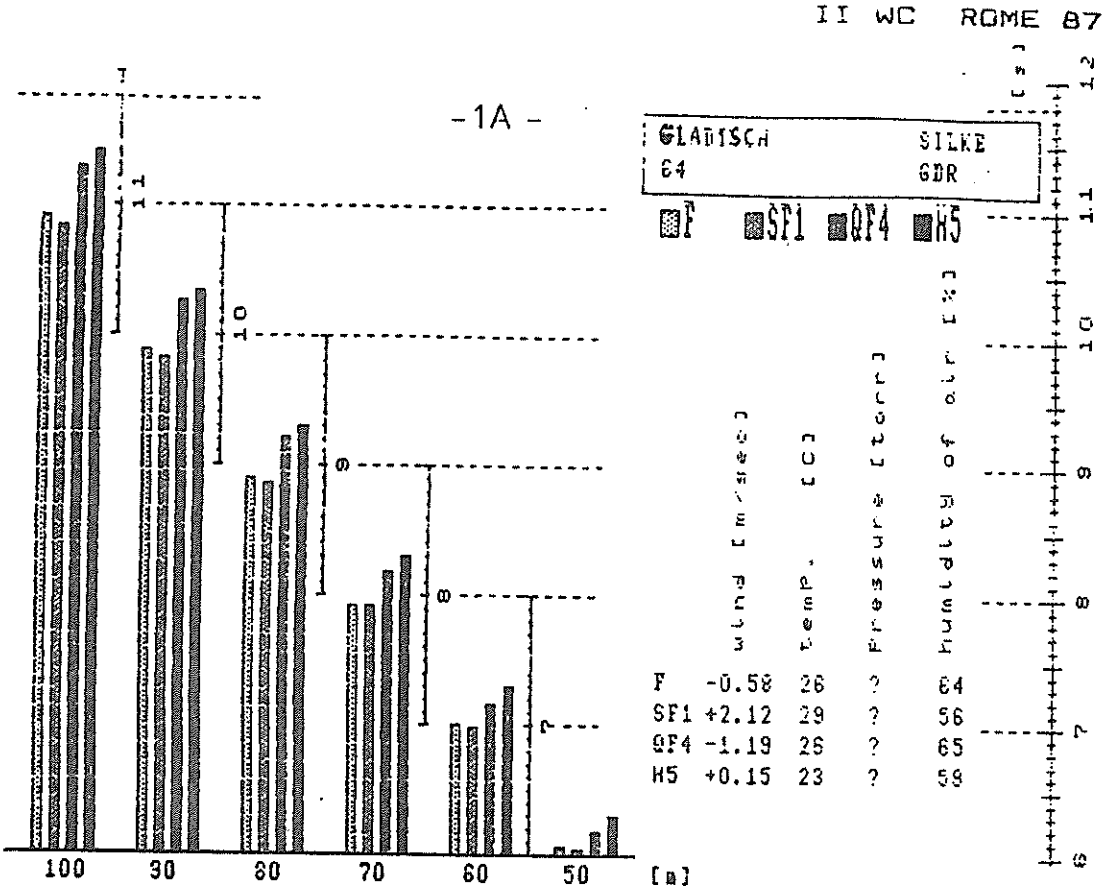
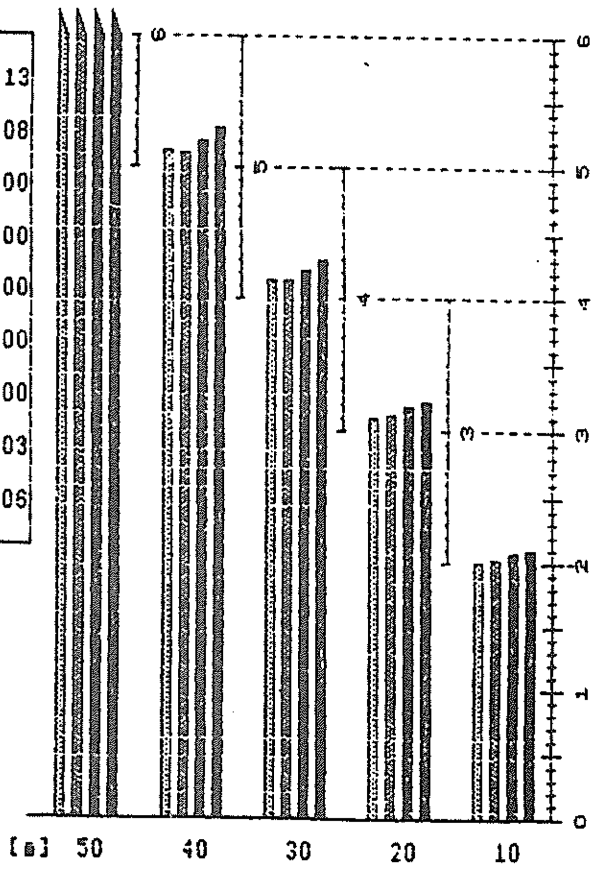
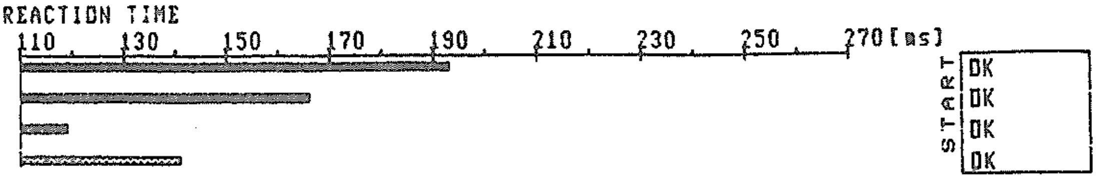


TIME ANALYSIS
100 m W

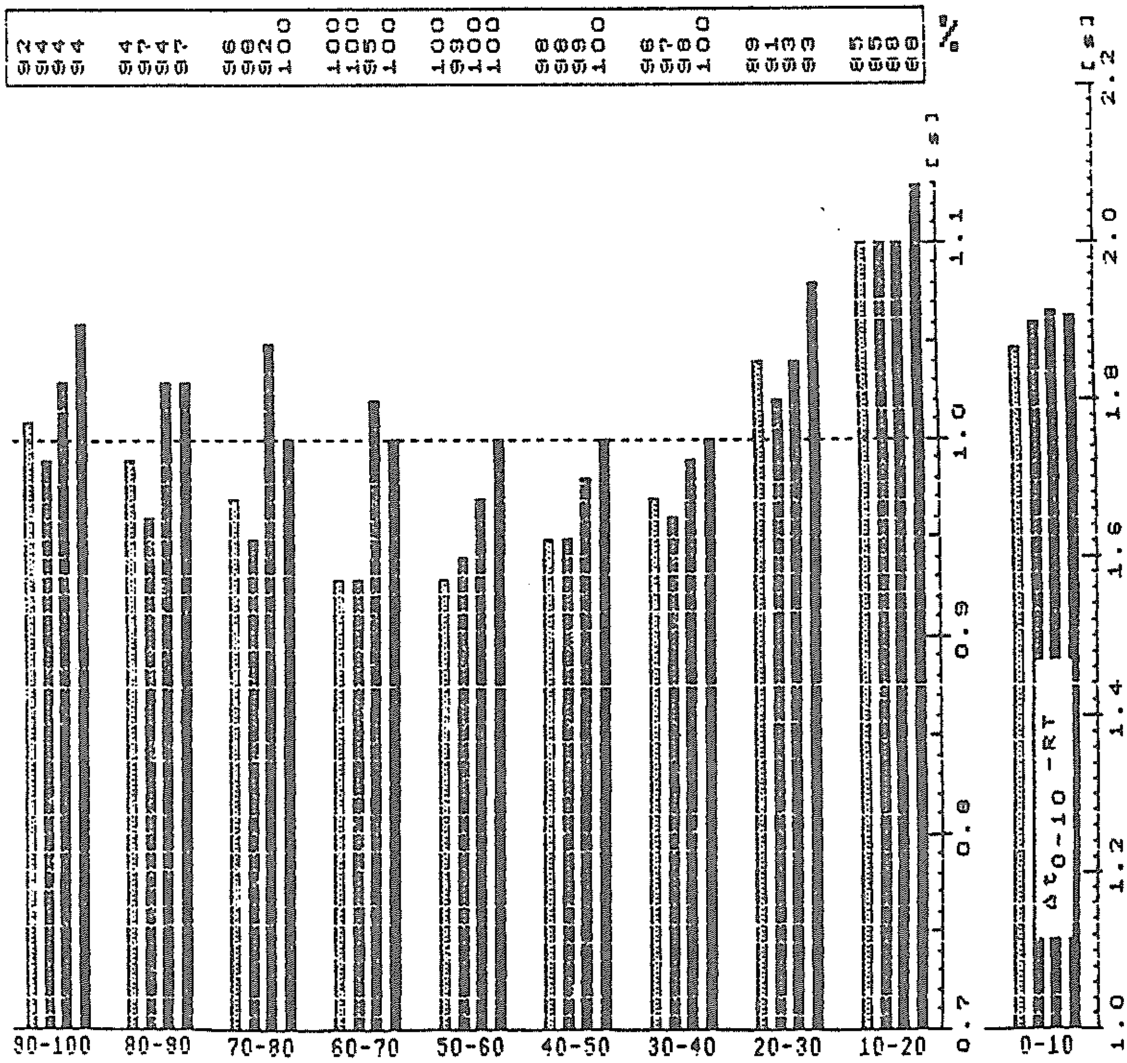
10.	2.01	2.02	2.08	2.10
	1.10	1.10	1.10	1.13
20.	3.11	3.12	3.18	3.23
	1.04	1.02	1.04	1.08
30.	4.15	4.14	4.22	4.31
	0.97	0.96	0.99	1.00
40.	5.12	5.10	5.21	5.31
	0.95	0.95	0.98	1.00
50.	6.07	6.05	6.19	6.31
	0.93	0.94	0.97	1.00
60.	7.00	6.99	7.16	7.31
	0.93	0.93	1.02	1.00
70.	7.93	7.92	8.18	8.31
	0.97	0.95	1.05	1.00
80.	8.90	8.87	9.23	9.31
	0.99	0.96	1.03	1.03
90.	9.89	9.83	10.26	10.34
	1.01	0.99	1.03	1.06
100.	10.90	10.82	11.29	11.40



GLADISCH	SILKE	64	GDR
H5 -11.40 [s]	QF4-11.29 [s]	SF1-10.82 [s]	F -10.90 [s]



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H5 PLACING 2	*	*	*	*	
	*	*	*	*	
	*	*	*	*	1.00 / 30-40
	*	*	*	*	
QF4 PLACING 2	*	*	*	*	
	*	*	*	*	0.97 / 50-60
	*	*	*	*	
	*	*	*	*	
SF1 PLACING 1	0-100	51.8	4.79	1.93	
	*	*	*	*	0.93 / 60-70
	*	*	*	*	
	*	*	*	*	
F PLACING 1	0-100	53	4.86	1.89	0.93 / 50-60
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	



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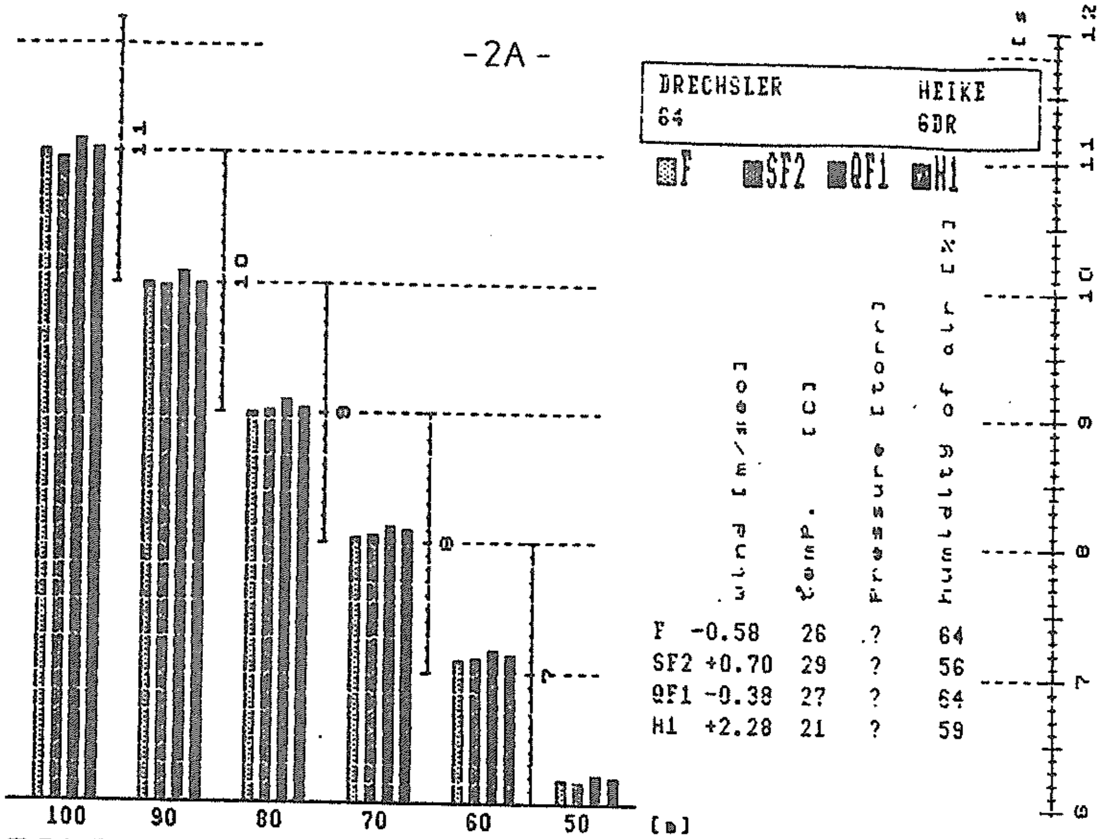
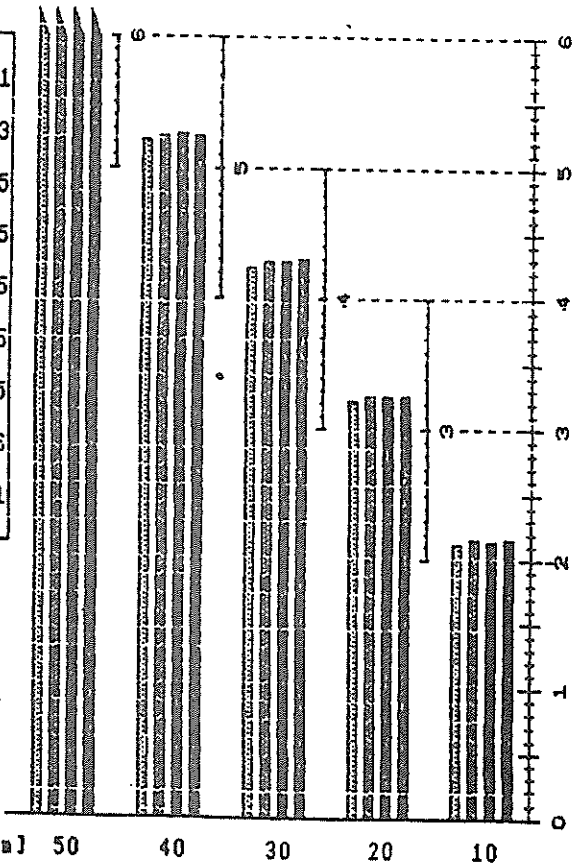
DRECHSLER HEIKE
64 GDR



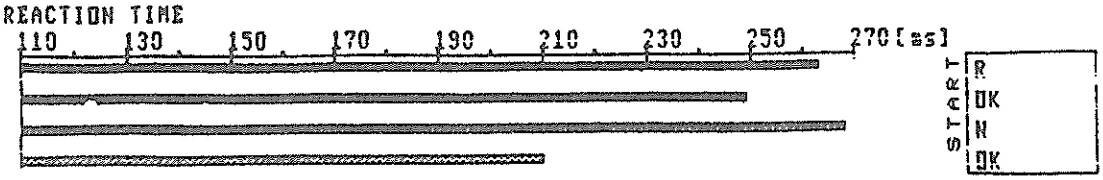
	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	-0.58	26	?	64
SF2	+0.70	29	?	56
QF1	-0.38	27	?	64
H1	+2.28	21	?	59

TIME ANALYSIS
100 m W

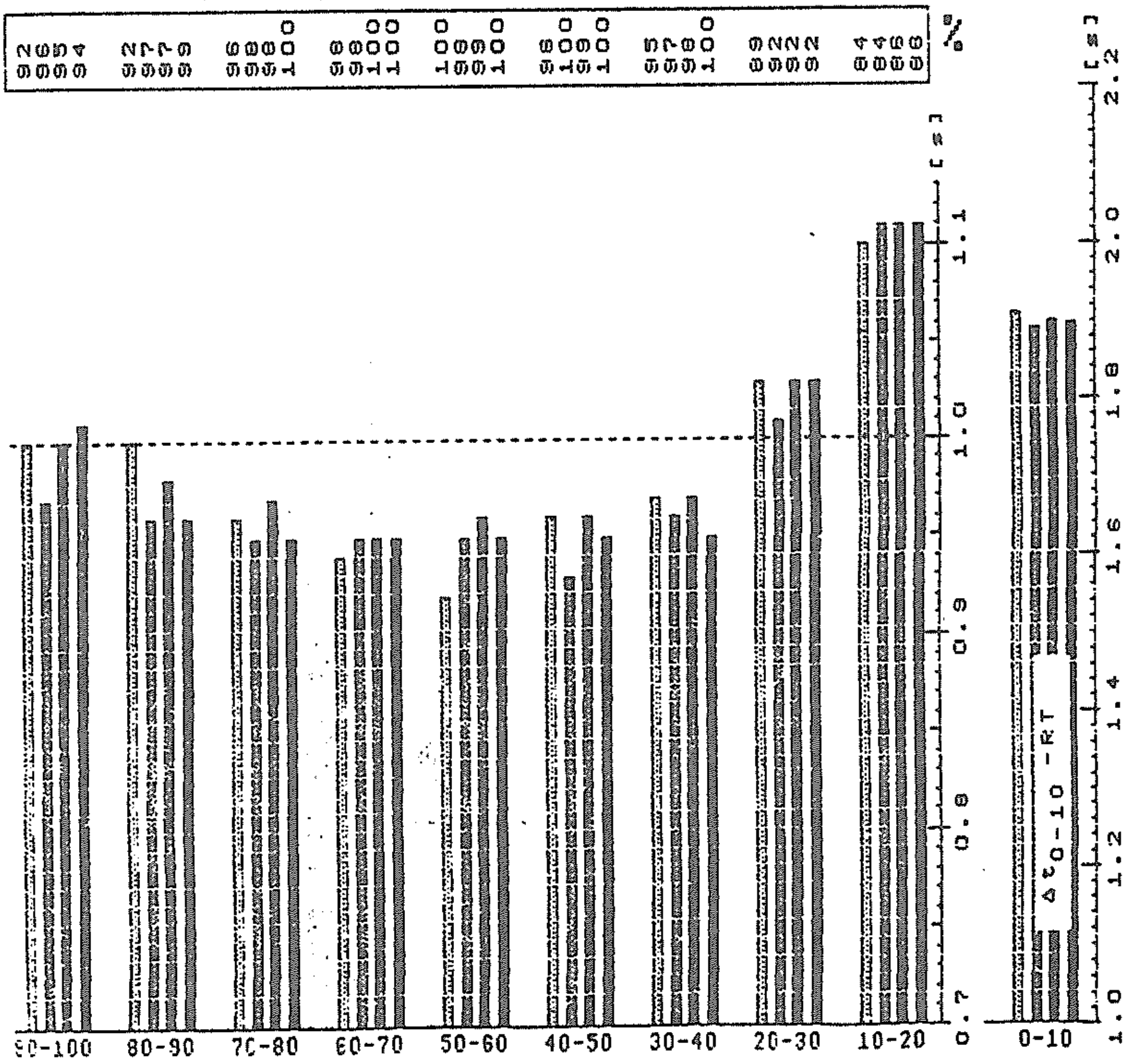
10.	2.12	2.16	2.15	2.16
	1.10	1.11	1.11	1.11
20.	3.22	3.27	3.26	3.27
	1.03	1.01	1.03	1.03
30.	4.25	4.28	4.29	4.3
	0.97	0.96	0.97	0.95
40.	5.22	5.24	5.26	5.25
	0.96	0.93	0.96	0.95
50.	6.18	6.17	6.22	6.2
	0.92	0.95	0.96	0.95
60.	7.10	7.12	7.18	7.15
	0.94	0.95	0.95	0.95
70.	8.04	8.07	8.13	8.10
	0.96	0.95	0.97	0.95
80.	9.00	9.02	9.1	9.05
	1.00	0.96	0.98	0.96
90.	10.00	9.98	10.08	10.01
	1.00	0.97	1.00	1.01
100.	11.00	10.95	11.08	11.02



DRECHSLER	HEIKE	64	GDR
H1 -11.02 [s]	QF1-11.08 [s]	SF2-10.95 [s]	F -11.00 [s]



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H1	*	*	*	*	
	*	*	*	*	0.95 / 30-40
PLACING 1	*	*	*	*	
	*	*	*	*	
QF1	*	*	*	*	
	*	*	*	*	0.95 / 60-70
PLACING 1	*	*	*	*	
	*	*	*	*	
SF2	0-100	46.0	4.20	2.17	
	*	*	*	*	0.93 / 40-50
PLACING 1	*	*	*	*	
	*	*	*	*	
F	0-100	46.8	4.25	2.14	0.92 / 50-60
	*	*	*	*	
PLACING 2	*	*	*	*	
	*	*	*	*	



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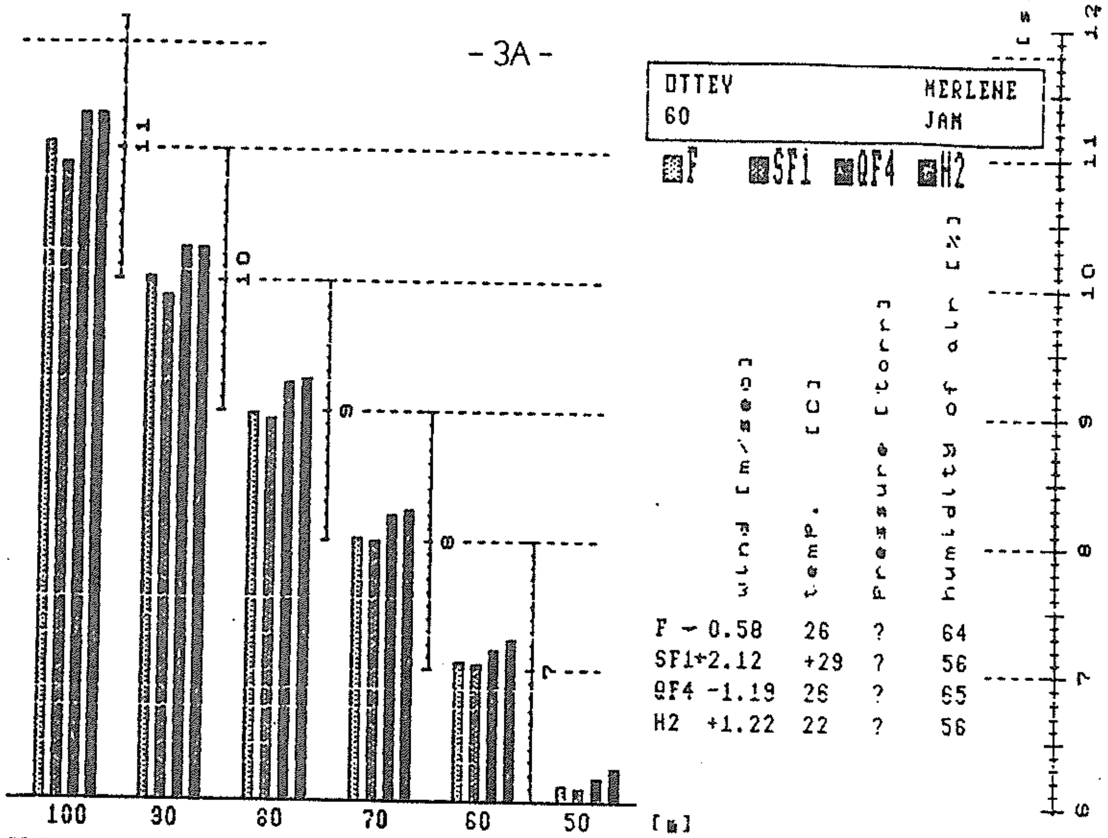
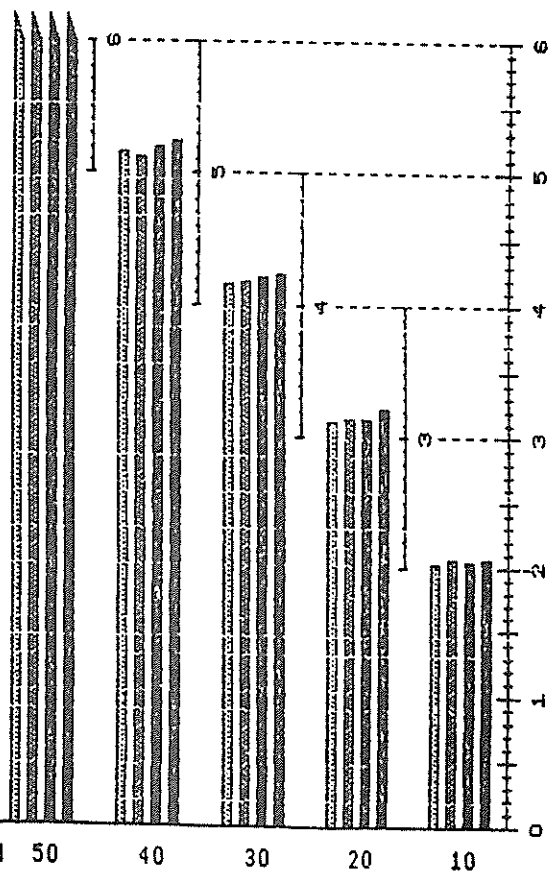
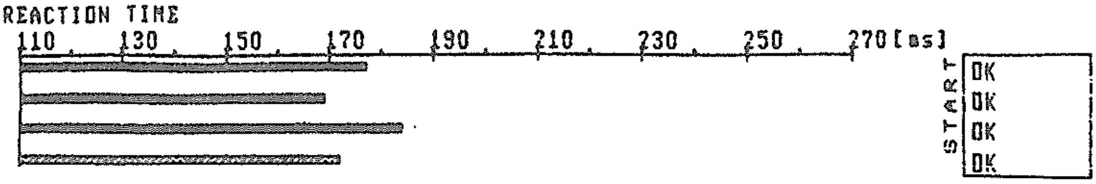


TIME ANALYSIS
100 m W

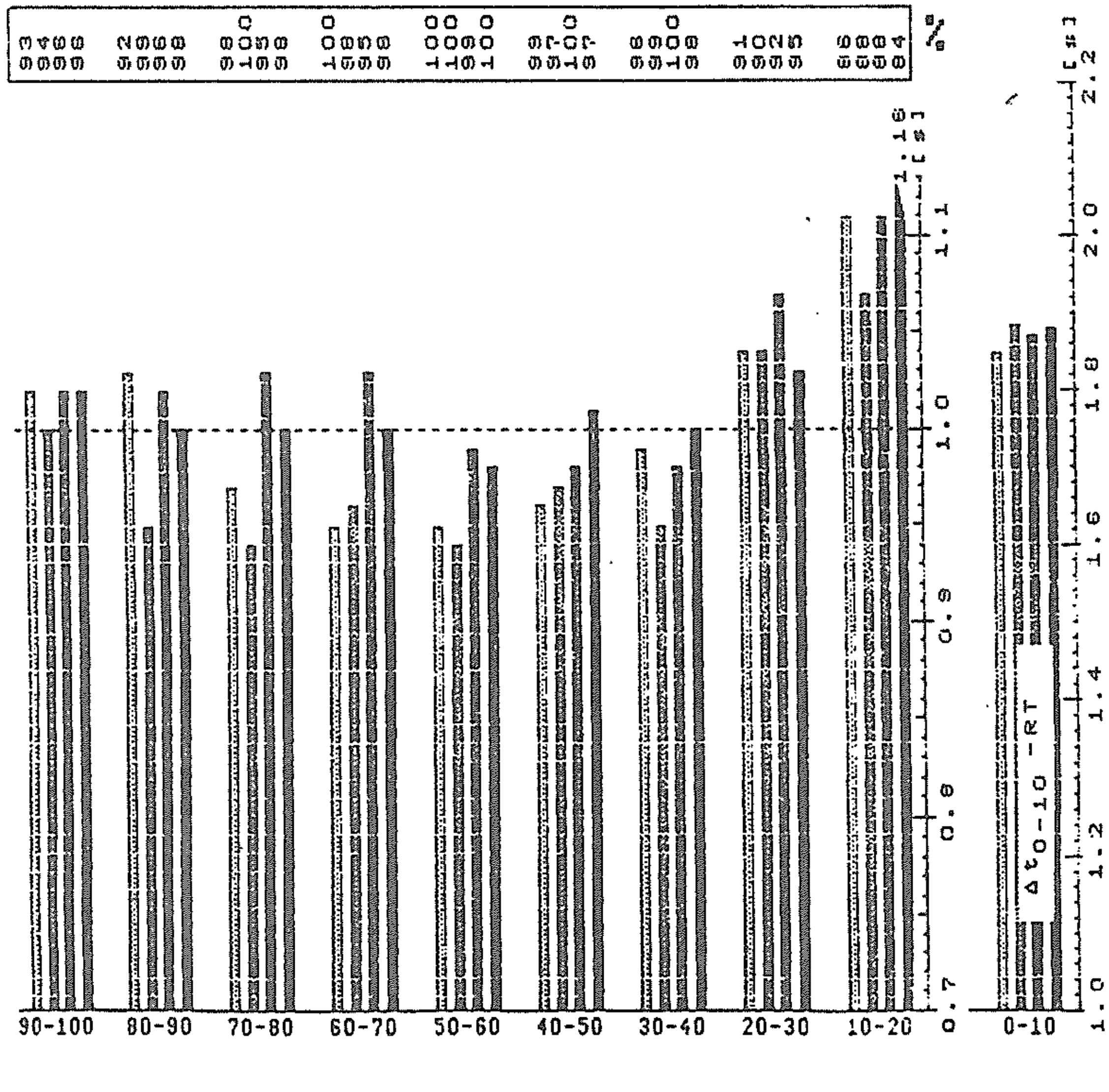
10.	2.02	2.07	2.04	2.06
	1.11	1.07	1.11	1.16
20.	3.13	3.14	3.15	3.22
	1.04	1.04	1.07	1.03
30.	4.17	4.18	4.22	4.25
	0.99	0.95	0.98	1.00
40.	5.16	5.13	5.20	5.25
	0.96	0.97	0.98	1.01
50.	6.12	6.10	6.18	6.26
	0.95	0.94	0.99	0.98
60.	7.07	7.04	7.17	7.24
	0.95	0.96	1.03	1.00
70.	8.02	8.00	8.20	8.24
	0.97	0.94	1.03	1.00
80.	8.99	8.94	9.23	9.24
	1.03	0.95	1.02	1.00
90.	10.02	9.89	10.25	10.24
	1.02	1.00	1.02	1.02
100.	11.04	10.89	11.27	11.26



OTTEY	MERLENE	GO	JAN
H2 -11.26 [s]	QF4-11.27 [s]	SF1-10.89 [s]	F -11.04 [s]

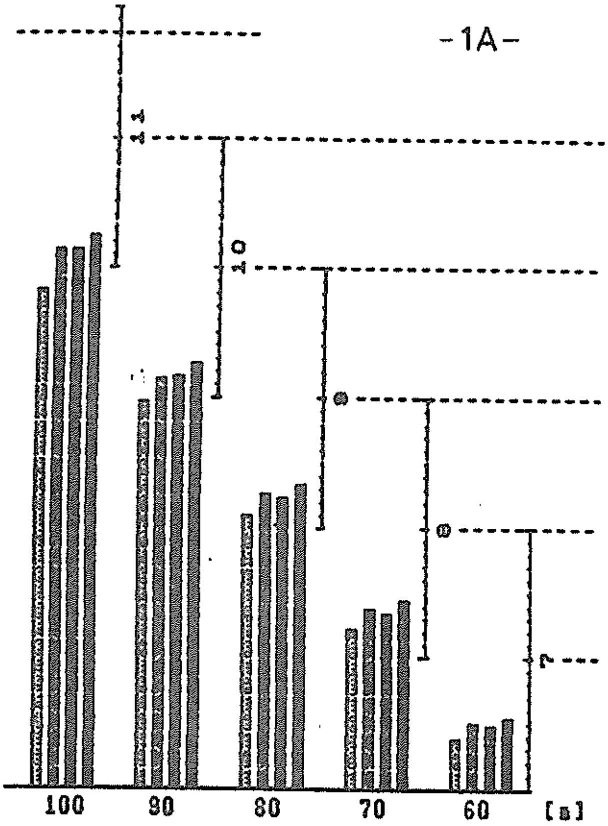


	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H2 PLACING 1	*	*	*	*	
	*	*	*	*	
	*	*	*	*	0.98 / 50-60
	*	*	*	*	
QF4 PLACING 1	*	*	*	*	
	*	*	*	*	
	*	*	*	*	0.98 / 30-40
	*	*	*	*	
SF1 PLACING 2	0-100	46.7	4.29	2.14	
	*	*	*	*	0.94 / 50-60
	*	*	*	*	
	*	*	*	*	
F PLACING 3	0-100	47.1	4.27	2.12	0.95 / 50-60
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	

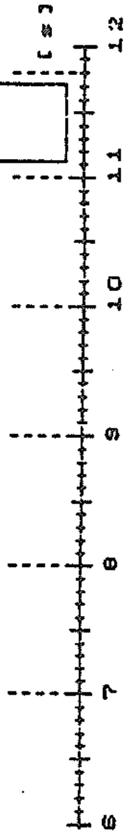


-1A-

JOHNSON	BEN
61	CAN

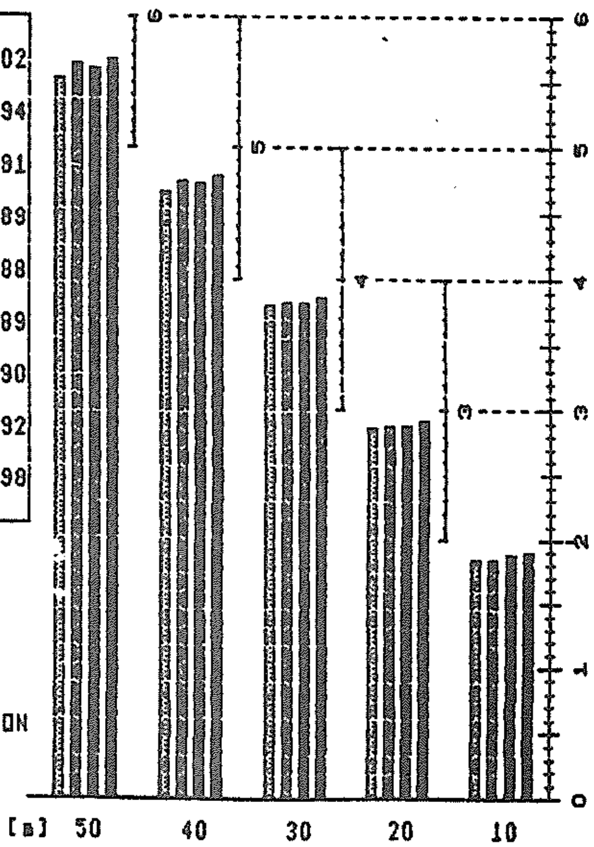


	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	+0.95	26	?	61
SF1	-0.38	30	?	54
QF4	-0.44	26	?	66
H5	+0.52	21	?	66



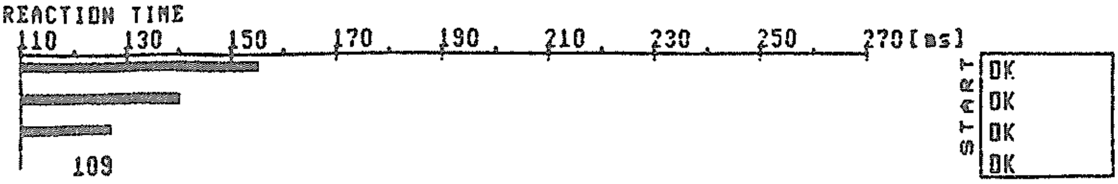
TIME ANALYSIS
100 m MEN

10.	1.84	1.84	1.88	1.91
	1.02	1.04	1.00	1.02
20.	2.86	2.88	2.88	2.93
	0.94	0.95	0.94	0.94
30.	3.80	3.83	3.82	3.87
	0.87	0.92	0.90	0.91
40.	4.67	4.75	4.72	4.78
	0.86	0.89	0.88	0.89
50.	5.53	5.64	5.60	5.67
	0.85	0.87	0.88	0.88
60.	6.38	6.51	6.48	6.55
	0.85	0.87	0.87	0.89
70.	7.23	7.38	7.35	7.44
	0.87	0.88	0.90	0.90
80.	8.10	8.26	8.25	8.34
	0.86	0.89	0.91	0.92
90.	8.96	9.15	9.16	9.26
	0.87	1.00	0.98	0.98
100.	9.83	10.15	10.14	10.24

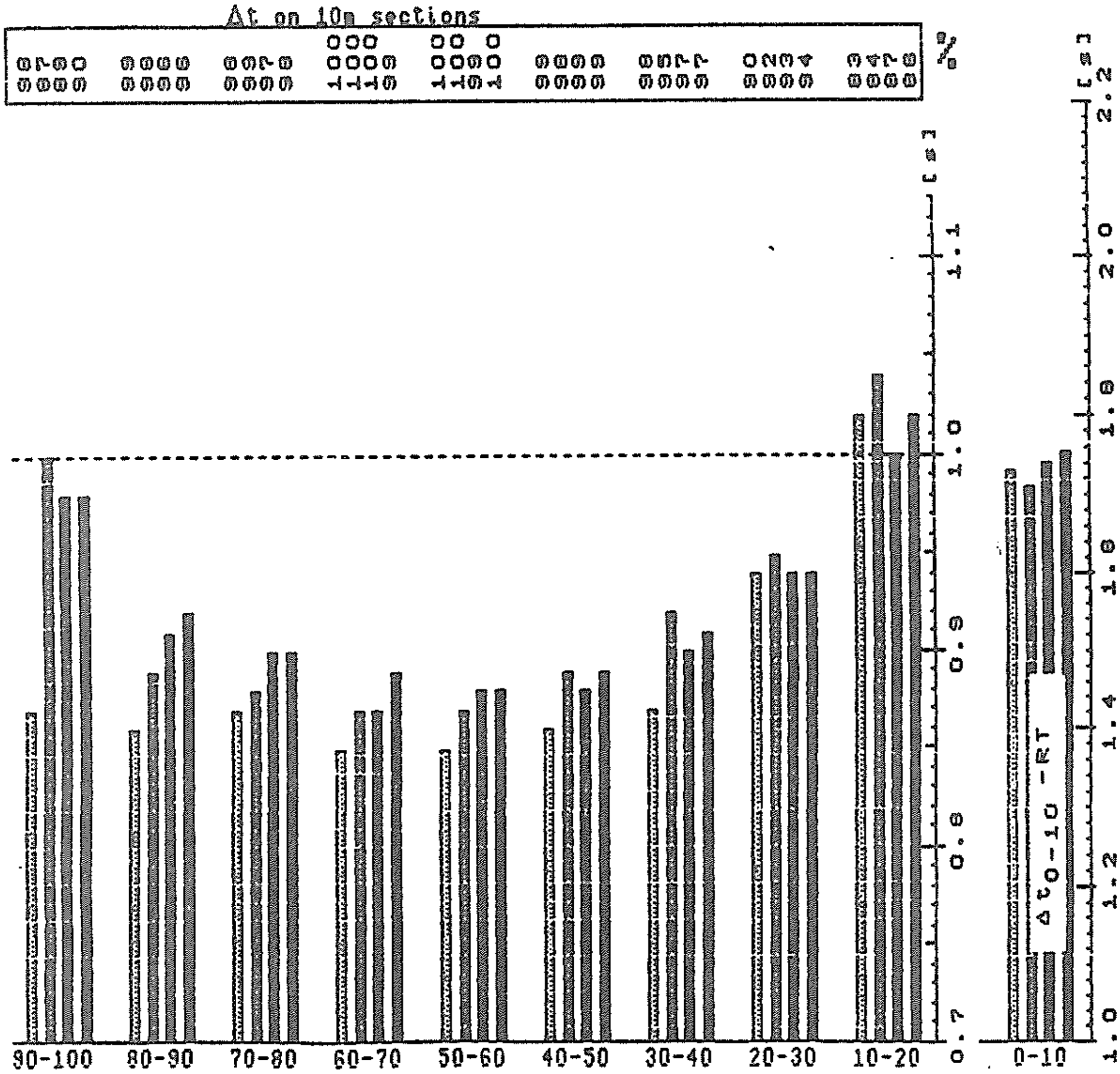


JOHNSON	BEN	61	CAN
H5 -10.24 [s]	QF4-10.14 [s]	SF1-10.15 [s]	F -9.83 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H5	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.88 /50-60
	*	*	*	*	
QF4	*	*	*	*	
	*	*	*	*	0.87 /60-70
PLACING 2	*	*	*	*	
	*	*	*	*	
SF1	0-100	45.5	4.48	2.20	
	*	*	*	*	0.87 /50-60
PLACING 1	*	*	*	*	
	*	*	*	*	
F	0-100	46.2	4.70	2.16	0.85 /50-60
	*	*	*	*	
PLACING 1	*	*	*	*	
	*	*	*	*	



II WC ROME 87

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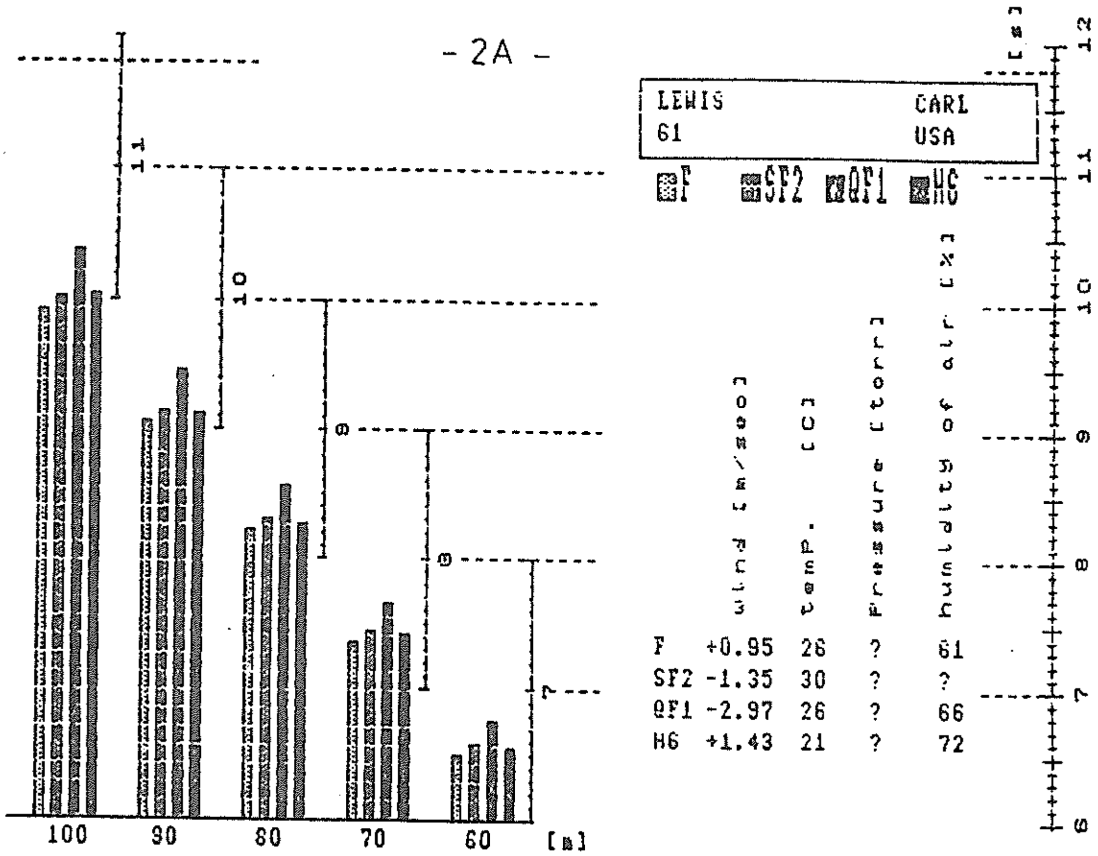
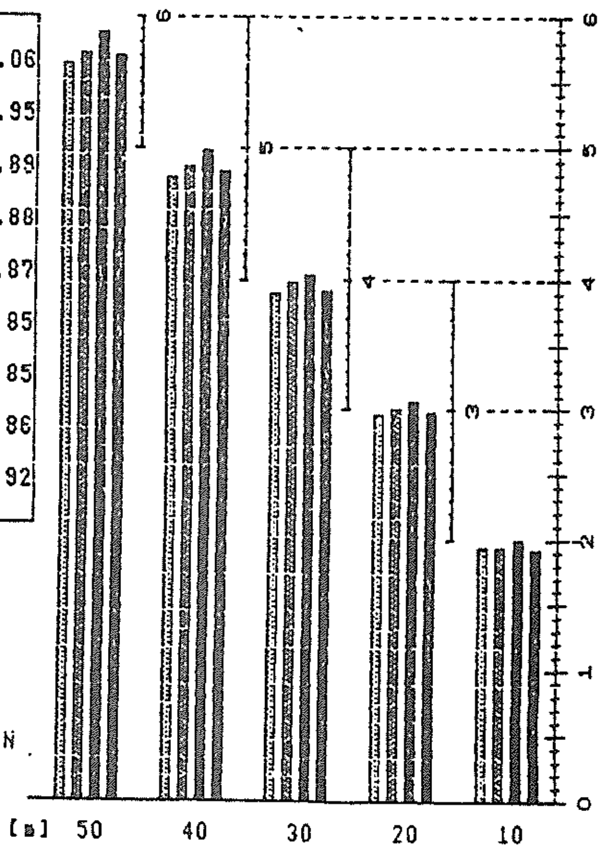


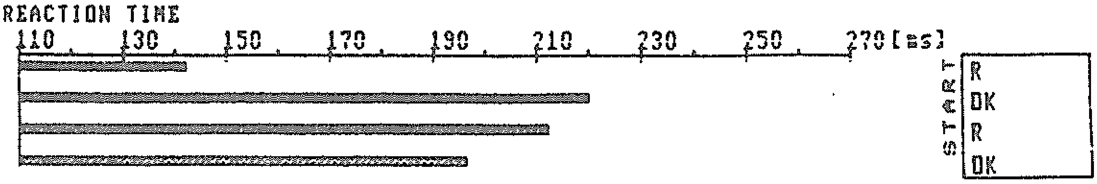
TIME ANALYSIS
100 m MEN

10.	1.94	1.94	2.01	1.92
	1.02	1.06	1.06	1.06
20.	2.96	3.00	3.07	2.98
	0.95	0.98	0.98	0.95
30.	3.91	3.98	4.05	3.93
	0.87	0.88	0.93	0.89
40.	4.78	4.86	4.98	4.82
	0.86	0.87	0.90	0.88
50.	5.64	5.73	5.88	5.70
	0.86	0.86	0.89	0.87
60.	6.50	6.59	6.77	6.57
	0.86	0.85	0.89	0.85
70.	7.36	7.44	7.66	7.42
	0.86	0.86	0.90	0.85
80.	8.22	8.30	8.56	8.27
	0.85	0.85	0.90	0.86
90.	9.07	9.15	9.46	9.13
	0.86	0.88	0.92	0.92
100.	9.93	10.03	10.38	10.05



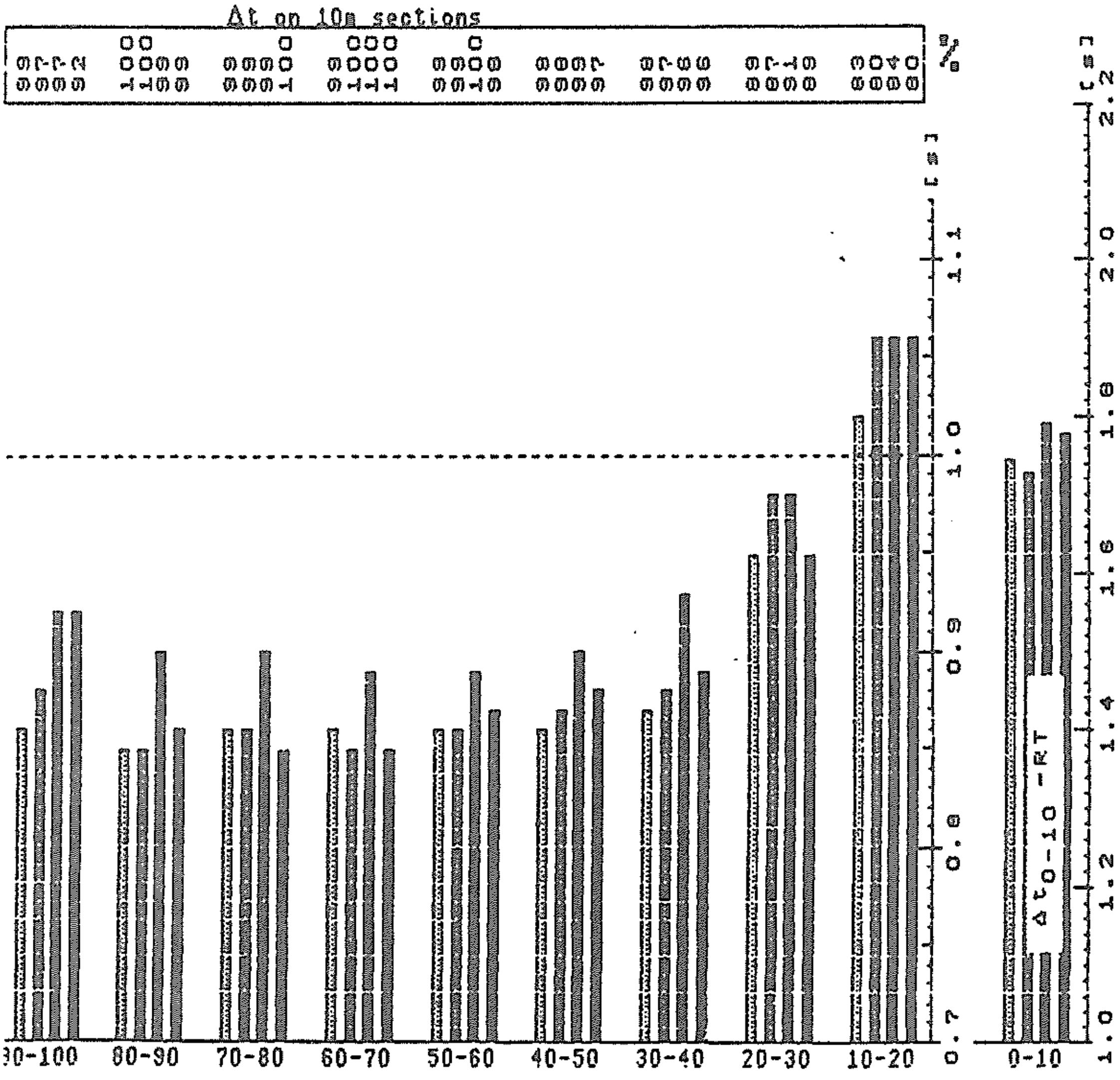
LEWIS	CARL	61	USA
H6 -10.05 [s]	QF1-10.38 [s]	SF2-10.03 [s]	F -9.93 [s]

REACTION TIME

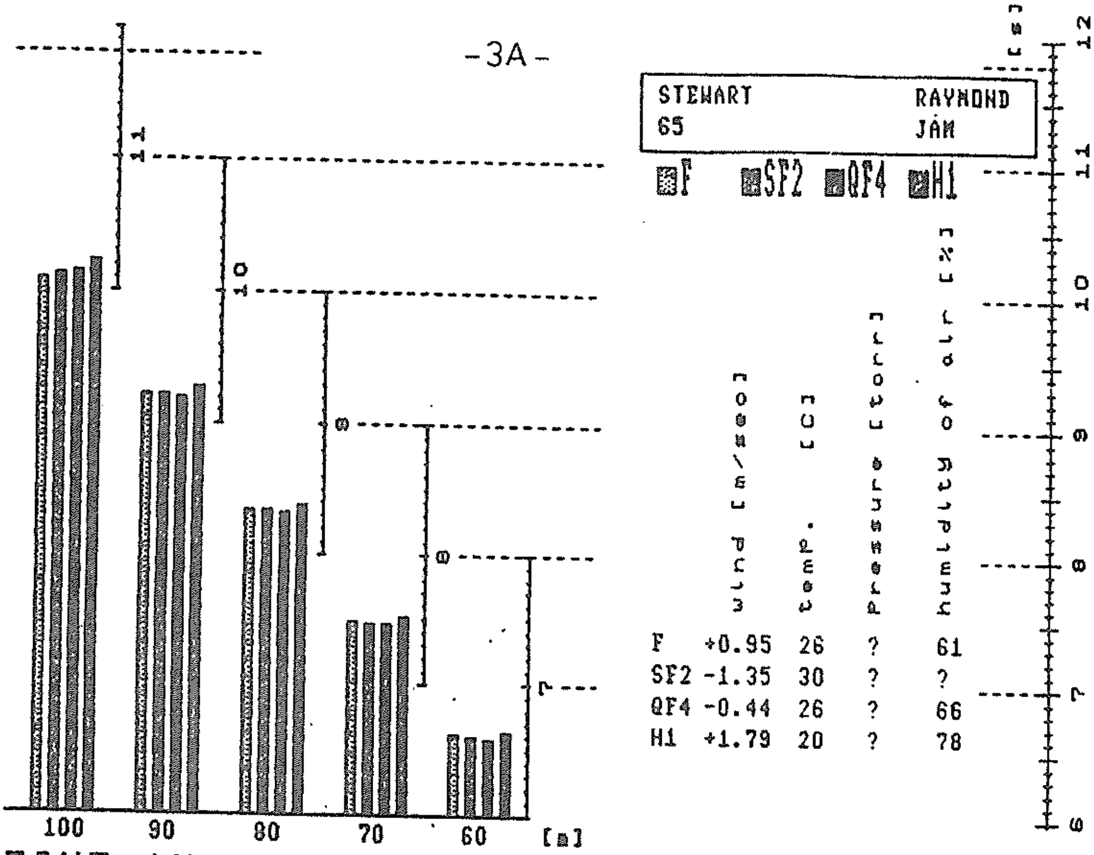


	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H6	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.85 / 60-70
	*	*	*	*	
QF1	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.89 / 50-60
	*	*	*	*	
SF2	0-100	43.6	4.35	2.29	
	*	*	*	*	0.85 / 60-70
PLACING 1	*	*	*	*	
	*	*	*	*	
F	0-100	44.6	4.49	2.24	0.85 / 80-90
	*	*	*	*	
PLACING 2	*	*	*	*	
	*	*	*	*	

Δt on 10m sections



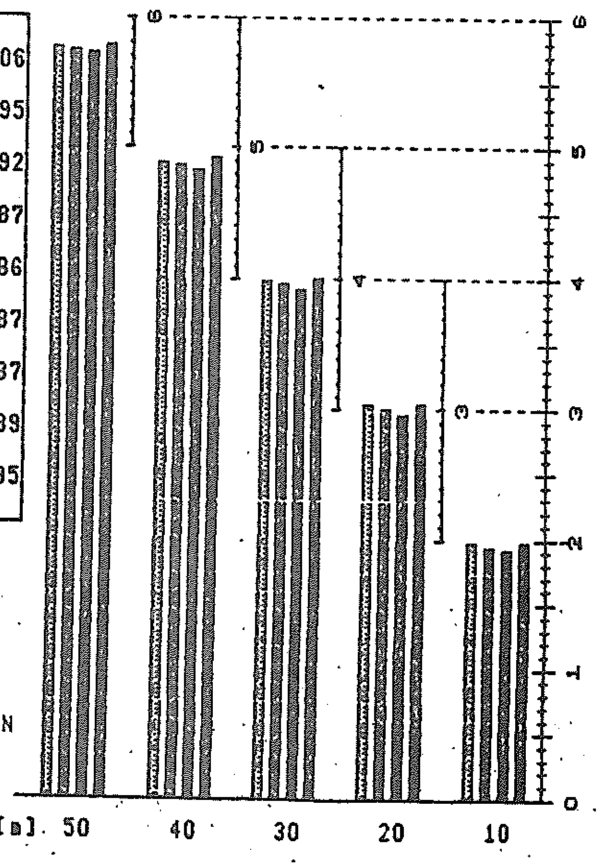
-3A-



	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	+0.95	26	?	61
SF2	-1.35	30	?	?
QF4	-0.44	26	?	66
H1	+1.79	20	?	78

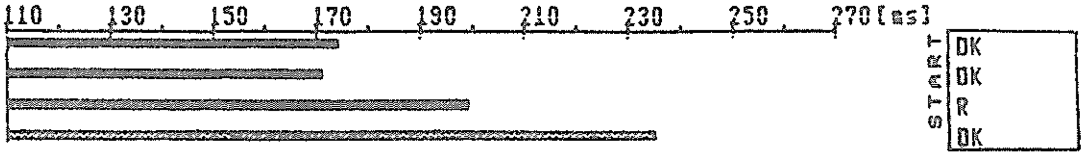
TIME ANALYSIS
100 m MEN

10.	1.99	1.94	1.92	1.99
	1.05	1.06	1.05	1.06
20.	3.04	3.00	2.97	3.05
	0.94	0.96	0.95	0.95
30.	3.98	3.96	3.92	4.00
	0.91	0.90	0.91	0.92
40.	4.89	4.86	4.83	4.92
	0.87	0.88	0.89	0.87
50.	5.76	5.74	5.72	5.79
	0.86	0.86	0.87	0.86
60.	6.62	6.60	6.59	6.65
	0.87	0.87	0.87	0.87
70.	7.49	7.47	7.46	7.52
	0.86	0.88	0.87	0.87
80.	8.35	8.35	8.33	8.39
	0.87	0.88	0.88	0.89
90.	9.22	9.23	9.21	9.28
	0.86	0.89	0.93	0.95
100.	10.08	10.12	10.14	10.23



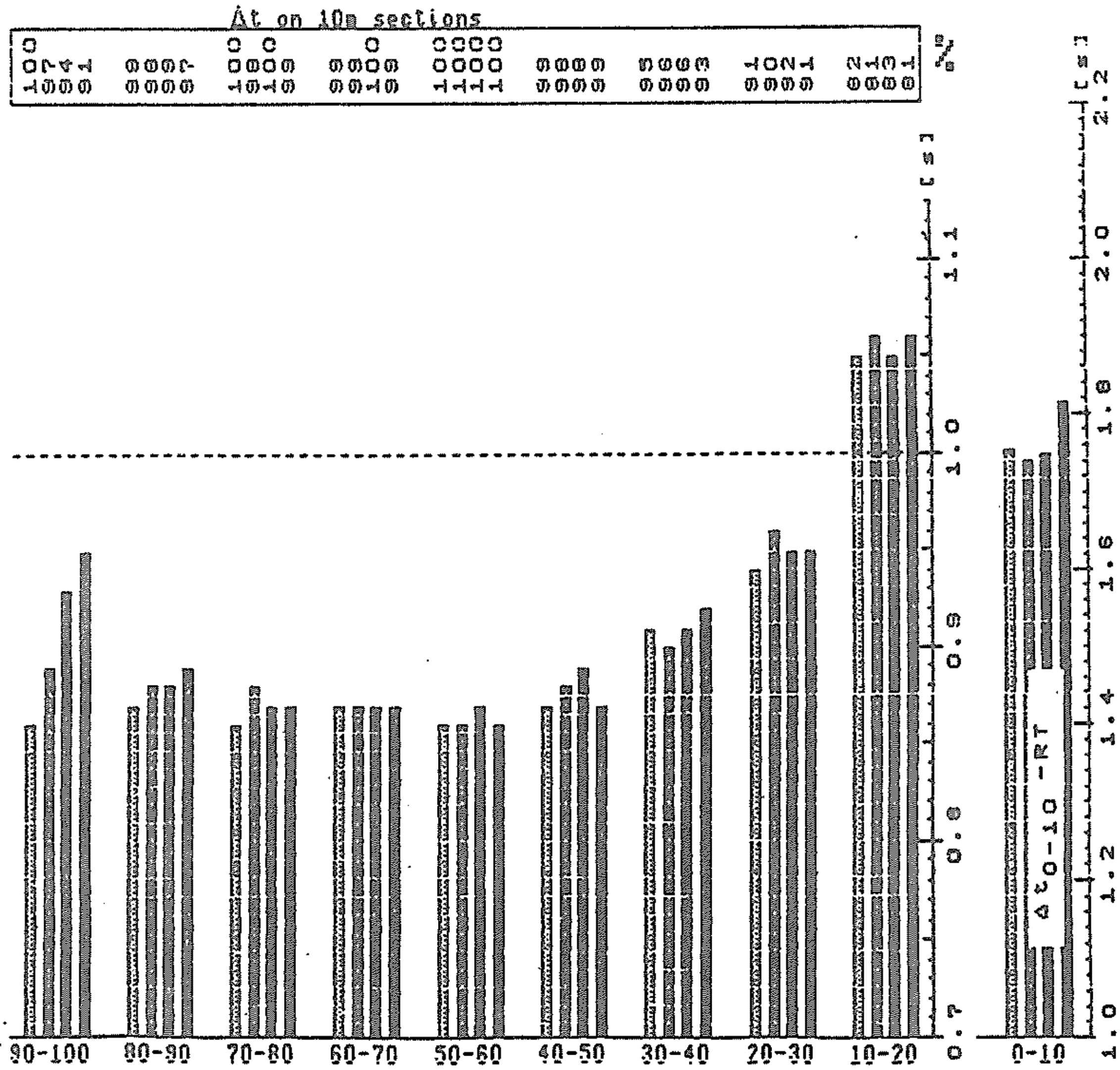
STEWART	RAYMOND	65	JAN
H1 -10.23 [s]	QF4-10.14 [s]	SF2-10.12 [s]	F -10.09 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H1	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.86 / 50-60
	*	*	*	*	
QF4	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.87 / 50-60
	*	*	*	*	
SF2	0-100	44.8	4.43	2.23	0.86 / 50-60
PLACING 2	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
F	0-100	45	4.46	2.22	0.86 / 50-60
PLACING 3	*	*	*	*	
	*	*	*	*	
	*	*	*	*	

Δt on 10m sections



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List of figures :

400 M

1	SCHOENLEBE	GDR	44.33	REPORT
2	EGBUNIKE	NGR	44.56	REPORT
3	REYNOLDS	USA	44.80	REPORT
4	HERNANDEZ	CUB	44.99	APPENDIX
5	REDMOND	GBR	45.06	APPENDIX
6	KITUR	KEN	45.34	APPENDIX
7	TIACOH	CIV	46.27	APPENDIX
8	HALEY	USA	46.77	APPENDIX

1	BRYZGINA	URS	49.38	REPORT
2	MUELLER	GDR	49.94	REPORT
3	EMMELMANN	GDR	50.20	REPORT
4	PINIGINA	URS	50.53	APPENDIX
5	LEATHERWOOD	USA	50.82	APPENDIX
6	RICHARDSON	CAN	51.03	APPENDIX
7	DIXON	USA	51.13	APPENDIX
8	NAZAROVA	URS	51.20	APPENDIX

B

TIME ANALYSIS OF THE SPRINTS

Moravec, P.; Růžička, J.; Dostál, E.; Sušanka, P.;
Kodejš, M.; Nosek, M.

CONTENTS

1. INTRODUCTION

The improving performance trends in the sprint events (see FIG. 1-6) are to some extent the result of improved starting and running techniques.

The improvement of the performance level can be demonstrated by the best performances in each year and by the mean of the first 3 and 10 best performances in the period 1960-88. The best way of showing the continuous improvement is by the 10-best average. Only in women's 400 m has the level stagnated, as a result of the retirement of KOCH, KRATOCHVILOVA and others from competitive running.

To provide better orientation before the final year of the Olympic preparation we present the unofficial statistics of the best world performances up to the 15th October 1987, and the differences between the performance achieved at the II World Championships in Athletics in Rome and that achieved during 1987 before the WC (see the last paragraph of TAB. 1-6).

The table indicates which athletes (with what kind of performances) may have a chance to make their mark in top world events like OG, WC, EC, i.e. the performance levels that may be expected to ensure qualifying for the semifinal or final (TAB. 1-6 in the Appendix).

FINAL 100 m 30/8 - 18.40

(+ 0.95 m/s)

1. 145	Johnson Ben	61	CAN	9.83 WR CR
2. 1053	Lewis Carl	61	USA	9.93
3. 624	Stewart Raymond	65	JAM	10.08
4. 421	Christie Linford	60	GBR	10.14
5. 541	Kovacs Attila	60	HUN	10.20
6. 947	Bryzgin Viktor	62	URS	10.25
7. 1062	Mc Rae Lee	66	USA	10.34
8. 601	Pavoni Pierfrancesco	63	ITA	16.23

Ore/Time 18:40 — Temp.: +26 °C
Press.: 1017 mBar — Umidità/Humidity: 61%

30/8 - 19.00

(- 0.58 m/s)

1. 292	Gladisch Silke	64	GDR	10.90 CR
2. 287	Drechsler Heike	64	GDR	11.00
3. 403	Ottey Merlene	60	JAM	11.04
4. 669	Williams Diane	60	USA	11.07
5. 88	Issajenko Angella	58	CAN	11.09
6. 70	Nouneva Anelia	62	BUL	11.09
7. 78	Bailey Angela	62	CAN	11.18
8. 645	Marshall Pam	60	USA	11.19

Ore/Time 19:00 — Temp.: +26 °C
Press.: 1017 mBar — Umidità/Humidity: 64%

FINAL 200 m 3/9 - 18.25

(- 0.49 m/s)

1. 1083	Smith Calvin	61	USA	20.16
2. 342	Queneherve Gilles	66	FRA	20.16
3. 446	Regis John	66	GBR	20.18
4. 86	Da Silva Robson Caetano	64	BRA	20.22
5. 971	Krylov Vladimir	64	URS	20.23
6. 1045	Heard Floyd	66	USA	20.25
7. 601	Pavoni Pierfrancesco	63	ITA	20.45
8. 151	Mahorn Atlee	65	CAN	20.78

Ore/Time 18:25 — Temp.: +26 °C
Press.: 1012 mBar — Umidità/Humidity: 68%

3/9 - 18.10

(+1.16 m/s)

1. 292	Gladisch Silke	64	GDR	21.74 CR
2. 631	Griffith Florence	59	USA	21.96
3. 403	Ottey Merlene	60	JAM	22.06
4. 645	Marshall Pam	60	USA	22.18
5. 661	Torrence Gwen	65	USA	22.40
6. 447	Onyali Mary	68	NGR	22.52
7. 467	Kasprzyk Ewa	57	POL	22.52
8. 60	Georgieva Nadejda	61	BUL	22.55

Ore/Time 18:10 — Temp.: +26 °C
Press.: 1012 mBar — Umidità/Humidity: 70%

FINAL 400 m 3/9 - 17.20

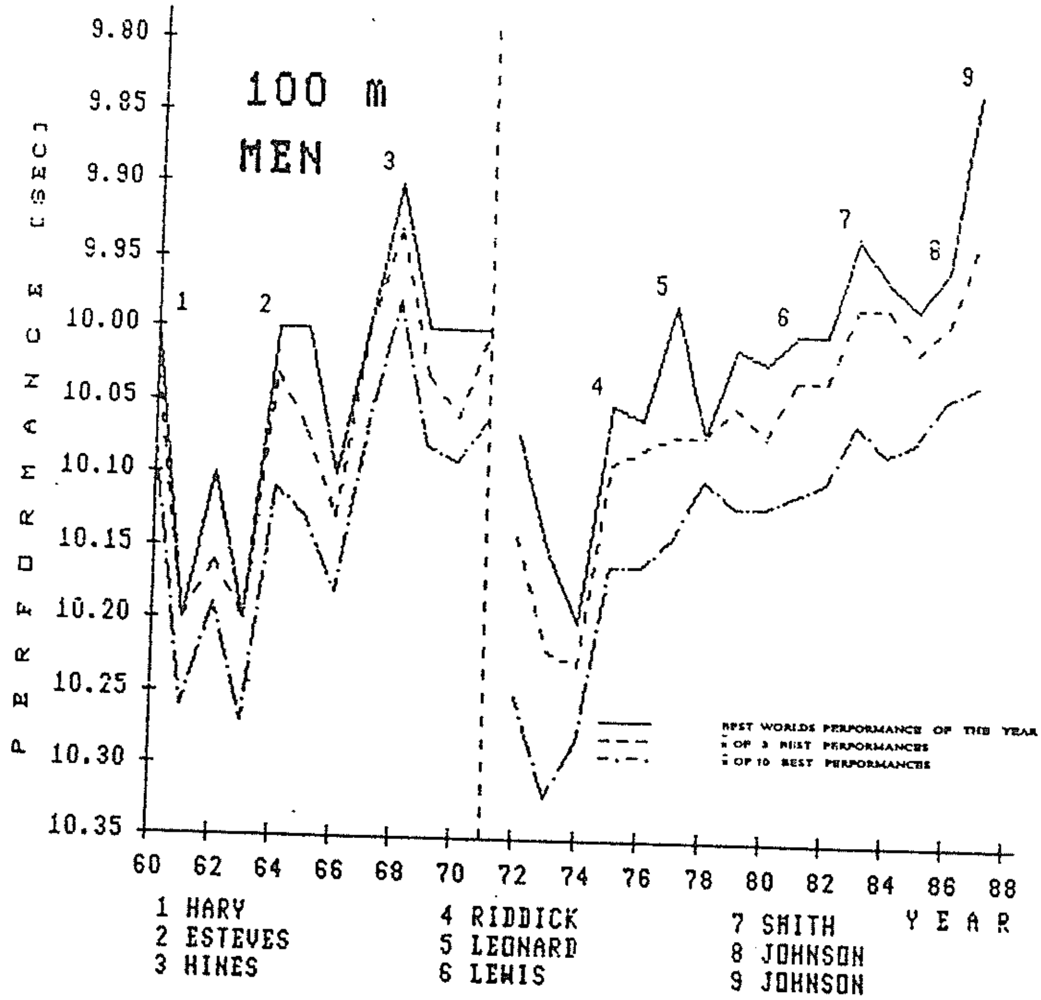
1. 485	Schoenlebe Thomas	65	GDR	44.33
2. 716	Egbunike Innocent	61	NGR	44.56
3. 1078	Reynolds Harry	64	USA	44.80
4. 206	Hernandez Roberto	67	CUB	44.99
5. 445	Redmond Derek	65	GBR	45.06
6. 657	Kitur David	62	KEN	45.34
7. 190	Tiacoh Gabriel	63	CIV	46.27
8. 1043	Haley Roddie	65	USA	46.77

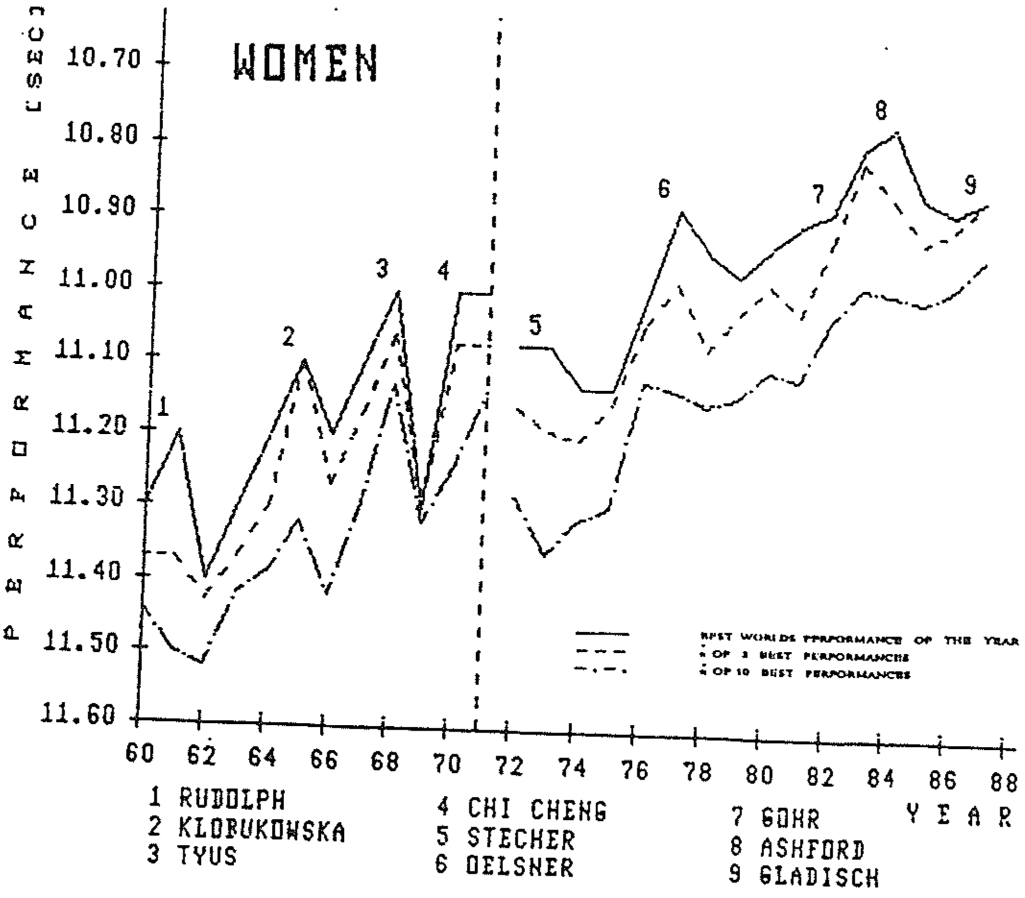
Ore/Time 17:22 — Temp.: +28 °C
Press.: 1012 mBar — Umidità/Humidity: 67%

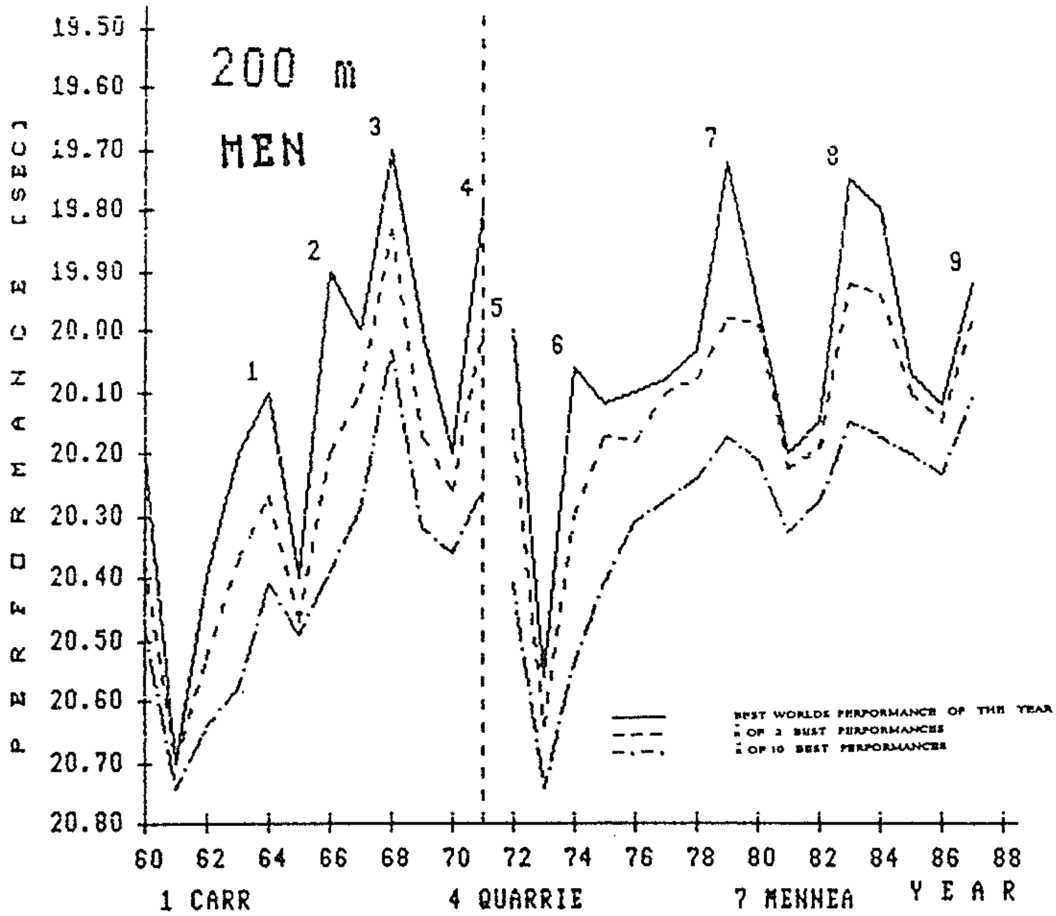
31/8 - 18.00

1. 557	Bryzgina Olga	63	URS	49.38
2. 305	Mueller Petra	65	GDR	49.94
3. 288	Emmelmann Kirsten	61	GDR	50.20
4. 589	Pinigina Maria	58	URS	50.53
5. 643	Leatherwood-King Lillie	64	USA	50.82
6. 99	Richardson Jillian	65	CAN	51.03
7. 625	Dixon Diane	64	USA	51.13
8. 584	Nazarova Olga	65	URS	51.20

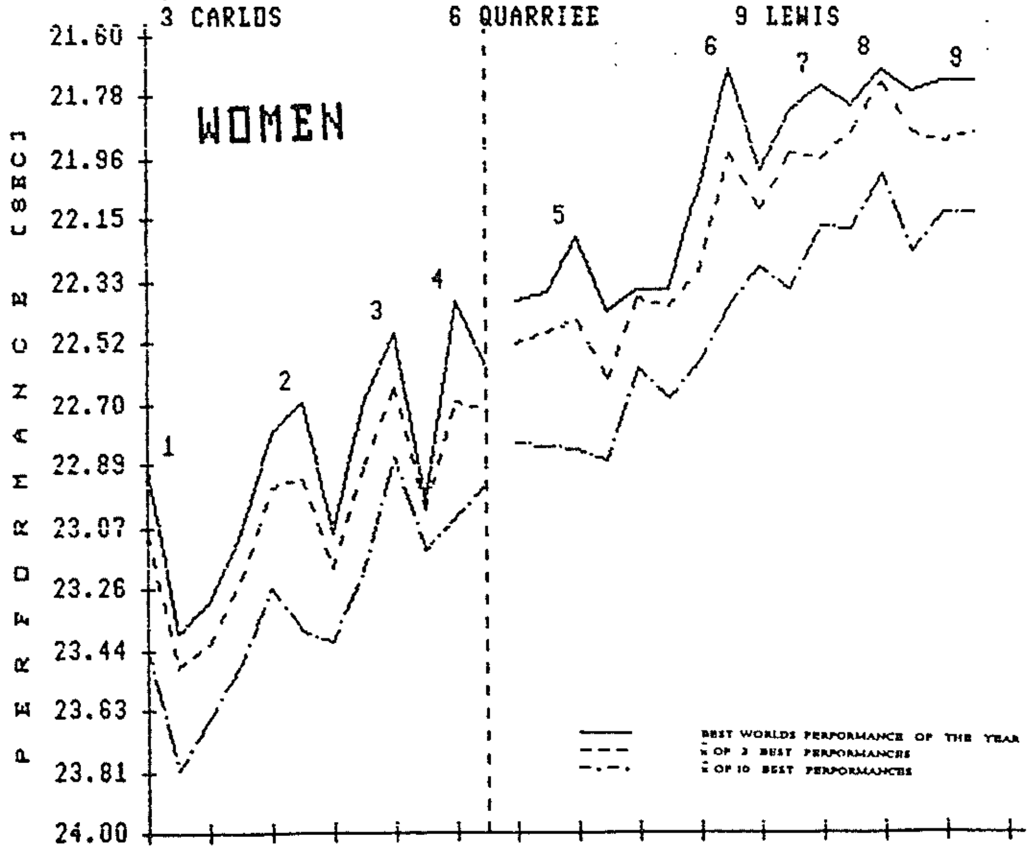
Ore/Time 18:00 — Temp.: +28 °C
Press.: 1017 mBar — Umidità/Humidity: 49%


100 m
MEN
PERFORMANCE [SEC]
9.80
9.85
9.90
9.95
10.00
10.05
10.10
10.15
10.20
10.25
10.30
10.35
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
YEAR
BEST WORLDS PERFORMANCE OF THE YEAR
OF 3 BEST PERFORMANCES
OF 10 BEST PERFORMANCES
1 HARY
2 ESTEVES
3 HINES
4 RIDDICK
5 LEONARD
6 LEWIS
7 SMITH
8 JOHNSON
9 JOHNSON

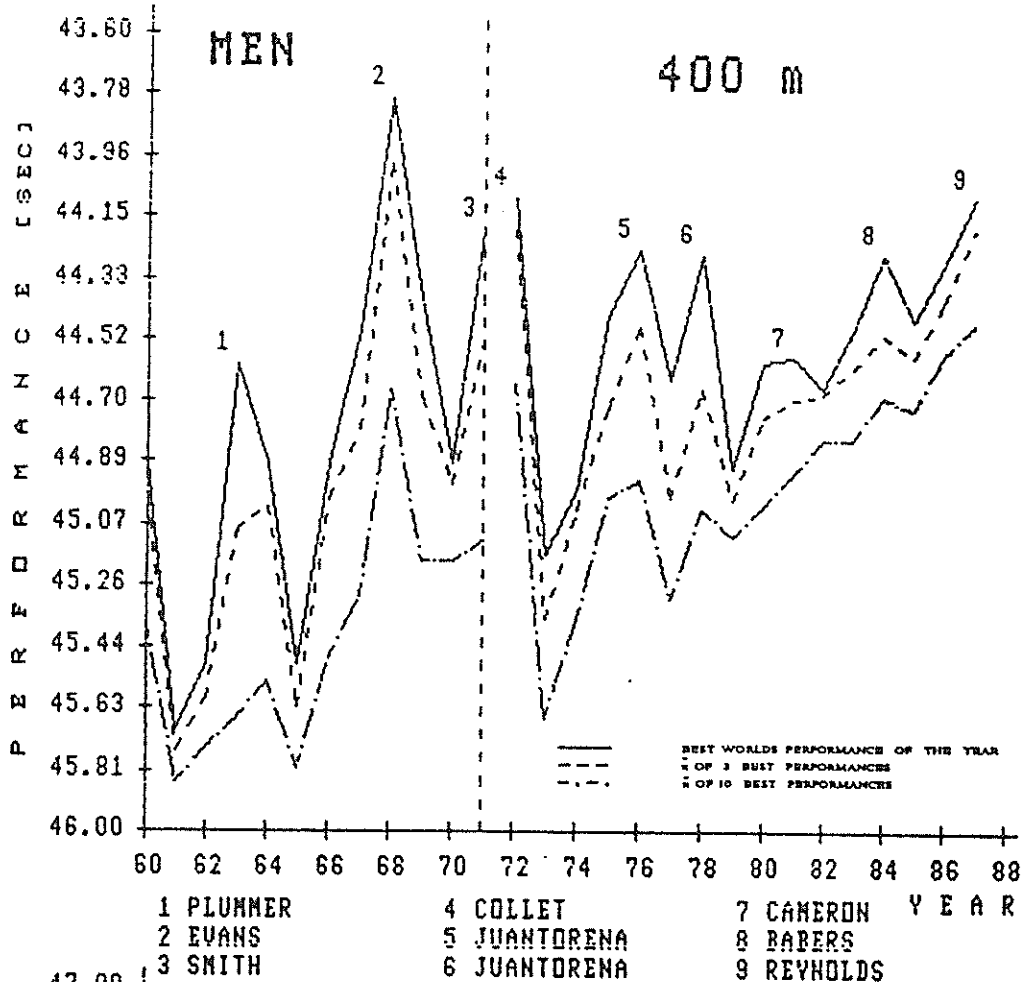

WOMEN
PERFORMANCE [SEC]
10.70
10.80
10.90
11.00
11.10
11.20
11.30
11.40
11.50
11.60
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
YEAR
BEST WORLDS PERFORMANCE OF THE YEAR
OF 3 BEST PERFORMANCES
OF 10 BEST PERFORMANCES
1 RUDOLPH
2 KLOBUKOWSKA
3 TYUS
4 CHI CHENG
5 STECHER
6 OELSNER
7 GOHR
8 ASHFORD
9 GLADISCH

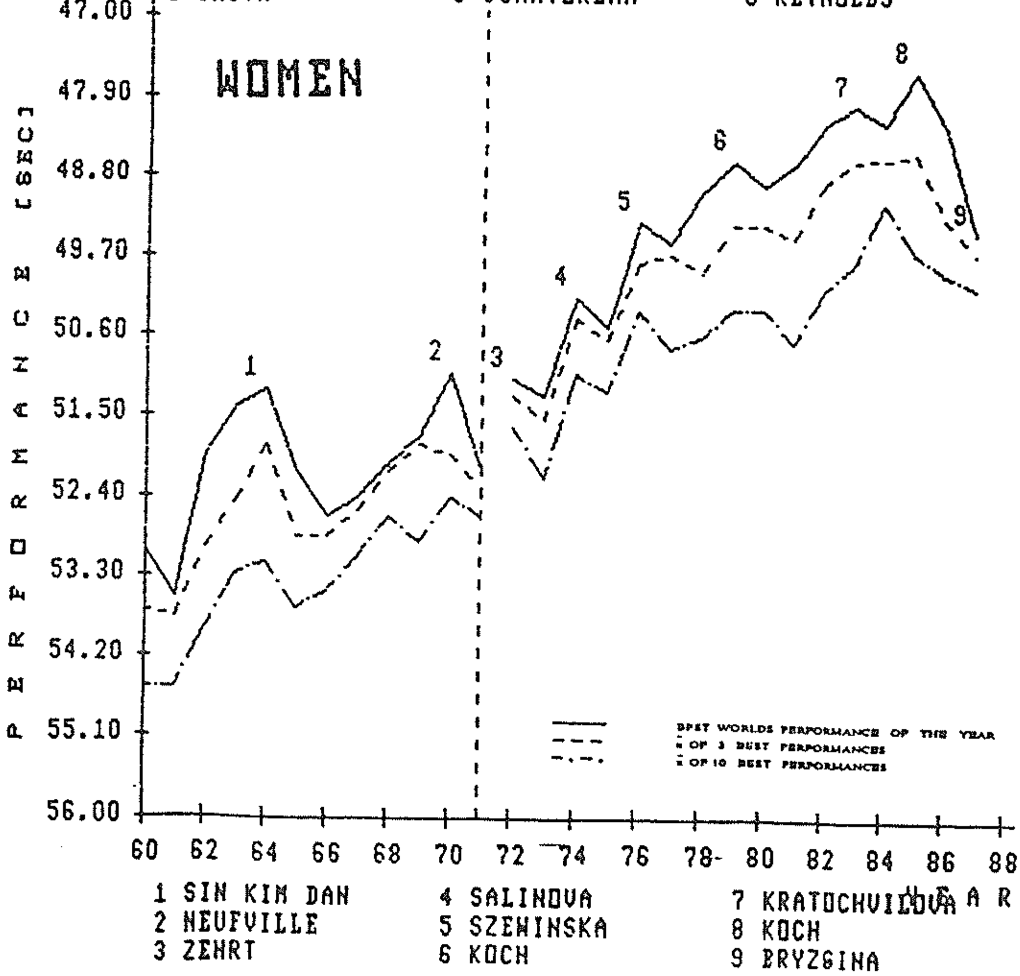


1 CARR
2 SMITH
3 CARLOS
4 QUARRIE
5 BORZOV
6 QUARRIEE
7 MENNEA
8 LEWIS
9 LEWIS



1 RUDOLPH
2 KIRSZENSTEIN
3 SZEWINSKA
4 CHI CHENG
5 SZEWINSKA
6 KOCH
7 KOCH
8 KOCH
9 GLADISCH


MEN
400 m
PERFORMANCE [SEC]
43.60
43.78
43.96
44.15
44.33
44.52
44.70
44.89
45.07
45.26
45.44
45.63
45.81
46.00
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
YEAR
BEST WORLDS PERFORMANCE OF THE YEAR
x̄ OF 3 BEST PERFORMANCES
x̄ OF 10 BEST PERFORMANCES
1 PLUMMER
2 EVANS
3 SMITH
4 COLLET
5 JUANTORENA
6 JUANTORENA
7 CAMERON
8 BABERS
9 REYNOLDS


WOMEN
PERFORMANCE [SEC]
47.00
47.90
48.80
49.70
50.60
51.50
52.40
53.30
54.20
55.10
56.00
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
YEAR
BEST WORLDS PERFORMANCE OF THE YEAR
x̄ OF 3 BEST PERFORMANCES
x̄ OF 10 BEST PERFORMANCES
1 SIN KIM DAN
2 NEUFVILLE
3 ZEHRT
4 SALINOVA
5 SZEWINSKA
6 KOCH
7 KRATOCHVILOVA
8 KOCH
9 BRYZGINA

2. METHODS AND PROCEDURES

Time analysis of sprint events was made on the basis of videorecordings made by 6 videocameras. Their location was determined by the character of each of the events (see FIG.7).

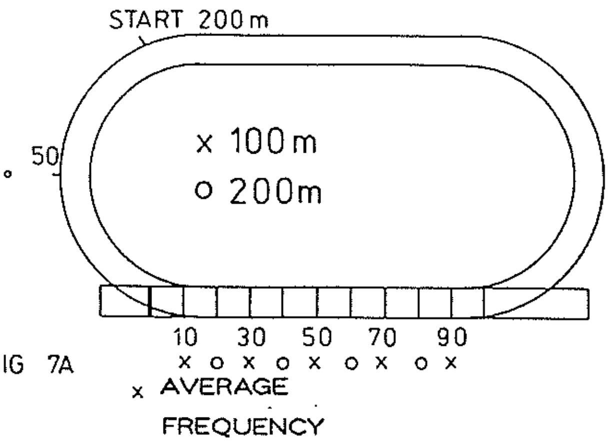


FIG 7A

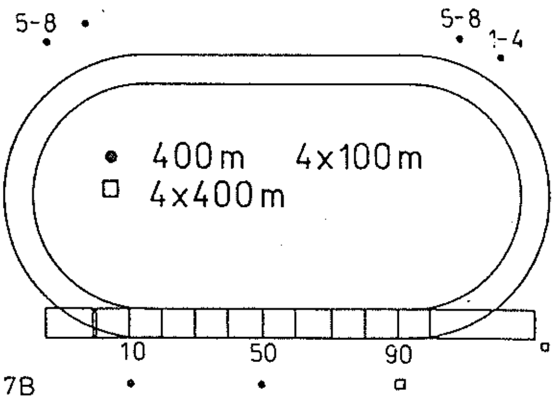


FIG 7B

Time synchronisation was ensured by a videorecording of the starter's gun.

Time analysis of 450 individuals was made:

- in the 100 m	91 men and 90 women
- in the 200 m	102 men and 53 women
- in the 400 m	67 men and 47 women.

In this report, the results are given for all the rounds of each athlete who qualified for the semifinal and final races.

In addition, the semifinal and final were filmed by synchronized Photosonics 500 high-speed cameras with a frequency of 200/100/frames/sec. The location of the cameras (see FIG. 8) enables 3-D analysis on the home straight (100 m and final 100 m of the 200 m).

POSITION OF CAMERAS

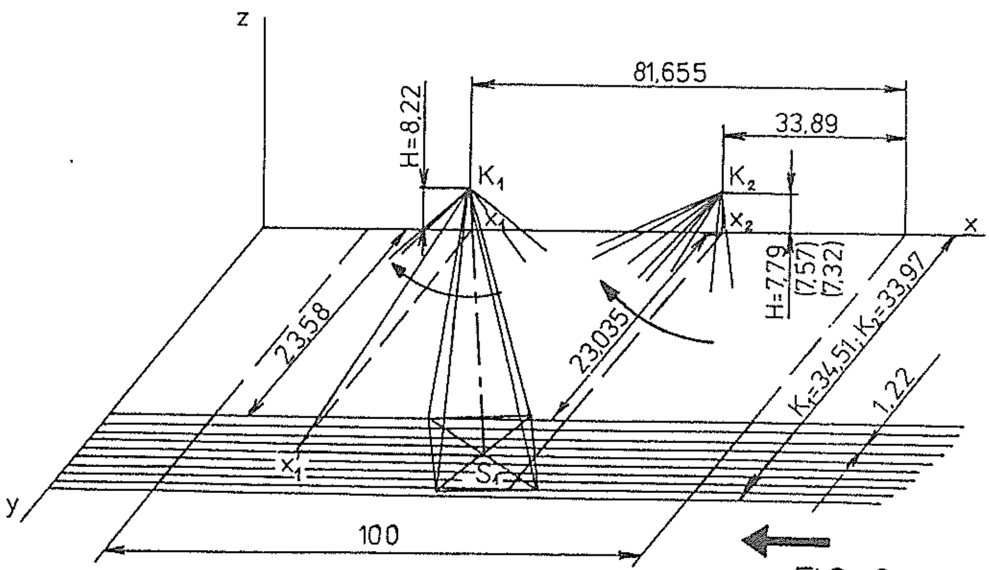


FIG 8

The present report concentrates on time analyses which can help coaches to get an idea of the conditions necessary for achieving performances that will enable athletes to be successful at the OG and other top world events.

Stride lenght and frequency, the functional course of acceleration and speed in the 100-m and the relay events will be published in specialised periodicals at a later stage.

3. ANALYSES OF THE COMPETITION AT THE II WORLD CHAMPIONSHIPS IN ATHLETICS

3.1. REACTION TIME

Measuring reaction times is an intractable problem in athletics.

Reaction times ought to be watched and analysed not only in races, but also in training. Measuring reaction times can have a considerable influence on the development of the starting technique in all sprint and hurdle events.

If reaction times are to be used as comparable quantities, uniform conditions for measuring must be laid down and should be obligatory for companies producing starting blocks with devices for the automatic recording of the reaction time.

Long-term investigations have confirmed that in measurements made at the World Junior Championships in Athens 1986 and the II WC, significantly longer reaction times were recorded than at EC 78, OG 80, EC 82 and WC 83 (TAB. 7).

REACTION TIMES MEASURED AT DIFFERENT ATHLETIC COMPETITION
[EUROPEAN AND WORLD CHAMPIOSHIPS,OLYMPIC GAMES]

MEN	100m			200m			400m		
	n	x	SD	n	x	SD	n	x	SD
EC78	51	151	20	43	179	41	48	247	67
OG80	118	154	17	112	159	21	106	172	41
EC82	52	147	19	47	171	29	50	226	67
WC83	121	157	25	107	189	34	105	220	41
OG84									
JWC86	138	174	21	131	191	37	71	238	65
EC86									
WC87	103	185	31	94	219	52	56	261	75
AVERAGE	583	164	23	534	186	35	436	220	55

WOMEN	100m			200m			400m		
	n	x	SD	n	x	SD	n	x	SD
EC78	46	159	20	48	180	37	42	248	56
OG80	84	152	27	83	164	24	62	195	45
EC82	42	155	15	24	177	32	24	271	65
WC83	103	173	23	96	201	37	83	235	59
OG84									
JWC86	80	185	41	83	205	41	21	272	75
EC86									
WC87	107	211	52	53	234	68	57	269	67
AVERAGE	462	177	33	387	194	39	286	244	65

TABLE 7

The term "reaction-time measurement", is used here only for the sake of simplicity. In fact, it is the time that elapses between the starter's gun and the moment the athlete is able to exert a certain amount of pressure on the starting blocks. This amount of pressure is subject to a variety of definitions. The current method of reaction time measurement includes both the duration of the sound-travel and the mechanical delay on the starting blocks.

In addition, no definite study exists that could be used as a basis for defining a premature start. There is no objective reason for laying down 120 ms (or any other value) as the limit.

One example for many was the final of the 100 m at the II WC in Rome. Many observers were of the opinion that B. JOHNSON jumped the gun.

Analysis of pictures made by highspeed cameras (196 frames/sec) and interpolation of the frames were used to calculate reaction time that passes between the recorded gun-shot smoke and the first noticeable motion of the athlete concerned (see TAB. 8).

NAME	JOHNSON	BRYZGIN	CHRISTIE	PAVONI	LEWIS	KOWACZ	Mc RAE	STEWART
PERFORMANCE	9.93	10.25	10.14	16.23	9.93	10.20	10.34	10.08
RANKING BY REACTION TIMES	1.	2.	3.	4.	5.	6.	7.	8.
LANE	5	1	8	2	6	4	7	3
A	0.143	0.158	0.163	0.173	0.199	0.214	0.224	0.230
B	0.109	0.139	0.135	0.163	0.196	0.201	0.225	0.235
C	0.034	0.018	0.008	0.010	0.003	0.013	-0.001	-0.005

A] REACTION TIMES OF FILM ANALYSIS (FREQUENCY 196 FRAMES PER SEC.)

B] OFFICIAL REACTION TIMES

C] DIFFERENCES BETWEEN REACTION TIMES OF FILM ANALYSIS AND OFFICIALLY PRINTED BY FIRM SEIKO

NOTE: RANKING OF RUNNERS ACCORDING TO REACTION TIMES IS IDENTICAL IN BOTH ROWS [A,B]

TABLE 8

Our conclusion is that JOHNSON was not guilty of a false start. The starter did not and could not notice a premature start. JOHNSON'S start differs from that of most other athletes: the take-off of the lower extremities preceds the motion ("take-off") of the upper extremities.

Another problem is the start of the 400 m flat and 400 m hurdles. There is a tendency of an increase in reaction times in proportion to the increasing distance between the starter and the athlete. This was one of the subjects dealt with in our analysis of the EC in Athens 82. After talks with the organizers concerning the subsequent evaluation of the reaction times at the I WC in Helsinki 83 the problem seemed to have been solved.

In Rome, though, the reaction times were again found to correlate significantly with the lane order, i.e. with the growing distance between the runner and the starter (see TAB. 9).

SPEARMAN'S COEFFICIENT OF ORDER CORRELATION WITHIN LANE AND REACTION TIME

DISCIPLINE

400m

MEN			WOMEN		
RUN	COEF.	REMARK	RUN	COEF.	REMARK
FINAL	0.28	*	FINAL	0.61	!
SF1	0.95	!	SF1	0.61	!
SF2	0.47		SF2	0.90	!
QF1	0.75	!	SF3	0.5	+
QF2	0.8	!	H1	0.90	!
QF3	0.61	!	H2	0.92	!
QF4	0.85	!	H4	0.80	!
			H5	0.14	*
			H6	0.00	*

* DOESN'T AGREE WITH OUR HYPOTHESIS

\+ WRONG MEASURMENT ON THE 7th LANE

TABLE 9

The times in the sprinting and hurdling events up to and including 400 m are stated in hundreths of a second. However the runners starting in the 7th or 8th lanes were severely handicapped (up to 0.1 s), compared with those in the 1st, 2nd or 3rd lanes.

A proposal has been submitted for tackling this problem to the I.A.A.F. technical committee. Within the framework of the International Athletic Foundation/ international research team we are ready to put forward specific proposals for coping with the problem. All the data on the reaction times in all the sprinting events obtained so far (more than 2600 measurements), are shown in TAB.7.

Our conclusion can be briefly expressed in the following points, formulated earlier in another study (DOSTÁL 1982):

1. In all the sprint events (heats, semifinals, finals), the reaction times of the best athletes were shorter than 200 ms. This conclusion was confirmed in more than 95%. Results from the II WC are marked by longer reaction times throughout: a fact probably caused by a lack of uniformity in the methods of measurement.

2. In identical events, the average reaction times of women are longer than those of men. This conclusion was confirmed in 75% of the results from Rome.
3. Reaction times grow in proportion to the length of the race distance. This conclusion was confirmed, without exception, by the results from Rome.
4. The variance in the range of reaction times grows in proportion to the race distance. This conclusion was confirmed, with rare exceptions, by the results from Rome.
5. For the best runners, the stability of reaction time is higher. This conclusion was not confirmed by the results from Rome.
6. Reaction time does not correlate with the performance level. This conclusion was fully confirmed by the results from Rome.
7. An evaluation scale has been drafted on the basis of statistical processing, to provide a clearer idea of the reaction-times problem.

Reaction times	valid generally		valid only for II WC	
100 m	Men(x=164)	Women(x=177)	Men(x=185)	Women(x=211)
1. Outstanding	(130	(135	(140	(140
2. Above average	(130; 150)	(135; 160)	(140; 170)	(140; 185)
3. Average	(150; 170)	(160; 195)	(170; 200)	(185; 235)
4. Bellow average	(170; 190)	(195; 230)	(200; 230)	(235; 285)
5. Substandard	) 190	) 230	) 230	) 285
200 m	Men(x=186)	Women(x=194)	Men(x=219)	Women(x=234)
1. Outstanding	(140	(140	(150	(150
2. Above average	(140; 170)	(140; 175)	(150; 195)	(150; 205)
3. Average	(170; 205)	(175; 215)	(195; 245)	(205; 260)
4. Bellow average	(205; 240)	(215; 255)	(245; 295)	(260; 310)
5. Substandard	) 240	) 255	) 295	) 310
400 m	Men(x=220)	Women(x=244)	Men(x=261)	Women(X=269)
1. Outstanding	(150	(150	(160	(170
2. Above average	(150; 195)	(150; 210)	(160; 225)	(170; 235)
3. Average	(195; 245)	(210; 280)	(225; 295)	(235; 305)
4. Bellow average	(245; 295)	(280; 340)	(295; 360)	(305; 370)
5. Substandard	) 295	) 340	) 360	) 370

3.2. TIME ANALYSIS OF THE 400 M WOMEN

Reaction speed

At this WC, it was again confirmed that reaction time does not significantly influence the performance at the 100 m distance. The reaction times of inferior female sprinters with performances over 12.00 s comparable both with the reaction times of sprinters with performances below 12.00 s, and with the semifinalists. Above average or excellent reaction times were found only in some of the finalists, but even here no correlation between reaction time and performance has been revealed.

Comparing the reaction times of the finalists we find that GLADISCH had the shortest (0.141 s) and MARSHALL the longest reaction time (0.242 s). This fully corresponds to the results of the race. Conversely, DRECHSLER'S reaction time was below average (0.210 s), as so was WILLIAMS' (0.240 s), but they placed 2nd and 4th, respectively.

Accelerration speed

The ability to accelerate is one of the factors that markedly influence performance. Most sprinters achieve maximum speed between 30 and 60 m (regardless of the performance level), but the quality of the acceleration (steepness of the speed increase and maximum level of speed achieved) correlates directly both with the performance and the quality of the sprinter. None of those who did not qualify from the heats (times over 12.00 s) achieved times better than 4.40 s for the first 30 m; and none of those who did not qualify from the quarter-finals (times over 11.50 s) times better than 4.30 s. A comparison of times at 30 m by the individual finalists (heats -final) shows a high stability of acceleration speed. Outstanding acceleration (0 - 30 m) was demonstrated by GLADISCH, ISSAJENKO, OTTEY and NOUNEVA; inferior acceleration by MARSHALL and DRECHSLER.

Maximum speed

Maximum running speed measured as a mean in separate 10m sections clearly corresponds to the performance achieved. Velocities of 9.00 - 9.50 m/s correspond to resulting times over 12.00 s; about 10 m/s to resulting times 11.50 - 12.00 s. All the finalists, i.e. runners with times below or slightly over 11.00 s were able to produce speeds higher than 10.50 m/s. The highest speeds were measured for DRECHSLER (10.87 m/s) and GLADISCH (10.75 m/s).

Speed endurance

Even in the 100m performance is markedly influenced by the ability to maintain a high running speed for as long as possible, i. e. by speed endurance. The time attained in a flying 30 m section (30 - 60m), in which most runners reach their maximum speed, deteriorates markedly with deteriorating performances. Sprinters slower than 12.00 s were not able to clock less than 3.30 s in this division and those slower than 11.50 s less than 3.30 s. Only sprinters faster than 11.50 s (the semifinalists and finalist) were able to maintain speed on a level that makes them capable of running this section at a time below 3.30 s. That was confirmed by a comparison of the data from various rounds (heats - final) for the finalists. The fastest women over this section were again DRECHSLER (2.84 s) and GLADISCH (2.85 s).

Specific endurance nad its relation to the resulting time can also be judged from the difference in times between the first and second halves of the race. Any analysis of a race in which the athlete has run the whole distance with full effort, without final relaxation in the case of clear qualifying, will show that the difference between the first and second halves of the distance increases with improved speed endurance. Thit means that a minor loss of speed in the final section of the distance occurs. This fact is obvious from a comparison of the data of athletes on different performance levels. Account should also be taken of the individual pecularities of sprinters (high level acceleration speed etc.).

More accurate information can be obtained from the functional course of speed. Assumptions found in literature, suggesting that the speed decreases for inferior sprinters at the end of the race (the average speed over a 10 m section is lower) were not confirmed. While inferior sprinters reach one peak of maximum speed which decreases gradually, more or less steeply, elite sprinters lose speed very gently (GLADISCH, DRECHSLER, WILLIAMS), or even have a two-peak course of the speed curve (OTTEY, BAILEY).

None of the finalists achieved a better performance in the finals than in the semifinal, although acceleration and maximum speed were mostly better in the final. This again highlights the importance of speed endurance. In this case, though, the results in the final were affected by several factors: head wind, undue output of energy in the first half of the race (despite the minus-wind, identical or better intermediate times were achieved) and, propably, accumulation of fatigue from the preliminary rounds resulted in final performances inferior to the semifinal times.

TIME ANALYSIS OF THE 100 M
MEN

Reaction speed

No significant correlation between reaction time and final performance was revealed in the men's 100 m. Very often, sprinters who achieved poor times and did not qualify for the next round from the heats had reaction times comparable with those of sprinters with outstanding performances and those of the finalists. Stability of reaction time and a generally poorer level of reaction times were confirmed in Rome. As indicated above, this is the sum of many factors.

In his reaction times, B. JOHNSON excelled among the finalists, he demonstrated both the highest stability and above-average to outstanding reaction times. Above-average reaction times can be observed in BRYZGIN and CHRISTIE and, conversely average to below-average ones in LEWIS and STEWART.

Acceleration speed

Remarkable differences between athletes of different levels could be observed in speed acceleration. Much like the women, most of the men achieved maximum speed in the section 30 - 60 m, some of the finalists even later.

Achieving a certain level of final time is not so strictly conditioned by acceleration capacity in men as it is in women. However, it holds true even here, that it is necessary to run the first 30 m below 4.00 s for a performance below 10.40 s. This is in keeping with the model intermediate times. The highest acceleration ability of all the finalists was clearly shown by B. JOHNSON (first 30 m always better than 3.90 s). In the final BRYZGIN and Mc RAE also showed a high acceleration ability.

It was acceleration ability that decided final race between winner and runner-up: over the first 30 m JOHNSON gained an advantage of 0.1 s which LEWIS was not able to even out. As with the women, better speed acceleration decided between these two competitors. (But reaction time difference is 0.056.)

Maximum speed

Maximum running speed is not always directly correlated with the performance either. Sprinters with speeds better than 11 m/s sometimes did not reach performances better than 10.50 s. Nevertheless, an outstanding sprinting performance can be said to be conditioned by the maximum running speed. All the finalists (as well as the semifinalists) achieved, in the fastest 10 m sections, times corresponding to an average velocity of 11 m/s and better. A high level of maximum running speed is not a guarantee but a precondition of an excellent performance.

The highest value of running speed was measured in JOHNSON and LEWIS (11.76 m/s).

Speed endurance

Neither reaction time, nor acceleration ability or maximum running speed correlated with the final result (that should be related to the strength potential of sprinters). However the correlation between performance and speed endurance was confirmed unequivocally in the time over the 30 - 60 m section (where most sprinters achieve the maximum running speed) or in the difference between the first and second half of the race and, in particular, in the functional course of maximum speed throughout the 100 m.

With times below 10.40 s, all sprinters covered the 30 - 60m section in 2,70 s or less (with the only exception of Mc RAE). The fastest of the finalists was JOHNSON (2.58 s in the world record) and LEWIS (2.59 s).

The difference between the first and second half of the 100m distance is greater in elite male sprinters, too (lower speed losses in the second half); in the finalists it is in the range of 1.20 s (Mc RAE) - 1.44 s (STEWARD).

The functional course of maximum speed can, for women, be considered the most important indicator of speed endurance (expressed by mean times over the 10m sections). The same holds true with men. Sprinters of an inferior level usually have a one-peak course of the maximum speed curve which drops in the final phase of the race, while elite sprinters are able to maintain high running speeds even in the final phase of a race. This can be easily seen in the diagram showing the functional course of speed. In the final, all the sprinters (in the case of PAVONI, we proceed from his time in the heat where he achieved his best result) achieved a two-peak course of speed, confirming the ability of the best sprinters to maintain a high running speed in the second half of the race.

Identical conclusions are confirmed by a comparison of the two final 20m sections: in the first half of the distance (30 - 50m) and in the second half (80 - 100m). Except Mc RAE all the finalists achieved faster times in the 80 - 100m section than in the 30 -50m section. Excluding the finalists, this was observed only 4 times (twice in the semifinals, twice in the quarterfinals).

The data obtained at the II WC provide a basis for evaluating the advatages and shortcomings of the athletes, for comparing athletes of different levels and for accessing, in general terms, the level a sprinter must attain in acceleration, maximum speed and sprint endurance in order to compete at the highest level.

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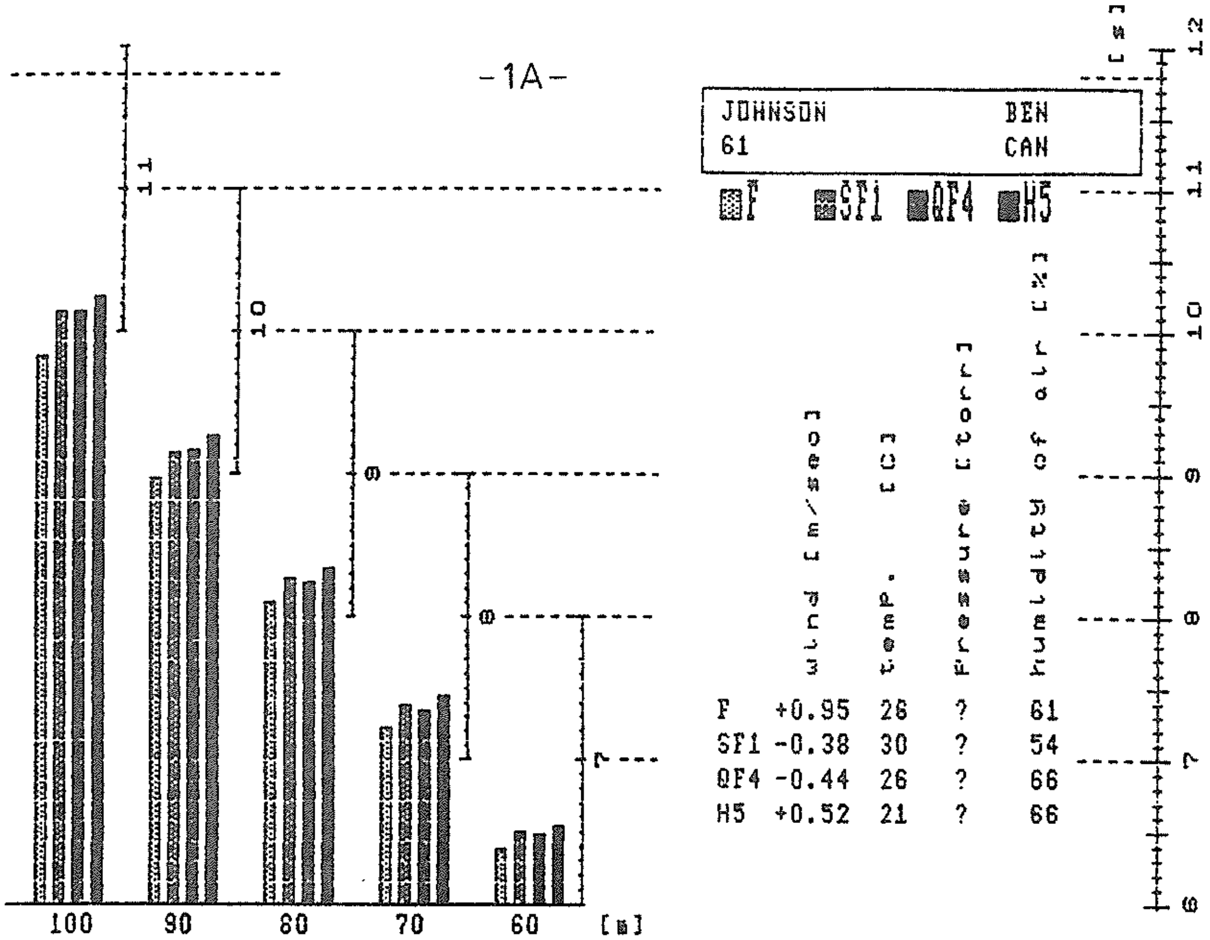
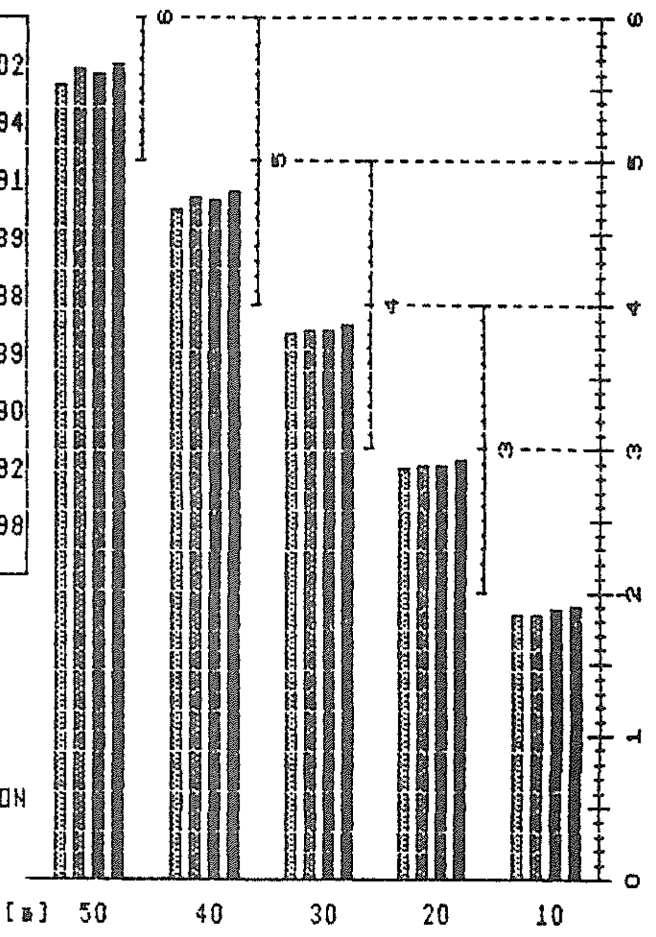
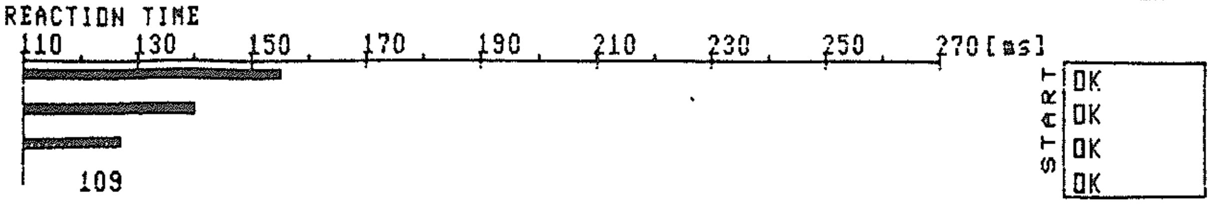


TIME ANALYSIS
100 m MEN

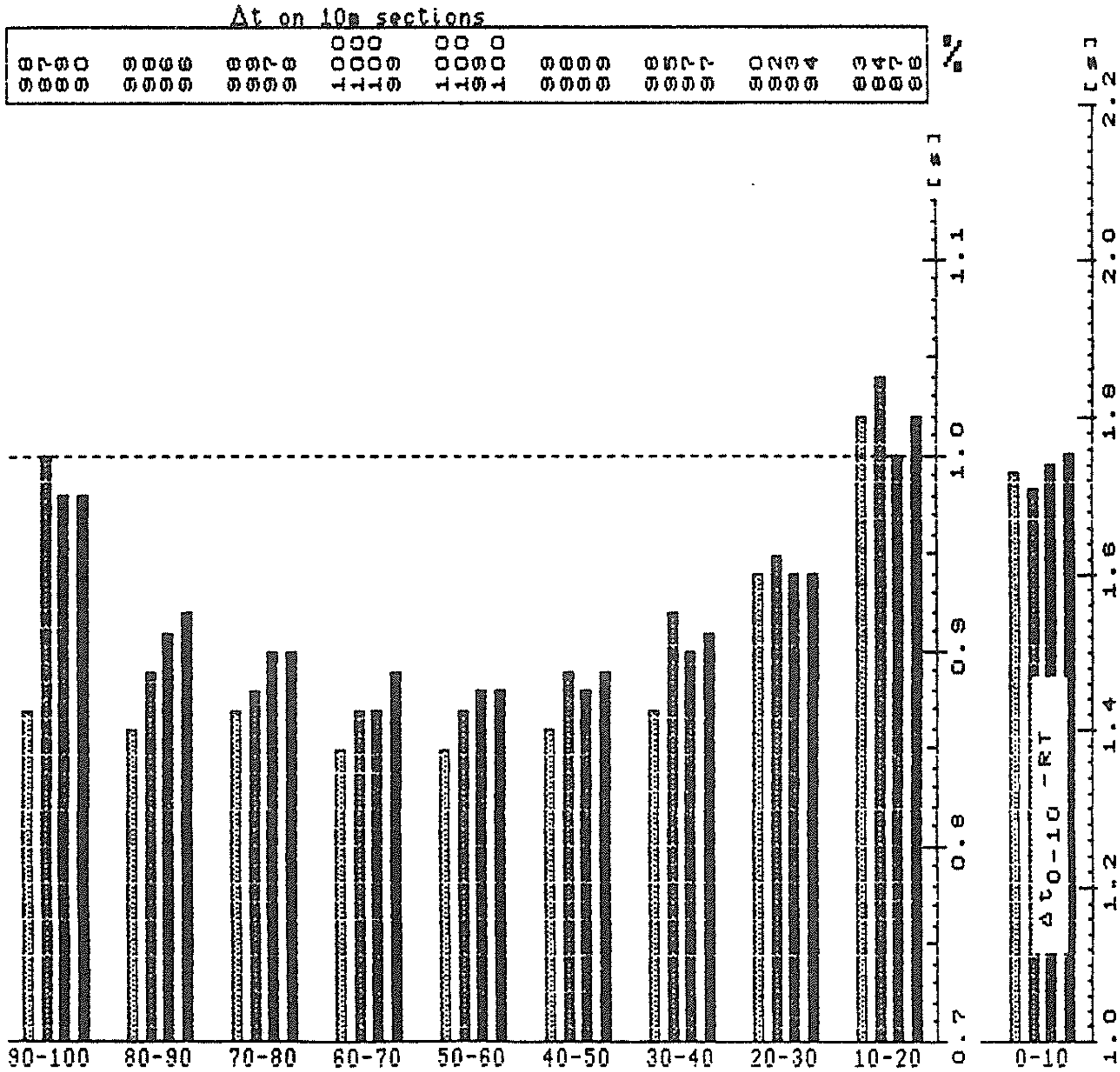
10.	1.84	1.84	1.88	1.91
	1.02	1.04	1.00	1.02
20.	2.86	2.88	2.88	2.93
	0.94	0.95	0.94	0.94
30.	3.80	3.83	3.82	3.87
	0.87	0.92	0.90	0.91
40.	4.67	4.75	4.72	4.78
	0.86	0.89	0.88	0.89
50.	5.53	5.64	5.60	5.67
	0.85	0.87	0.88	0.88
60.	6.38	6.51	6.48	6.55
	0.85	0.87	0.87	0.89
70.	7.23	7.38	7.35	7.44
	0.87	0.88	0.90	0.90
80.	8.10	8.26	8.25	8.34
	0.86	0.89	0.91	0.92
90.	8.96	9.15	9.16	9.26
	0.87	1.00	0.98	0.98
100.	9.83	10.15	10.14	10.24



JOHNSON	BEN	61	CAN
H5 -10.24 [s]	QF4-10.14 [s]	SF1-10.15 [s]	F -9.83 [s]



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H5	*	*	*	*	
	*	*	*	*	
PLACING 1	*	*	*	*	0.88 / 50-60
	*	*	*	*	
QF4	*	*	*	*	
	*	*	*	*	
PLACING 2	*	*	*	*	0.87 / 60-70
	*	*	*	*	
SF1	0-100	45.5	4.48	2.20	
	*	*	*	*	0.87 / 50-60
PLACING 1	*	*	*	*	
	*	*	*	*	
F	0-100	46.2	4.70	2.16	0.85 / 50-60
	*	*	*	*	
PLACING 1	*	*	*	*	
	*	*	*	*	



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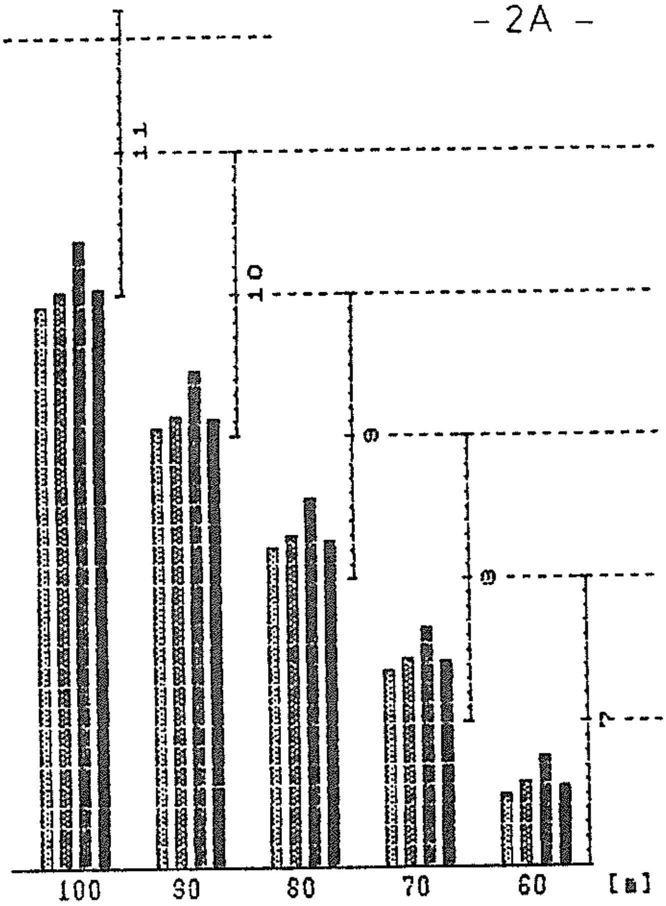
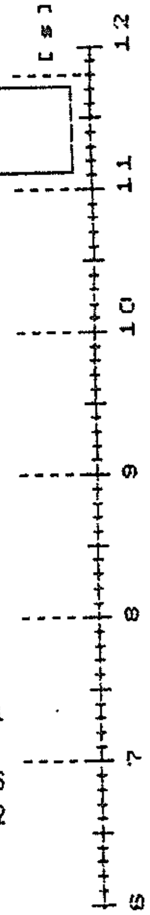


LEWIS	CARL
61	USA

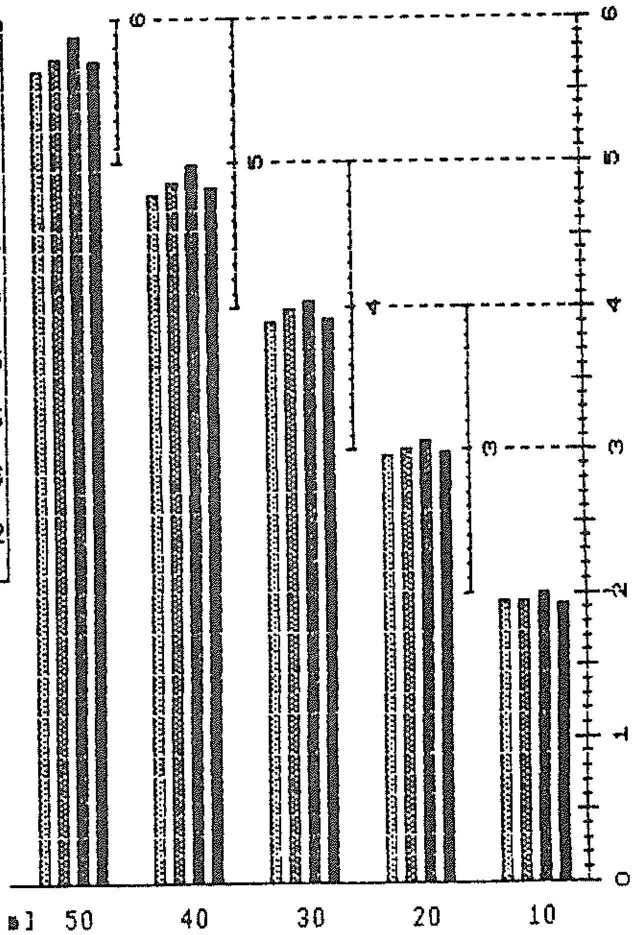
F SF2 QF1 H6

	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	+0.95	26	?	61
SF2	-1.35	30	?	?
QF1	-2.97	26	?	66
H6	+1.43	21	?	72



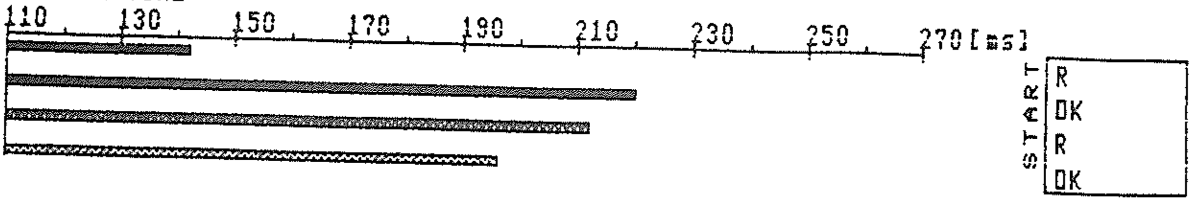
TIME ANALYSIS
100 m MEN

10.	1.94	1.94	2.01	1.92
	1.02	1.06	1.06	1.06
20.	2.96	3.00	3.07	2.98
	0.95	0.98	0.98	0.95
30.	3.91	3.98	4.05	3.93
	0.87	0.88	0.93	0.89
40.	4.78	4.86	4.98	4.82
	0.86	0.87	0.90	0.88
50.	5.64	5.73	5.88	5.70
	0.86	0.86	0.89	0.87
60.	6.50	6.59	6.77	6.57
	0.86	0.85	0.89	0.85
70.	7.36	7.44	7.66	7.42
	0.86	0.86	0.90	0.85
80.	8.22	8.30	8.56	8.27
	0.85	0.85	0.90	0.86
90.	9.07	9.15	9.46	9.13
	0.86	0.88	0.92	0.92
100.	9.93	10.03	10.38	10.05

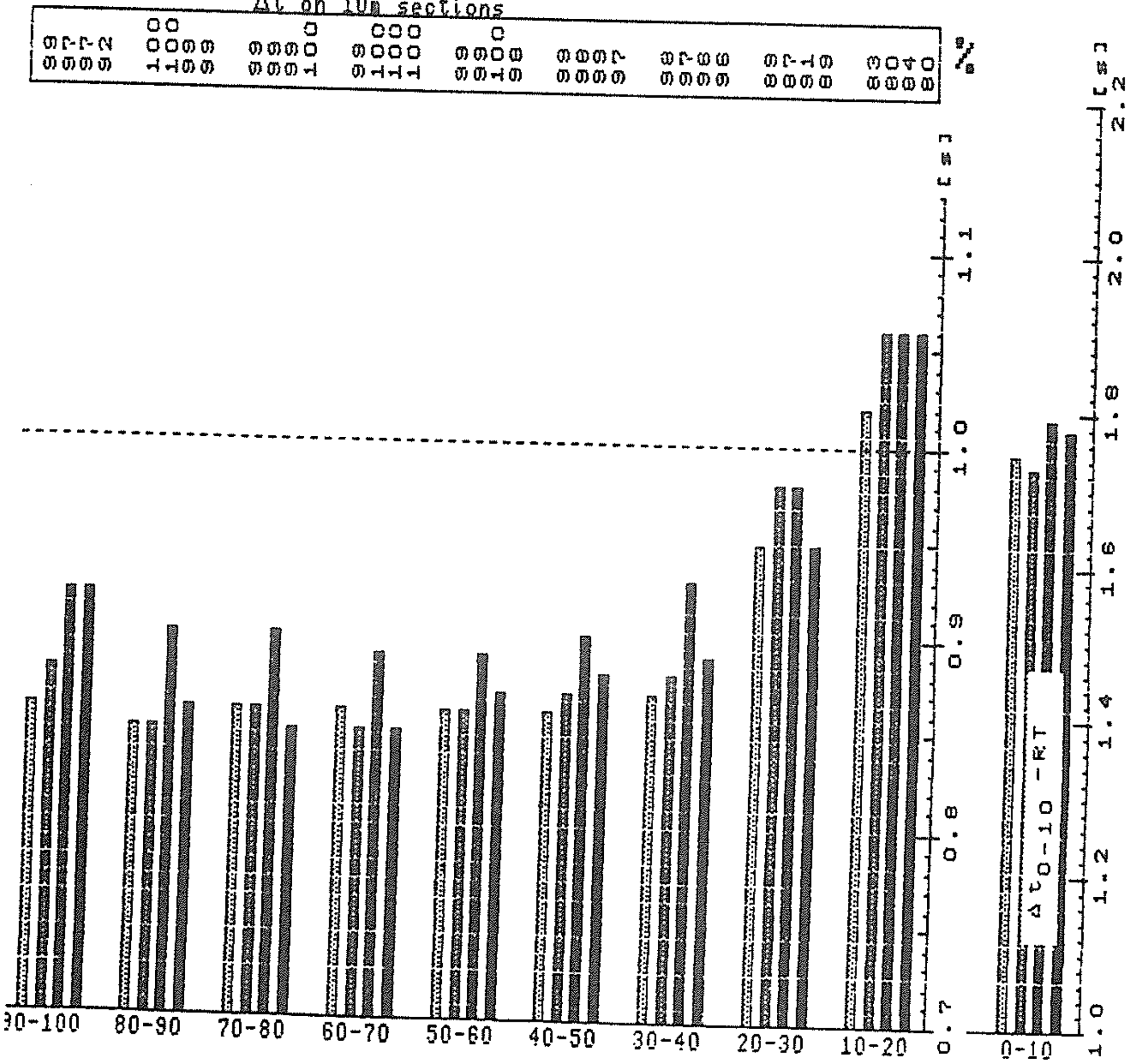


LEWIS	CARL	61	USA
H6 -10.05 [s]	QF1-10.38 [s]	SF2-10.03 [s]	F -9.93 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H6 PLACING 1	*	*	*	*	0.85 / 60-70
QF1 PLACING 1	*	*	*	*	0.89 / 50-60
SF2 PLACING 1	0-100	43.6	4.35	2.29	0.85 / 60-70
F PLACING 2	0-100	44.6	4.49	2.24	0.85 / 80-90



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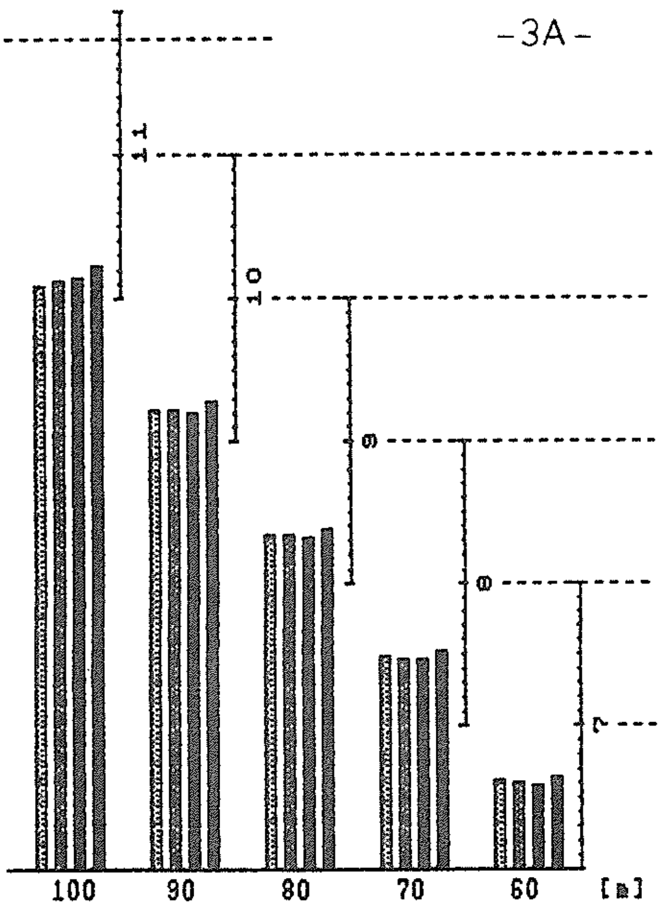
STEWART	RAYMOND
65	JAM

F SF2 QF4 H1

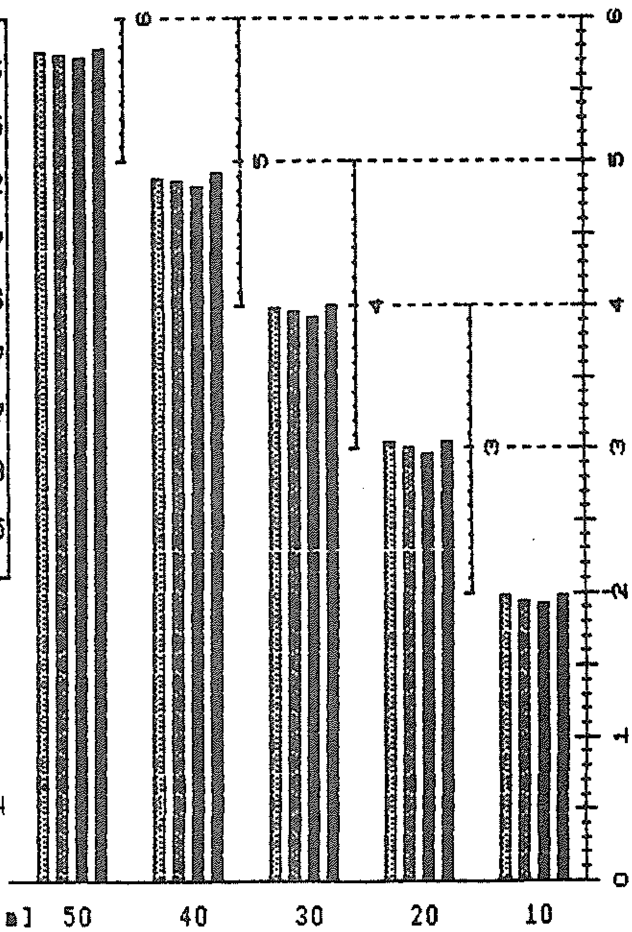


	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	+0.95	26	?	61
SF2	-1.35	30	?	?
QF4	-0.44	26	?	66
H1	+1.79	20	?	78

[s]

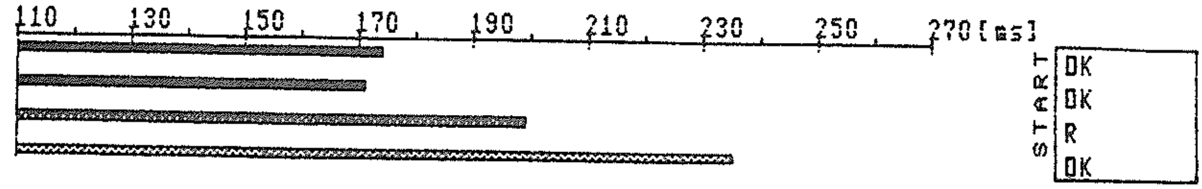
TIME ANALYSIS
100 m MEN

10.	1.99	1.94	1.92	1.99
	1.05	1.06	1.05	1.06
20.	3.04	3.00	2.97	3.05
	0.94	0.96	0.95	0.95
30.	3.98	3.96	3.92	4.00
	0.91	0.90	0.91	0.92
40.	4.89	4.86	4.83	4.92
	0.87	0.88	0.89	0.87
50.	5.76	5.74	5.72	5.79
	0.86	0.86	0.87	0.86
60.	6.62	6.60	6.59	6.65
	0.87	0.87	0.87	0.87
70.	7.49	7.47	7.46	7.52
	0.86	0.88	0.87	0.87
80.	8.35	8.35	8.33	8.39
	0.87	0.88	0.88	0.89
90.	9.22	9.23	9.21	9.28
	0.86	0.89	0.93	0.95
100.	10.08	10.12	10.14	10.23



STEWART	RAYMOND	65	JAH
H1 -10.23 [s]	QF4-10.14 [s]	SF2-10.12 [s]	F -10.08 [s]

REACTION TIME

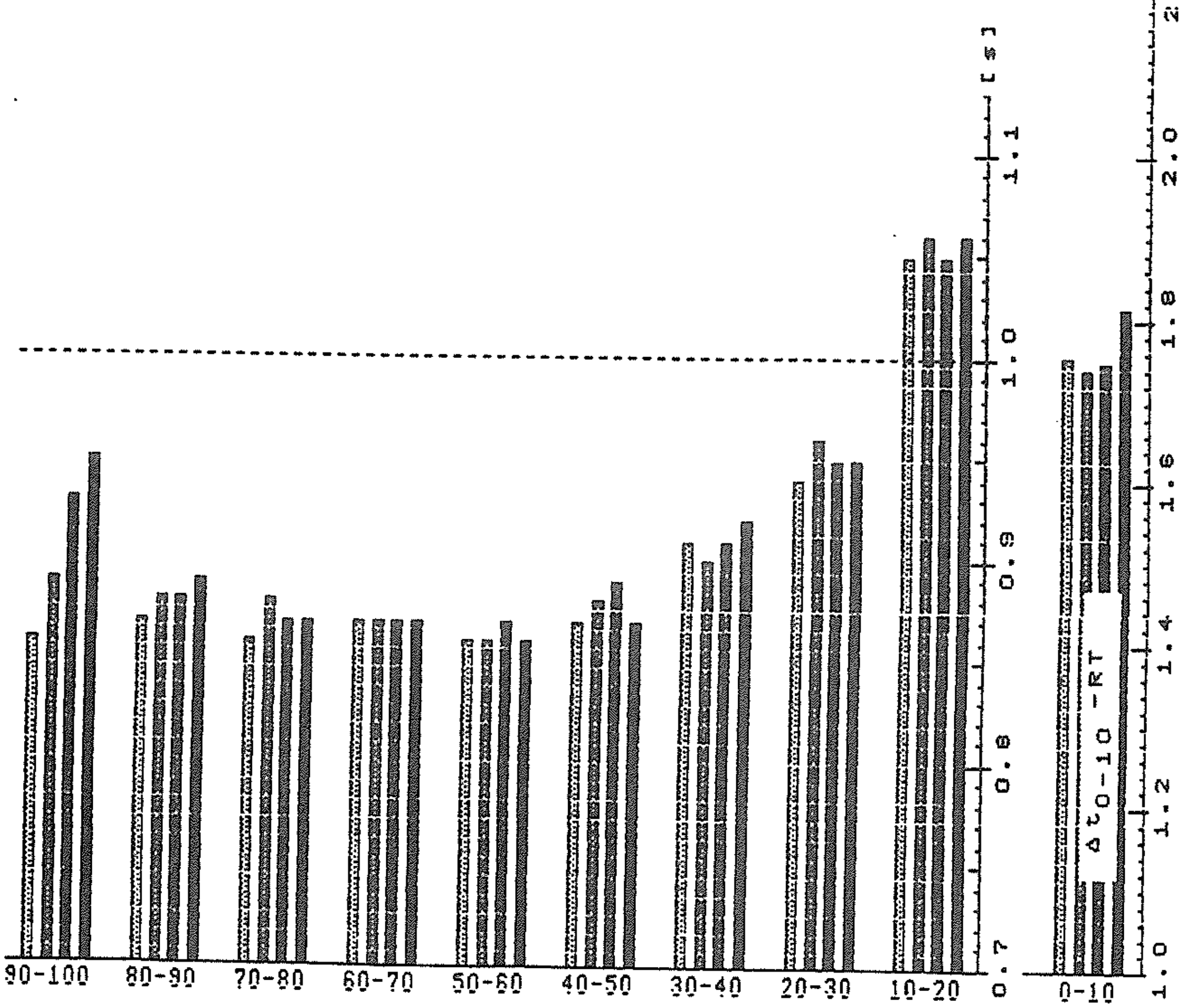


	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H1 PLACING 1	*	*	*	*	
	*	*	*	*	
	*	*	*	*	0.86 / 50-60
	*	*	*	*	
QF4 PLACING 1	*	*	*	*	
	*	*	*	*	
	*	*	*	*	0.87 / 50-60
	*	*	*	*	
SF2 PLACING 2	0-100	44.8	4.43	2.23	
	*	*	*	*	0.86 / 50-60
	*	*	*	*	
	*	*	*	*	
F PLACING 3	0-100	45	4.46	2.22	
	*	*	*	*	0.86 / 50-60
	*	*	*	*	
	*	*	*	*	

Δt on 10m sections

	90-100	80-90	70-80	60-70	50-60	40-50	30-40	20-30	10-20
1	100	99	100	99	100	99	95	91	82
2	97	98	98	99	100	98	96	90	81
3	94	99	100	100	100	98	96	92	83
4	91	97	99	99	100	99	93	91	81

%



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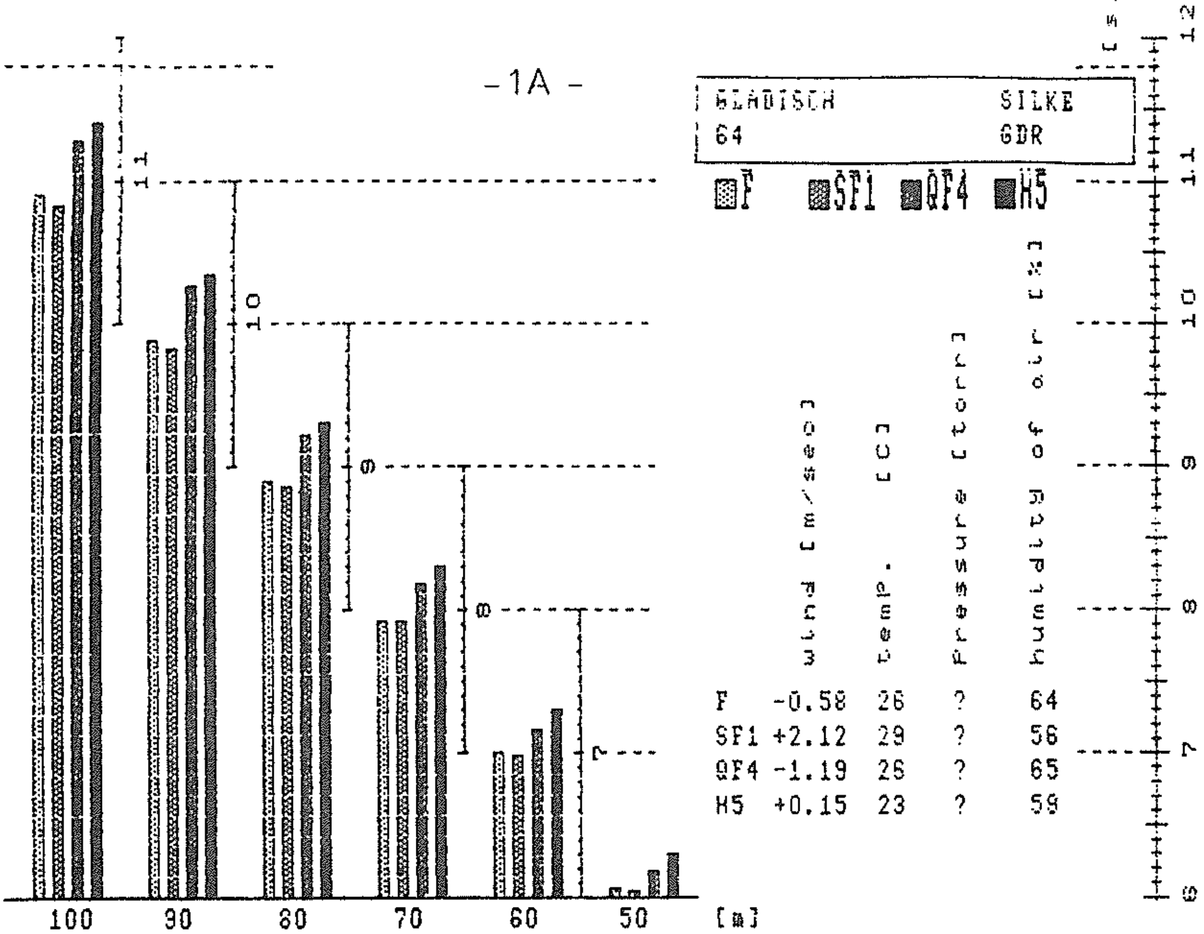
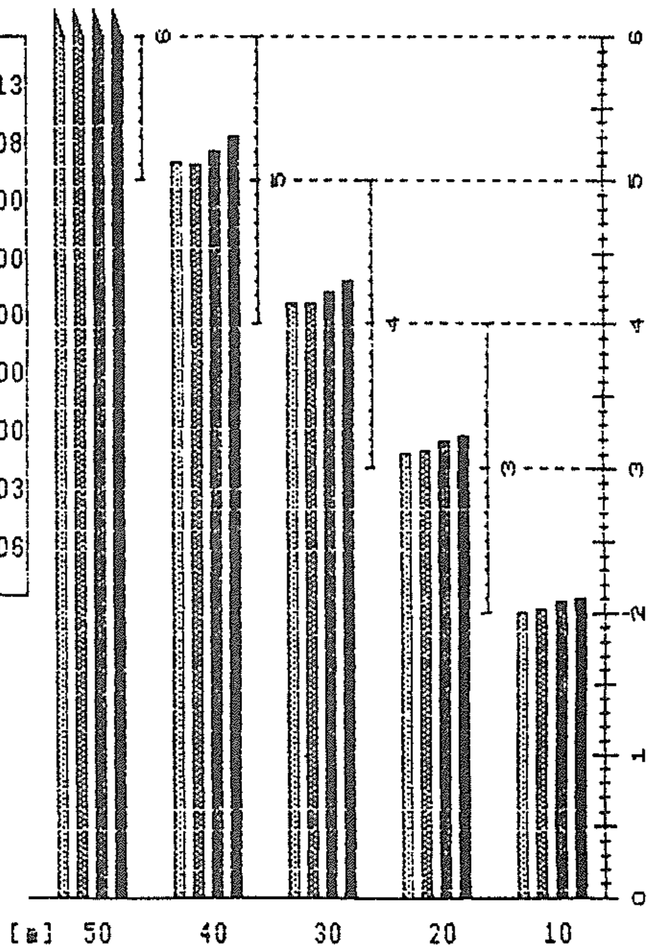


	wind [m/sec]	temp. [C]	Pressure [torr]	humidity of air [%]
F	-0.58	26	?	64
SF1	+2.12	29	?	56
QF4	-1.19	26	?	65
H5	+0.15	23	?	59

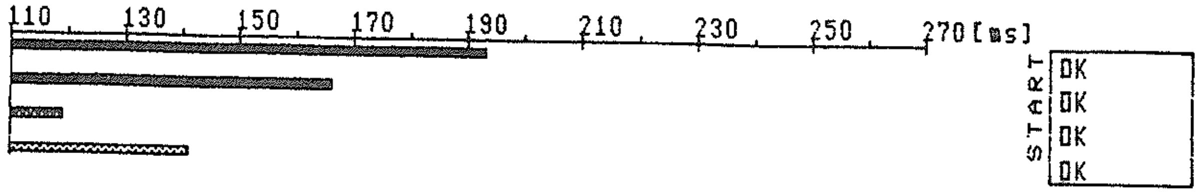
TIME ANALYSIS
100 m W

10.	2.01	2.02	2.08	2.10
	1.10	1.10	1.10	1.13
20.	3.11	3.12	3.18	3.23
	1.04	1.02	1.04	1.08
30.	4.15	4.14	4.22	4.31
	0.97	0.96	0.99	1.00
40.	5.12	5.10	5.21	5.31
	0.95	0.95	0.98	1.00
50.	6.07	6.05	6.19	6.31
	0.93	0.94	0.97	1.00
60.	7.00	6.99	7.16	7.31
	0.93	0.93	1.02	1.00
70.	7.93	7.92	8.18	8.31
	0.97	0.95	1.05	1.00
80.	8.90	8.87	9.23	9.31
	0.99	0.96	1.03	1.03
90.	9.89	9.83	10.26	10.34
	1.01	0.99	1.03	1.06
100.	10.90	10.82	11.29	11.40

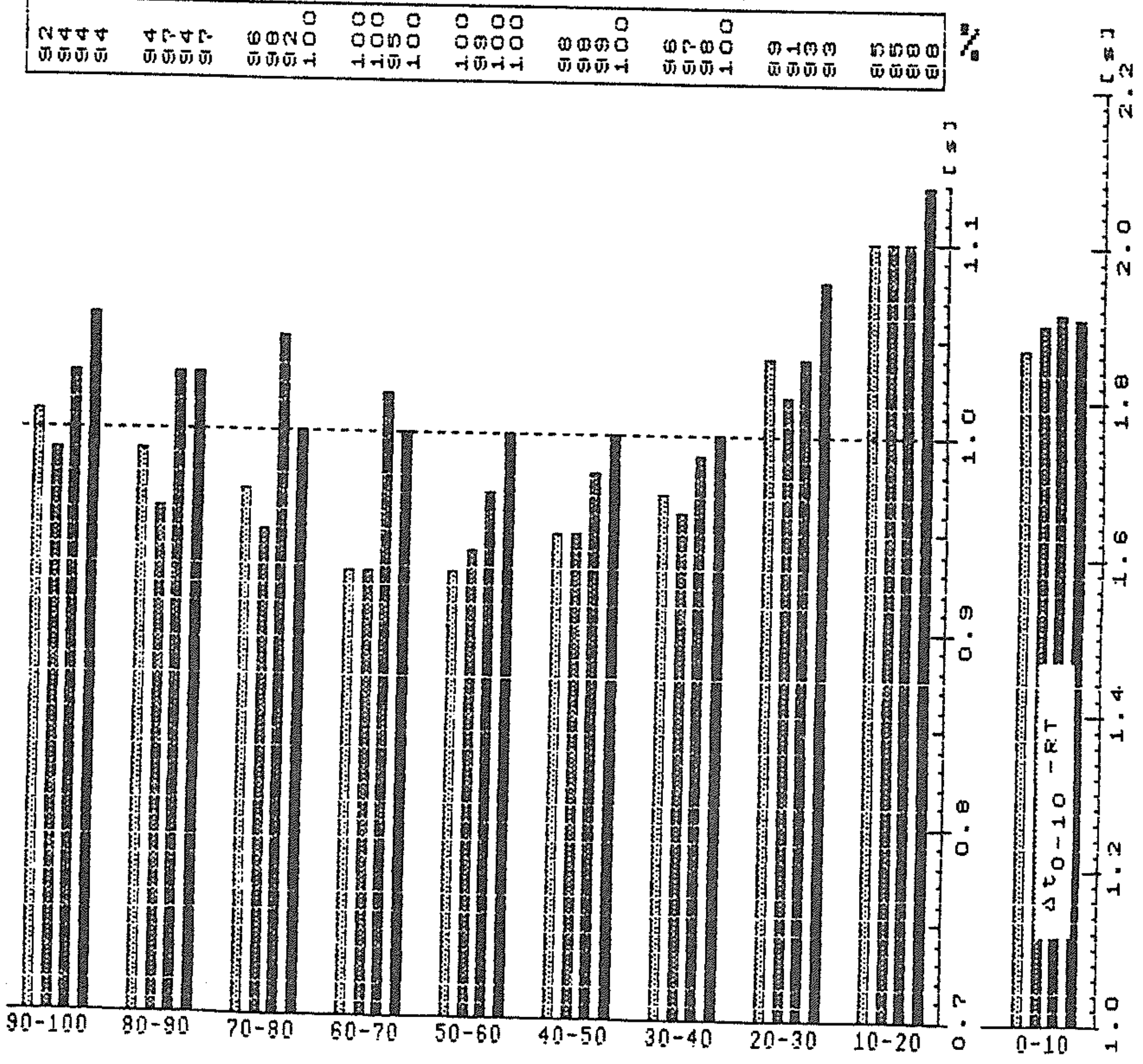


GLADISCH	SILKE	64	GDR
H5 -11.40 [s]	QF4-11.29 [s]	SF1-10.82 [s]	F -10.90 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H5 PLACING 2	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	1.00 / 30-40
QF4 PLACING 2	*	*	*	*	
	*	*	*	*	
	*	*	*	*	0.97 / 50-60
	*	*	*	*	
SF1 PLACING 1	0-100	51.8	4.79	1.93	
	*	*	*	*	0.93 / 60-70
	*	*	*	*	
	*	*	*	*	
F PLACING 1	0-100	53	4.86	1.89	
	*	*	*	*	0.93 / 50-60
	*	*	*	*	
	*	*	*	*	



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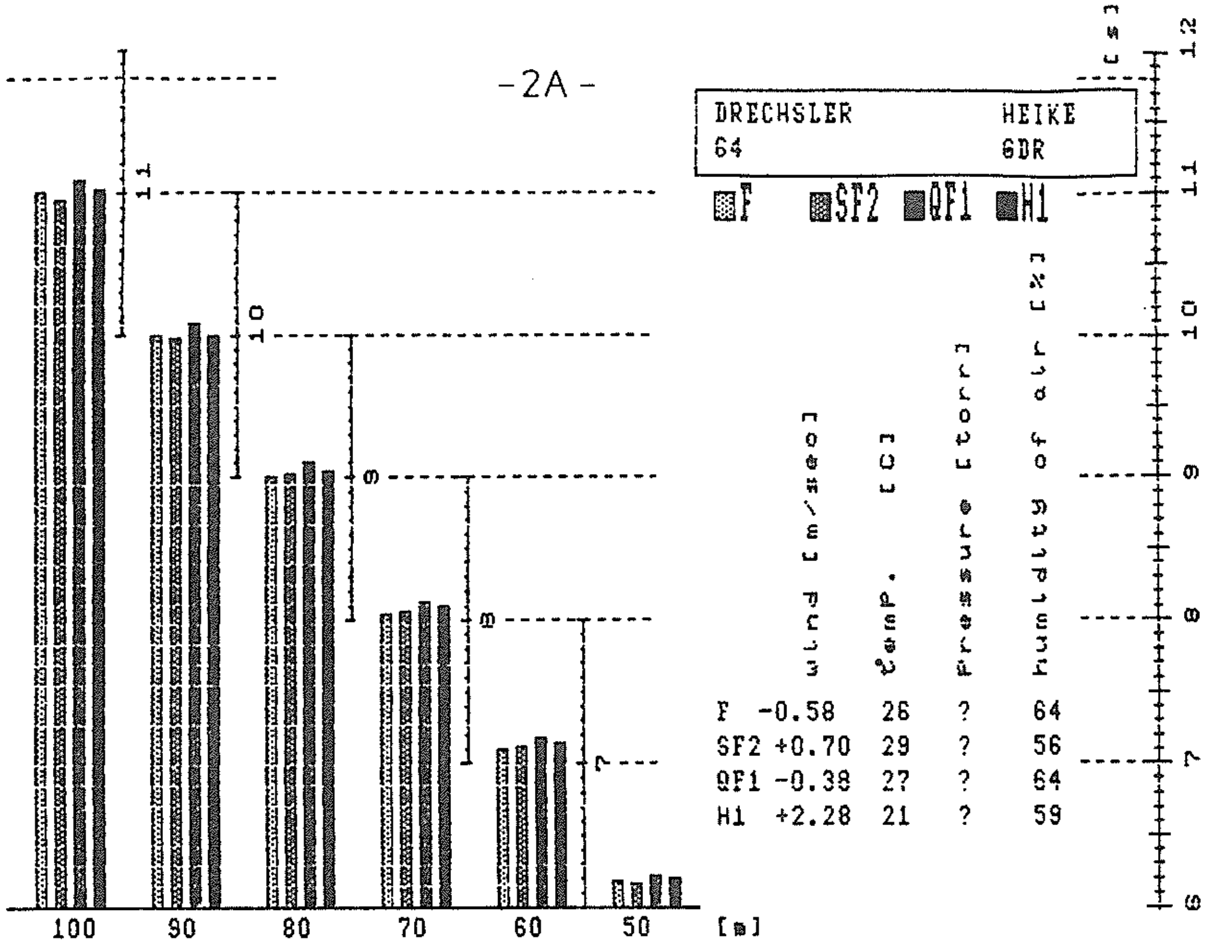
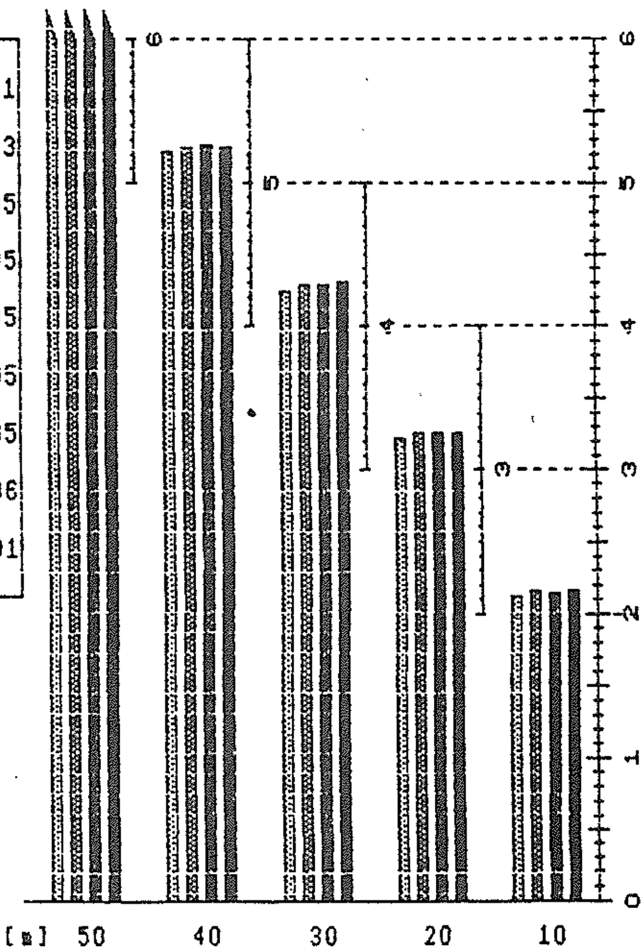


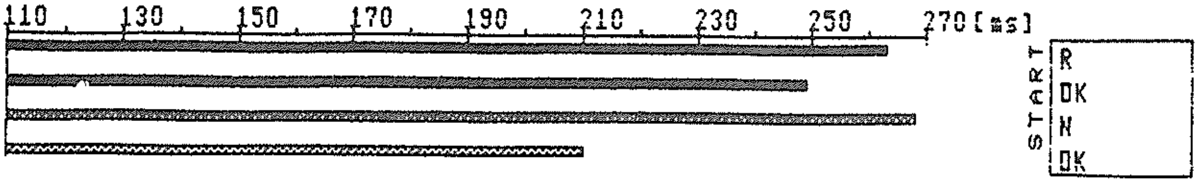
TIME ANALYSIS
100 m W

10.	2.12	2.16	2.15	2.16
	1.10	1.11	1.11	1.11
20.	3.22	3.27	3.26	3.27
	1.03	1.01	1.03	1.03
30.	4.25	4.28	4.29	4.3
	0.97	0.96	0.97	0.95
40.	5.22	5.24	5.26	5.25
	0.96	0.93	0.96	0.95
50.	6.18	6.17	6.22	6.2
	0.92	0.95	0.96	0.95
60.	7.10	7.12	7.18	7.15
	0.94	0.95	0.95	0.95
70.	8.04	8.07	8.13	8.10
	0.96	0.95	0.97	0.95
80.	9.00	9.02	9.1	9.05
	1.00	0.96	0.98	0.96
90.	10.00	9.98	10.08	10.01
	1.00	0.97	1.00	1.01
100.	11.00	10.95	11.08	11.02



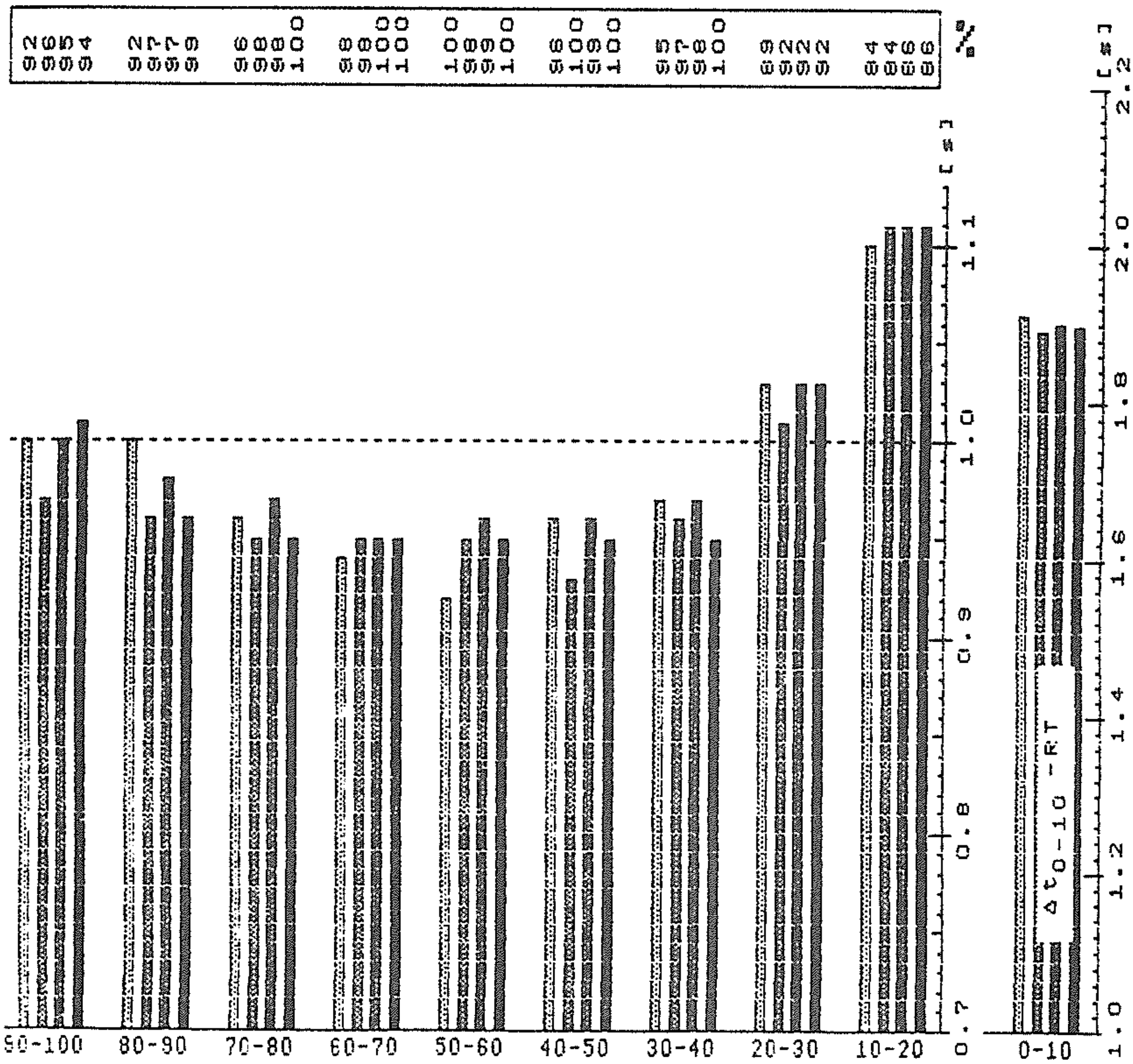
DRECHSLER	HEIKE	64	GDR
H1 -11.02 [s]	QF1-11.08 [s]	SF2-10.95 [s]	F -11.00 [s]

REACTION TIME

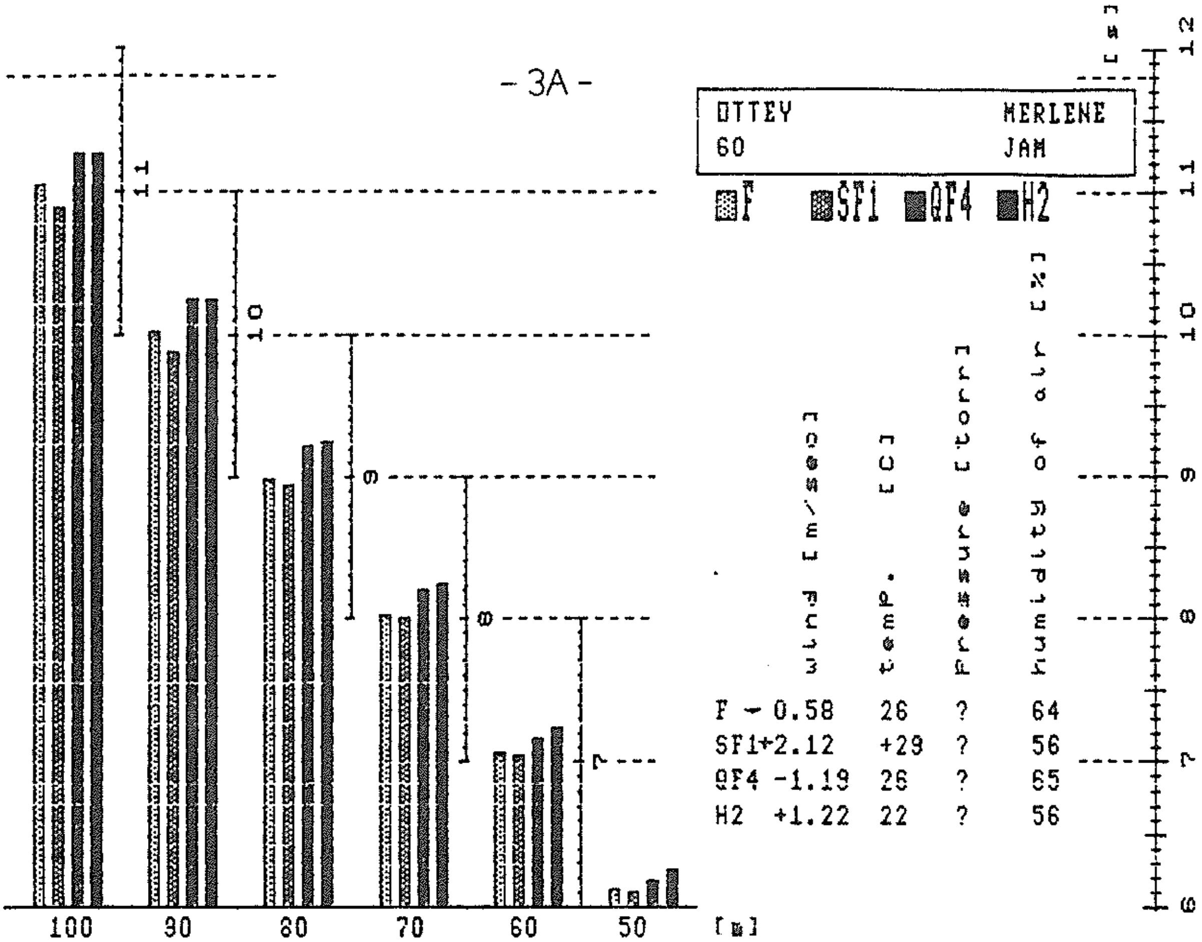


	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H1 PLACING 1	*	*	*	*	0.95 / 30-40
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
QF1 PLACING 1	*	*	*	*	0.95 / 60-70
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
SF2 PLACING 1	0-100	46.0	4.20	2.17	0.93 / 40-50
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
F PLACING 2	0-100	46.8	4.25	2.14	0.92 / 50-60
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	

90-100	80-90	70-80	60-70	50-60	40-50	30-40	20-30	10-20	%
92	92	96	98	100	96	95	89	84	
96	97	98	98	98	100	97	92	84	
95	97	98	100	99	99	98	92	86	
94	99	100	100	100	100	100	92	86	

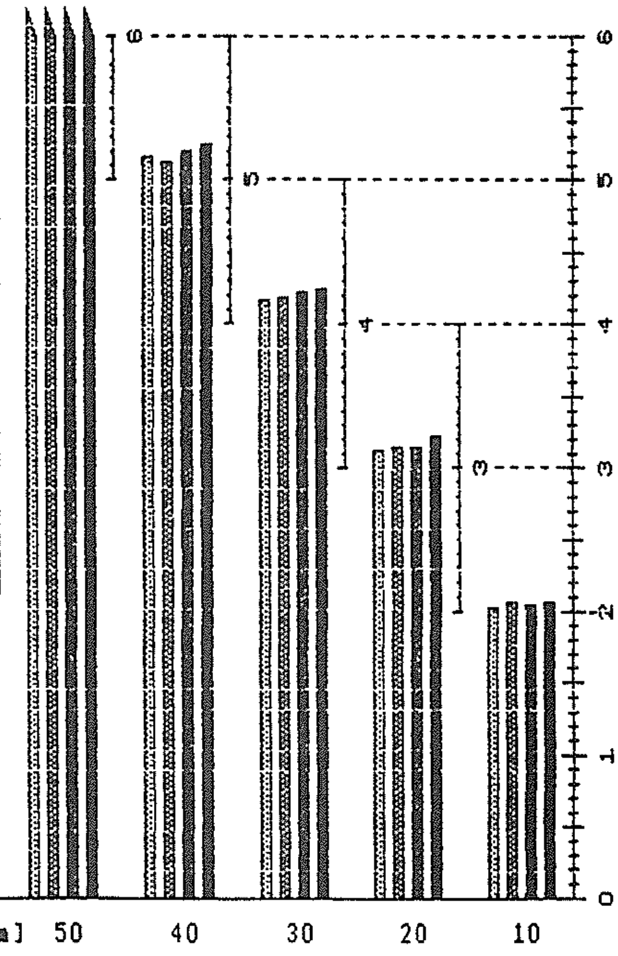


-3A-



TIME ANALYSIS
100 m W

10.	2.02	2.07	2.04	2.06
	1.11	1.07	1.11	1.16
20.	3.13	3.14	3.15	3.22
	1.04	1.04	1.07	1.03
30.	4.17	4.18	4.22	4.25
	0.99	0.95	0.98	1.00
40.	5.16	5.13	5.20	5.25
	0.96	0.97	0.98	1.01
50.	6.12	6.10	6.18	6.26
	0.95	0.94	0.99	0.98
60.	7.07	7.04	7.17	7.24
	0.95	0.96	1.03	1.00
70.	8.02	8.00	8.20	8.24
	0.97	0.94	1.03	1.00
80.	8.99	8.94	9.23	9.24
	1.03	0.95	1.02	1.00
90.	10.02	9.89	10.25	10.24
	1.02	1.00	1.02	1.02
100.	11.04	10.89	11.27	11.26

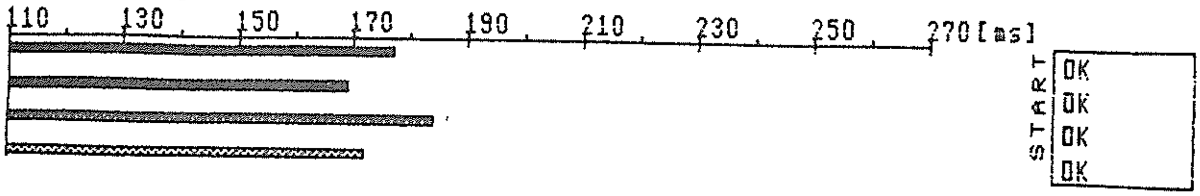


100 m W

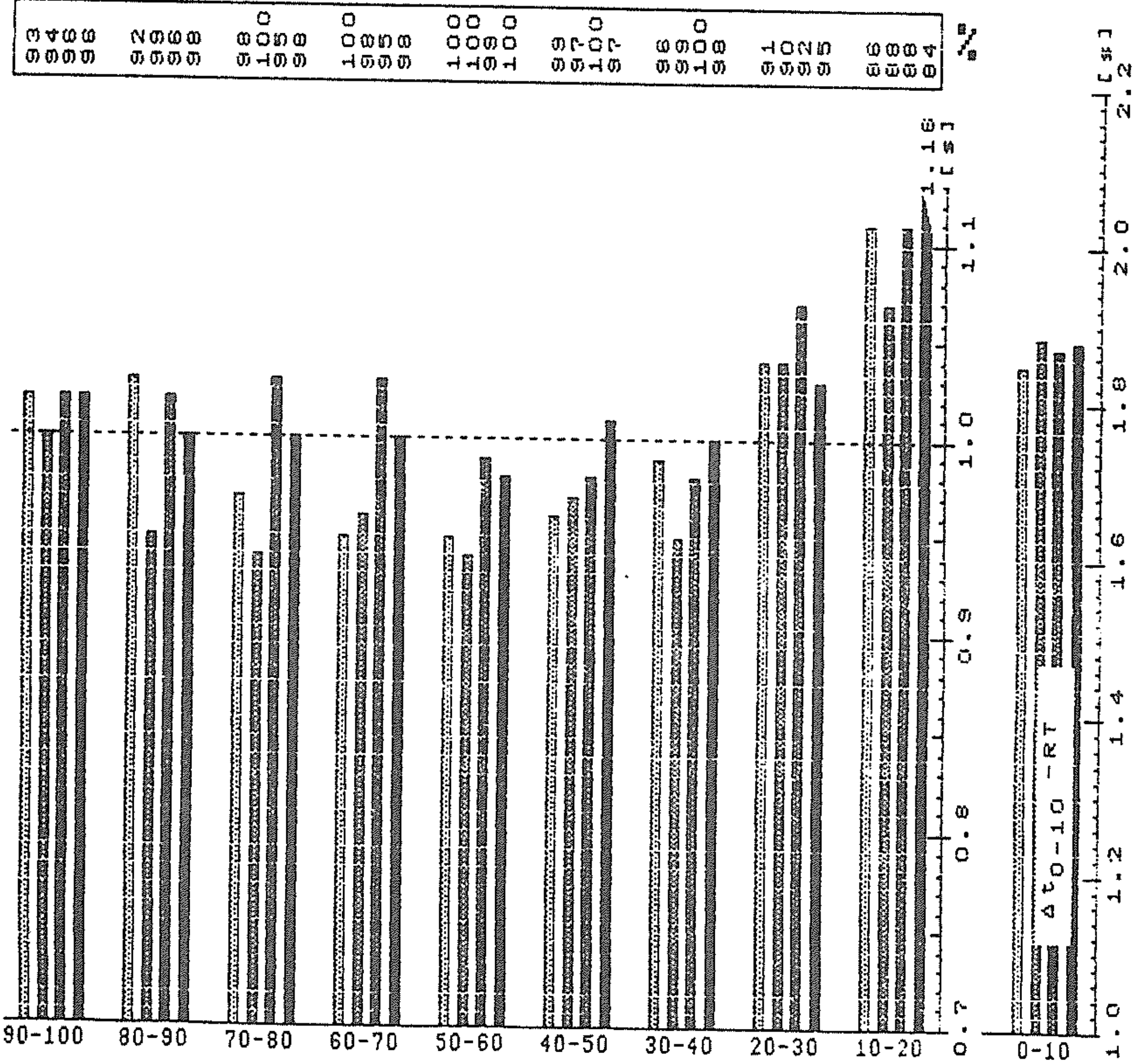
II WC ROME 87

OTTEY	MERLENE	GO	JAM
H2 -11.26 [s]	QF4-11.27 [s]	SF1-10.89 [s]	F -11.04 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGHT STEPS	THE FASTEST 10m SECTION
H2 PLACING 1	*	*	*	*	
	*	*	*	*	0.98 / 50-60
	*	*	*	*	
	*	*	*	*	
QF4 PLACING 1	*	*	*	*	
	*	*	*	*	0.98 / 30-40
	*	*	*	*	
	*	*	*	*	
SF1 PLACING 2	0-100	46.7	4.29	2.14	0.94 / 50-60
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	
F PLACING 3	0-100	47.1	4.27	2.12	0.95 / 50-60
	*	*	*	*	
	*	*	*	*	
	*	*	*	*	



3.3 TIME ANALYSIS OF THE 200 M (MEN AND WOMEN)

The course of velocity in the 200 m is evaluated in terms of the factors decisive for the performance, i.e. reaction speed, acceleration speed, maximum speed and speed endurance.

Reaction time and acceleration speed

An evaluation of the reaction time and acceleration speed in terms of the first 50m section in the semifinals and final reveals that the initial time loss, caused by a slow reaction to the starter's gun or by poor acceleration, need not necessarily be significant, owing to the length of the event. Evidence to support this contention is plentiful; e.g. the best reaction times in the semifinal were measured in athletes who did not qualify for the final (BERGER 136ms, IKAUNITSE 146 ms). The mean reaction time of the finalists was rather poor: 0.216 (s=0.085). Negative placement correlation r = -0.262 was found, i.e. the better the final placement, the worse the reaction time. The fastest man over the first 50 m was KRYLOV (5.87 s), fifth overall in the final.

A comparison of the mean values of the indices used for evaluating the aspects of peformance (TAB. 10, 11) revealed that in the final the athletes who finished 1st - 4th were the best in all the indices. In the semifinals, all the athletes who qualified for the final were better in the indices than those who did not qualify. The only exception was the reaction time: better results were achieved by non-qualifiers.

AVERAGE VALUES OF SOME TIME DATA IN 200m MEN

ROUND	PLACEMENT	REACTION TIME [ms]	200m	1.50	2.50	3.50	4.50	1.100	2.100	1.-2.100
F	1.-4.	208	20.18	5.93	4.63	4.68	4.94	10.56	9.62	0.94
F	5.-8.	223	20.43	5.96	4.72	4.71	5.04	10.68	9.75	0.93
F	1.-8.	215	20.30	5.95	4.66	4.70	4.99	10.61	9.69	0.92
SF1	1.-4.	199	20.64	6.00	4.78	4.79	5.07	10.78	9.86	0.92
SF2	1.-4.	240	20.33	5.96	4.67	4.67	5.03	10.63	9.70	0.93
SF1+2 QUAL.	1.-4.	220	20.49	5.98	4.73	4.73	5.05	10.71	9.78	0.93
SF1	5.-8.	175	21.09	6.05	4.89	4.91	5.23	10.94	10.15	0.79
SF2	5.-8.	238	20.68	6.01	4.67	4.79	5.21	10.68	10.00	0.68
SF1+2 NOTQ.	5.-8.	206	20.88	6.03	4.84	4.85	5.22	10.81	10.07	0.74
SF1	1.-8.	187	20.87	6.03	4.84	4.85	5.15	10.87	10.01	0.85
SF2	1.-8.	239	20.51	5.98	4.68	4.73	5.12	10.66	9.85	0.81

TABLE 10

AVERAGE VALUES OF SOME TIME DATA IN 200m WOMEN

ROUND	PLACEMENT	REACTION TIME [ms]	200m	1.50	2.50	3.50	4.50	1.100	2.100	1.-2.100
F	1.-4.	167	21.99	6.22	5.13	5.13	5.51	11.35	10.64	0.71
F	5.-8.	230	22.50	6.44	5.24	5.24	5.58	11.68	10.82	0.86
F	1.-8.	199	22.54	6.33	5.18	5.18	5.55	11.51	10.73	0.78
SF1	1.-4.	248	22.59	6.40	5.12	5.32	5.75	11.52	11.07	0.45
SF2	1.-4.	223	22.53	6.38	5.09	5.41	5.65	11.47	11.06	0.41
SF1+2 QUAL.	1.-4.	236	22.56	6.40	5.10	5.36	5.70	11.50	11.06	0.44
SF1	5.-8.	217	23.21	6.52	5.26	5.50	5.93	11.78	11.43	0.35
SF2	5.-8.	261	22.98	6.43	5.17	5.51	5.87	11.60	11.38	0.22
SF1+2 NOTQ.	5.-8.	239	23.09	6.47	5.22	5.51	5.90	11.69	11.40	0.29
SF1	1.-8.	233	22.90	6.46	5.19	5.41	5.84	11.65	11.25	0.40
SF2	1.-8.	242	22.76	6.41	5.13	5.46	5.76	11.54	11.22	0.31

TABLE 11

In the women's event, none of the athletes who failed to qualify from the 1st round (times over 23.26 s) clocked a time of less than 6.40 s for the first 50m section. The men who did not qualify from the heats (times over 21.35 s) failed to clock times of less than 6.00 s. The male non-qualifiers from the quarterfinals (times over 20.90 s) failed to clock times of less than 5.93 s.

Maximum speed

Maximum mean velocity, measured in 10m sections in the second half of the 200 m was achieved in 100 - 140 m. The highest velocity measured in men was 11.11m/s, in women 10.00 m/s. The fastest 20 m section in the 100-140m section was 1.82s in men, 2.00s in women. None of the non-qualifiers from the women's quarterfinals were able to clock times under 2.08 s for a 20m section with a flying start. None of the non-qualifiers from the men's heats were able to clock times of less than 1.88s.

If the fastest 10 m section in the second half of the 200 m in each finalist is laid down as 100%, a continuous decrease in velocity is found more or less throughout the second half, most noticeably from 130 m (TAB. 12, 13).

DECREASE OF SPEED BY 10-m-SECTIONS IN THE 2nd HALF OF THE FINAL RACE
OF THE 200m MEN EXPRESSED IN %
[100%=BEST TIME ON 10-m-SECTION IN EACH INDIVIDUAL]

NAME	PLACE-MENT	1.100	2.100	1.a2. 100	t10 max.	100-110	110-120	120-130	130-140	140-150	150-160	160-170	170-180	180-190	190-200
SMITH	1.	10.63	9.53	1.10	0.92	1.1	1.1	-	-	4.2	4.2	4.2	6.1	6.1	7.1
QUENE-HERVE	2.	10.57	9.59	0.98	0.93	-	-	1.1	-	2.1	4.1	4.1	6.1	-6.1	6.1
REGIS	3.	10.53	9.65	0.88	0.90	2.2	-	5.3	5.3	6.2	6.2	9.1	9.1	10.9	11.8
DA SILVA ROBSON	4.	10.51	9.71	0.80	0.92	-	-	2.1	3.1	6.2	5.2	5.2	10.7	8.9	9.8
KRYLOV	5.	10.52	9.71	0.81	0.91	-	1.1	2.2	6.2	6.2	7.1	6.2	11.7	9.0	11.7
HEARD	6.	10.69	9.56	1.13	0.90	-	3.2	2.1	2.1	5.3	8.2	8.2	7.2	10.9	10.0
PAVONI	7.	10.65	9.80	0.85	0.90	-	6.2	4.3	4.3	8.2	8.2	10.9	10.0	13.5	16.3
MAHORN	8.	10.85	9.93	0.92	0.93	-	3.1	4.1	3.1	6.1	6.1	7.9	7.9	10.6	13.1
					$F_1 : \bar{x}$	1.7	2.9	3.0	4.0	5.6	6.2	7.0	8.6	9.5	10.7
					$F_1 : \bar{x}$	1.7		2.8	4.2	4.7	4.9	5.7	8.0	8.0	8.7
					$F_5 : \bar{x}$		3.4	3.2	3.9	6.5	7.4	8.3	9.2	11.0	12.8

TABLE 12

DECREASE OF SPEED BY 10-m-SECTIONS IN THE 2nd HALF OF THE FINAL RACE
OF THE 200m WOMEN EXPRESSED IN %
[100%=BEST TIME ON 10-m-SECTION IN EACH INDIVIDUAL]

NAME	PLACE-MENT	1.100	2.100	1.a2. 100	t10 max.	100-110	110-120	120-130	130-140	140-150	150-160	160-170	170-180	180-190	190-200
GLADISCH	1.	11.09	10.65	0.44	1.00	-	-	2.0	1.0	6.0	4.0	9.0	9.0	16.0	18.0
GRIFFITH	2.	11.39	10.57	0.82	1.01	3.0	1.0	-	1.0	1.0	5.0	5.0	7.9	9.9	12.9
OTTEY	3.	11.35	10.71	0.64	1.01	2.0	-	1.0	2.0	4.0	5.0	6.0	8.9	9.9	21.8
MARSHALL	4.	11.57	10.61	0.96	1.02	1.0	2.0	-	1.0	3.9	2.9	2.9	5.9	9.8	10.8
TORRENCE	5.	11.69	10.71	0.98	1.03	1.9	1.9	0.97	-	2.9	2.9	2.9	6.8	7.9	11.7
ONYALI	6.	11.67	10.85	0.82	1.03	1.9	1.9	0.97	-	2.9	3.9	5.8	9.7	13.6	12.6
KASPRZYK	7.	11.68	10.84	0.84	1.04	0.96	-	0.96	-	1.9	5.8	4.8	5.8	10.6	11.5
GEORGIEVA	8.	11.68	10.87	0.81	1.03	1.9	2.9	-	-	2.9	2.9	6.8	9.7	12.6	15.5
					$F_1 : \bar{x}$	1.8	1.9	1.2	1.3	3.2	4.1	5.4	8.0	11.3	14.4
					$F_{1\,4}\ \bar{x}$	2.0	1.5	1.5	1.3	3.7	4.2	5.7	7.9	11.4	15.9
					$F_5 : \bar{x}$	1.7	2.2	1.0		2.7	3.9	5.1	8.0	11.2	12.8

TABLE 13

Higher maximum velocities over the 50-100m section would probably have been found if all the 10m sections had been measured.

The second 50m section was predominantly faster for the men (1st-5th finalists). In the women's event, more runners achieved their fastest times in the third 50m section. The mean difference between the second and third 50m sections in all the finalists was 0.04s (s= 0.03). For finalists placed 1 - 4, the difference was slightly higher: 0.05s (s=0.04) than in the other, "inferior" group of finalists: 0.03 s (s=0.02). In percentages, the drop in velocity in the third 50m section compared with the preceding second 50m section amounted to 1.13% (s=0.74) in the first group of finalists, and 0,55% (s=0.95) in the second group. The drop in velocity in the last 50m section, compared with the preceding, (third) 50m section for the finalists was 0.29 s (s=0,05). In the "better" group the drop was smaller, 0.26 s (s=0.04), in the "inferior" group it was higher, 0.33s (s=0.03). In percentages,the drop for all the finalists amounts to 6.2% (s=1.0), in the "better" group 5.5% (s=0.9), in the "inferior" group 6.9% (s=0.5).

Speed endurance

The level of speed endurance is evaluated in terms of the drop in velocity in the second 100m section. The speed drops in all athletes in the second half of the race. The medallists differ from the rest of the field in that their decrease is slower, they are better able to maintain maximum speed. The last 50m sections were covered in less than 5.00 s. The fastest man here was SMITH (4.87s) who won the gold medal with an irresistible finish, clocking the same time as the runner-up QUENEHERVE; at the 150m mark, he was running in the fifth position!

The second half of the race is faster than the first. The time difference between the two 100m sections is another criterion for judging speed endurance. In all the finalists and semifinalists the second section was run faster than the first. The mean difference between the first and second 100m sections in the finalists was 0.93s (s=0.13). No correlation was found between the final placement and the above difference (r=0.131). The difference was most notable in HEARD and SMITH (1.13 and 1.10 respectively), here caused by a slower start of the race. That seems to point to a considerable improvement potential in the acceleration abilities of the two athletes. After the first 50 m, the subsequent winner of the race was running in the 6th place, while HEARD was running last.

In training, a good and useful pointer to the level of speed endurance is the timing of 150 m. None of the non-qualifiers in the women's event were able to clock times better than 17.11 s, in the men's event none of the non-qualifiers were able to clock times beter than 15.70s. The non-qualifiers from the heats in the men's event failed to clock times better than 15.95s.

The fastest times in the second (flying-start) 100 m section were clocked by black-skinned athletes (SMITH 9.53s, HEARD 9.56s, GRIFFITH 10.27s, MARSHALL 10.61s). This is probably the result of better anatomical and physiological conditions for sprinting: a higher percentage of fast muscle fibres, better conductibility of nerve fibres, higher muscular viscosity etc.

The time differences that decided the final placements in the men's 200 m were infinitesimal. The time analysis of the final shows that the fast finish (the last 50m section) was decisive. SMITH would not have had such a tough time contesting the first place with QUENEHERVE if he had clocked a better time in the first 100m section, which was fully within his potential. The third man in, REGIS, and the fourth, DA SILVA, had led the field as late as the 170m mark. REGIS won the bronze medal, thanks to a faster finish. In the last 30 m he was 0.04s faster than DA SILVA who threw himself over the line, thus relegating KRYLOV to the 5th place by 0.01 s. The two men had the same intermediate time at the 190m mark.

The characteristic features of the sprinting distance provide the basis for analyzing changes in the dynamics of running velocity. In the short sprints, the athlete has to run flat-out throughout the race. This is the point in which the sprinting events differ from the other running events. The 200m distance was divided in 50m sections for the purpose of comparison. The performance over 200 m is 100%. The percentage share of each 50m section in the overall performance was calculated on the basis of an analysis of the semifinals and the final (see TAB 14).

Women clock relatively better times in the first half of the race than men, but conversely, tend to suffer heavier losses in the second half.

TAB. 14: Percentage share of 50m sections in the overall time -200m

	1. 50m	2. 50m	3. 50m	4. 50m	1. 100m	2. 100m	2.+3. 50m
MEN	29.1	23.0	23.2	24.7	52.1	47.9	46.2
WOMEN	28.3	22.8	23.6	25.3	51.1	48.9	46.4

– FIG 1 –

TIME ANALYSIS: 200m MEN

SMITH CALVIN 61 USA

****

5. HEAT

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1 .	20.62	246	5.92	10.56	11.47	12.45	13.43	14.40	15.39	16.39	17.41	18.45	19.51	10.06
10 meters sections					0.91	0.98	0.98	0.97	0.99	1.00	1.02	1.04	1.06	1.11
% ?					100.00	92.85	92.85	93.81	91.91	91.00	89.21	87.50	85.84	81.98
20 meters sections					1.89		1.95		1.99		2.06		2.17	
50 meters sections				4.64		4.83					5.23			

2. QUARTER-FINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1 .	20.38	246	5.89	10.55	11.48	12.43	13.43	14.39	15.33	16.30	17.30	18.29	19.31	9.83
10 meters sections					0.93	0.95	1.00	0.96	0.94	0.97	1.00	0.99	1.02	1.07
% ?					100.00	97.89	93.00	96.87	98.93	95.87	93.00	93.93	91.17	86.91
20 meters sections					1.88		1.96		1.91		1.99		2.09	
50 meters sections				4.66		4.78					5.05			

1. SEMIFINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 2 .	20.54	256	6.02	10.76	11.71	12.67	13.60	14.57	15.54	16.51	17.50	18.49	19.49	9.78
10 meters sections					0.95	0.96	0.93	0.97	0.97	0.97	0.99	0.99	1.00	1.05
% ?					97.89	96.87	100.00	95.87	95.87	95.87	93.93	93.93	93.00	88.57
20 meters sections					1.91		1.90		1.94		1.98		2.05	
50 meters sections				4.74		4.78					5.00			

FINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1 .	20.16	284	5.98	10.63	11.56	12.49	13.41	14.33	15.29	16.25	17.21	18.19	19.17	9.53
10 meters sections					0.93	0.93	0.92	0.92	0.96	0.96	0.96	0.98	0.98	0.99
% ?					98.92	98.92	100.00	100.00	95.83	95.83	95.83	93.87	93.87	92.92
20 meters sections					1.86		1.84		1.92		1.94		1.97	
50 meters sections				4.65		4.66					4.87			

– FIG 2 –

TIME ANALYSIS: 200m MEN

QUENEHERVE GILLES 66 FRA

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3. HEAT

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1.	20.59	193	5.95	10.56	11.51	12.49	13.46	14.43	15.44	16.40	17.41	18.47	19.51	10.03
10 meters sections					0.95	0.98	0.97	0.97	1.01	0.96	1.01	1.06	1.04	1.08
% ?					100.00	96.93	97.93	97.93	94.05	98.95	94.05	89.62	91.34	87.96
20 meters sections						1.93		1.94		1.97		2.07		2.12
50 meters sections				4.61					4.88					5.15

3. QUARTER-FINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1.	20.48	271	5.94	10.72	11.65	12.63	13.61	14.55	15.46	16.46	17.46	18.47	19.47	9.76
10 meters sections					0.93	0.98	0.98	0.94	0.91	1.00	1.00	1.01	1.00	1.01
% ?					97.84	92.85	92.85	96.80	100.00	91.00	91.00	90.09	91.00	90.09
20 meters sections						1.91		1.92		1.91		2.01		2.01
50 meters sections				4.78					4.74					5.02

2. SEMIFINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1.	20.31	264	6.01	10.70	11.63	12.56	13.50	14.41	15.34	16.31	17.30	18.29	19.29	9.61
10 meters sections					0.93	0.93	0.94	0.91	0.93	0.97	0.99	0.99	1.00	1.02
% ?					97.84	97.84	96.80	100.00	97.84	93.81	91.91	91.91	91.00	89.21
20 meters sections						1.86		1.85		1.90		1.98		2.02
50 meters sections				4.69					4.64					4.97

FINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 2.	20.16	207	5.96	10.57	11.50	12.43	13.37	14.30	15.25	16.22	17.19	18.18	19.17	9.59
10 meters sections					0.93	0.93	0.94	0.93	0.95	0.97	0.97	0.99	0.99	0.99
% ?					100.00	100.00	98.93	100.00	97.89	95.87	95.87	93.93	93.93	93.93
20 meters sections						1.86		1.87		1.92		1.96		1.98
50 meters sections				4.61					4.68					4.91

- FIG 3 -

TIME ANALYSIS: 200m MEN

REGIS JOHN 66 GBR

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	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
6.HEAT														
PLACING 1 .	20.76	225	6.05	10.67	11.61	12.58	13.57	14.52	15.54	16.54	17.56	18.62	19.67	10.09
10 meters sections					0.94	0.97	0.99	0.95	1.02	1.00	1.02	1.06	1.05	1.09
% ?					100.00	96.90	94.94	98.94	92.15	94.00	92.15	88.67	89.52	86.23
20 meters sections					1.91		1.94		2.02		2.08		2.14	
50 meters sections				4.62			4.87					5.22		
3.QUARTER-FINAL														
PLACING 3 .	20.60	248	5.99	10.64	11.57	12.53	13.50	14.44	15.42	16.40	17.42	18.47	19.53	9.96
10 meters sections					0.93	0.96	0.97	0.94	0.98	0.98	1.02	1.05	1.06	1.07
% ?					100.00	96.87	95.87	98.93	94.89	94.89	91.17	88.57	87.73	86.91
20 meters sections					1.89		1.91		1.96		2.07		2.13	
50 meters sections				4.65			4.78					5.18		
1.SEMIFINAL														
PLACING 1 .	20.54	195	5.99	10.69	11.63	12.59	13.54	14.48	15.45	16.45	17.45	18.46	19.46	9.85
10 meters sections					0.94	0.96	0.95	0.94	0.97	1.00	1.00	1.01	1.00	1.08
% ?					100.00	97.91	98.94	100.00	96.90	94.00	94.00	93.06	94.00	87.03
20 meters sections					1.90		1.89		1.97		2.01		2.08	
50 meters sections				4.70			4.76					5.09		
FINAL														
PLACING 3 .	20.18	146	5.89	10.53	11.45	12.35	13.30	14.25	15.21	16.17	17.16	18.15	19.16	9.65
10 meters sections					0.92	0.90	0.95	0.95	0.96	0.96	0.99	0.99	1.01	1.02
% ?					97.82	100.00	94.73	94.73	93.75	93.75	90.90	90.90	89.10	88.23
20 meters sections					1.82		1.90		1.92		1.98		2.03	
50 meters sections				4.64			4.68					4.97		

- FIG 1 -

TIME ANALYSIS: 200m WOMEN

GLADISCH SILKE 64 GDR

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1.HEAT

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1 .	22.44	280	6.38	11.42	12.37	13.39	14.45	15.51	16.59	17.69	18.85	20.02	21.21	11.02
10 meters sections					0.95	1.02	1.06	1.06	1.08	1.10	1.16	1.17	1.19	1.23
% ?					100.00	93.13	89.62	89.62	87.96	86.36	81.89	81.19	79.83	77.23
20 meters sections					1.97		2.12		2.18		2.33		2.42	
50 meters sections				5.04			5.17					5.85		

1.SEMIFINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 2 .	22.54	263	6.37	11.40	12.44	13.50	14.57	15.63	16.73	17.84	18.93	20.07	21.24	11.14
10 meters sections					1.04	1.06	1.07	1.06	1.10	1.11	1.09	1.14	1.17	1.30
% ?					100.00	98.11	97.19	98.11	94.54	93.69	95.41	91.22	88.88	80.00
20 meters sections					2.10		2.13		2.21		2.23		2.47	
50 meters sections				5.03			5.33					5.81		

FINAL

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
PLACING 1 .	21.74	155	6.13	11.09	12.09	13.09	14.11	15.12	16.18	17.22	18.31	19.40	20.56	10.65
10 meters sections					1.00	1.00	1.02	1.01	1.06	1.04	1.09	1.09	1.16	1.18
% ?					100.00	100.00	98.03	99.00	94.33	96.15	91.74	91.74	86.20	84.74
20 meters sections					2.00		2.03		2.10		2.18		2.34	
50 meters sections				4.96			5.09					5.56		

- FIG 2 -

TIME ANALYSIS: 200m WOMEN

GRIFFITH FLORENCE 59 USA

	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
4. HEAT														
PLACING 1 .	22.56	229	6.37	11.49	12.52	13.58	14.65	15.71	16.84	17.95	19.05	20.21	21.36	11.07
10 meters sections					1.03	1.06	1.07	1.06	1.13	1.11	1.10	1.16	1.15	1.20
% ?					100.00	97.16	96.26	97.16	91.15	92.79	93.63	88.79	89.56	85.83
20 meters sections						2.09		2.13		2.24		2.26		2.35
50 meters sections				5.12					5.35					5.72
2. SEMIFINAL														
PLACING 1 .	22.38	208	6.39	11.42	12.43	13.45	14.56	15.67	16.77	17.85	18.97	20.09	21.23	10.96
10 meters sections					1.01	1.02	1.11	1.11	1.10	1.08	1.12	1.12	1.14	1.15
% ?					100.00	99.01	90.99	90.99	91.81	93.51	90.17	90.17	88.59	87.82
20 meters sections						2.03		2.22		2.18		2.24		2.29
50 meters sections				5.03					5.35					5.61
FINAL														
PLACING 2 .	21.96	141	6.14	11.39	12.43	13.45	14.46	15.48	16.50	17.56	18.62	19.71	20.82	10.57
10 meters sections					1.04	1.02	1.01	1.02	1.02	1.06	1.06	1.09	1.11	1.14
% ?					97.11	99.01	100.00	99.01	99.01	95.28	95.28	92.66	90.99	88.59
20 meters sections						2.06		2.03		2.08		2.15		2.25
50 meters sections				5.25					5.11					5.46

- FIG 3 -

TIME ANALYSIS: 200m WOMEN

OTTEY MERLENE 60 JAM

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	200 [s]	RT [ms]	50 [s]	100 [s]	110 [s]	120 [s]	130 [s]	140 [s]	150 [s]	160 [s]	170 [s]	180 [s]	190 [s]	2.100 [s]
4.HEAT														
PLACING 3.	23.19	170	6.46	11.78	12.86	13.93	15.04	16.15	17.28	18.43	19.58	20.71	21.93	11.41
10 meters sections					1.08	1.07	1.11	1.11	1.13	1.15	1.15	1.13	1.22	1.26
% ?					99.07	100.00	96.39	96.39	94.69	93.04	93.04	94.69	87.70	84.92
20 meters sections					2.15		2.22		2.28		2.28		2.48	
50 meters sections			5.32			5.50					5.91			
1.SEMIFINAL														
PLACING 1.	22.43	277	6.43	11.60	12.63	13.67	14.71	15.75	16.84	17.89	18.96	20.07	21.23	10.83
10 meters sections					1.03	1.04	1.04	1.04	1.09	1.05	1.07	1.11	1.16	1.20
% ?					100.00	99.03	99.03	99.03	94.49	98.09	96.26	92.79	88.79	85.83
20 meters sections					2.07		2.08		2.14		2.18		2.36	
50 meters sections			5.17			5.24					5.59			
FINAL														
PLACING 3.	22.06	177	6.24	11.35	12.38	13.39	14.41	15.44	16.49	17.55	18.62	19.72	20.83	10.71
10 meters sections					1.03	1.01	1.02	1.03	1.05	1.06	1.07	1.10	1.11	1.23
% ?					98.05	100.00	99.01	98.05	96.19	95.28	94.39	91.81	90.99	82.11
20 meters sections					2.04		2.05		2.11		2.17		2.34	
50 meters sections			5.11			5.14					5.57			

3.4 TIME ANALYSIS OF THE 400 M (MEN)

Evaluation of the event

The chief characteristics of this event at the II WC were the following:

- high average performance level, consequently, tough competition in the qualifying rounds;
- close contest among the finalists (leading performers for the year).

The crucial factor for success proved to be the capacity to run 4 races in 5 days and to continue to improve performance. The question remains, whether the one-day interval between the semifinal and final helped to improve the level or not.

The experience and potential of the participating countries were important in terms of the regeneration of the athletes' energy between the races and their daily routine during the championschips. In a demanding contest like this, those circumstances undoubtedly have a considerable impact on toughness of the 400m competition. This is best shown by the fact that 6 of 8 finalists clocked final times that were inferior to those they recorded in the semifinal. Only SCHOENLEBE and REYNOLDS were able to go on improving their performance throughout the championships. SCHOENLEBE's performance was particulary impressive: in the final he set a new and European record whereas REYNOLDS fell below his best time of the year. The very best result was achieved by EGBUNIKE in the semifinal (44,26 s) but he did not manage to repeat it.

The analysis shows that SCHOENLEBE beat all his rivals with the most important qualities of a 400m runner: specific endurance, as well as optimum pace distribution. In the final, he chose a relatively slower beginning (at the 200 m and 300 m mark he was 0.22 s and 0.32 s behind model intermediate times) and had an impressive finish on the home straight. The SPEARMAN coefficient of rank correlation was calculated for selected indices relating to the final placing (see TAB.15). The critical value of the coefficient on the significance level = 0.05 is r=0.707.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\overline{x}$	COEF. OF RC
TIME[s]	44.33	44.56	44.80	44.99	45.06	45.34	46.27	46.77	45.265	
PLACING	1.	2.	3.	4.	5.	6.	7.	8.		

TABLE 15

Evaluation of the indices

(a) 0 - 100 m

The correlation coefficient indicates that placing after the first 100 m is unimportant. In this part of the race it is important to maintain the optimum pace, i.e. stick to the model intermediate time as closely as possible and try to conserve energy. The greatest deviation from the model can be observed in HALEY in the final (+ 0.71 s); the pace corresponds to an overall of 43.90s which was clearly beyond his scope. The fastest man over the first 100m section was EGBUNIKE (10.87 s) in the semifinal, corresponding to an overall time of 43.85 s. His resulting time was the best time of the championship as mentioned above. The slowest of the finalists over the first 100 m was TIACOH (11.56s) who has a typically slower beginning; in his semifinal performance of 44.61 s he clocked 11.36 s over the first 100 m (0.28 s behind the model intermediate time), but he was not able to improve the pace still further in the final.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\overline{x}$	COEF. OF RC
TIME[s]	11.11	10.91	11.22	11.07	11.10	11.41	11.56	10.88	11.16	
PLACING	5.	2.	6.	3.	4.	7.	8.	1.		0.0714

TABLE 16

(b) 100 - 200 m

In this index too, the correlation coefficient is lower than its critical value; that means that placing by intermediate times is not important for the final placement. What was stated about the first section, goes for the second one, as well, but an even greater emphasis should be put on the economy of running. For all competitors, this is the fastest section of the 400m distance but the highest momentary velocity is probably attained as early as the first 100m section (judging from a comparison of the first 100m section, run from a crouch start, and the second 100m section, run with a flying start).

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\overline{x}$	COEF. OF RC
TIME[s]	10.29	10.23	10.49	10.41	10.26	10.32	10.61	10.42	10.379	
PLACING	3.	1.	7.	5.	2.	4.	8.	6.		0.532

TABLE 17

(c) 200 - 300 m

The correlation coefficent indicates that not even the third 100m section significantly influences the result of the race. Differences among the first 6 finalists are minimal and show convincingly what a close race this was. Only HALEY and TIACOH deviated markedly from the model, corresponding to the overall performance.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\bar{X}$	COEF. OF RC
TIME[s]	11.04	11.18	11.03	11.18	11.19	11.03	11.39	11.49	11.191	
PLACING	3.	4.-5.	1.-2.	4.-5.	6.	1.-2.	7.	8.		0.595

TABLE 18

(d) 300 - 400 m

The correlation coefficent indicates that it was here that the whole race was largely decided. Placement by intermediate times over the last 100 m corresponds to the final placement in the race, except the 2nd and 3rd places; in this 100m section, the differences in the times achieved are the highest. The winner, SCHOENLEBE, gained an advantage of 0.35 s over the runner up, EGBUNIKE, in this section; EGBUNIKE's time for the last 100m section corresponds to an overall time of 44.35s, while SCHOENLEBE's time (11.89 s) corresponded to an overal time of 43.00s. The time clocked by REYNOLDS is remarkable, too, because it brought him from down in the 5th place to the 3rd place. HALEY's time, the slowest, is the result partly of his resignation before the finish line.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\bar{X}$	COEF. OF RC
TIME[s]	11.89	12.24	12.06	12.33	12.51	12.58	12.71	13.98	12.538	
PLACING	3.	1.	2.	4.	5.	6.	7.	8.		0.976

TABLE 19

(e) 0 - 200 m

The ranking after the first half of the race correlates only marginally with the final result. A more marked deviation from model intermediate times among the first finalists could be observed only in REYNOLDS (-0.31 s); his intermediate time corresponds to a final time which is 0.6 s less than the time achieved. A marked deviation in the opposing sense, i.e. too much speed in the first half of the race, could be observed in the final only in HALEY (8th) who started the race with the first half good for a final time 44.60 s. His official time (46.77s) was marked as stated above by his resignation on the home straight.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\bar{x}$	COEF. OF RC
TIME[s]	21.40	21.14	21.71	21.48	21.36	21.73	22.17	21.30	21.536	
PLACING	4.	1.	6.	5.	2.	7.	8.	3.		0.333

TABLE 20

(f) 0 - 300 m

Placing at the 300 mark in the final correlates significantly with the final placing, although the range of the times achieved in the 1st - 6th places is as little as 0.44 s at the 300m mark, rising to 1.01 s at the finish.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\bar{x}$	COEF. OF RC
TIME[s]	32.44	32.32	32.74	32.66	32.55	32.76	33.56	32.79	32.728	
PLACING	2.	1.	5.	4.	3.	6.	8.	7.		0.857

TABLE 21

(g) 200 - 400 m

Placing according to the times achieved in the second half of the final correlates very significantly with the final placing, supporting the hypothesis of the crucial importance of specific endurance in the 400 m as against absolute speed.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\bar{x}$	COEF. OF RC
TIME[s]	22.93	23.42	23.09	23.51	23.70	23.61	24.10	25.47		
PLACING	1.	3.	2.	4.	6.	5.	7.	8.		0.952

TABLE 22

Performance in the semifinal

The fact that ranking by the times achieved in the semifinal correlates only slightly with the final ranking, shows that this race was a very close affair. REYNOLDS who had barely qualified (7th by his semifinal time), won the bronze medal in the final. Identical ranking by times in the semifinal and final (8th place) can be found only in HALEY.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\overline{X}$	COEF. OF RC
TIME[s]	44.60	44.26	44.94	44.83	44.50	44.73	44.69	45.21		
PLACING	3.	1.	7.	6.	2.	5.	4.	8.		0.476

TABLE 23

Difference between the 1st and 2nd 200 m

Extreme difference found in REYNOLDS (1.38 s) and HALEY (4.17 s); in the former the difference probably caused by the slow first half of the race (corresponding to 45.40 s according to the model rather than an extremely fast second half. In HALEY, the difference is explained by the relaxation at the end of the race. After eliminating both extreme values, the average value between the times in the 1st and 2nd half is 1.998 s.

NAME	SCHON-LEBE	EGBU-NIKE	REY-NOLDS	HER-NANDEZ	RED-MOND	KITUR	TIACOH	HALEY	$\overline{X}$	COEF. OF RC
TIME[s]	1.53	2.28	1.38	2.03	2.34	1.88	1.93	4.17	2.193	
PLACING	2.	6.	1.	5.	7.	3.	4.	8.		0.476

TABLE 24

3.4. TIME ANALYSIS OF THE 400 M (WOMEN)

General evaluation of the event

The women's 400 m was inferior to previous top-level events. The winning time at the II WC was worse than the times of all winners at previous OG, EC and WC from 1976 through 1986. This was partly the result of the absense of the former great athletes in this event, and partly because some of the competing athletes failed to perform up to their personal bests. The women's contest unlike the men's, comprised only 3 rounds. Only 3 runners in the final clocked times inferior to their semifinal performances: they were placed 6th, 7th and 8th in the final. The athletes who led the field did not have to expend all their energy in qualifying. As with men, the most important quality of female 400m runners is specific endurance. The winner BRYZGINA chose a tactics similar to that of the winner of the men's event, i.e. a slower beginning.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	49.38	49.94	50.20	50.53	50.82	51.03	51.13	51.20	50.529	
PLACING	1.	2.	3.	4.	5.	6.	7.	8.		

TABLE 25

Evaluation of the indices

(a) 0 - 100 m

Judging from the intermediate times at the 100m mark, only 5 runners started the race with real medal possibilities (intermediate time better than 12.40s). After the first 100 m the others could hardly aspire to a notable success. The difference between the best and the worst intermediate time is 0.70 s.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	12.34	12.20	12.21	12.40	12.70	12.82	12.32	12.90	12.486	
PLACING	4.	1.	2.	5.	6.	7.	3.	8.		0.634

TABLE 26

(b) 100 - 200 m

The difference between the best and the worst time over the 2nd 100m section is much less than over the first section (0.50 s). Placement by the times clocked in the second section correlates with the overall results, i.e. the women's race was decided much earlier than the men's.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\overline{x}$	COEF. OF RC
TIME[s]	11.48	11.44	11.54	11.45	11.67	11.94	11.62	11.78	11.615	
PLACING	3.	1.	4.	2.	6.	8.	5.	7.		0.762

TABLE 27

(c) 200 - 300 m

Placement by times over the 3rd 100m section correlates more closely with the final finishing times than any other 100m section. In this section the subsequent winner, BRYZGINA, started to advance, while PINIGINA and DIXON began to fall behind, eventually to clock the slowest 4th 100m sections.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\overline{x}$	COEF. OF RC
TIME[s]	12.33	12.43	12.60	12.68	12.70	12.56	13.07	12.72	12.636	
PLACING	1.	2.	4.	5.	6.	3.	8.	7.		0.810

TABLE 28

(d) 300 - 400 m

The winner's time over this section was the fastest. The gap between her time and the second fastest in this section, RICHARDSON, was 0.48 s and the overall runner up, MUELLER, was 0.64 s. The time range between the others is fairly small (0.41 s) between the 2nd and 8th. BRYZGINA'S speed over the last section corresponds to a time of 48.25 s, indicating the potential of a better performance, with a more "determined" beginning of the race.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\overline{x}$	COEF. OF RC
TIME[s]	13.23	13.87	13.85	14.00	13.75	13.71	14.12	13.80	13.791	
PLACING	1.	6.	5.	7.	3.	2.	8.	4.		0.214

TABLE 29

(e) 0 - 200 m

The hight coefficient of rank correlation indicates that the final placements (except the medallists) were decided to a great extent as early as in the first half of the race. Compared with the intermediate times achieved in the top performances of KOCH and KRATOCHVILOVA, BRYZGINA was slower at the 200m mark by 0.8 - 1.2 s.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	23.82	23.64	23.75	23.85	24.37	24.76	23.94	24.68	24.101	
PLACING	3.	1.	2.	4.	6.	8.	5.	7.		0.810

TABLE 30

(f) 0 - 300 m

A comparison of the range of times at the 300m mark between men and women in the 1st to the 6th places reveals that the women's race was not so close as the men's. After the intermediate times at the 300m mark, there was no real chance of times under 49 s for any competitor.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	36.15	36.07	36.35	36.53	37.07	37.32	37.01	37.40	36.738	
PLACING	2.	1.	3.	4.	6.	7.	5.	8.		0.905

TABLE 31

(g) 200 - 400 m

A considerable difference between BRYZGINA and the others can be seen in the times clocked in the 2nd half of the race; but most of the time gain is due to the last 100m. By model intermediate times, the winner's time in the second half of the race corresponds to 49.10 s, i.e. a better time than the one actually achieved; in the other finalists, the very opposite is true.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	25.56	26.30	26.45	26.68	26.45	26.27	27.19	26.52	26.428	
PLACING	1.	3.	4.-5.	7.	4.-5.	2.	8.	6.		0.601

TABLE 32

Performance in the semifinal

The winners did not have to do their best in the semifinal; in the last part of the race there were tactical run-ins, so that the athletes could conserve energy. Therefore the ranking by performance in the semifinal does not correlate with the final ranking.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	$\bar{x}$	COEF. OF RC
TIME[s]	50.88	50.15	50.53	50.83	50.95	50.91	50.83	51.07	50.769	
PLACING	5.	1.	2.	3.-4.	7.	6.	3.-4.	8.		0.589

TABLE 33

Difference between the 1st and the 2nd 200 m

Difference found in RICHARDSON (1.51 s) and DIXON (3.25 s) can be attributed to poor pace judgement and energy output. The average value in the other runners is 2.308 s, i.e. roughly 0.3 s more than in the men's event.

NAME	BRYZ-GINA	MUEL-LER	EMMEL-MANN	PINI-GINA	LEATHER-WOOD	RICHARD-SON	DIXON	NAZA-ROVA	x	COEF. OF RC
TIME[s]	1.74	2.66	2.70	2.83	2.08	1.51	3.25	1.84	2.326	
PLACING	2.	5.	6.	7.	4.	1.	8.	3.		0.048

TABLE 34

- FIG 1 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — MEN

		400	0100	1.100	2.100	3.100	4.100	1.200	2.200	300
SCHOENLEBE T.	H 4	45.85	11.46	11.48	10.52	11.35	12.50	22.00	23.85	33.35
	QF2	44.81	11.20	11.52	10.27	10.97	12.05	21.79	23.02	32.76
65 GDR	SF1	44.60	11.15	11.09	10.18	11.01	12.32	21.27	23.33	32.28
	F	44.33	11.08	11.11	10.29	11.04	11.89	21.40	22.93	32.44

HEAT — PLACING 2. — 30.08.87

Performance:	45.85	11.46	11.48	10.52	11.35	12.50	22.00	23.85	33.35
Model intermediate times:	45.85	11.46	11.37	10.56	11.31	12.61	21.93	23.92	33.24
Diff. from interm. times :	-	-	-0.11	+0.04	-0.04	+0.11	-0.07	+0.07	-0.11
Diff. from 0100 m (model):	-	-	+0.09	+0.90	+0.15	-1.15	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.02	+0.94	+0.11	-1.04	-	-	-
Corresponding to Perform.:	-	-	46.30	45.70	46.00	45.40	46.00	45.70	46.00

QUARTER-FINAL — PLACING 1. — 31.08.87

Performance:	44.81	11.20	11.52	10.27	10.97	12.05	21.79	23.02	32.76
Model intermediate times:	44.80	11.20	11.10	10.30	11.05	12.35	21.40	23.40	32.45
Diff. from interm. times :	-	-	-0.42	+0.03	+0.08	+0.30	-0.39	+0.38	-0.31
Diff. from 0100 m (model):	-	-	+0.10	+0.90	+0.15	-1.15	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.32	+0.93	+0.23	-0.85	-	-	-
Corresponding to Perform.:	-	-	46.45	44.70	44.45	43.60	45.60	44.05	45.20

SEMIFINAL — PLACING 2. — 01.09.87

Performance:	44.60	11.15	11.09	10.18	11.01	12.32	21.27	23.33	32.28
Model intermediate times:	44.60	11.15	11.05	10.25	11.00	12.30	21.30	23.30	32.30
Diff. from interm. times :	-	-	-0.04	+0.07	-0.01	-0.02	+0.03	-0.03	+0.02
Diff. from 0100 m (model):	-	-	+0.10	+0.90	+0.15	-1.15	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.06	+0.97	+0.14	-1.17	-	-	-
Corresponding to Perform.:	-	-	44.75	44.35	44.65	44.70	44.55	44.65	44.55

FINAL — PLACING 1. — 03.09.87

Performance:	44.33	11.08	11.11	10.29	11.04	11.89	21.40	22.93	32.44
Model intermediate times:	44.35	11.09	10.99	10.19	10.94	12.23	21.18	23.17	32.12
Diff. from interm. times :	-	-	-0.12	-0.10	-0.10	+0.34	-0.22	+0.24	-0.32
Diff. from 0100 m (model):	-	-	+0.10	+0.90	+0.15	-1.14	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.03	+0.79	+0.04	-0.81	-	-	-
Corresponding to Perform.:	-	-	44.85	44.75	44.75	43.00	44.80	43.85	44.80

- FIG 2 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — MEN

		400	Ø100	1.100	2.100	3.100	4.100	1.200	2.200	300
EGBUNIKE I.	H 2	45.84	11.46	11.32	10.62	11.56	12.34	21.94	23.90	33.50
	QF3	45.46	11.37	11.09	10.14	11.34	12.89	21.23	24.23	32.57
61 NGR	SF1	44.26	11.07	10.87	10.10	11.13	12.16	20.97	23.29	32.10
	F	44.56	11.14	10.91	10.23	11.18	12.24	21.14	23.42	32.32

HEAT — PLACING 2. — 30.08.87

Performance:	45.84	11.46	11.32	10.62	11.56	12.34	21.94	23.90	33.50
Model intermediate times:	45.85	11.46	11.37	10.56	11.31	12.61	21.93	23.92	33.24
Diff. from interm. times :	-	-	+0.05	-0.06	-0.25	+0.27	-0.01	+0.02	-0.26
Diff. from Ø100 m (model):	-	-	+0.09	+0.90	+0.15	-1.15	-	-	-
Diff. from Ø100 m (act.) :	-	-	+0.14	+0.84	-0.10	-0.88	-	-	-
Corresponding to Perform.:	-	-	45.65	46.10	46.85	44.75	45.90	45.80	46.20

QUARTER-FINAL — PLACING 1. — 31.08.87

Performance:	45.46	11.37	11.09	10.14	11.34	12.89	21.23	24.23	32.57
Model intermediate times:	45.45	11.36	11.27	10.46	11.21	12.51	21.73	23.72	32.94
Diff. from interm. times :	-	-	+0.18	+0.32	-0.13	-0.38	+0.50	-0.51	+0.37
Diff. from Ø100 m (model):	-	-	+0.09	+0.90	+0.15	-1.15	-	-	-
Diff. from Ø100 m (act.) :	-	-	+0.28	+1.23	+0.03	-1.52	-	-	-
Corresponding to Perform.:	-	-	44.75	44.15	45.95	46.95	44.45	46.45	44.95

SEMIFINAL — PLACING 1. — 01.09.87

Performance:	44.26	11.07	10.87	10.10	11.13	12.16	20.97	23.29	32.10
Model intermediate times:	44.25	11.06	10.97	10.16	10.91	12.21	21.13	23.12	32.04
Diff. from interm. times :	-	-	+0.10	+0.06	-0.22	+0.05	+0.16	-0.17	-0.06
Diff. from Ø100 m (model):	-	-	+0.09	+0.90	+0.15	-1.15	-	-	-
Diff. from Ø100 m (act.) :	-	-	+0.20	+0.97	-0.06	-1.09	-	-	-
Corresponding to Perform.:	-	-	43.85	44.00	45.10	44.05	43.95	44.60	44.35

FINAL — PLACING 2. — 03.09.87

Performance:	44.56	11.14	10.91	10.23	11.18	12.24	21.14	23.42	32.32
Model intermediate times:	44.55	11.14	11.04	10.24	10.99	12.28	21.28	23.27	32.27
Diff. from interm. times :	-	-	+0.13	+0.01	-0.19	+0.04	+0.14	-0.15	-0.05
Diff. from Ø100 m (model):	-	-	+0.10	+0.90	+0.15	-1.14	-	-	-
Diff. from Ø100 m (act.) :	-	-	+0.23	+0.91	-0.04	-1.10	-	-	-
Corresponding to Perform.:	-	-	44.05	44.55	45.30	44.35	44.30	44.85	44.65

- FIG 3 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — MEN

		400	0100	1.100	2.100	3.100	4.100	1.200	2.200	300
REYNOLDS H.	H 1	45.51	11.38	11.56	10.94	11.30	11.71	22.50	23.01	33.80
	QF3	45.49	11.37	11.58	10.47	11.41	12.03	22.05	23.44	33.46
64 USA	SF2	44.94	11.24	11.46	10.34	11.20	11.94	21.80	23.14	33.00
	F	44.80	11.20	11.22	10.49	11.03	12.06	21.71	23.09	32.74

HEAT — PLACING 1. — 30.08.87

Performance:	45.51	11.38	11.56	10.94	11.30	11.71	22.50	23.01	33.80
Model intermediate times:	45.50	11.38	11.28	10.47	11.23	12.52	21.75	23.75	32.98
Diff. from interm. times :	-	-	-0.28	-0.47	-0.07	+0.81	-0.75	+0.74	-0.82
Diff. from 0100 m (model):	-	-	+0.10	+0.91	+0.15	-1.14	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.18	+0.44	+0.08	-0.33	-	-	-
CorresPonding to Perform.:	-	-	46.65	47.35	45.80	42.25	47.00	44.00	46.60

QUARTER-FINAL — PLACING 2. — 31.08.87

Performance:	45.49	11.37	11.58	10.47	11.41	12.03	22.05	23.44	33.46
Model intermediate times:	45.50	11.38	11.28	10.47	11.23	12.52	21.75	23.75	32.98
Diff. from interm. times :	-	-	-0.30	0.00	-0.18	+0.49	-0.30	+0.31	-0.48
Diff. from 0100 m (model):	-	-	+0.10	+0.91	+0.15	-1.14	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.21	+0.90	-0.04	-0.66	-	-	-
CorresPonding to Perform.:	-	-	46.70	45.50	46.25	43.55	46.10	44.90	46.15

SEMIFINAL — PLACING 4. — 1.09.87

Performance:	44.94	11.24	11.46	10.34	11.20	11.94	21.80	23.14	33.00
Model intermediate times:	44.95	11.24	11.14	10.34	11.09	12.38	21.48	23.47	32.57
Diff. from interm. times :	-	-	-0.32	0.00	-0.11	+0.44	-0.32	+0.33	-0.43
Diff. from 0100 m (model):	-	-	+0.10	+0.90	+0.15	-1.14	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.22	+0.90	+0.04	-0.70	-	-	-
CorresPonding to Perform.:	-	-	46.25	44.95	45.40	43.15	45.60	44.30	45.55

FINAL — PLACING 3. — 03.09.87

Performance:	44.80	11.20	11.22	10.49	11.03	12.06	21.71	23.09	32.74
Model intermediate times:	44.80	11.20	11.10	10.30	11.05	12.35	21.40	23.40	32.45
Diff. from interm. times :	-	-	-0.12	-0.19	+0.02	+0.29	-0.31	+0.31	-0.29
Diff. from 0100 m (model):	-	-	+0.10	+0.90	+0.15	-1.15	-	-	-
Diff. from 0100 m (act.) :	-	-	-0.02	+0.71	+0.17	-0.86	-	-	-
CorresPonding to Perform.:	-	-	45.25	45.55	44.70	43.65	45.40	44.20	45.20

- FIG 1 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — WOMEN

		400	0100	1.100	2.100	3.100	4.100	1.200	2.200	300
BRYZGINA O.	H 1	51.62	12.91	12.51	11.99	12.72	14.40	24.50	27.12	37.22
	SF2	50.88	12.72	12.21	11.88	12.65	14.14	24.09	26.79	36.74
63 USR	F	49.38	12.35	12.34	11.48	12.33	13.23	23.82	25.56	36.15

HEAT — PLACING 1. — 29.08.87

Performance:	51.62	12.91	12.51	11.99	12.72	14.40	24.50	27.12	37.22
Model intermediate times:	51.60	12.90	12.80	11.95	12.75	14.10	24.75	26.85	37.50
Diff. from interm. times :	-	-	+0.29	-0.04	+0.03	-0.30	+0.25	-0.27	+0.28
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.20	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.40	+0.92	+0.19	-1.49	-	-	-
CorresPonding to Perform.:	-	-	50.45	51.75	51.45	52.75	51.10	52.15	51.25

SEMIFINAL — PLACING 2. — 30.08.87

Performance:	50.88	12.72	12.21	11.88	12.65	14.14	24.09	26.79	36.74
Model intermediate times:	50.90	12.73	12.63	11.77	12.58	13.92	24.40	26.50	36.98
Diff. from interm. times :	-	-	+0.42	-0.11	-0.07	-0.22	+0.31	-0.29	+0.24
Diff. from 0100 m (model):	-	-	+0.10	+0.96	+0.15	-1.19	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.51	+0.84	+0.07	-1.42	-	-	-
CorresPonding to Perform.:	-	-	49.25	51.35	51.20	51.75	50.30	51.50	50.60

FINAL — PLACING 1. — 31.08.87

Performance:	49.38	12.35	12.34	11.48	12.33	13.23	23.82	25.56	36.15
Model intermediate times:	49.40	12.35	12.25	11.40	12.20	13.55	23.65	25.75	35.85
Diff. from interm. times :	-	-	-0.09	-0.08	-0.13	+0.32	-0.17	+0.19	-0.30
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.20	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.01	+0.87	+0.02	-0.88	-	-	-
CorresPonding to Perform.:	-	-	49.75	49.75	49.90	48.25	49.75	49.10	49.80

- FIG 2 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — WOMEN

		400	0100	1.100	2.100	3.100	4.100	1.200	2.200	300
MUELLER P.	H 2	51.68	12.92	12.59	12.22	12.49	14.38	24.81	26.87	37.30
	SF2	50.15	12.54	12.11	11.87	12.45	13.72	23.98	26.17	36.43
65 GDR	F	49.94	12.49	12.20	11.44	12.43	13.87	23.64	26.30	36.07

HEAT		PLACING 1.						29.08.87	
Performance:	51.68	12.92	12.59	12.22	12.49	14.38	24.81	26.87	37.30
Model intermediate times:	51.70	12.93	12.83	11.97	12.78	14.12	24.80	26.90	37.58
Diff. from interm. times :	-	-	+0.24	-0.25	+0.29	-0.26	-0.01	+0.03	+0.28
Diff. from 0100 m (model):	-	-	+0.10	+0.96	+0.15	-1.19	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.33	+0.70	+0.43	-1.46	-	-	-
CorresPonding to Perform.:	-	-	50.75	52.70	50.55	52.70	51.70	51.65	51.35

SEMIFINAL		PLACING 1.						30.08.87	
Performance:	50.15	12.54	12.11	11.87	12.45	13.72	23.98	26.17	36.43
Model intermediate times:	50.15	12.54	12.44	11.59	12.39	13.73	24.03	26.12	36.42
Diff. from interm. times :	-	-	+0.33	-0.28	-0.06	+0.01	+0.05	-0.05	-0.01
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.18	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.43	+0.67	+0.09	-1.18	-	-	-
CorresPonding to Perform.:	-	-	48.85	51.30	50.40	50.10	50.05	50.25	50.15

FINAL		PLACING 2.						31.08.87	
Performance:	49.94	12.49	12.20	11.44	12.43	13.87	23.64	26.30	36.07
Model intermediate times:	49.95	12.49	12.39	11.54	12.34	13.68	23.93	26.02	36.27
Diff. from interm. times :	-	-	+0.19	+0.10	-0.09	-0.19	+0.29	-0.28	+0.20
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.19	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.29	+1.05	+0.06	-1.38	-	-	-
CorresPonding to Perform.:	-	-	49.20	49.55	50.30	50.70	49.40	50.50	49.70

- FIG 3 -

ANALYSIS OF INTERMEDIATE TIMES IN 400 m

II WORLD CHAMPIONSHIPS IN ATHLETICS — WOMEN

		400	0100	1.100	2.100	3.100	4.100	1.200	2.200	300
EMMELMANN K.	H 6	51.62	12.91	12.32	11.66	12.76	14.88	23.98	27.64	36.74
	SF3	50.53	12.63	12.39	11.76	12.63	13.75	24.15	26.38	36.78
61 GDR	F	50.20	12.55	12.21	11.54	12.60	13.85	23.75	26.45	36.35

HEAT — PLACING 1. — 29.08.87

Performance:	51.62	12.91	12.32	11.66	12.76	14.88	23.98	27.64	36.74
Model intermediate times:	51.60	12.90	12.80	11.95	12.75	14.10	24.75	26.85	37.50
Diff. from interm. times :	-	-	+0.48	+0.29	-0.01	-0.78	+0.77	-0.79	+0.76
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.20	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.59	+1.25	+0.15	-1.97	-	-	-
Corresponding to Perform.:	-	-	49.65	50.45	51.65	54.75	50.05	53.10	50.60

SEMIFINAL — PLACING 1. — 30.08.87

Performance:	50.53	12.63	12.39	11.76	12.63	13.75	24.15	26.38	36.78
Model intermediate times:	50.55	12.64	12.54	11.69	12.49	13.83	24.23	26.32	36.72
Diff. from interm. times :	-	-	+0.15	-0.07	-0.14	+0.08	+0.08	-0.06	-0.06
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.19	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.24	+0.87	0.00	-1.12	-	-	-
Corresponding to Perform.:	-	-	49.95	50.85	51.10	50.20	50.40	50.65	50.65

FINAL — PLACING 3. — 31.08.87

Performance:	50.20	12.55	12.21	11.54	12.60	13.85	23.75	26.45	36.35
Model intermediate times:	50.20	12.55	12.45	11.60	12.40	13.75	24.05	26.15	36.45
Diff. from interm. times :	-	-	+0.24	+0.06	-0.20	-0.10	+0.30	-0.30	+0.10
Diff. from 0100 m (model):	-	-	+0.10	+0.95	+0.15	-1.20	-	-	-
Diff. from 0100 m (act.) :	-	-	+0.34	+1.01	-0.05	-1.30	-	-	-
Corresponding to Perform.:	-	-	49.25	49.95	51.05	50.60	49.60	50.80	50.05

4. CONCLUSIONS

The present study comprehends the results of the time analyses of all the semifinals and finals of the sprint events at the II WC. It points out the inaccuracy in measuring reaction times, especially in 400 m (and by implication the 400 m hurdles). On the basis of long-term measurements evaluating scales have been listed to help coaches in evaluating reaction times. No relevant relationship was found between reaction time and performance .

The report reviews the course of acceleration, the maximum speed area and the specific endurance level of various performance groups participating at the II WC.

The 400 m was evaluated in terms of the final where specific endurance and pace distribution were found to be decisive for the performance.

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List of figures :

100 M

1	A-B	JOHNSON	CAN	9.83	REPORT
2	A-B	LEWIS	USA	9.93	REPORT
3	A-B	STEWART	JAM	10.08	REPORT
4	A-B	CHRISTIE	GBR	10.14	APPENDIX
5	A-B	KOVACS	HUN	10.20	APPENDIX
6	A-B	BRYZGIN	URS	10.25	APPENDIX
7	A-B	MC RAE	USA	10.34	APPENDIX
8	A-B	PAVONI	ITA	16.23	APPENDIX

1	A-B	GLADISH	GDR	10.90	REPORT
2	A-B	DRECHSLER	GDR	11.00	REPORT
3	A-B	OTTEY	JAM	11.04	REPORT
4	A-B	WILLIAMS	USA	11.07	APPENDIX
5	A-B	ISSAJENKO	CAN	11.09	APPENDIX
6	A-B	NOUNEVA	BUL	11.09	APPENDIX
7	A-B	BAILEY	CAN	11.18	APPENDIX
8	A-B	MARSHALL	USA	11.19	APPENDIX

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200 M

1	SMITH	USA	20.16	REPORT
2	QUENEHERVE	FRA	20.16	REPORT
3	REGIS	GBR	20.18	REPORT
4	DA SILVA	BRA	20.22	APPENDIX
5	KRYLOV	URS	20.23	APPENDIX
6	HEARD	USA	20.25	APPENDIX
7	PAVONI	ITA	20.45	APPENDIX
8	MAHORN	CAN	20.78	APPENDIX

1	GLADISCH	GDR	21.74	REPORT
2	GRIFFITH	USA	21.96	REPORT
3	OTTEY	JAM	22.06	REPORT
4	MARSHALL	USA	22.18	APPENDIX
5	TORRENCE	USA	22.40	APPENDIX
6	ONYALI	NGR	22.52	APPENDIX
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8	GEORGIEVA	BUL	22.55	APPENDIX

C

TIME ANALYSIS OF THE 100m AND 110m HURDLES

Sušanka, P.; Miskos, G.; Millerová, V.; Dostál, E.; Barac, F.

CONTENTS

1. INTRODUCTION

The statistical processing and evaluation of sports performances have a tradition of long standing, providing an excellent method for judging the overall improvement of performances in an event as well as the improvement of individual athletes. The trend of improvement in performances in 100m and 110m hurdles is shown in FIG. 1 and 2. The solid line shows the course of the world's best performances in a year while the other two lines indicate the course of the mean of the maximum peformances of the top three and top ten athletes respectively. Electronic time measurement was introduced in 1972; in the development graph, that moment is marked with a vertical line.

The 110m hurdles event has been dominated by US athletes for dozens of years. Four US athletes claim the major share of the 25 world all time best performances. Among the first ten athletes, by best performance, there are only two non-Americans: CARISTAN of France and CASANAS of Cuba. A full two thirds of the first thirty are Americans.

The women's 100m hurdles is a much more open affair. The 1987 world tables seem to indicate a further distribution of top performances to athletes from a number of countries (TAB. 1, 2). The rise in the performance level has been the result of improved training methods, the application of new knowledge provided by a variety of scientific disciplines, improved technical equipment etc.. The curve of the best performances in any year will be extremely uneven as it can be markedly influenced by exceptional performances or athletes like NEHEMIAH in 1979-81. A more telling indication of the changes in world performances is the curve of the mean best performances of the ten best athletes. Ignoring the exceptional year 1960, the improvement in performances by the men was 0.37 s over the period 1961-71, and another 0.29 s over the period 1972-87. In the women's event the improvement amounted to 0.70 s over the period 1963-71 (statistics of the women's 100m hurdles were first kept in 1963), and to another 0.53 s from 1971 to 1987. The greatest improvement was recorded in 1969, the year the event was officially introduced at athletic meetings, and in 1970.

The gain or loss in a major competition against the particular athlete's personal best in the year concerned is a good pointer to his or her ability to prepare for a top-level competition. These differences for all semifinalists in Rome are shown in TAB. 1, 2.

FINAL 3/9 - 17.50

			(+ 0,50 m/s)
1. 1034 Foster Greg	58	USA	13.21
2. 448 Ridgeon Jon	67	GBR	13.29
3. 433 Jackson Colin	67	GBR	13.30
4. 1072 Pierce Jack	62	USA	13.41
5. 963 Kazanov Igor	63	URS	13.48
6. 269 Sala Carlos	60	ESP	13.55
7. 154 Mc Koy Mark	61	CAN	13.71
281 Bryggare Arto	58	FIN	DNS

Ore/Time 17 52 — Temp +27 °C
Press 1012 mBar — Umidità/Humidity 68%

4/9 - 18.30

			(-0.56 m/s)
1. 74 Zagorcheva Ginka	58	BUL	12.34 CR
2. 312 Uibel Gloria	64	GDR	12.44
3. 308 Oschkenat Cornelia	61	GDR	12.46
4. 59 Donkova Yordanka	61	BUL	12.49
5. 210 Piquerau Anne	64	FRA	12.82
6. 199 Elloy Laurence	59	FRA	12.83
7. 247 Zaczkiewicz Claudia	62	FRG	12.98
8. 646 Martin Lavonna	66	USA	13.06

Ore/Time 18 32 — Temp.: +21 °C
Press.: 1013 mBar — Umidità/Humidity: 84%

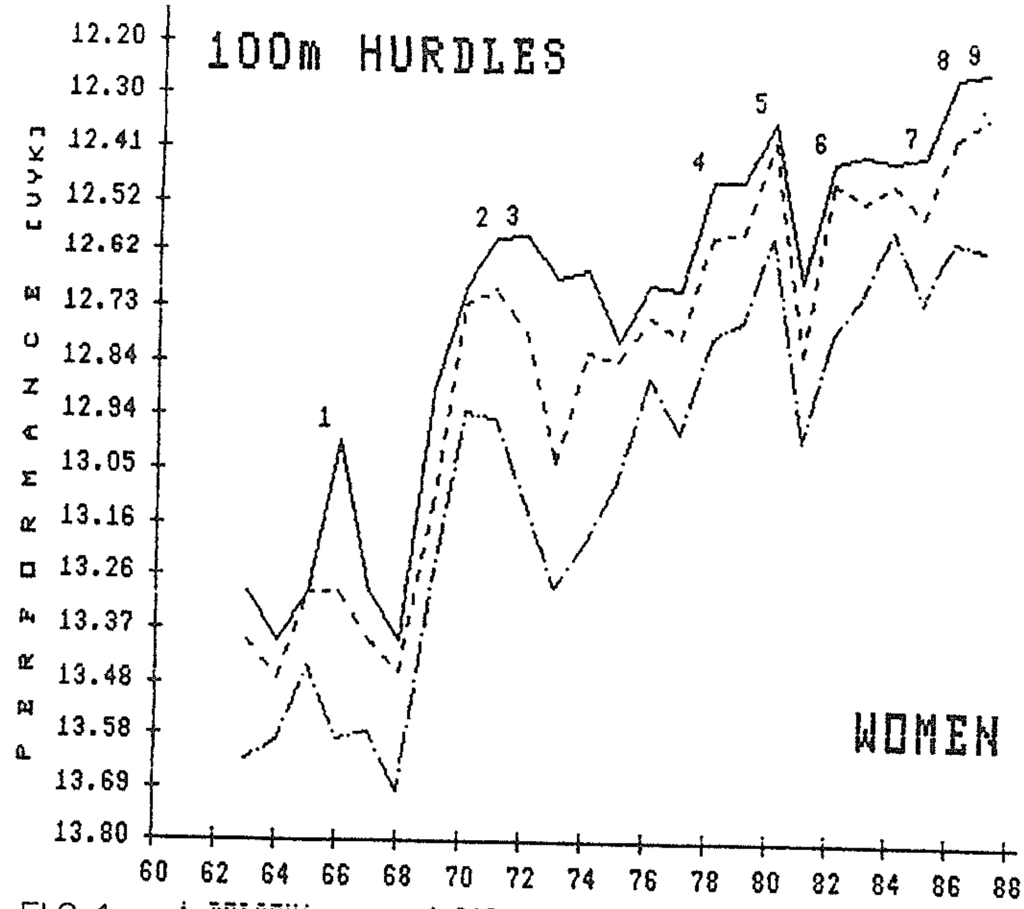


FIG 1

1 BOLSOVA
2 BALZER
3 ERHARDT
4 RABSZTYN
5 RABSZTYN
6 DONKOVA
7 ZAGORCEVA
8 DONKOVA
9 ZAGORCEVA

YEAR

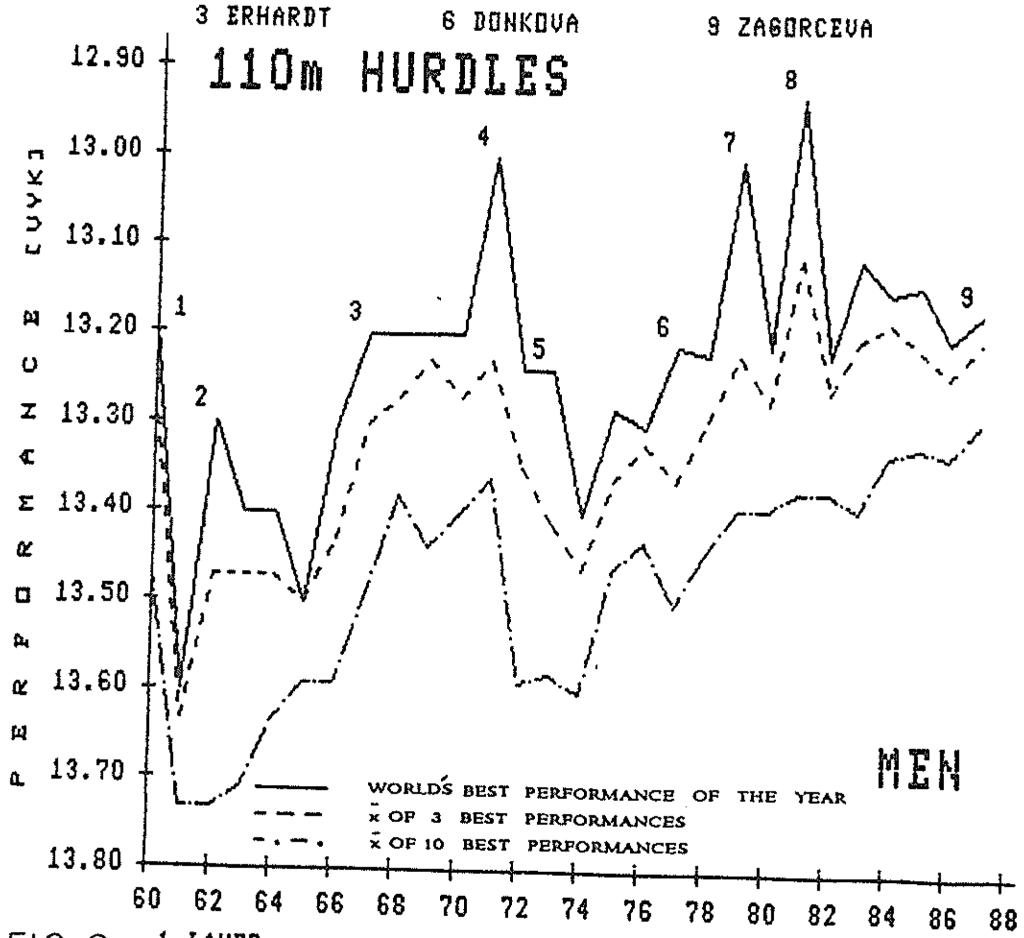


FIG 2

1 LAUER
2 TARR
3 McCULLOUCH
4 MILBURN
5 MILBURN
6 CASANAS
7 NEHEMIAH
8 NEHEMIAH
9 FOSTER

YEAR

WORLD LIST 1987 (at 15th October 1987) 110m Hurdles MEN

13.17	+0.6	Greg	Foster	58	USA	1	Lausanne	1509	1.	-0.04
13.19	+0.9	Tonie	Campbell	60	USA	1r1	Modesto S&W	0905	R	
13.23	+0.1	Mark	McKoy	61	CAN	2	Budapest BGP	0607	7.	-0.48
13.29	+1.9	Rod	Woodson	65	USA	1	Irvine	1406	R	
13.29	-0.1	Jonathan	Ridgeon	67	GBR	1	Zagreb WUG	1507	2.	0.00
13.29		Arthur	Blake	66	USA	2	Durham NSF	2607	R	
13.30	+0.5	Colin	Jackson	67	GBR	3	Roma WCh	0309	3.	+0.11
13.38	+1.4	Igor	Kazanov	63	URS	1	Moskva Znam	0706	5.	-0.10
13.39	+1.4	Sergej	Usov	64	URS	2	Moskva Znam	0706	N	-0.61
13.39	+2.0	Cletus	Clark	62	USA	2h1	San Jose TAC	2506	N	-0.42
13.40	-0.1	Keith	Talley	64	USA	3	Zagreb WUG	1507	R	
13.41		Jack	Pierce	62	USA	4	Durham NSF	2607	4.	0.00
13.42	+0.8	Javier	Moracho	57	ESP	1	Barcelona NC	1608	dns	
13.44	+0.8	Carlos	Sala	60	ESP	2	Barcelona NC	1608	6.	-0.11
13.44	+0.9	Stephane	Caristan	64	FRA	1h5	Roma WCh	0109	9.	-0.18
13.48	+1.4	Jiří	Hudec	64	TCH	4h1	Roma WCh	0109	16.	-0.58
13.49	0.0	Vernon	George	64	USA	1h2	Des Moines Drake	2404	R	
13.50	+1.5	Eric	Reid	65	USA	1	Houston	2305	R	
13.51	0.0	Andrew	Parker	65	JAM	1	Tempe SAng	0404	N	-0.43
13.51	+0.8	Roger	Kingdom	62	USA	2h2	Budapest BGP	0607	R	
13.51	+0.6	Arto	Bryggare	58	FIN	1	Lahti	1108	dns	
13.52	+0.6	Alexandr	Markin	62	URS	1	Moskva	2308	10.	-0.11
13.53	+1.4	Aleš	Höffer	62	TCH	3	Moskva Znam	0706	13.	-0.25
13.54	+1.8	Alejandro	Casañas	54	CUB	1	Habana Barr	1403	-	
13.54	+0.8	Anton	Isajev	62	URS	1h	Celjabinsk	2006	R	
13.55	+1.4	Vladimir	Šiškin	64	URS	4	Moskva Znam	0706	R	
13.56	+1.4	György	Bakos	60	HUN	5	Moskva Znam	0706	14.	-0.34
13.57	+0.9	Milan	Stewart	60	USA	3r1	Modesto S&W	0905	R	
13.57	-0.9	Steve	Kerho	64	CAN	2	Corvallis Pac10	2305	dns	
13.58	+1.7	Tomasz	Nagorka	67	POL	1	Warszawa	1005	-	
13.59	+0.9	James	Purvis	66	USA	2	Knoxville Gator	2305	R	
13.60	+1.9	Ionas	Jakštis	59	URS	4	Brjansk NC	1707	R	
13.61	+0.6	William	Skinner	64	USA	1h3	Philadelphia Penn	2504	R	
13.61	+0.3	Andreas	Oschkenat	62	GDR	1	Potsdam	0707	-	
13.62	+1.3	John	Register	65	USA	1h1	Lubbock SWC	1605	R	
13.62	+1.9	James	McCraney	55	USA	3	Irvine	1406	R	
13.62	+0.7	Holger	Pohland	63	GDR	4	Praha EP/A	2806	-	
13.62	+0.8	Nigel	Walker	63	GBR	3h2	Budapest BGP	0607	11.	-0.06
13.62	+0.6	Krzysztof	Platek	62	POL	1	Poznan NC	1608	11.	-0.06
13.64	+1.8	Robert	Reading	67	USA	1r2	Modesto S&W	0905	R	
	↑ 1					↑ 2			↑ 3	↑ 4

1 - WIND
2 - PLACEMENT IN THE COMPETITION
3 - PLACEMENT IN THE II WC
R - REDUCED RANKING LISTS
N - DID NOT PASS THE QUALIFICATION II WC
4 - DIFFERENCE BETWEN THE PERFORMANCE AT THE II WC AND BEST PERFORMANCE 1987

TABLE 1

WORLD LIST 1987 (at 15th October 1987) 100m Hurdles WOMEN

12.25	+1.4	Ginka	Zagorčeva	58	BUL	1	Drama vCS,Gre	0808	1.	-0.09
12.33	+1.4	Jordanka	Donkova	61	BUL	1	Fürth	1406	4.	-0.16
12.44	-0.5	Gloria	Uibel	64	GDR	2	Roma WCh	0409	2.	+0.11
12.45	+1.3	Cornelia	Oschkenat	61	GDR	1	Neubrandenburg	1006	3.	-0.01
12.70	+1.6	Mihaela	Pogacian	58	RUM	1	Tel Aviv Hapoel	0905	-	
12.76	+1.4	Kerstin	Knabe	59	GDR	3	Fürth	1406	-	
12.80	+0.6	Jackie	Joyner	62	USA	1	Westwood Pepsi	1505	R	
12.80	+1.3	LaVonna	Martin	66	USA	1	San Jose TAC	2606	8.	-0.26
12.80	+0.4	Tatjana	Rešetnikova	66	URS	1	Leningrad	0507	-	
12.80	-0.2	Claudia	Zaczkiewicz	62	FRG	1	Gelsenkirchen NC	1107	7.	-0.18
12.80	+1.0	Laurence	Elloy	59	FRA	2	Gelnhausen	1309	6.	-0.03
12.82	+0.7	Eva	Sokolova	61	URS	1	Brjansk NC	1807	-	
12.82	+1.8	Stephanie	Hightower	58	USA	2	Indianapolis PAG	1508	11.	-0.30
12.82	-0.5	Anne	Piquereau	64	FRA	5	Roma WCh	0409	5.	+0.05
12.83		Heike	Theele	64	GDR	1s1	Zagreb WUG	1507	-	
12.84	+1.5	Aliuska	Lopez	69	CUB	2	Zagreb WUG	1607	15.	-0.47
12.84	+1.5	Florence	Colle	65	FRA	3	Zagreb WUG	1607	9.	-0.20
12.91	+1.1	Natalja	Grigorjeva	62	URS	1	Moskva Znam	0606	-	
12.91	+0.4	Jelena	Sinjutina	64	URS	3	Leningrad	0507	-	
12.91	-0.0	Jelena	Politika	64	URS	1h	Leningrad	1908	-	
12.96	+1.5	Sophia	Hunter	64	USA	6	Zagreb WUG	1607	13.	-0.30
12.97	+1.5	Ulrike	Denk	64	FRG	1	Rhede	2006	-	
12.98	-0.3	Monique	Ewanje-Epee	67	FRA	3	Nice Nik	1307	R	
13.01	+1.2	Sally	Gunnell	66	GBR	3	Oslo Bisl	0407	10.	-0.05
13.02		Liliana	Nastase	62	RUM	2	Bucuresti	2305	-	
13.02	+0.1	Kim	McKenzie	61	USA	1	Knoxville Gator	2305	R	
13.02	+1.1	Lidia	Okolo-Kulak	67	URS	3	Moskva Znam	0606	-	
13.03	+0.7	Rosalind	Council	65	USA	1h4	San Jose TAC	2506	R	
13.05	+0.5	Ljudmila	Olijar	58	URS	1h	Čeljabinsk	2006	-	
13.06	+0.7	Jackie	Humphrey	65	USA	1h3	Baton Rouge NCAA	0406	R	
13.06	+0.5	Lynda	Tolbert	67	USA	1	Durham NSF	2407	R	
13.06	-0.2	Larisa	Narožilenko	63	URS	3	Leningrad	2008	-	
13.07	-1.1	Lesley-Ann	Skeete	67	GBR	2	London IAC	1408	N	-0.33
13.07		Rita	Heggli	62	SUI			09	12.	-0.13
13.10		Patrizia	Lombardo	58	ITA	2	Livorno vSov	3005	16.	-0.28
13.11		Kristin	Patzwahl	65	GDR	3s2	Zagreb WUG	1507	-	
13.13		Ljubov	Stoljar	61	URS	1h	Soči	1605	-	
13.13	+1.3	Bentita	Fitzgerald	61	USA	5	San Jose TAC	2606	R	
13.14	+1.5	Svetlana	Buraga	65	URS	H	Gotzis	2305	-	
13.16	0.0	Rhonda	Blanford	63	USA	1	Denver	1406	R	
13.16	+0.2	Nancy	Vallecilla	55	ECU	2h1	Indianapolis PAG	1308	14.	-0.12
	↑ 1					↑ 2			↑ 3	↑ 4

1 - WIND
2 - PLACEMENT IN THE COMPETITION
3 - PLACEMENT IN THE II WC
R - REDUCED RANKING LISTS
N - DID NOT PASS THE QUALIFICATION II WC
4 - DIFFERENCE BETWEN THE PERFORMANCE AT THE II WC AND BEST PERFORMANCE 1987

TABLE 2

2. METHODS AND PROCEDURES

The 100 and 110m hurdles events in Rome were analysed by means of three SONY videocameras and two PHOTOSONICS 500 high-speed cameras. Three videocameras were used for the time analysis of all the races concerned. Two of the videocameras photographed the whole race including the starter's gun (picture of the smoke). The third camera recorded the athlete's start from the blocks up to the landing after the first hurdle. The siting of the videocameras is shown in FIG. 3.

The synchronized PHOTOSONICS 500 high-speed cameras were placed (see FIG. 4) with a view to facilitating 3-D analysis of the athlete's stride, with special emphasis on stride length and frequency. The films were also used for comparing with the material obtained from the videorecordings.

The cameras were positioned by means of a second theodolite from Carl Zeiss Jena.

The cameras worked at a frequency of 200 (150) fps. The semifinals and the finals were filmed without the use of zoom. One of the cameras also photographed the starter's gun. The moment of the firing of the gun (the smoke in the picture) was used for visual assessment of the reaction time and for comparisons with the official measurements of the reaction time.

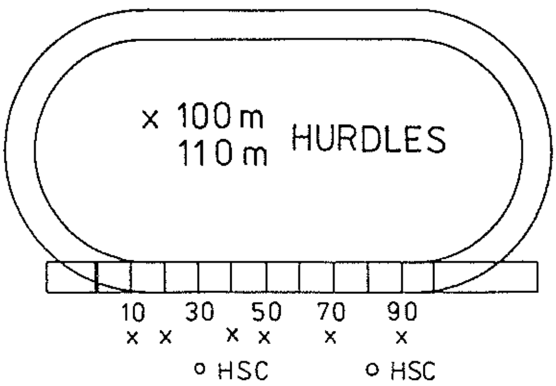


FIG 3

POSITION OF CAMERAS

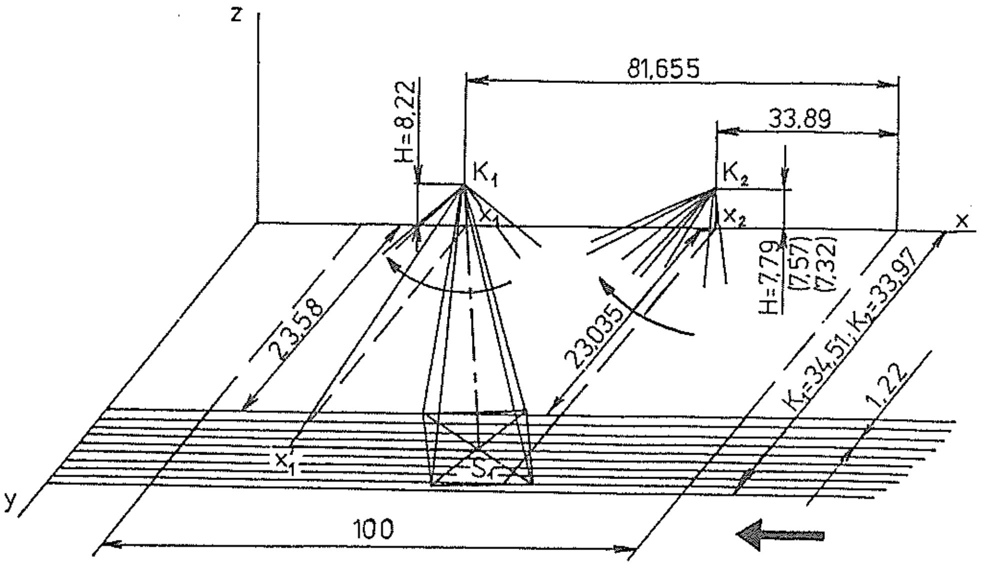


FIG 4

MODEL INTERMEDIATE TIMES

The material used for plotting the model intermediate times was provided by the time analyses of performances at events like EC, WC and Olympic Games between 1980-86. The times of touchdowns after the hurdles (1-10) were related to the performances. The results were regression straight lines whose correlation coefficient has a continuously rising tendency. In the relation between touchdown after the 10th hurdle and the performance, the correlation approximates I.

The regression straight lines were subsequently turned according to x to start in the beginning of the coordinates-system . The tangents of the straight lines make up a regression parabola which can be used for laying down model intermediate times. A tolerance field has been provided for each intermediate time, taking account of possible errors of measurements. The mathematical procedure is described in more detail in SUSANKA (1987).

This report presents the results of analyses of the first tree finalists in the 100m hurdles (women) and the 110m hurdles (men). Analyses of the semifinalists and the rest of finalists are available in a special Appendix. The results of all the competitors are stored in a computer memory and they can be retrieved, processed and supplied at special request.

3. ANALYSIS OF THE COMPETITION AT THE II WORLD CHAMPIONSHIPS IN ATHLETICS

In the hurdles the performance is the sum of the reaction time (RT), the time of the approach run, the time of the nine rhythmic units (RU), and the time of the run-in.

3.1. REACTION TIME

In real terms, an athlete's reaction time is shorter than that officially measured. The difference is due to time required for the transmission of the starting signal (sound propagation from the starter's gun to the starting spot), and by mechanical delays inherent in the design of the starting blocks and the level of the reaction force set on the blocks. . The electronic device in the starting blocks stops measuring the reaction time at the moment the pressure on the blocks reaches the preset value (e.g. 250 N).

The results of measurements of reaction time at events such as the EC, WC and Olympic Games in the period 1978-87 are shown in TAB. 3. The differences recorded in mean reaction times at the I WJC the II WC 87 and other events seem to indicate a lack of uniformity in the methods of measuring reaction time.

Higher mean RTs were measured at I WJC and II WC 87 in the sprint hurdles as well as in other events (the sprints and the 400m hurdles), although an increase of actual reaction times is extremely unlikely.

A rule-of thumb scale for evaluating RT has been plotted on the basis of RT statistics.

Generally valid	**Men** and **Women**	
Outstanding	$<$ 130	(ms)
Above average	(130;150)	
Average	(155;185)	
Below average	(185;210)	
Substandard	$>$ 210	

The following scale has been plotted only for the II WC in Rome, owing to the considerable difference in the reaction times measured there.

	Men	Women	
Outstanding	< 130	< 140	(ms)
Above average	(130 ; 170)	(140 ; 180)	
Average	(170 ; 210)	(180 ; 220)	
Below average	(210 ; 250)	(220 ; 260)	
Substandard	> 250	> 260	

The following minimum RT were measured at II WC.

	100m H	110m H	(ms)
Men	x	133	
Women	111	x	

TAB. 3: Reaction times measured at different athletic competitions (European, World Championships, World Junior Championships and Olympic Games)

Men	110m H			Women	100m H		
	n	$\bar{x}$	SD		n	$\bar{x}$	SD
EC 78	43	157	29		19	149	22
OG 80	46	151	14		43	157	21
EC 82	44	160	19		24	153	25
WC 83	50	178	37		90	162	24
OG 84							
WJC 86	34	191	38		35	187	20
EC 86							
WC 87	65	192	39		46	201	40
Average	282	172	30		257	170	26

n ... number of measurements ; $\bar{x}$ ... mean value ; SD ... standard deviation

3.2. APPROACH RUN

Beginning:
(a) from the gun
(b) from the athlete's first movement, i. e. minus RT (for determining the acceleration level)

End:
moment of touchdown after the first hurdle

Objective:
achieving an optimal (model) intermediate time that would make it possible for the athlete to achieve a personal best; providing the conditions for smooth clearance of the hurdles.

	Men	Women
For performances:	13.25 / 13.50	12.30 / 12.50
approach run	2.52 / 2.60	2.45 / 2.58
approach run minus RT (for determining acceleration level)	2.27 / 2.45	2.33 / 2.40

3.3. RHYTHMIC UNITS

Beginning:
moment of touchdown after hurdle

End:
moment of touchdown after next hurdle

Objective:
(a) the shortest time possible in a rhythmic unit
(b) standardisation of the above time, with a maximum difference of 3%
(c) the fastest average time possible over the nine rhythmic units

	Men	Women
RU minimal	0.98 / 1.30	0.94 / 0.98
RU average	1.20 / 1.50	0.97 / 0.99
Number of RUs with maximal 3% difference	4 / 6	4 / 7

The 3 % difference from the minimal time has been laid down with a view to the errors the coach can make in his time analysis of the videorecording.

3.4. RUN-IN

Beginning:
moment of touchdown after 10th hurdle

End :
moment of reaching the finishing line

Objective :
The smooth continuation of the running between the hurdles into the run-in. This can be practised only in actual race situations, not training sessions. A well-trained athlete should make full use of each race for practising this phase of the race. This will not involve any significant losses of energy for a physiologically well-trained athlete.

In the heats of the II WC the results were clear well before the end of each race. However only a few of the qualifiers (e.g. ZAGORCHEVA) finished the race at flat-out speed. The following figure indicates the fastest and slowest time for the run-in achieved in the II WC.

	Men	Women
Run - in	1.30 / 1.40	1.05 / 1.10

3.5. EVALUATING ACCELERATION AND SPEED ENDURANCE

A number of criteria are used for evaluating the above abilities of athletes in coaching practice. For the sake of simplicity, the performances achieved can be used as a basis, without any need for calculations of mean or momentary velocities or acceleration.

Acceleration :
the ability to achieve maximum speed (or a speed amounting to 97 % of the athlete's maximum speed) over the shortest possible section of the track.

Time used as indices :
approach- run times minus RT, and the times in the 1st and 2nd RUs (of their sum).

Fastest and slowest times achieved in the II WC

	Men	Women
(a) approach-run minus RT	2.27 / 2.45	2.33 / 2.40
(b) (approach-run minus RT) + 1st RU	3.38 / 3.53	3.36 / 3.50
(c) (approach-run minus RT) + 1st RU + 2nd RU	4.41 / 4.57	4.34 / 4.50

The difference between (b) and (c) shows clearly that in practice, watching any one of the indices will do.

Speed endurance is manifested in the athlete's ability to achieve the best intermediate times even in the final stages of the race.

	Men	Women
(a) Run-in	1.30 / 1.40	1.05 / 1.10
(b) Run-in + 9th RU	2.36 / 2.71	2.03 / 2.22
(c) Run-in + 8th RU + 9th RU	3.41 / 3.83	3.00 / 3.26

The athlete's level of acceleration and speed endurance can be judged on the basis of his or her closeness to the extremes of the obove variation ranges - but only in the races run out, i.e. with maximum effort.

4. EVALUATION OF INDIVIDUALS AT THE II WORLD CHAMPIONSHIPS IN ATHLETICS

110 m.HURDLES -1A-

TIME ANALYSIS

FOSTER GREG 58 USA

PLACING 1. — 1. 1st RUN — RESULT 13.20

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.63	4.64	5.64	6.64	7.62	8.63	9.67	10.72	11.79	13.20
B.	2.48	3.50	4.52	5.54	6.56	7.58	8.61	9.66	10.71	11.79	13.20
C.		1.03	1.01	1	1	0.98	1.01	1.04	1.05	1.07	1.41
D.		1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.06	1.08	1.41
E.	-0.07	-0.08	-0.07	-0.05	-0.03	---	---	---	---	---	

PLACING 2. — 1. SEMIFINAL — RESULT 13.41

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.65	4.68	5.70	6.72	7.76	8.79	9.85	10.93	11.99	13.41
B.	2.51	3.56	4.60	5.63	6.67	7.70	8.75	9.81	10.88	11.98	13.41
C.		1.05	1.03	1.02	1.02	1.04	1.03	1.06	1.08	1.06	1.42
D.		1.04	1.04	1.03	1.04	1.04	1.05	1.06	1.07	1.09	1.43
E.	-0.04	-0.04	-0.03	-0.02	---	-0.01	---	---	-0.01	---	

PLACING 1. — FINAL — RESULT 13.21

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.64	4.64	5.64	6.64	7.65	8.67	9.72	10.76	11.81	13.21
B.	2.48	3.51	4.53	5.55	6.57	7.59	8.62	9.66	10.72	11.80	13.21
C.		1.04	1	1	1	1.01	1.02	1.05	1.04	1.05	1.40
D.		1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.06	1.08	1.41
E.	-0.07	-0.08	-0.06	-0.04	-0.02	-0.01	---	-0.01	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

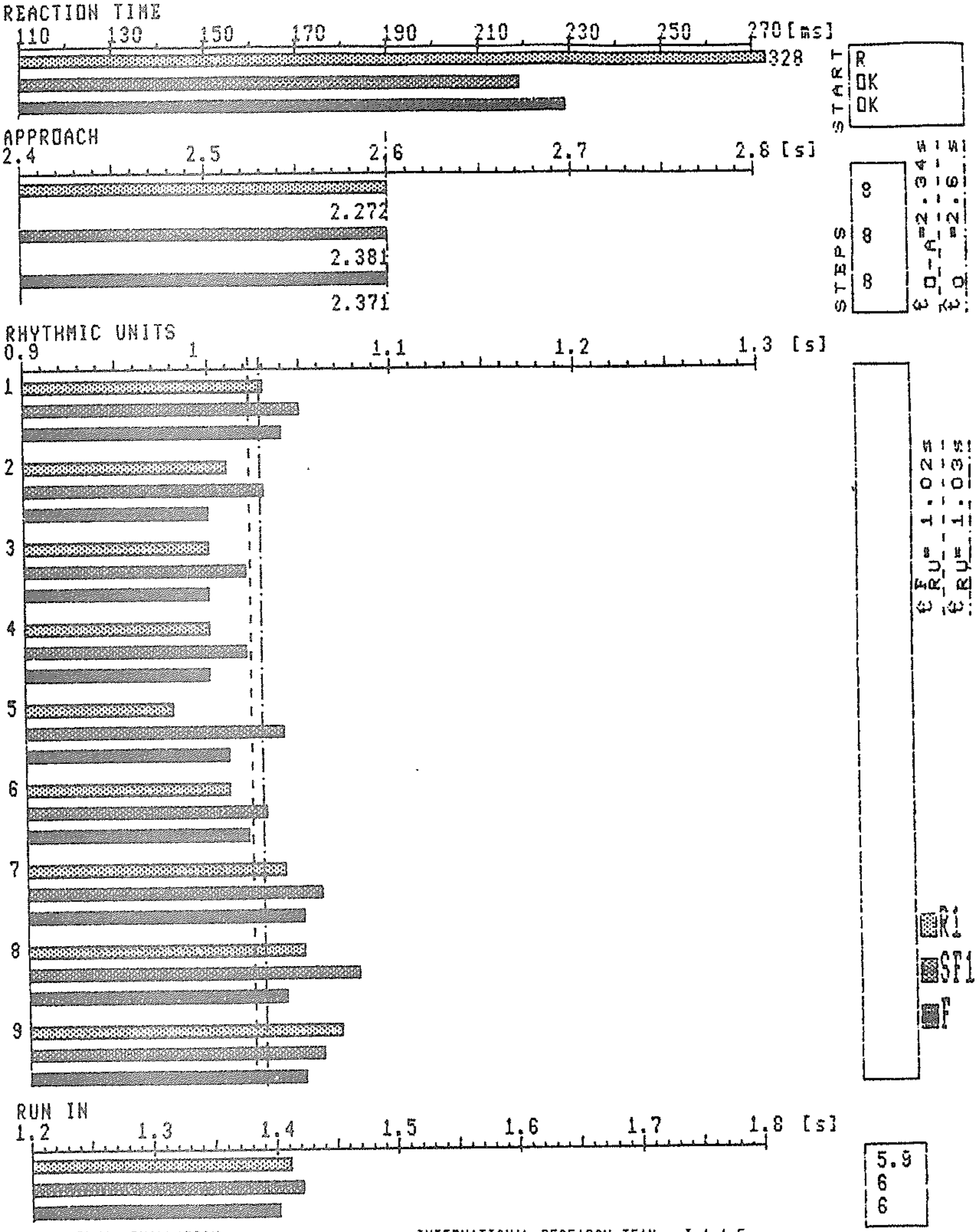
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

110 m. HURDLES -1B- II WC ROME 1987

FOSTER	GREG	58	USA
R1 -13.20 [s]	SF1-13.41 [s]	F -13.21 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT in the heat substandard, in successive rounds poor mean time of approach, after substracting RT, the best of all finalists, the fastest in the heat. Acceleration section shortened processively. Maximum specific speed scored in a heat, in the 5th RU -0.98s; in the final, in the second RU (1.00s). Relative stabilization of specific speed ends with the 6th RU. Specific speed reduction occured last 3 RU in all rounds. Time of run-in stable. All rounds run without colliding with hurdles. Main advantage: explosive strength and maximum specific running speed; shortcomings in reaction time and specific endurance.

* DATA NOT MEASURED
R RESTART
W WARNING

110 m. HURDLES -2A- II WC ROME 1987

TIME ANALYSIS RIDGEON JON 67 GBR

PLACING 1.	3. 1st RUN	RESULT 13.46

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.72	3.77	4.81	5.85	6.88	7.94	8.98	10.02	11.06	12.15	13.46
B.	2.52	3.57	4.61	5.65	6.69	7.73	8.78	9.85	10.92	12.02	13.46
C.		1.05	1.04	1.04	1.03	1.06	1.04	1.04	1.04	1.09	1.31
D.		1.05	1.04	1.04	1.04	1.04	1.05	1.06	1.08	1.10	1.44
E.	-0.15	-0.15	-0.15	-0.15	-0.14	-0.16	-0.15	-0.12	-0.10	-0.09	

PLACING 1.	1. SEMIFINAL	RESULT 13.34

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.65	4.72	5.73	6.75	7.78	8.85	9.89	10.93	11.98	13.34
B.	2.50	3.54	4.57	5.60	6.63	7.66	8.71	9.76	10.83	11.91	13.34
C.		1.05	1.07	1.01	1.02	1.03	1.07	1.04	1.04	1.05	1.36
D.		1.04	1.03	1.03	1.03	1.03	1.04	1.05	1.07	1.09	1.43
E.	-0.05	-0.06	-0.10	-0.08	-0.07	-0.07	-0.09	-0.08	-0.06	-0.03	

PLACING 2.	FINAL	RESULT 13.29

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.64	4.70	5.72	6.76	7.79	8.82	9.88	10.93	11.96	13.29
B.	2.49	3.53	4.55	5.58	6.61	7.64	8.67	9.72	10.79	11.87	13.29
C.		1.04	1.06	1.02	1.04	1.03	1.03	1.06	1.05	1.03	1.33
D.		1.03	1.03	1.03	1.03	1.03	1.04	1.05	1.06	1.08	1.42
E.	-0.06	-0.06	-0.10	-0.09	-0.10	-0.10	-0.10	-0.11	-0.10	-0.05	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

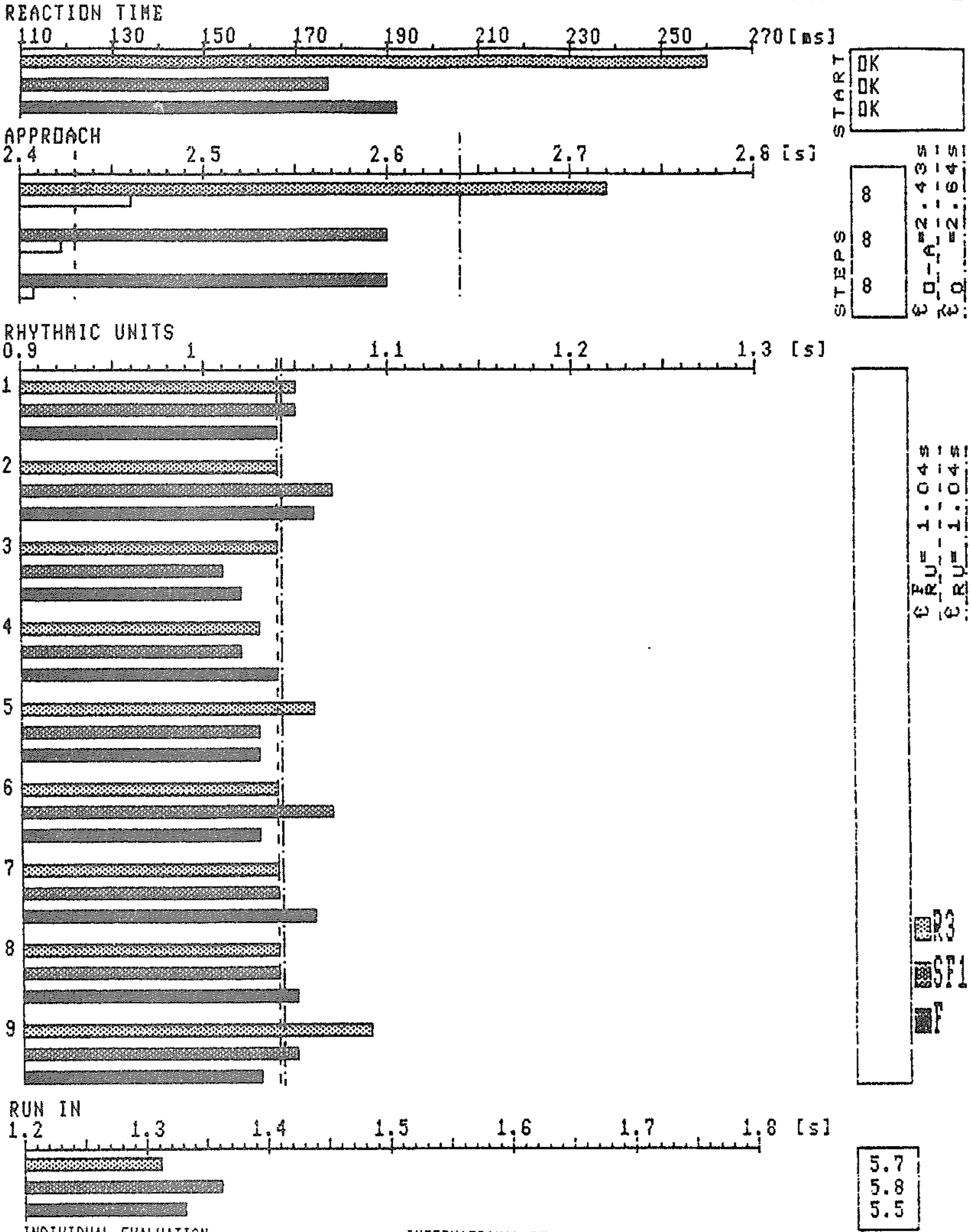
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

110 m. HURDLES -2B- II WC ROME 1987

RIDGEON	JON	67	GBR
R3 -13.46 [s]	SF1-13.34 [s]	F -13.29 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT in the heat substandard, in successive rounds average. Average of approach times without RT among the finalists. Acceleration over 2 RUs/in semifinal and final had an unsteady speed curve. Fastest specific speed in the 3rd RU in the semifinal (0.01s). In the relative stabilization of specific speed in each round, at least one RU featured a pronounced drop of speed (the 2nd RU in the final). In the final, speed increased over the last two RUs. The fastest man on the run-in. In all rounds, the run-in run with full effort: average of run-in times 1.33s (0.08s faster than the 2nd runner). Main advantage: very well trained in specific endurance, including run-in; shortcomings in reaction speed, explosive strength and ability of keeping up specific speed (unbalanced curve of running speed).

* DATA NOT MEASURED
R RESTART
W WARNING

110 m.HURDLES -3A- II WC ROME 1987

TIME ANALYSIS

JACKSON COLIN 67 GBR

PLACING 2.	1. 1st RUN	RESULT 13.37

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.61	3.67	4.70	5.71	6.73	7.73	8.75	9.79	10.87	11.95	13.37
B.	2.51	3.55	4.58	5.61	6.65	7.68	8.73	9.78	10.85	11.94	13.37
C.		1.06	1.03	1.01	1.02	1	1.02	1.04	1.08	1.08	1.42
D.		1.04	1.03	1.03	1.03	1.04	1.04	1.06	1.07	1.09	1.43
E.	-0.05	-0.07	-0.07	-0.05	-0.03	---	---	---	---	---	

PLACING 3.	2. SEMIFINAL	RESULT 13.58

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.64	3.68	4.77	5.80	6.84	7.88	8.92	10.00	11.08	12.17	13.58
B.	2.55	3.60	4.65	5.70	6.75	7.80	8.86	9.93	11.02	12.13	13.58
C.		1.04	1.09	1.03	1.04	1.04	1.04	1.08	1.08	1.09	1.41
D.		1.06	1.05	1.05	1.05	1.05	1.06	1.07	1.09	1.11	1.45
E.	-0.04	-0.03	-0.07	-0.05	-0.04	-0.03	-0.01	-0.02	-0.02	---	

PLACING 3.	FINAL	RESULT 13.38

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.65	4.71	5.75	6.76	7.80	8.83	9.88	10.94	11.99	13.38
B.	2.51	3.55	4.59	5.62	6.65	7.69	8.73	9.79	10.86	11.95	13.38
C.		1.05	1.06	1.04	1.01	1.04	1.03	1.05	1.06	1.05	1.39
D.		1.04	1.03	1.03	1.03	1.04	1.04	1.06	1.07	1.09	1.43
E.	-0.04	-0.05	-0.07	-0.08	-0.06	-0.06	-0.05	-0.04	-0.04	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

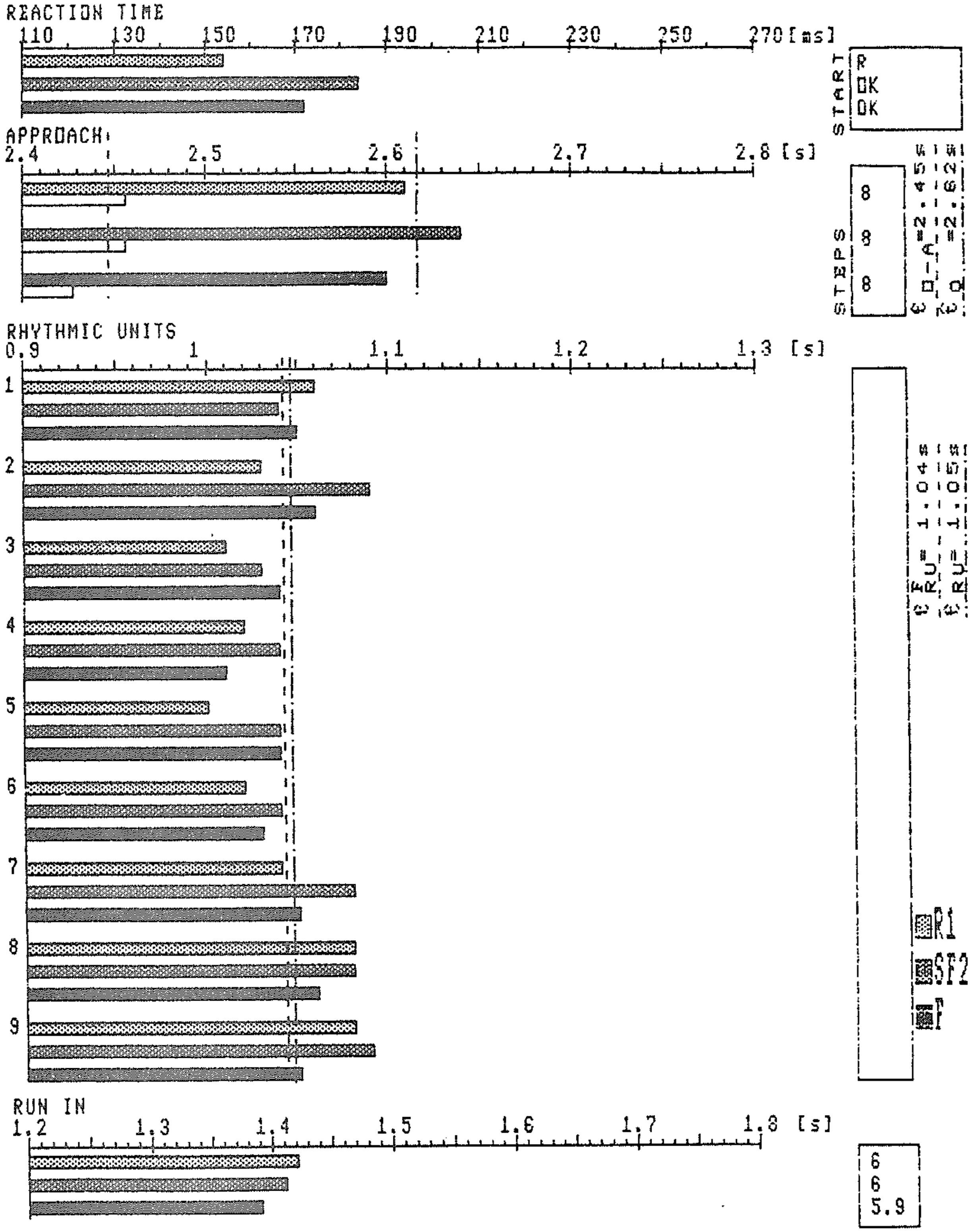
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

110 m.HURDLES -3B- II WC ROME 1987

JACKSON	COLIN	67	GBR
R1 -13.37 [s]	SF2-13.58 [s]	F -13.38 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT in the heat above average, in successive rounds average. In the approach time without RT 6th among the finalists. The best approach-time achieved in the final. Acceleration varies in length. Not an optimum running speed curve in the acceleration section in the semifinal and final. The fasted RU in the heat 1.00s. Relative stabilization of specific speed over 3-4 RUs. Specific speed reduction usually 3 RUs. Run-in time stabilized at about 1.40s. Advantage in high run-in speed and maximum specific speed; shortcomings in explosive strength, running speed in acceleration and ability keep specific speed.

* DATA NOT MEASURED
R RESTART
N WARNING

100m HURDLES -1A-

II WC ROME 1987

TIME ANALYSIS

ZAGORCHEVA GINKA 58 BUL

PLACING 1.	1. 1st RUN	RESULT 12.51

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.56	3.57	4.57	5.57	6.54	7.53	8.49	9.46	10.45	11.45	12.51
B.	2.49	3.49	4.48	5.46	6.43	7.41	8.39	9.38	10.38	11.41	12.51
C.		1.01	1	1	0.97	0.99	0.96	0.97	0.99	1	1.06
D.		1.00	0.99	0.98	0.97	0.97	0.98	0.99	1.01	1.03	1.10
E.	-0.02	-0.03	-0.04	-0.06	-0.06	-0.07	-0.05	-0.03	-0.03	---	

PLACING 2.	1. SEMIFINAL	RESULT 12.75

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.60	3.63	4.65	5.66	6.66	7.64	8.62	9.62	10.62	11.69	12.75
B.	2.54	3.56	4.57	5.56	6.56	7.55	8.55	9.56	10.58	11.63	12.75
C.		1.03	1.02	1.01	1	0.98	0.98	1	1	1.07	1.06
D.		1.02	1.01	1.00	0.99	0.99	1.00	1.01	1.02	1.04	1.12
E.	-0.01	-0.02	-0.03	-0.05	-0.05	-0.04	-0.02	-0.01	---	-0.02	

PLACING 1.	FINAL	RESULT 12.34

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.51	3.52	4.49	5.46	6.44	7.41	8.38	9.34	10.31	11.28	12.34
B.	2.46	3.44	4.42	5.38	6.34	7.31	8.27	9.25	10.24	11.25	12.34
C.		1.01	0.97	0.97	0.98	0.97	0.97	0.96	0.97	0.97	1.06
D.		0.99	0.97	0.97	0.96	0.96	0.97	0.98	0.99	1.01	1.09
E.	---	-0.03	-0.02	-0.03	-0.05	-0.05	-0.06	-0.04	-0.03	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

C. REAL RHYTHMIC UNITS

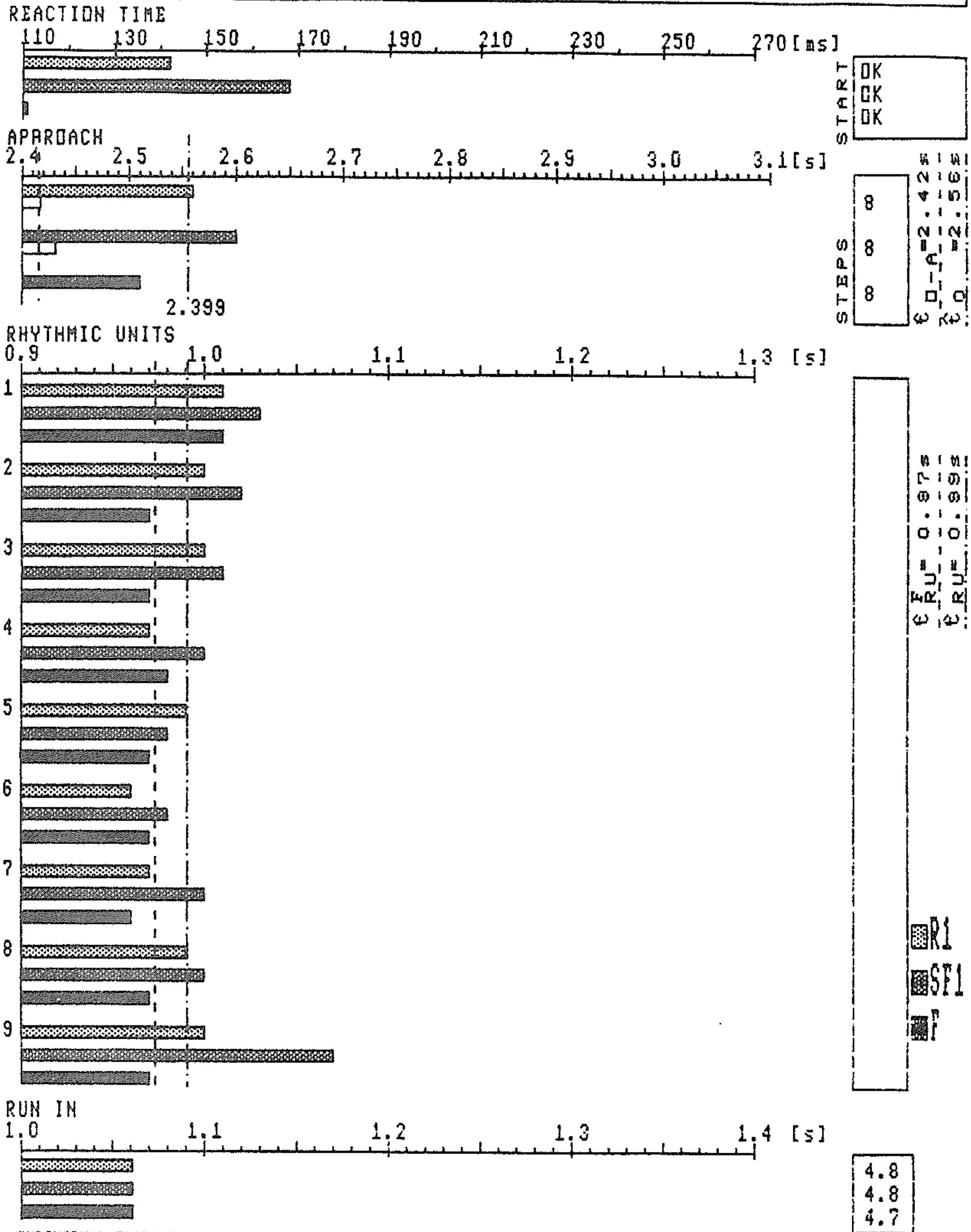
D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

100m HURDLES -1B-

II WC ROME 1987

ZAGORCHEVA	GINKA	58	BUL
R1 -12.51 [s]	SF1-12.75 [s]	F -12.34 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT about average and outstanding in the final, the best of all. In terms of the average approach times without RT, 4th of the finalists. Acceleration gradually shortening in successive rounds. Highest specific speed achieved in 6th and 7th RUs in the heat and the final (0.96s). Relative stabilization of specific speed the longest of all in the final-from 2nd to 9th RU. The average time of all RUs in the final 0.97s, without any reduction of running speed. Times of running clearly show special preparation. Although the speed in the last RU of the semifinal was reduced, the run-in was completed with full effort; run-in times in all rounds identical -1.06s. Advantages in reaction speed and high level of specific endurance including the run-in. Shortcomings in explosive strength.

* DATA NOT MEASURED
R RESTART
N WARNING

100m HURDLES -2A- II WC ROME 1987

TIME ANALYSIS UIBEL GLORIA 64 GDR

PLACING 1.	4. 1st RUN	RESULT 12.81

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.61	3.63	4.60	5.59	6.58	7.58	8.57	9.59	10.60	11.67	12.81
B.	2.54	3.56	4.57	5.58	6.58	7.58	8.58	9.60	10.63	11.68	12.81
C.		1.02	0.97	0.99	0.99	1	0.99	1.02	1.01	1.07	1.14
D.		1.02	1.01	1.00	1.00	1.00	1.01	1.02	1.03	1.05	1.13
E.	*	-0.02	---	---	---	---	---	---	---	---	

PLACING 1.	2. SEMIFINAL	RESULT 12.68

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.65	3.66	4.65	5.63	6.60	7.57	8.54	9.53	10.54	11.55	12.68
B.	2.51	3.53	4.53	5.52	6.51	7.50	8.50	9.50	10.52	11.56	12.68
C.		1.01	0.99	0.98	0.97	0.97	0.97	0.99	1.01	1.01	1.13
D.		1.01	1.00	0.99	0.99	0.99	1.00	1.01	1.02	1.04	1.12
E.	-0.09	-0.08	-0.07	-0.06	-0.04	-0.02	---	---	---	---	

PLACING 2.	FINAL	RESULT 12.44

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.57	3.58	4.56	5.50	6.48	7.44	8.42	9.36	10.33	11.34	12.44
B.	2.47	3.46	4.44	5.42	6.39	7.36	8.33	9.32	10.32	11.34	12.44
C.		1.01	0.98	0.94	0.98	0.96	0.98	0.94	0.97	1.01	1.10
D.		1.00	0.98	0.97	0.97	0.97	0.98	0.99	1.00	1.02	1.10
E.	-0.05	-0.07	-0.07	-0.03	-0.04	-0.03	-0.04	---	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

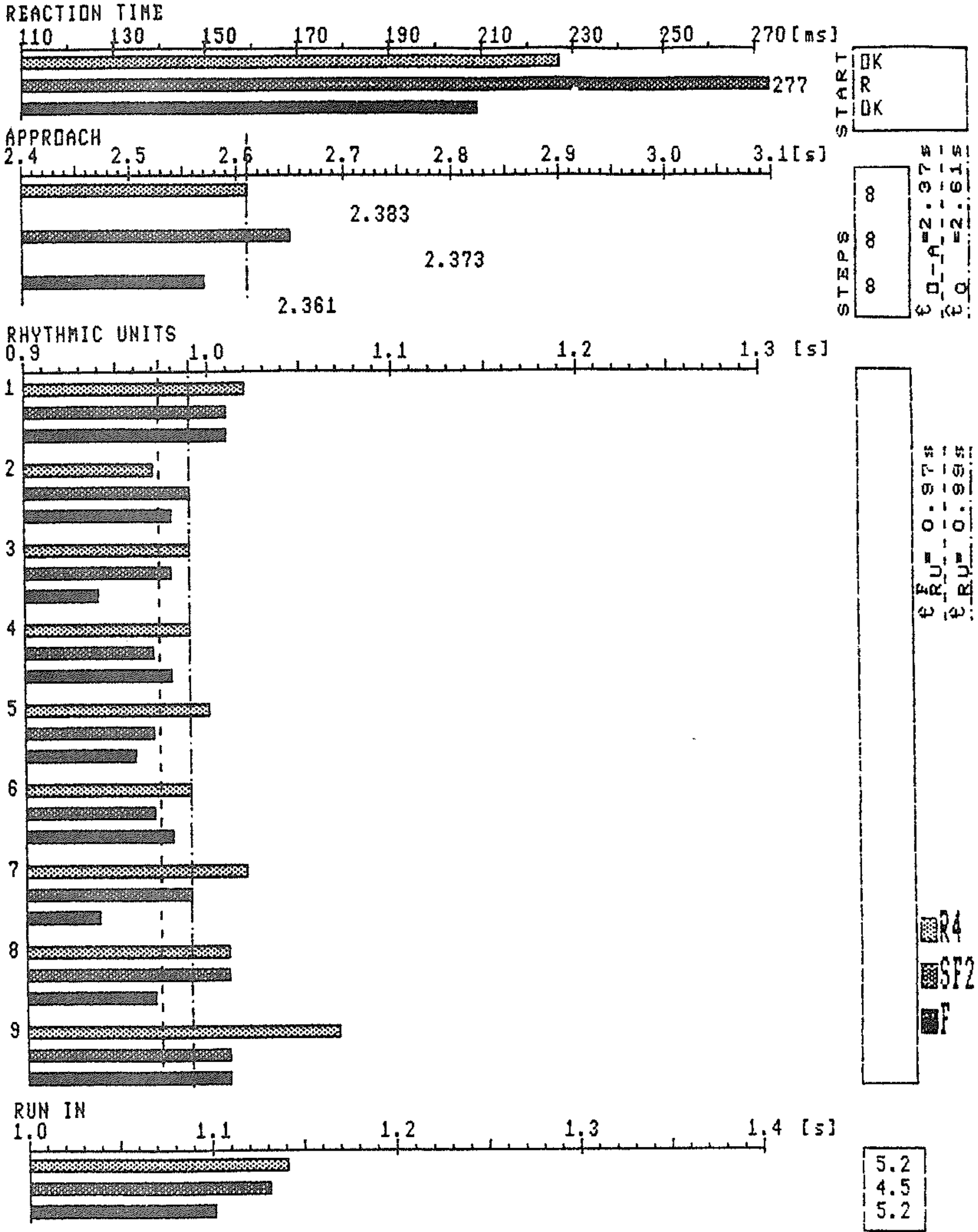
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

100m HURDLES -2B- II WC ROME 1987

UIBEL	GLORIA	64	GDR
R4 -12.81 [s]	SF2-12.68 [s]	F -12.44 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT below average, in semifinal substandard. Approach times without RT and the times of the first RU are evidence of a fairly good level of explosive strength. Acceleration over 1-2 RUs; the highest specific speed of all hurdlers in the final, at 0.94s. The optimum curve of running speed demonstrated in the semifinal; in the stabilization in the final irregular curve of running speed. Speed reduced usually in the last RU. Average times of all RUs and run-in times gradually improved in successive rounds. Advantages in the level of explosive strength, maximum specific speed and specific endurance; improvement potential in reaction speed, ability to maintain specific speed and speed in the run-in.

* DATA NOT MEASURED
R RESTART
N WARNING

100m HURDLES -3A- II WC ROME 1987

TIME ANALYSIS

OSCHKENAT CORNELIA 61 GDR

PLACING 1. — 3. 1st RUN — RESULT 12.83

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.62	3.66	4.66	5.63	6.62	7.62	8.61	9.62	10.62	11.66	12.83
B.	2.54	3.57	4.58	5.59	6.59	7.59	8.60	9.61	10.65	11.70	12.83
C.		1.04	1	0.97	0.99	1	0.99	1.01	1	1.04	1.17
D.		1.03	1.01	1.00	1.00	1.00	1.01	1.02	1.03	1.05	1.13
E.	-0.03	-0.04	-0.03	---	---	---	---	---	---	---	

PLACING 1. — 1. SEMIFINAL — RESULT 12.65

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.47	3.54	4.56	5.56	6.52	7.51	8.50	9.49	10.49	11.53	12.65
B.	2.51	3.52	4.52	5.51	6.49	7.48	8.48	9.48	10.50	11.54	12.65
C.		1.07	1.02	1	0.96	0.99	0.99	0.99	1	1.04	1.12
D.		1.01	1.00	0.99	0.99	0.99	0.99	1.00	1.02	1.04	1.11
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 3. — FINAL — RESULT 12.46

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.50	3.50	4.48	5.46	6.43	7.40	8.38	9.36	10.35	11.36	12.46
B.	2.47	3.47	4.45	5.43	6.40	7.37	8.35	9.34	10.34	11.36	12.46
C.		1	0.98	0.98	0.97	0.97	0.98	0.98	0.99	1.01	1.10
D.		1.00	0.98	0.98	0.97	0.97	0.98	0.99	1.00	1.02	1.10
E.	---	---	---	---	---	---	---	---	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

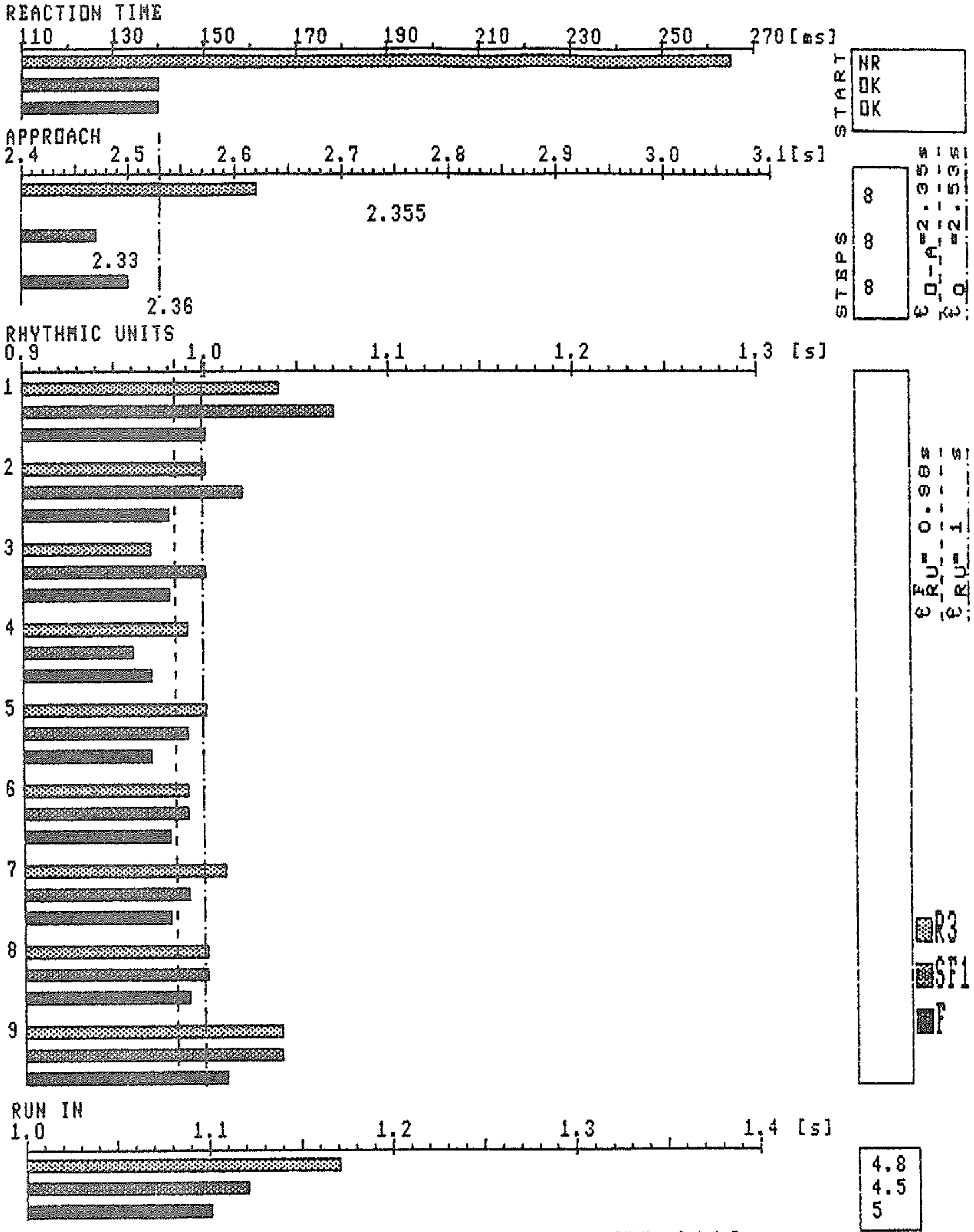
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

100m HURDLES -3B- II WC ROME 1987

DSCHKENAT	CORNELIA	61	GDR
R3 -12.83 [s]	SF1-12.65 [s]	F -12.46 [s]	



INDIVIDUAL EVALUATION

INTERNATIONAL RESEARCH TEAM I.A.A.F
CHARLES UNIVERSITY FTVS & VMD-UV CSTU

RT in the heat substandard, in the following rounds excellent. The best in the approach time, even after substracting the RT. Length of acceleration irregular. Highest specific speed in the final from 2nd to 8th RU. Notable speed reduction in the last RU. Run-in times gradually improved in successive rounds. Advantages in reaction speed and explosive strength; shortcomings in maximum specific speed and run-in speed.

* DATA NOT MEASURED
R RESTART
N WARNING

5. CONCLUSION

This report has been written with a view to the application of intermediate times in evaluating the athlete's level of training for a particular event, in assessing the whole race, and in judging some of the fundamental movement- abilities of the athlete.

This report outlines the way towards using computer technology for simplifying the work of coaches, all the way to the automatic evaluating of each start, each race or each individual.

6. REFERENCES

ČECH, P. (1979) : Některé aspekty kinematické analýzy běhu na 100 a 110 m překážek. Diplomová práce, FTVS UK, Praha.

SUŠANKA, P. (1987) : Hints of computer processing of biomechanical data and their practical application. Fifth Intern.Symp.of Biomechanics in Sports. The Hellenic Sports Research Institute, Pag.30, Athens.

List of tables

			HEATS /s/	SF /s/	F /s/	
1 A-B	FOSTER	USA	13.20	13.41	13.21	REPORT
2 A-B	RIDGEON	GBR	13.46	13.34	13.29	REPORT
3 A-B	JACKSON	GBR	13.37	13.58	13.30	REPORT
4 A-B	PIERCE	USA	13.61	13.45	13.41	APPENDIX
5 A-B	KAZANOV	URS	13.80	13.58	13.48	APPENDIX
6 A-B	SALA	ESP	13.48	13.60	13.55	APPENDIX
7 A-B	MC KOY	CAN	13.50	13.42	13.71	APPENDIX
8 A-B	BRYGGARE	FIN	13.62	13.62	DNS	APPENDIX

1 A-B	ZAGORCHEVA	BUL	12.51	12.75	12.34	REPORT
2 A-B	UIBEL	GDR	12.81	12.68	12.44	REPORT
3 A-B	OSCHKENAT	GDR	12.83	12.65	12.46	REPORT
4 A-B	DONKOVA	BUL	12.97	12.76	12.49	APPENDIX
5 A-B	PIQUERAU	FRA	13.24	12.95	12.82	APPENDIX
6 A-B	ELLOY	FRA	13.08	12.88	12.83	APPENDIX
7 A-B	ZACZKIEWICZ	FRG	13.15	13.01	12.98	APPENDIX
8 A-B	MARTIN	USA	13.19	12.94	13.06	APPENDIX

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D

TIME ANALYSIS OF THE 400m HURDLES

Sušanka, P.; Kodejš, M.; Miskos, G.

CONTENTS

1. INTRODUCTION

The performance levels in both the men's and women's 400 m hurdles have shown a steadily rising trend in recent years as shown in FIG. 1 and 2. The solid lines show the top performance of each year while the other lines show the courses of the mean maximum performance of the top 3 and top 10 athletes, respectively. Especially striking are the rises of the mean maximum performance of the top 10, indicating the overall development of both the men's and women's events.

Even so, it should be stated, quite unequivocally, that women still have considerable difficulties in coping with this event both physically and, consequently, technically. Evidence to support this can be found not only in the striking difference between the best times over 400m flat and 400m hurdles but also in the considerable variability in performances during the course of the season, and, last but not least, in the course of the 400m hurdles race itself. Women athletes differ significantly from men in the technique of hurdle clearance and in coping with the rhytmic units.

Only two of the women athletes who qualified for the semifinals and for the final in Rome improved on their personal bests in 1987 and one clocked practically the same time as her personal best (-0.03). All the others clocked times inferior to performances achieved before Rome (TAB. 2).

The men's category, despite the commanding position and long-term dominance of Edvin Moses, which might be expected to lead to stagnation, has been characterized by continuing improvements in performances and technique. All the Rome finalists clearly showed both a fine level of training and stability of performance. The first four finishers improved on their 1987 bests in the Rome final - NYLANDER by as much as 0.91s (TAB. 1).

FINAL 1/9 - 16.50

1.	1065	Moses Edwin	55	USA	47.46	CR
2.	1044	Harris Danny	65	USA	47.48	
3.	389	Schmid Harald	57	FRG	47.48	
4.	862	Nylander Sven	62	SWE	48.37	
5.	796	Dia Ba Amadou	58	SEN	48.37	
6.	715	Amike Henry	61	NGR	48.63	
7.	410	Akabusi Kriss	58	GBR	48.74	
8.	246	Alonso Jose	57	ESP	49.46	

Ore/Time 16:50 — Temp.: +28 °C
Press.: 1016 mBar — Umidità/Humidity: 63%

3/9 - 17.40

1.	286	Busch Sabine	62	GDR	53.62	CR
2.	11	Flintoff King Debra	60	AUS	54.19	
3.	314	Ulrich Cornelia	63	GDR	54.31	
4.	400	Farmer Sandra	62	JAM	54.38	
5.	177	Helander Kuusisto Tuija	61	FIN	54.62	
6.	551	Ambrazene Anna	55	URS	55.68	
7.	668	Williams Schowonda	66	USA	55.86	
8.	617	Brown-King Judi	61	USA	56.10	

Ore/Time 17:40 — Temp.: +27 °C
Press.: 1012 mBar — Umidità/Humidity: 68%

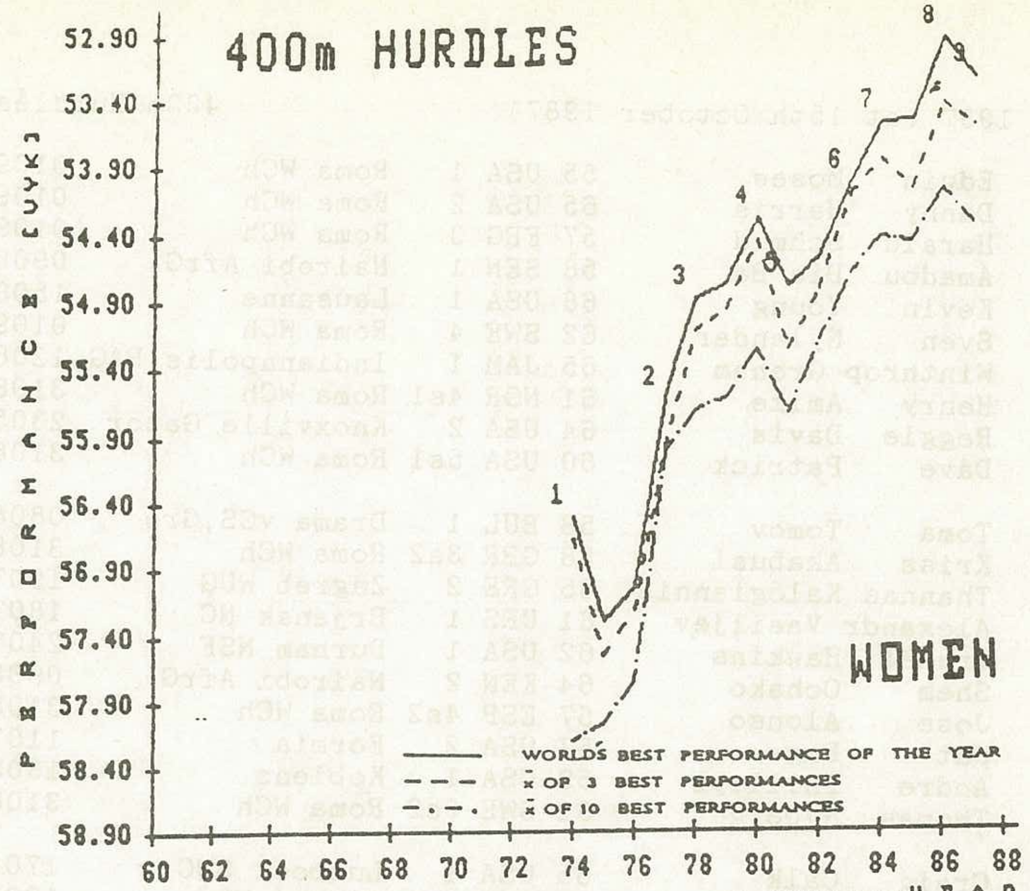


FIG 1

1 KACPERCZYK
2 ROSSLEY
3 ZELENCOVOVA
4 ROSSLEY
5 NEUMANN
6 AMBRAZIENE
7 PONOMARJEV
8 STEPANOV
9 BUSCH

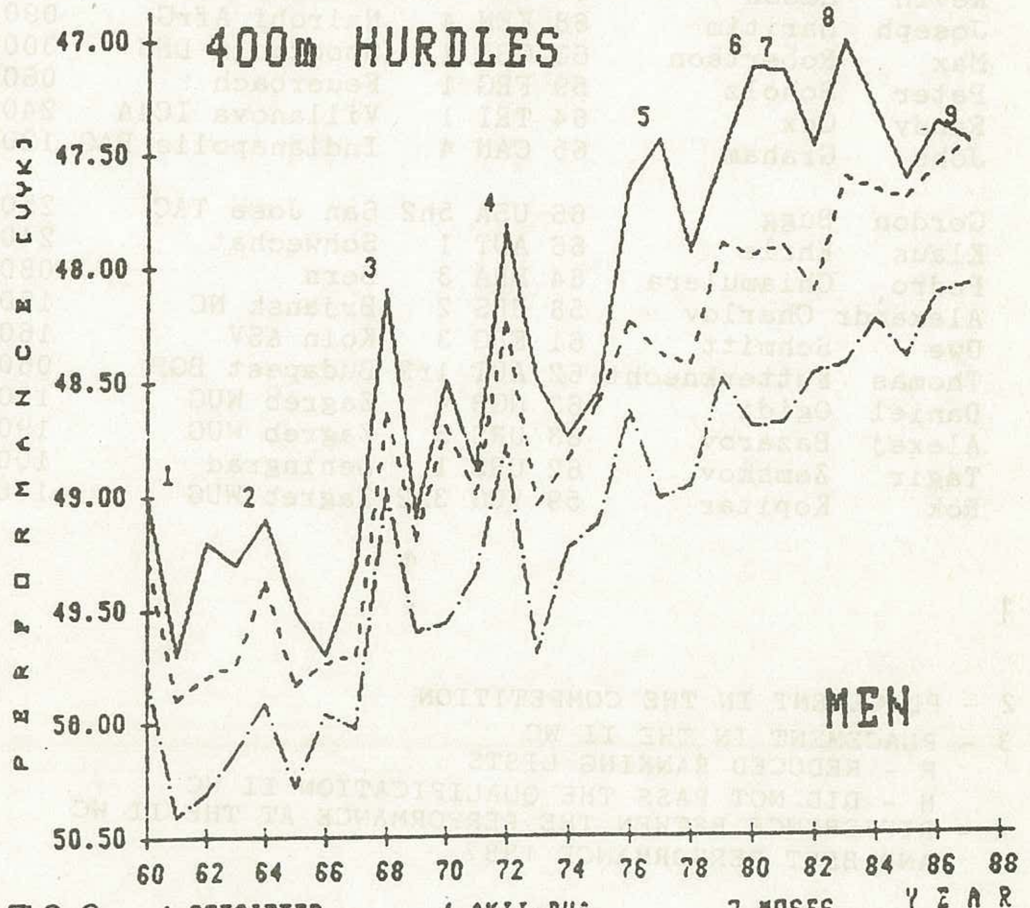


FIG 2

1 POTGIETER
2 CAWLEY
3 HEMERY
4 AKII-BUA
5 MOSES
6 MOSES
7 MOSES
8 MOSES
9 MOSES

47.46	Edwin	Moses	55	USA	1	Roma WCh	0109	1.	+0.23
47.48	Danny	Harris	65	USA	2	Roma WCh	0109	2.	+0.02
47.48	Harald	Schmid	57	FRG	3	Roma WCh	0109	3.	+0.12
48.03	Amadou	Dia Ba	58	SEN	1	Nairobi AfrG	0908	5.	-0.34
48.15	Kevin	Young	66	USA	1	Lausanne	1509	R	
48.37	Sven	Nylander	62	SWE	4	Roma WCh	0109	4.	+0.91
48.49	Winthrop	Graham	65	JAM	1	Indianapolis PAG	1208	10.	-0.15
48.50	Henry	Amike	61	NGR	4s1	Roma WCh	3108	6.	-0.13
48.52	Reggie	Davis	64	USA	2	Knoxville Gator	2305	R	
48.56	Dave	Patrick	60	USA	5s1	Roma WCh	3108	9.	+0.20
48.59	Toma	Tomov	58	BUL	1	Drama vCS,Gre	0808	12.	-0.52
48.64	Kriss	Akabusi	58	GBR	3s2	Roma WCh	3108	7.	-0.10
48.80	Thannas	Kalogiannis	65	GRE	2	Zagreb WUG	1907	N	-3.14
48.85	Alexandr	Vasiljev	61	URS	1	Brjansk NC	1807	16.	(RET)
48.89	Tranel	Hawkins	62	USA	1	Durham NSF	2407	R	
48.97	Shem	Ochako	64	KEN	2	Nairobi AfrG	0908	14.	-0.90
49.00	Jose	Alonso	57	ESP	4s2	Roma WCh	3108	8.	-0.46
49.02	Nat	Page	57	USA	2	Formia	1107	R	
49.02	Andre	Phillips	59	USA	1	Koblenz	1308	R	
49.03	Thomas	Nyberg	62	SWE	5s2	Roma WCh	3108	11.	+0.48
49.05	Craig	Calk	65	USA	1	Lubbock SWC	1705	R	
49.14	Edgar	Itt	67	FRG	1r2	Zürich WK	1908	N	-2.04
49.20	Ryoichi	Yoshida	65	JAP	3	Zagreb WUG	1907	13.	-0.19
49.26	Bart	Williams	56	USA	2	Athenai	2006	R	
49.27	Kevin	Mason	67	USA	5s2	San Jose TAC	2606	R	
49.33	Joseph	Maritim	68	KEN	4	Nairobi AfrG	0908	N	-0.71
49.35	Max	Robertson	63	GBR	1	Stockholm DNG	3006	15.	-0.55
49.41	Peter	Scholz	59	FRG	1	Feuerbach	0606	R	
49.43	Randy	Cox	64	TRI	1	Villanova IC4A	2405	N	-0.71
49.51	John	Graham	65	CAN	4	Indianapolis PAG	1208	N	-0.72
49.54	Gordon	Bugg	66	USA	5h2	San Jose TAC	2506	R	
49.55	Klaus	Ehrle	66	AUT	1	Schwechat	2406	N	-1.36
49.64	Pedro	Chiamulera	64	BRA	3	Bern	0807	N	-1.07
49.65	Alexandr	Charlov	58	URS	2	Brjansk NC	1807	-	
49.69	Uwe	Schmitt	61	FRG	3	Koln ASV	1608	N	-0.85
49.71	Thomas	Futterknecht	62	AUT	1r2	Budapest BGP	0607	N	-0.73
49.74	Daniel	Ogidi	63	NGR	4	Zagreb WUG	1907	N	-0.77
49.76	Alexej	Bazarov	63	URS	5	Zagreb WUG	1907	-	
49.76	Tagir	Zemskov	62	URS	1	Leningrad	1008	-	
49.77	Rok	Kopitar	59	YUG	3s2	Zagreb WUG	1707	N	-1.76
					↑ 2			↑ 3	↑ 4

TABLE 1

2 - PLACEMENT IN THE COMPETITION
3 - PLACEMENT IN THE II WC
R - REDUCED RANKING LISTS
H - DID NOT PASS THE QUALIFICATION II WC
4 - DIFFERENCE BETWEN THE PERFORMANCE AT THE II WC AND BEST PERFORMANCE 1987

53.24	Sabine	Busch	62	GDR	1	Potsdam NC	2108	1.	-0.38
53.58	Cornelia	Ulrich	63	GDR	2	Potsdam NC	2108	3.	-0.73
53.95	Debbie	Flintoff	60	AUS	1	Koln ASV	1608	2.	-0.24
54.23	Judi	Brown King	61	USA	1	Indianapolis PAG	1208	8.	-1.87
54.38	Sandra	Farmer	62	JAM	4	Roma WCh	0309	4.	+0.19
54.58	Margarita	Chromova	63	URS	1	Leningrad	0808	9.	-0.28
54.62	Tuija	Helander	61	FIN	5	Roma WCh	0309	5.	+0.36
54.82	Schowonda	Williams	66	USA	4s1	Roma WCh	0109	7.	-1.04
54.96	Genowefa	Blaszak	57	POL	4	Budapest BGP	0607	dq	
55.05	LaTanya	Sheffield	63	USA	3	San Jose TAC	2706	13.	-1.60
55.18	Nawal el	Moutawakil	62	MAR	3	Köln ASV	1608	N	-2.03
55.19	Anna	Ambraziene	55	URS	1	Brjansk NC	1807	6.	-0.49
55.25	Jelena	Filipišina	62	URS	1	Čeljabinsk	2106	-	
55.25	Marina	Stepanova	50	URS	2	Helsinki WG	0207	-	
55.30	Nicoleta	Carutasu	64	RUM	1	Göteborg EP/B	2706	-	
55.40	Jelena	Gončarova	64	URS	3	K-Marx-St. vGDR	2006	-	
55.40	Sophia	Hunter	64	USA	5	San Jose TAC	2706	R	
55.55	Linetta	Wilson	67	USA	1	Baton Rouge NCAA	0506	R	
55.55	Helene	Huart	65	FRA	1	Annecy NC	0908	N	-1.58
55.56	Gudrun	Abt	62	FRG	2	Koblenz	1308	10.	-0.03
55.62	Maria	Usifo	64	NGR	3	Zürich WK	1908	16.	dns
55.73	P.T.	Usha	64	IND	3h3	Roma WCh	3108	11.	-0.16
55.76	Sametra	King	66	USA	1	Knoxville Gator	2305	R	
55.79	Leslie	Maxie	67	USA	2	Baton Rouge NCAA	0506	R	
55.94	Rose	Tata-Muya	60	KEN	2	Nairobi AfrG	0808	14.	-1.71
56.02	Olga	Nazarova	65	URS	1	Žitomir	0909	-	
56.03	Jelena	Mitrukova	64	URS	2	Žitomir	0909	-	
56.07	Marina	Sereda	64	URS	3	Brjansk NC	1807	-	
56.09	Susanne	Losch	66	GDR	3	Potsdam NC	2108	-	
56.10	Kathy	Freeman	62	USA	6	San Jose TAC	2706	R	
56.15	Sally	Fleming	61	AUS	1	Sydney NC	2903	N	-2.72
56.33	Tania	Fernandez	67	CUB	4	Indianapolis PAG	1208	N	-2.45
56.37	Olga	Petrova	63	URS	3	Žitomir	0909	-	
56.40	Margarita	Navickaite	61	URS	4	Zagreb WUG	1407	-	
56.51	Irmgard	Trojer	64	ITA	3	Göteborg EP/B	2707	15.	-1.35
56.54	Nadine	Debois	61	FRA	2	Dijon	1306	-	
56.56	Christina	Wennberg	63	SWE	7s2	Roma WCh	0109	17.	+0.35
56.64	Monika	Klebe	64	SWE	2	Lawrence	1804	-	
56.69	Anita	Protti	64	SUI			09	-	
56.77	Vera	Ordina	68	URS	.h	Brjansk NC	1707	-	

TABLE 2

2. METHODS AND PROCEDURES

The time analysis of the 400m hurdles was based on videos recorded by six SONY videocameras sited on the opposite straights of the track (see FIG.3). Synchronisation was made by the picture of the smoke from the starter's gun. A total of 124 individual analyses was made. This report includes the analyses of all the athletes who qualified for the semifinals and the final (46 analyses). The semifinals and the final were also filmed by two synchronized high-speed PHOTOSONICS 500 cameras with a speed of 200 (100) frames per second. The sitting of the cameras (FIG. 4) facilitated 3-D analysis on the home straight. 3-D material has been used in this report:

a) to check the time-data obtained from the videorecordings, i.e. to check the accuracy of measurements;
b) to determine the distance between takeoff before and landing after the hurdle (9th and 10th barriers).

The material obtained will be further utilised for 3-D analysis of the running over the last 100 m and, more specifically, for determining stride length and for evaluating the technique of hurdle clearance (9th and 10th barriers).

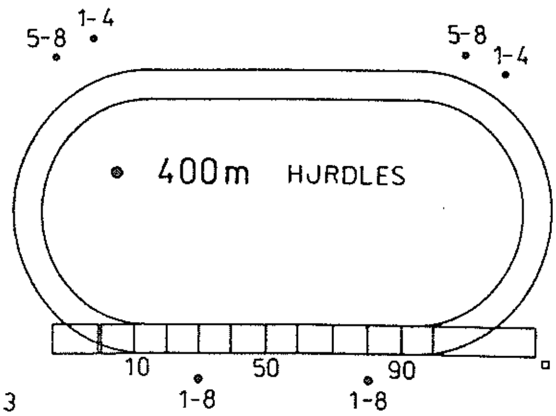


FIG 3

POSITION OF CAMERAS

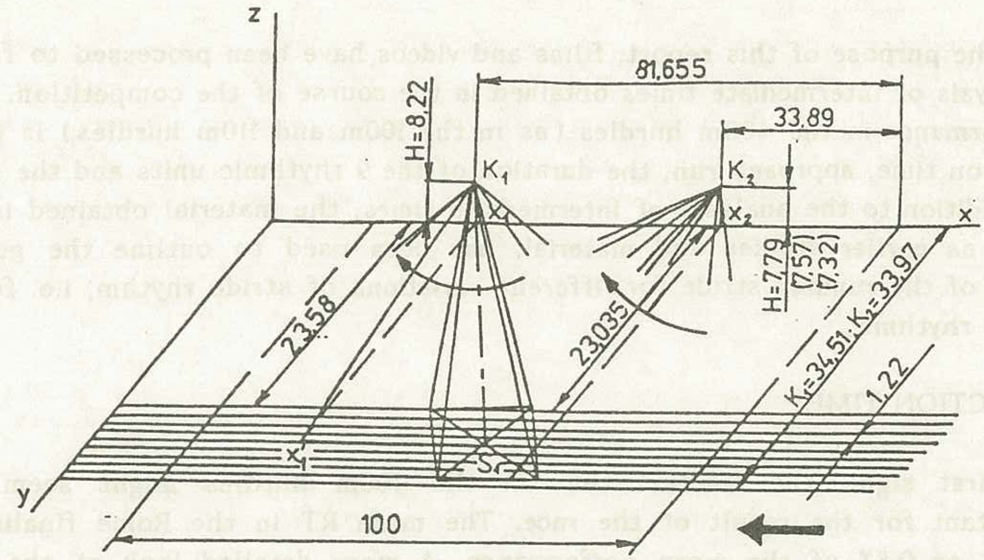


FIG 4

MODEL INTERMEDIATE TIMES

Model intermediate times for full range of performances have been plotted on the basis of long-term measurements and data collection. The mathematical method is described in SUSANKA (1978). The statistical processing can be roughly summarized as follows:

Touchdowns after the hurdles were related to performance. 10 regression straight lines were thus obtained, whose correlation-coefficient has a steadily rising tendency. In the relationship between touchdown after the 10th hurdle and performance, the correlation approximates 1.

The tangents of the regression straight lines make up the model intermediate times. A tolerance field has also been provided which pays due respect to possible errors in measurements.

The time analysis tables marked A can thus be used for finding - in addition to the values measured in each individual - deviations from model intermediate times in any particular performance.

3. ANALYSIS OF THE COMPETITION AT THE II WORLD CHAMPIONSHIPS IN ATHLETICS

For the purpose of this report, films and videos have been processed to facilitate the analysis of intermediate times obtained in the course of the competition.

Performance in the 400m hurdles (as in the 100m and 110m hurdles) is the sum of reaction time, approach run, the duration of the 9 rhythmic units and the run-in.

In addition to the analysis of intermediate times, the material obtained in Rome, as well as earlier studies and material, has been used to outline the geometric features of the running stride for different variations of stride rhythm, i.e. for 13 to 17 stride rhythms.

3.1. REACTION TIME

At first sight, the reaction time in the 400m hurdles might seem to be unimportant for the result of the race. The mean RT in the Rome finalists was 246 ms , or 0.5% of the mean performance. A more detailed look at the results shows that, as a matter of fact, the reaction time speed decided the placings of the medallists, as well as the 4th and 5th men in. The shortest RT by far was that of MOSES whose outstanding reaction time meant a gain of 0.06 s on HARRIS and 0.08 s on SCHMID.

The mean reaction speed and its significant deviations in most important world events in 1978-87 are shown in TAB. 3. The longer reaction times, as computed for the sprint hurdles and the flat sprints, are characterized in all the events concerned by the mean values of the reaction time (men - 235 ms; women - 255 ms).

TAB. 3: Reaction times measured at different athletic competitions (European, World Championships, World Junior Championshisps and Olympic Games)

MEN	400 mH			Women 400mH		
	n	x	SD	n	x	SD
EC 78	48	230	66	51	267	58
OG 80	23	203	46			
EC 82	45	237	66	24	242	59
WC 83	58	224	42	53	237	47
OG 84						
WJC 86	60	241	63	43	249	64
EC 86						
WC 87	54	256	61	21	301	60
AVERAGE	288	235	58	192	255	57

As in all the other events where a start from blocks is used, measurements done by the various commercial companies obviously do not guarantee identical standards of results. That is why, in trying to evaluate the level of reaction speed, account should be taken of both the event concerned and long-term averages.

Statistical methods have been used to work out the following evaluating scale.

1. Outstanding	$< x - 1.5s$
2. Above average	$(x - 1.5 ; x - s/2)$
3. Average	$(x - s/2; x + s/2)$
4. Below average	$(x + s/2; x + 1.5s)$
5. Substandard	$> x + 1.5s$

(x - average ; s - significant deviation)

Variations in reaction times in the 400 m hurdles are as follows :

	valid generally		valid only for II WC Rome	
	men (x=235ms)	women(x=255ms)	men (=256ms)	women(x=301ms)
1.	(155	(175	(170	(210
2.	(155 ; 205	(175 ; 230	(170 ; 230	(210 ; 270
3.	(205 ; 265	(230 ; 280	(230 ; 290	(270 ; 330
4.	(265 ; 320	(280 ; 335	(290 ; 350	(330 ; 390
5.	)320	)335	)350	)390

The tendency of the reaction time to be longer, in proportion to the distance between the athlete and the starter, has already been discussed in our analysis of the 1982 EC in Athens. Following negotiations with the organizers, and measures taken at the I World Championships in Athletics in Helsinki 1983, the problem seemed to have been solved. However, we are able to show that the II WC reaction times correlated significantly with the order of lanes or, in other words, with each athlete's distance from the starter (TAB. 4). As in the 400m flat, athletes in the outside lanes (e.g. 7th, 8th) suffer losses of 0.1 to 0.15 s. An offer to deal with this problem is included in report A - Time Analysis of the Sprints.

TAB. 4 : SPEARMAN's coefficient of rank correlation between lane and reaction time

400M HURDLES MEN			400M HURDLES WOMEN		
RUN	COEFF.	REMARK	RUN	COEFF.	REMARK
FINAL	0.26	*	FINAL	0.14	°
H1	0.28	*	SF1	0.48	°°
H2	0.69	!	SF2	0.92	!
H3	0.76	!			
H4	0.78	!			
H5	0.95	!			
H6	0.02	*			

* Does not agree with our hypothesis
° Wrong measurement in the 6th lane
°° Wrong measurement in the 3th lane

3.2. APPROACH RUN

Beginning:

(a) the moment of the gun shot
(b) the moment of the athlete's first movement, i.e. RT (for determining the acceleration level)

End:

Moment of touchdown after the first hurdle

Objective:

Achieving the optimal (model) intermediate time that makes it possible to run a personal best. Providing the conditions for smooth running between the hurdles.

The number of strides of the approach run for all but one of the 16 semifinalists (men) was 20 - 21. In the women's event the number was 22 - 26 strides, predominantly 23 strides (7 athletes), and 22 strides (4 athletes). MOSES is the only athlete who uses a 19-stride approach run, made possible by his extraordinary physique, and by the great distance between his takeoff-point and the hurdle.

In the final, the fastest approach run was achieved by MOSES (a gain of 0.18 s on SCHMID, running second, - but 0.08 s of that had been gained by the short RT). MOSES' approach run was 0.1 s faster.

It should be noted that SCHMID uses a 21-stride approach. Trying to reduce the number of strides of the approach in an effort to save energy and to gain time is of questionable value and should always be judged in terms of the individual potential of the athlete concerned.

A slower start, probably done quite subconsciously, cannot result in any energy saving, and can only affect overall performance and final placing (see above).

In the women's event, the fastest approach was measured for FLINTOFF (AUS) : 6.55s using over 23 strides.

	MEN [s]	WOMEN [s]
For the finalists' performances	47.46 - 49.46	53.60 - 56.10
Approach run	5.82 - 6.27	6.55 - 6.77
Mean approach-run time in all the races of each athlete	5.88 - 6.29	6.59 - 6.84
Approach run minus RT (for determining acceleration)	5.64 - 5.85	6.20 - 6.46

3.3. RHYTHMIC UNITS

Beginning:

moment of touchdown after hurdle

End:

moment of touchdown after next hurdle

Objective:

(a) achieving the fastest time for a RU as soon possible (maximum acceleration)
(b) minimizing time losses up to 5th RU, as against the fastest RU
(c) achieving the shortest mean time possible for the 9 RUs

The highest absolute velocities are reached by men and women between the 1st and 2nd hurdles (exceptionally between the 2nd and 3rd), in other words on the bend, contradicting the expectation that the highest speed would be reached between the 3rd and 4th hurdles (on the straight).

The fastest rhythmic unit was run by HARRIS between the 1st and 2nd hurdles (3.65 s), representing the incredible average velocity of 9.59 m/s (which, in a flying start 100m flat, would result in a time of 10.42 s).

For MOSES the section that was fastest in relation to the model intermediate time (see chap. 4) was between the 4th and 7th hurdles where he made gains of 0.34 s and 0.12 s on HARISS and SCHMID, respectively. Following the touchdown after the 7th hurdle, MOSES was ahead of SCHMID (at that moment running second) by 0.44 s. In the final part of the race, MOSES was clearly tiring: his last RU (between 9th and 10th hurdles) was slower than in the heat and the semifinal! The most significant slowing down for MOSES in the final occurred between the 7th and 8th hurdles: the difference between the time of the 6th and 7th RUs amounted to a drop in mean velocity by 0.63 m/s. Between the 7th hurdle and the finish (a distance of 145 m) Moses lost 0.42 s and 0.57 s on SCHMID and HARRIS, respectively.

HARRIS and SCHMID slowed down perceptibly in approximately the same part of the race. HARRIS' time for the 6th RU was 0.30 s slower than his 5th RU; SCHMID's time for the 7th RU was 0.24 s slower than his 6th RU. The smallest speed differences were measured in AMIKE (NIG) and ALONSO (SPA). The former's greatest slowing down amounted to 0.20 s (between hurdles 6 and 7), the latter's was 0.21 s (between hurdles 7 and 8).

The most marked drop in speed usually occurs between hurdles 7 and 8 (less frequently between hurdles 6 and 7 or 8 and 9), whether a change of rhythm (the number of strides between the hurdles) occurs or not.

This section can be described as critical, keeping with the findings of physiologists who described the 250 m mark as critical.

The number of strides between hurdles varies from 13 to 15 in men and between 14 and 18 in women. MOSES is the only hurdler to keep consistently to 13 strides in all RUs. All the other hurdlers tend to shorten their strides and to increase the number of strides in the RUs (for men see FIG. 5, for women see FIG. 6).

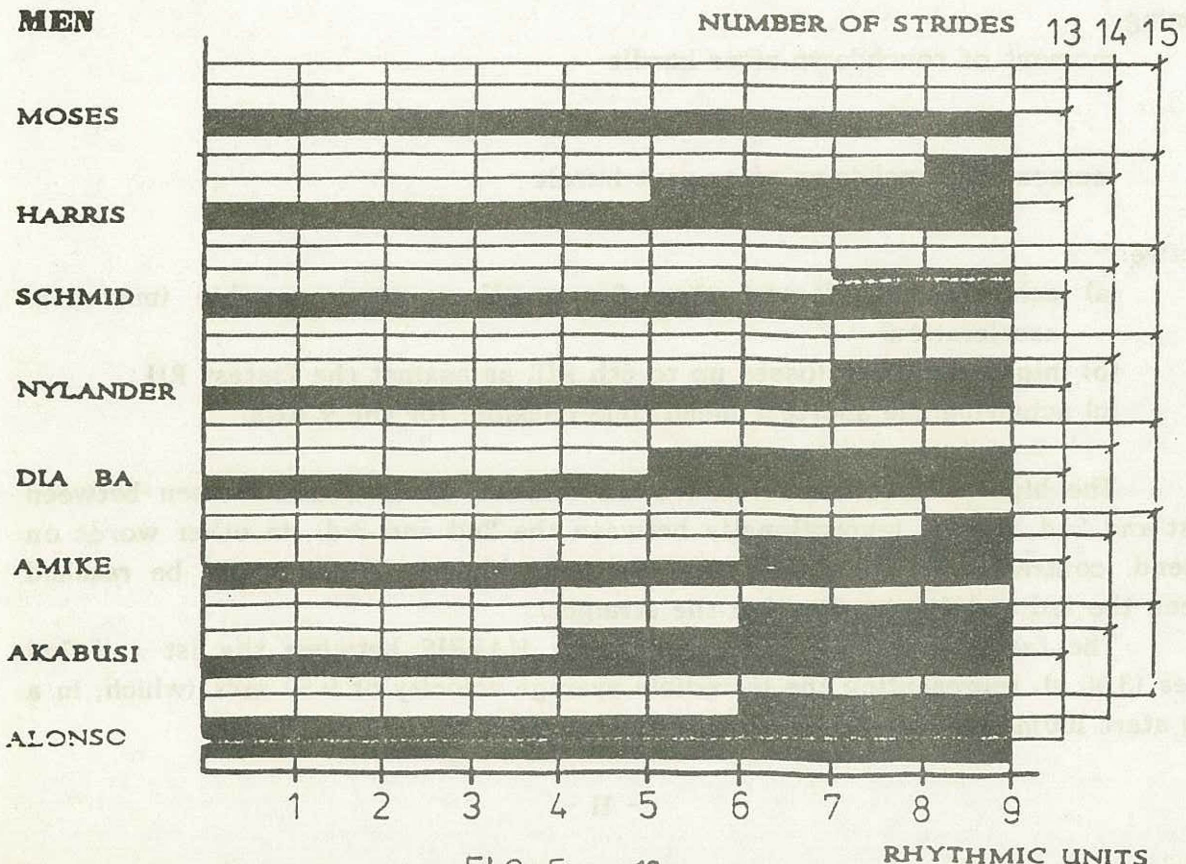


FIG 5

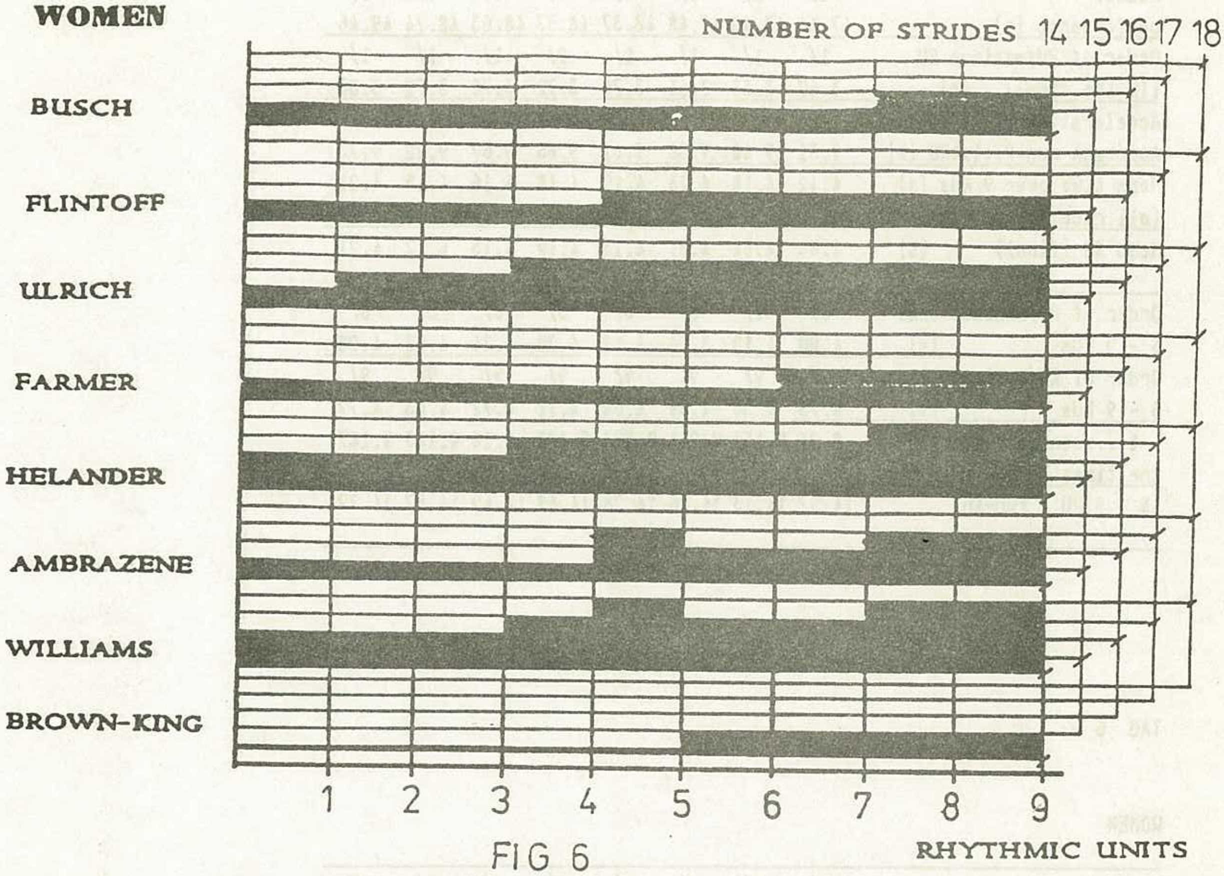


FIG 6

The above shows that a hurdler should aim at

men: adopting and perfecting a 13 stride rhythm and also mastering takeoff after the hurdle from both the left and the right foot

women: adopting and perfecting a 15 stride rhythm and also mastering takeoff after the hurdle from both the left and the right foot.

The analysis of all the hurdle races enables us to state that:

- the best hurdlers (all the finalists) have mastered takeoff from both the left and the right foot
- in order to achieve performances on the level of 49 s and less (men) and 56 s and less (women), hurdlers must master running between the hurdles and hurdle clearance so that they can achieve the intermediate times quoted in TAB. 5,6.

TAB. 5

MEN

Place/ performance (s)	1/ 47.46	2/ 47.48	3/ 47.48	4/ 48.37	5/ 48.37	6/ 48.63	7/ 48.74	8/ 49.46
Order of RU/minimum RU (in the final) (s)	1/ 3.67	1/ 3.65	1/ 3.64	1/ 3.76	2/ 3.72	1/ 3.76	1/ 3.72	1/ 3.83
Acceleration-RT+1stRU Approach run-RT+1stRU (s)	9.31	9.48	9.38	9.61	9.65	9.67	9.72	9.73
Mean time over 9 RUs (s) (all races)	4.12	4.10	4.13	4.19	4.18	4.16	4.15	4.21
Mean RU (final) (s)	4.04	4.04	4.04	4.13	4.10	4.15	4.12	4.21
Order of RU/minimum time 6 - 9 RUs (s)	6/ 4.00	7/ 4.18	6/ 3.96	6/ 4.12	6/ 4.20	6/ 4.24	6/ 4.20	6/ 4.28
Order of RU/maximum time 6 - 9 RUs (s)	9/ 4.73	9/ 4.66	9/ 4.59	9/ 4.64	9/ 4.72	9/ 4.72	9/ 4.63	9/ 4.72
t...mean increments of the times of the last 5 RUs	0.24	0.157	0.211	0.173	0.173	0.16	0.143	0.147
(8 + 9)RU + run-in	14.57	14.13	14.26	14.28	14.69	14.49	14.57	14.77

TAB. 6

WOMEN

Place/ performance (s)	1/ 53.62	2/ 54.19	3/ 54.31	4/ 54.38	5/ 54.62	6/ 55.86	7/ 55.86	8/ 56.10
Order of RU/minimum RU (in the final) (s)	1/ 4.21	1/ 4.16	1/ 4.17	1/ 4.20	1/ 4.35	1/ 4.36	1/ 4.32	1/ 4.32
Acceleration (s) Approach run-RT+1stRU	-	10.47	10.47	10.55	10.77	10.80	10.79	10.76
Mean time over 9 RUs (s) (all races)	4.68	4.73	4.73	4.74	-	4.80	4.76	4.77
Mean RU (final) (s)	4.63	4.65	4.67	4.66	4.67	4.78	4.81	4.78
Order of RU/minimum time 5 - 9 RUs (s)	5/ 4.68	5/ 4.70	5/ 4.77	6/ 4.78	6/ 4.64	5/ 4.80	6/ 4.87	5/ 4.84
Order of RU/maximum time 5 - 9 RUs (s)	9/ 4.93	9/ 5.07	9/ 5.00	9/ 5.05	9/ 5.14	9/ 5.21	9/ 5.29	8/ 5.19
t...mean increments of the times of the last 5 RUs	0.065	0.013	0.058	0.09	0.125	0.103	0.105	0.117
(8 + 9)RU + run-on	15.16	15.16	15.56	15.71	16.02	16.27	16.47	16.59

Index 7 (TAB.7) indicates that the time for the last 4 or 5 RUs in the women's event is lengthened far less significantly than in the men's. The difference in the 9th RU between the men and the women is less than the difference in the first RUs and the difference of the average of all RUs. All this seems to point to a higher level of endurance in the women than in the men.

It is more likely, though, that for the women, the effort is not distributed optionally throughout the race. The first half of the race could be run at a faster rate.

The trend, clearly discernible in the semifinalists and finalists at competitions like Olympic Games and World Championships, with regard to stride frequency, is as follows:

men: 13 and 14 stride rhythm

women: 15 and 16 stride rhythm.

A trend that is clearly promising for the future can be seen in one of the finalists, BROWN-KING. Although she finished last in the final she was able to use a 14 and 15-stride rhythm.

3.4. RUN-IN

Beginning:

moment of touchdown after 10th hurdle

End:

reaching the finish line

In the run-in the athlete does not need to control the length of the strides. This results in considerable differences between hurdlers in the run-in, as shown in TAB. 7, 8.

TAB. 7

MEN (performances 47,46 - 49,46 s)

Place in final		1	2	3	4	5	6	7	8
1st run-in min	(s)	5.31	5.06	5.16	4.36	5.01	5.16	5.15	5.17
2nd run-in min	(s)	5.31	5.20	5.16	4.95	5.10	5.28	5.25	5.23
Stride min	(n)	15.8	17.0	16.9	17.3	17.0	17.5	17.5	18.0
Stride max	(n)	16.7	18.1	17.7	17.6	17.3	18.0	18.4	18.4

TAB. 8

WOMEN (performances 53.62 - 56.10 s)

Place in final		1	2	3	4	5	6	7	8
1st run-in min	(s)	5.31	5.69	5.64	5.67	5.60	5.79	5.73	5.58
2nd run-in min	(s)	5.66	6.04	6.08	5.83	5.62	5.87	5.99	5.78
Stride min	(n)	18.1	19.4	20.2	19.0	18.8	20.3	21.5	18.1
Stride max	(n)	18.8	20.0	21.1	20.1	20.1	20.6	21.5	18.9

3.5. GEOMETRIC PARAMETERS OF THE RUNNING STRIDE IN THE 400 M HURDLES

The length of the running stride undergoes significant changes in the course of the race. This is more notable in the final part of the race where the rhythm of running suffers heavily, particularly in the women's event. Clearance of hurdles 9 and 10 cannot be considered as typical or exemplary. Changes also occur in the distance of takeoff and touchdown before and after the hurdle (TAB. 9).

TAB. 9 Actual distances of takeoff before hurdle and touchdown after hurdle and sum of the two distances (flight distance)

Name	Country	Race	Performance	Hurdle	Strides between hurdles	Takeoff-distance	Touchdown-distance	Flight-distance	
Moses	USA	final M	47.50	5.	13	238	161	399	I WC Helsinki
Schmid	FRG		48.50	5.	13	189	183	372	
Fesenko	URS	final W	--	3.		209	112	321	
Brown	JAM			3.		186	150	336	
Fredrikson	NOR			3.		215	104	391	
Barksdale	USA			3.		203	170	373	
		final		9.	16	-	170	-	
Busch	GDR	W	53.62	10.	16	124	166	290	II WC Rome
				9.	17	180	96	276	
Hellander	SWE		54.62	10.	17	147	89	236	
				9.	16	177	132	309	
Farmer	JAM		54.38	10.	16	130	139	269	
				9.	16	138	133	271	
Flintoff	AUS		54.19	10.	16	-	110	-	
				9.	17	157	133	290	
Ulrich	GDR		54.31	10.	17	128	113	241	

In the course of the race, stride length changes according to the following patterns:

a) Approach run - stride lengthens from the start to the point where maximum speed has been generated;

b) Rhythmic unit - stride shortens due to preparation for take-off before clearance (last stride before hurdle)
   - change in stride length in hurdle clearance (distance between takeoff and touchdown)
   - running strides after touchdown are shorter (the two following strides).

All strides of a RU are considered as having uniform length (being stabilized), with the exception of:

- last stride before takeoff
- clearance stride
- first two strides after touchdown.

In the course of the race, rising fatigue causes even more notable changes in stride length, concurrent with a rising number of strides in the RUs, forcing the hurdler to reduce the takeoff distance.

The values of all these changes are shown in TAB. 10, and should be of great practical help to coaches. The tolerance range (actual deviations from theoretical assumptions) cannot be determined at this point owing to the insufficient number of measurements.

TAB. 10: Geometric conditions of the running stride in 400 m hurdles

Number of strides between hurdles	a	17	16	15	14	13
Mean distance of takeoff before hurdle (cm)	b	185	190	195	200	205
Mean distance of touchdown after hurdle (cm)	c	132	138	145	152	160
Distance of takeoff and touchdown (cm)	d=b+c	317	328	340	352	365
Distance between hurdles (cm)	e=3500-d	3 183	3 172	3 160	3 148	3 135
Mean stride length between hurdles (cm)	f= a	187	198	211	225	241
Overall shortening of 1st, 2nd and last strides (cm)	g	19	21	23	25	28
Number of stabilised strides	h=a-3	14	13	12	11	10
Mean increment of length per one stabilised stride as against mean stride length	i=g/h	1	2	2	2	3
Mean lengthening of one stride with even number of strides (cm)	j	-	1	-	1	-
Mean length of stabilised stride between hurdles (cm)	k=f+i+j	188	201	213	228	244
Corresponding number of strides of approach run to 1st hurdle	l	24-26	23-25	22-23	21-22	19-21
Corresponding number of strides of run-in from the last hurdle to the finish	m	20-22	19-21	18-19	17-18	16-17

4. EVALUATION OF INDIVIDUALS AT THE II WORLD CHAMPIONSHIPS IN ATHLETICS

This report presents the results of the analysis of the first three finalists (see time analysis 1 - 3 A, B). Analyses of the semifinalists and the rest of semifinalists are available in a separate Appendix. The results of all the other competitors at the II WC in Rome 1987 are stored in a computer memory: they can be retrieved, processed and supplied on special request.

400m HURDLES MEN -1A- II WC ROME 87

TIME ANALYSIS MOSES EDWIN 55 USA

PLACING 1. — 1. 1st RUN — RESULT 49.03

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	5.90	9.75	13.69	17.62	21.68	25.77	30.07	34.44	38.96	43.60	49.03
B.	5.97	9.76	13.64	17.61	21.68	25.85	30.13	34.52	39.04	43.69	49.03
C.		3.85	3.94	3.93	4.06	4.09	4.3	4.37	4.52	4.64	5.43
D.		3.80	3.88	3.97	4.07	4.17	4.28	4.40	4.52	4.65	5.34
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 1. — 2. SEMIFINAL — RESULT 48.38

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	5.92	9.61	13.37	17.17	21.14	25.26	29.47	33.82	38.37	43.07	48.38
B.	5.89	9.63	13.46	17.38	21.39	25.50	29.73	34.06	38.52	43.11	48.38
C.		3.69	3.76	3.8	3.97	4.12	4.21	4.35	4.55	4.7	5.31
D.		3.75	3.83	3.92	4.01	4.11	4.22	4.34	4.46	4.59	5.27
E.	---	---	---	+0.01	+0.05	+0.04	+0.06	+0.04	---	---	

PLACING 1. — FINAL — RESULT 47.46

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	5.82	9.49	13.21	16.97	20.73	24.58	28.58	32.89	37.42	42.15	47.46
B.	5.77	9.45	13.21	17.05	20.98	25.02	29.16	33.42	37.79	42.29	47.46
C.		3.67	3.72	3.76	3.76	3.85	4	4.31	4.53	4.73	5.31
D.		3.68	3.76	3.84	3.94	4.04	4.14	4.25	4.37	4.50	5.17
E.	---	---	---	---	+0.05	+0.24	+0.38	+0.33	+0.17	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.3	±0.3	±0.3	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

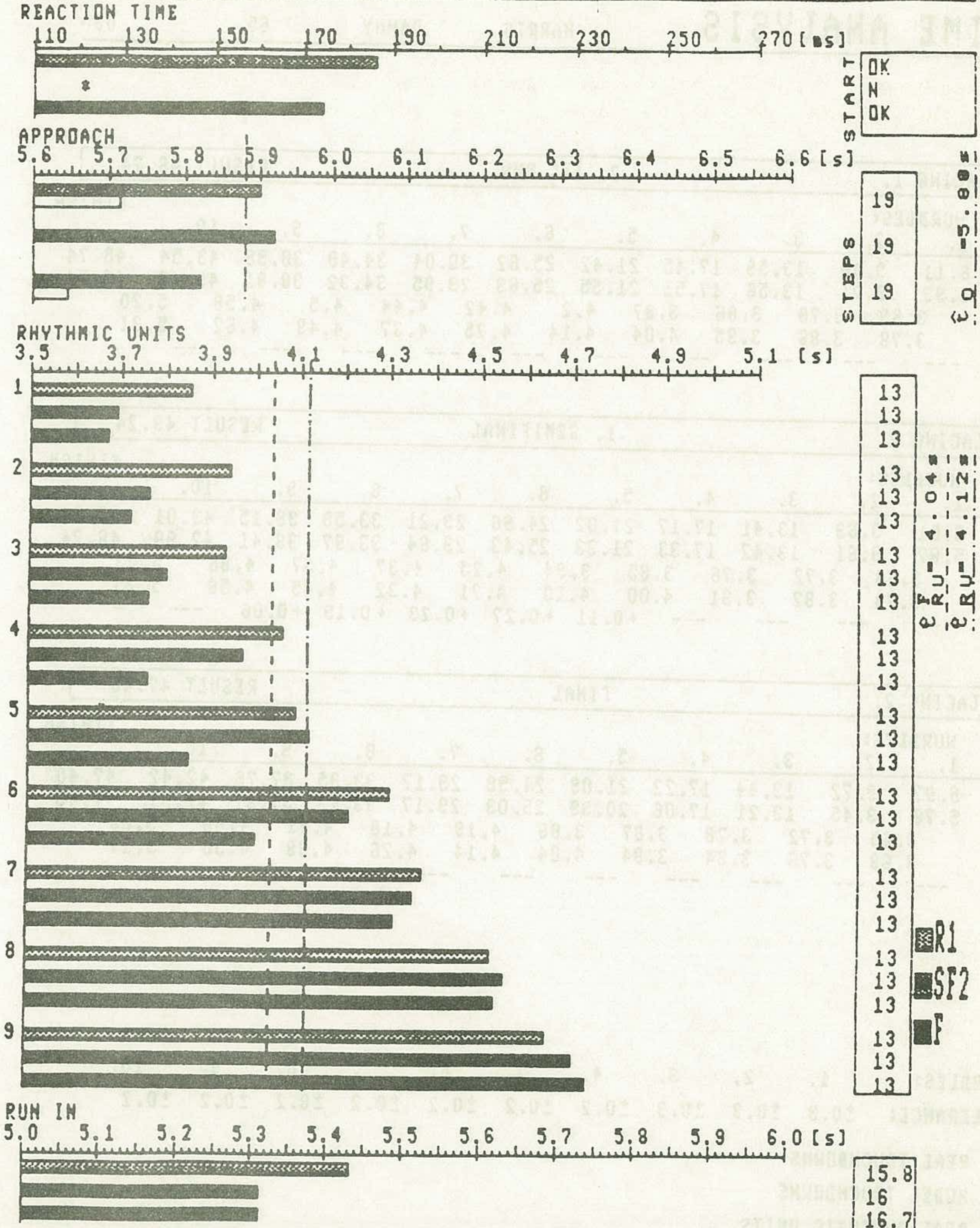
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES MEN -1B- I. WC ROME 87

MOSES	EDWIN	55	USA
R1 -49.03 [s]	SF2-48.38 [s]	F -47.46 [s]	



400m HURDLES MEN -2A- II WC ROME 87

TIME ANALYSIS HARRIS DANNY 65 USA

PLACING 1. 2. 1st RUN RESULT 48.74

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.11	9.80	13.59	17.45	21.42	25.62	30.04	34.48	38.98	43.54	48.74
B.	5.93	9.71	13.56	17.51	21.55	25.69	29.95	34.32	38.81	43.43	48.74
C.		3.69	3.79	3.86	3.97	4.2	4.42	4.44	4.5	4.56	5.20
D.		3.78	3.86	3.95	4.04	4.14	4.25	4.37	4.49	4.62	5.31
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 2. 1. SEMIFINAL RESULT 48.24

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.01	9.69	13.41	17.17	21.02	24.96	29.21	33.58	38.15	43.01	48.24
B.	5.87	9.61	13.42	17.33	21.33	25.43	29.64	33.97	38.41	42.99	48.24
C.		3.68	3.72	3.76	3.85	3.94	4.25	4.37	4.57	4.86	5.23
D.		3.74	3.82	3.91	4.00	4.10	4.21	4.32	4.45	4.58	5.25
E.	---	---	---	---	+0.11	+0.27	+0.23	+0.19	+0.06	---	

PLACING 2. FINAL RESULT 47.48

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.07	9.72	13.44	17.22	21.09	24.98	29.17	33.35	37.76	42.42	47.48
B.	5.78	9.45	13.21	17.06	20.99	25.03	29.17	33.43	37.81	42.31	47.48
C.		3.65	3.72	3.78	3.87	3.89	4.19	4.18	4.41	4.66	5.06
D.		3.68	3.76	3.84	3.94	4.04	4.14	4.26	4.38	4.50	5.17
E.	---	---	---	---	---	---	---	---	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.3	±0.3	±0.3	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

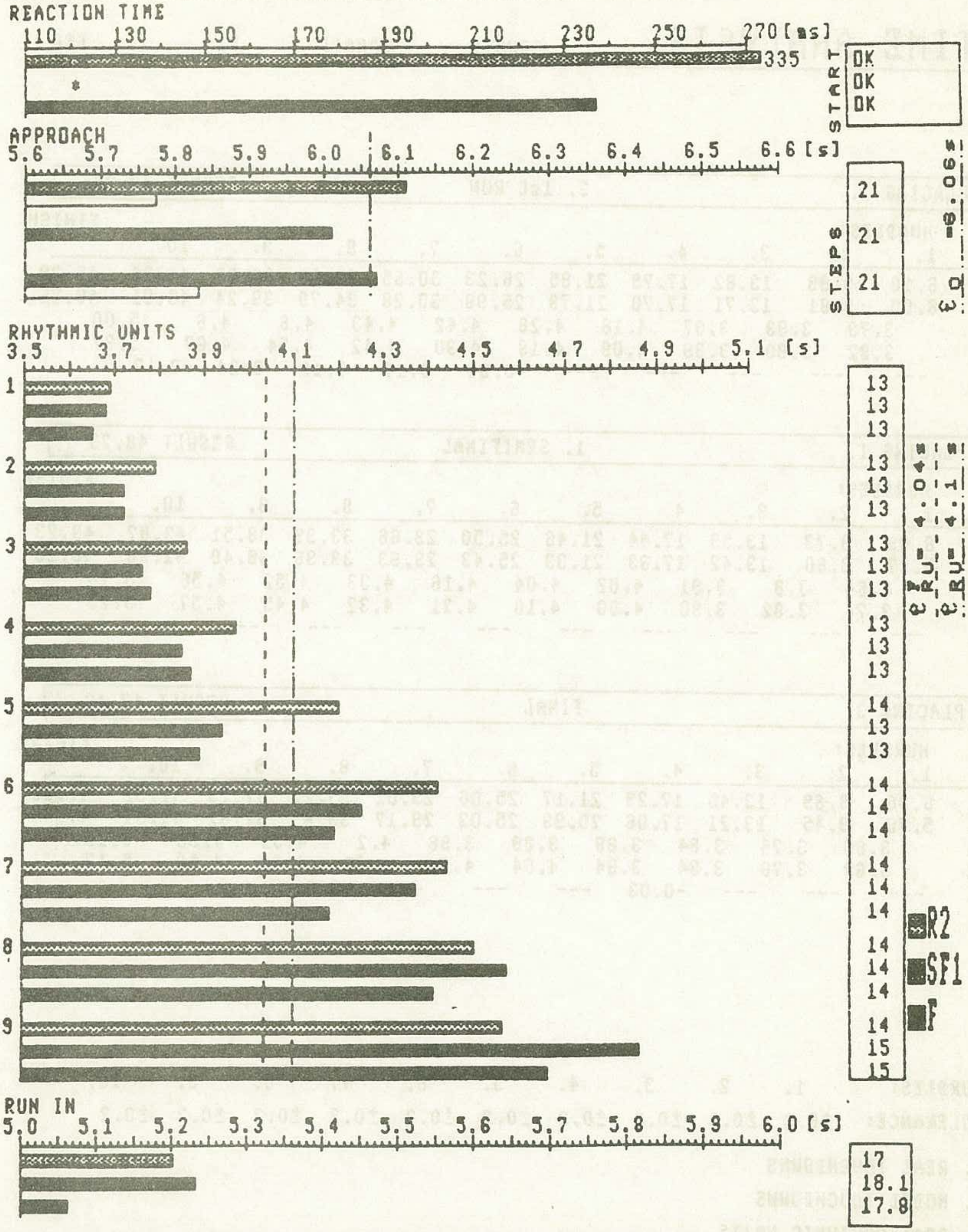
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES MEN -2B- II WC ROME 87

HARRIS	DANNY	65	USA
R2 -48.74 [s]	SF1-48.24 [s]	F -47.48 [s]	



400m HURDLES MEN -3A-

II WC ROME 87

TIME ANALYSIS

SCHMID HARALD 57 FRG

PLACING 1. — 3. 1st RUN — RESULT 49.28

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.10	9.89	13.82	17.79	21.95	26.23	30.65	35.08	39.68	44.28	49.28
B.	6.00	9.81	13.71	17.70	21.79	25.98	30.28	34.70	39.24	43.91	49.28
C.		3.79	3.93	3.97	4.16	4.28	4.42	4.43	4.6	4.6	5.00
D.		3.82	3.90	3.99	4.09	4.19	4.30	4.42	4.54	4.67	5.37
E.	---	---	---	---	---	-0.05	-0.17	-0.18	-0.24	-0.17	

PLACING 1. — 1. SEMIFINAL — RESULT 48.23

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.09	9.73	13.53	17.44	21.48	25.50	29.66	33.99	38.51	43.07	48.23
B.	5.87	9.60	13.42	17.33	21.33	25.43	29.63	33.96	38.40	42.98	48.23
C.		3.64	3.8	3.91	4.02	4.04	4.16	4.33	4.52	4.56	5.16
D.		3.74	3.82	3.90	4.00	4.10	4.21	4.32	4.45	4.57	5.25
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 3. — FINAL — RESULT 47.48

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.00	9.69	13.45	17.29	21.17	25.06	29.02	33.22	37.73	42.32	47.48
B.	5.78	9.45	13.21	17.06	20.99	25.03	29.17	33.43	37.81	42.31	47.48
C.		3.69	3.76	3.84	3.88	3.89	3.96	4.2	4.51	4.59	5.16
D.		3.68	3.76	3.84	3.94	4.04	4.14	4.26	4.38	4.50	5.17
E.	---	---	---	-0.03	---	---	---	+0.01	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.3	±0.3	±0.3	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

C. REAL RHYTHMIC UNITS

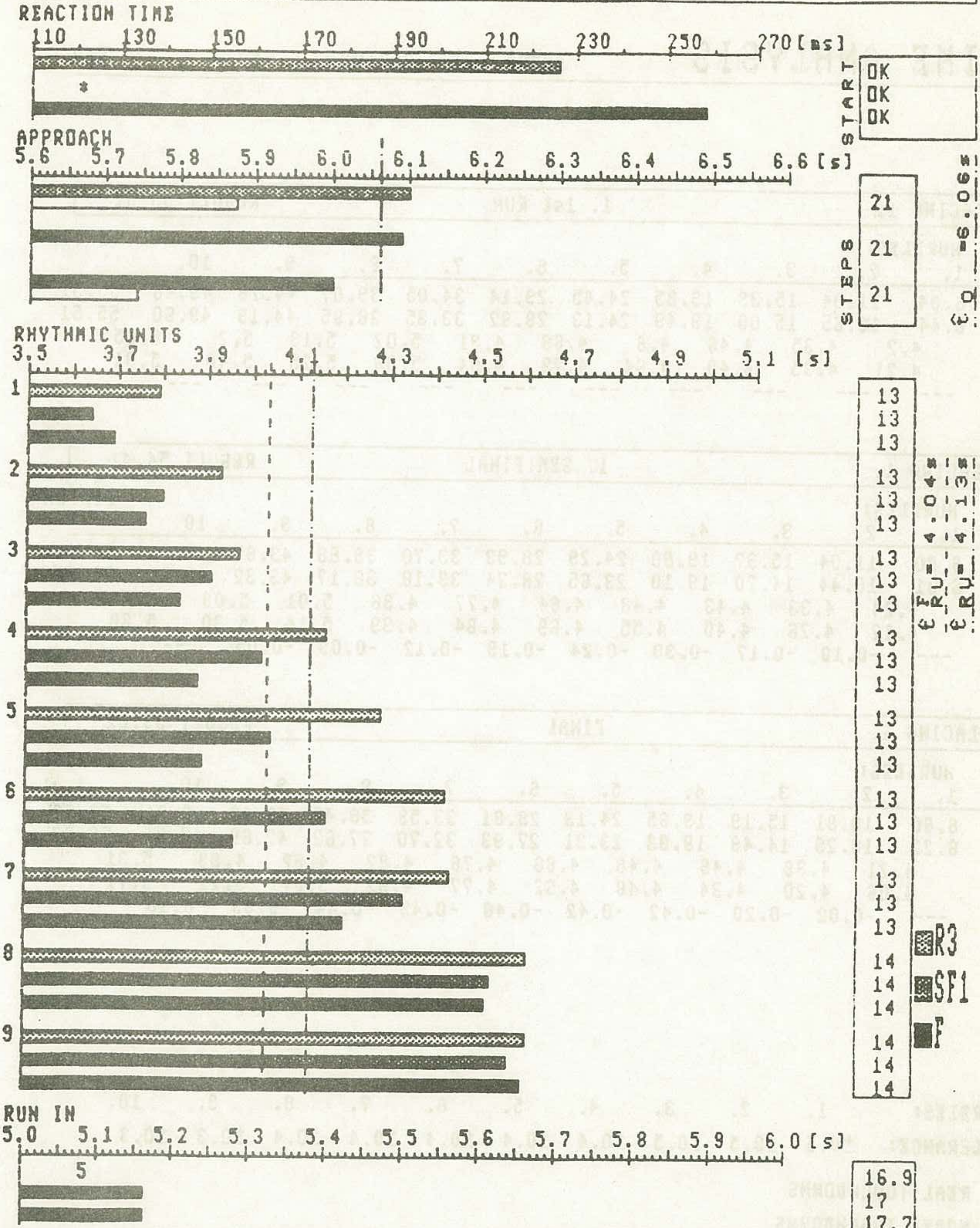
D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES MEN -3B-

II WC ROME 87

SCHMID	HARALD	57	FRG
R3 -49.28 [s]	SF1-48.23 [s]	F -47.48 [s]	



TIME ANALYSIS

BUSCH SABINE 62 GDR

PLACING 1. — 1. 1st RUN — RESULT 55.51

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.84	11.04	15.39	19.85	24.45	29.14	34.05	39.07	44.26	49.46	55.51
B.	6.44	10.65	15.00	19.49	24.13	28.92	33.85	38.95	44.19	49.60	55.51
C.		4.2	4.35	4.46	4.6	4.69	4.91	5.02	5.19	5.2	6.05
D.		4.21	4.35	4.49	4.64	4.79	4.94	5.09	5.25	5.40	5.91
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 1. — 1. SEMIFINAL — RESULT 54.41

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.80	11.04	15.37	19.80	24.29	28.93	33.70	38.66	43.67	48.75	54.41
B.	6.31	10.44	14.70	19.10	23.65	28.34	33.18	38.17	43.32	48.61	54.41
C.		4.24	4.33	4.43	4.49	4.64	4.77	4.96	5.01	5.08	5.66
D.		4.12	4.26	4.40	4.55	4.69	4.84	4.99	5.14	5.30	5.80
E.	---	-0.10	-0.17	-0.30	-0.24	-0.19	-0.12	-0.09	-0.05	---	

PLACING 1. — FINAL — RESULT 53.62

	HURDLES: 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.60	10.81	15.19	19.65	24.13	28.81	33.59	38.46	43.38	48.31	53.62
B.	6.22	10.29	14.49	18.83	23.31	27.93	32.70	37.62	42.69	47.91	53.62
C.		4.21	4.38	4.46	4.48	4.68	4.78	4.87	4.92	4.93	5.31
D.		4.06	4.20	4.34	4.48	4.62	4.77	4.92	5.07	5.22	5.71
E.	---	-0.02	-0.20	-0.42	-0.42	-0.48	-0.49	-0.44	-0.39	-0.10	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.5	±0.5	±0.5	±0.4	±0.4	±0.4	±0.4	±0.4	±0.3	±0.3

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

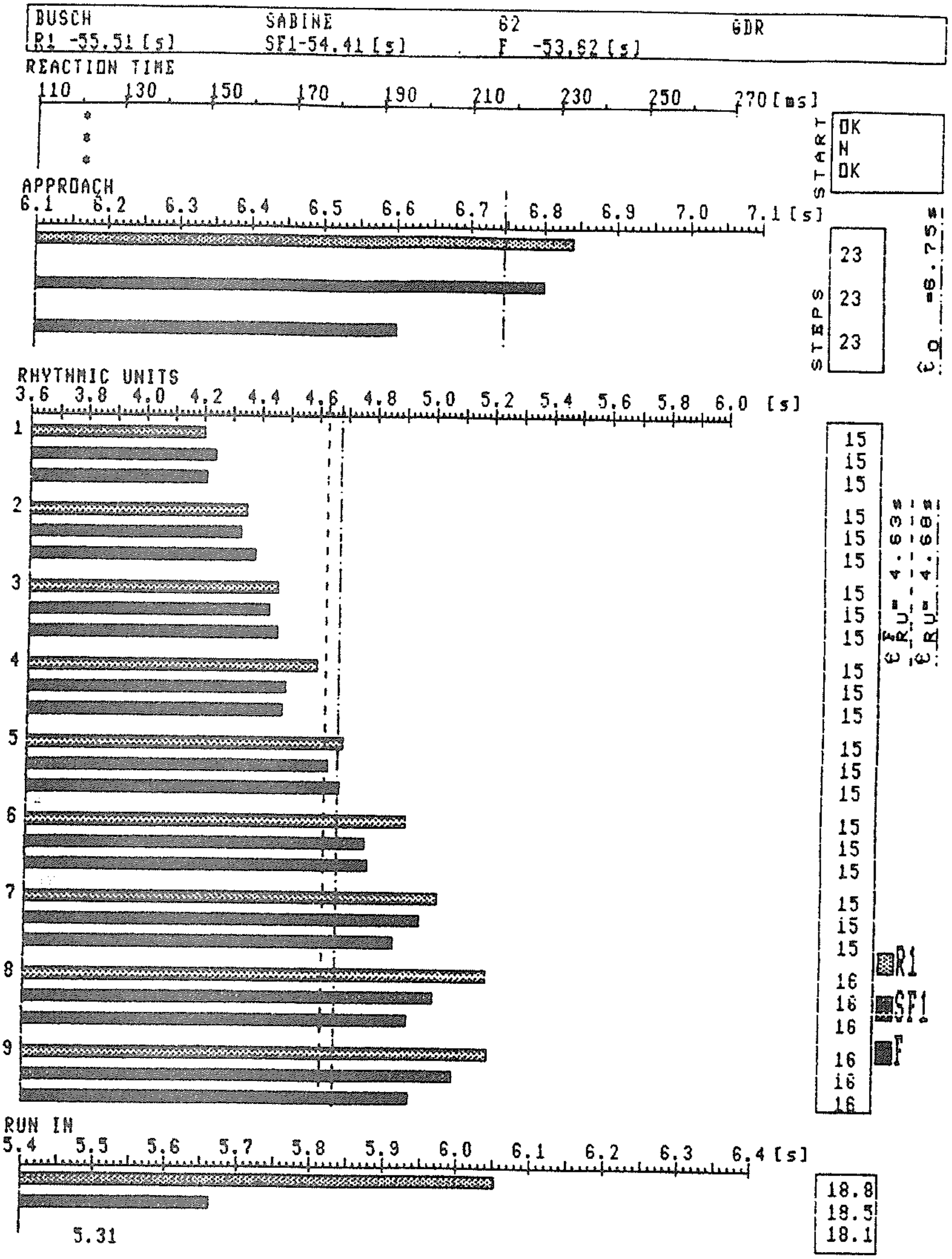
C. REAL RHYTHMIC UNITS

D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES W -1B-

WC ROME 87



400m HURDLES W -2A- II WC ROME 87

TIME ANALYSIS

FLINTOFF DEBRA 60 AUS

PLACING 2. 2. 1st RUN RESULT 56.31

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.55	10.68	14.96	19.32	23.81	28.74	33.83	39.10	44.46	49.92	56.31
B.	6.53	10.80	15.21	19.77	24.48	29.33	34.34	39.51	44.83	50.31	56.31
C.		4.13	4.28	4.36	4.49	4.93	5.09	5.27	5.36	5.46	6.39
D.		4.27	4.41	4.56	4.71	4.86	5.01	5.16	5.32	5.48	6.00
E.	---	---	---	+0.05	+0.27	+0.19	+0.11	+0.01	+0.07	+0.09	

PLACING 2. 2. SEMIFINAL RESULT 55.08

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.60	10.76	14.97	19.24	23.69	28.42	33.28	38.34	43.62	49.04	55.08
B.	6.39	10.57	14.88	19.34	23.94	28.69	33.59	38.64	43.85	49.21	55.08
C.		4.16	4.21	4.27	4.45	4.73	4.86	5.06	5.28	5.42	6.04
D.		4.17	4.32	4.46	4.60	4.75	4.90	5.05	5.21	5.36	5.87
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 2. FINAL RESULT 54.19

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.61	10.77	15.09	19.45	23.94	28.64	33.42	38.44	43.43	48.50	54.19
B.	6.29	10.40	14.64	19.03	23.56	28.23	33.05	38.02	43.14	48.42	54.19
C.		4.16	4.32	4.36	4.49	4.7	4.78	5.02	4.99	5.07	5.69
D.		4.11	4.25	4.39	4.53	4.67	4.82	4.97	5.12	5.27	5.77
E.	---	---	---	-0.02	---	-0.01	---	-0.02	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.5	±0.5	±0.5	±0.4	±0.4	±0.4	±0.4	±0.4	±0.3	±0.3

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

C. REAL RHYTHMIC UNITS

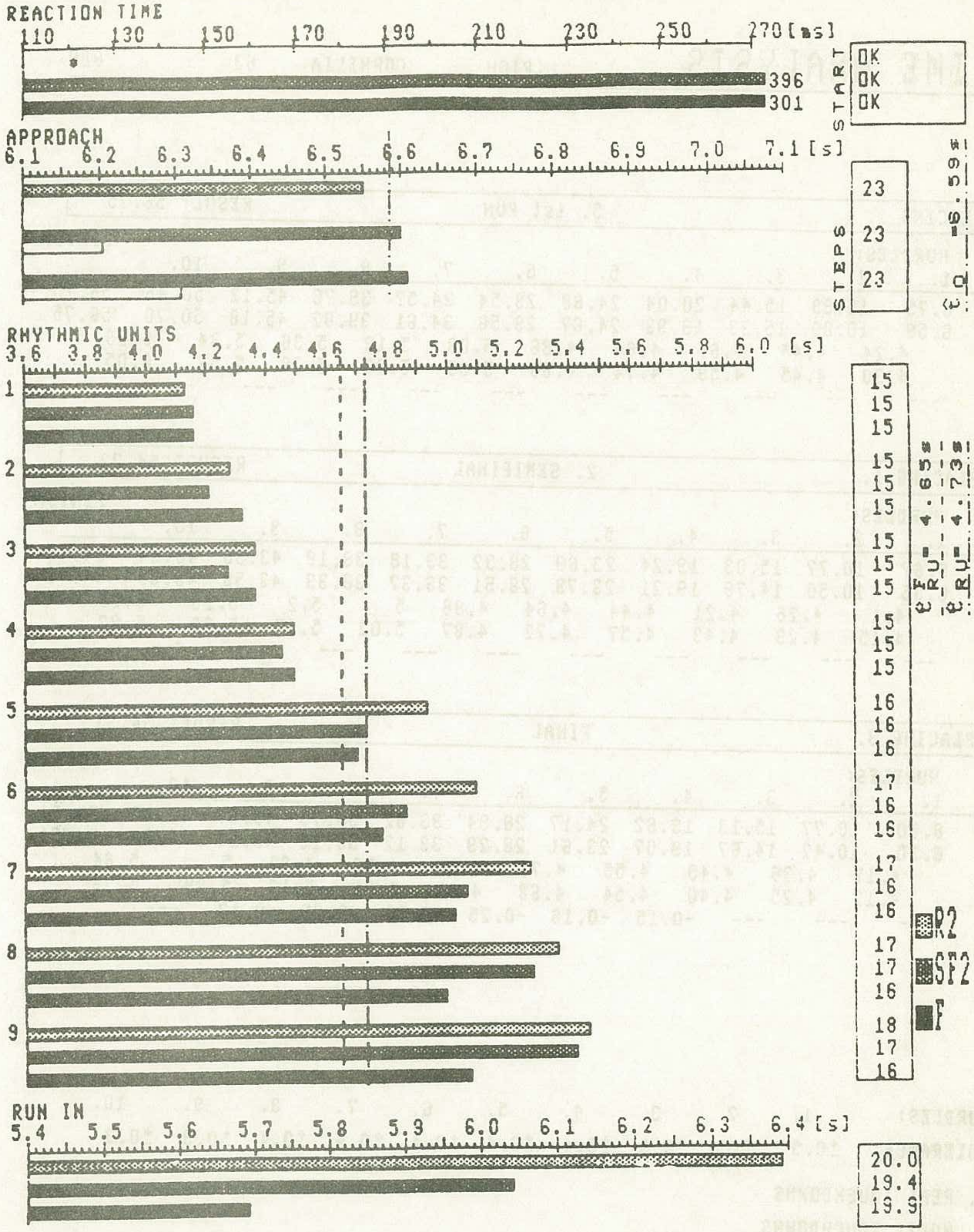
D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES W -2B-

II WC ROME 87

FLINTOFF	DEBRA	60	AUS
R2 -56.31 [s]	SF2-55.08 [s]	F -54.19 [s]	



400m HURDLES W -3A-

TIME ANALYSIS

ULRICH CORNELIA 63 GDR

PLACING 1. — 5. 1st RUN — RESULT 56.75

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.75	10.99	15.44	20.04	24.68	29.54	34.57	39.76	45.12	50.46	56.75
B.	6.59	10.89	15.33	19.93	24.67	29.56	34.61	39.82	45.18	50.70	56.75
C.		4.24	4.45	4.6	4.64	4.86	5.03	5.19	5.36	5.34	6.29
D.		4.30	4.45	4.59	4.74	4.89	5.05	5.20	5.36	5.52	6.05
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 1. — 2. SEMIFINAL — RESULT 54.72

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.67	10.77	15.03	19.24	23.68	28.32	33.18	38.18	43.38	48.64	54.72
B.	6.35	10.50	14.78	19.21	23.79	28.51	33.37	38.39	43.56	48.89	54.72
C.		4.1	4.26	4.21	4.44	4.64	4.86	5	5.2	5.26	6.08
D.		4.15	4.29	4.43	4.57	4.72	4.87	5.02	5.17	5.33	5.83
E.	---	---	---	---	---	---	---	---	---	---	

PLACING 3. — FINAL — RESULT 54.31

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	6.60	10.77	15.13	19.62	24.17	28.94	33.82	38.75	43.67	48.67	54.31
B.	6.30	10.42	14.67	19.07	23.61	28.29	33.12	38.10	43.24	48.52	54.31
C.		4.17	4.36	4.49	4.55	4.77	4.88	4.93	4.92	5	5.64
D.		4.12	4.25	4.40	4.54	4.68	4.83	4.98	5.13	5.29	5.79
E.	---	---	---	-0.15	-0.16	-0.25	-0.30	-0.25	-0.13	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.5	±0.5	±0.5	±0.4	±0.4	±0.4	±0.4	±0.4	±0.3	±0.3

A. REAL TOUCHDOWNS

B. MODEL TOUCHDOWNS

C. REAL RHYTHMIC UNITS

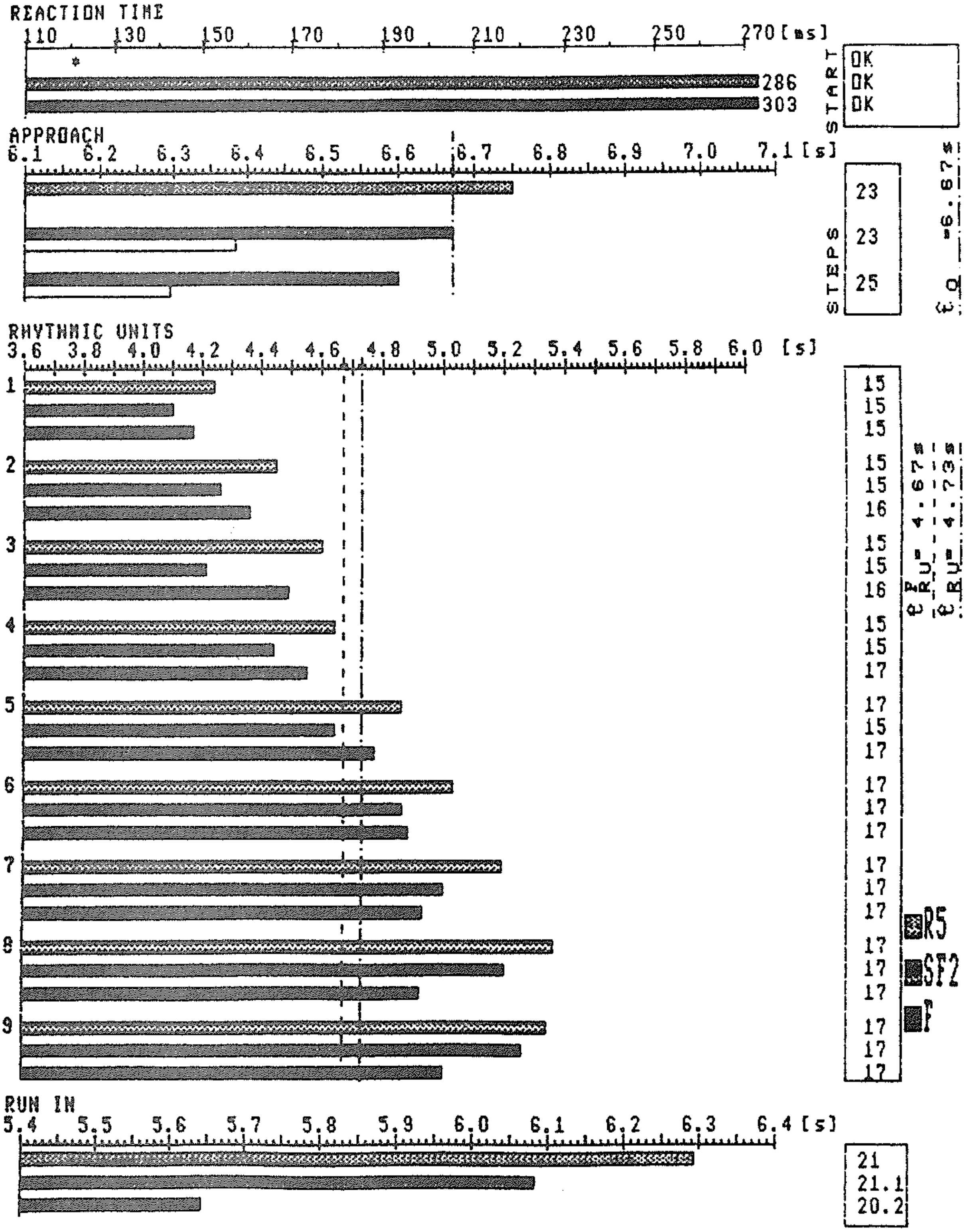
D. MODEL RHYTHMIC UNITS

E. DEVIATIONS FROM THE MODEL TOUCHDOWNS

400m HURDLES W -3B-

II WC ROME 87

ULRICH CORNELIA 63 GDR
R5 -56.75 [s] SF2-54.72 [s] F -54.31 [s]



5. CONCLUSIONS

Coaching practice will benefit from the following features of the present report:

- a scale for evaluating reaction time
- the geometric parameters of the running stride in the 400 m hurdles
- model intermediate times and rhythmic units (using the finalists of II WC as examples)

6. REFERENCES

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E

BIOMECHANICAL ANALYSIS OF THE LONG JUMP

Nixdorf, E.; Brüggemann, P.

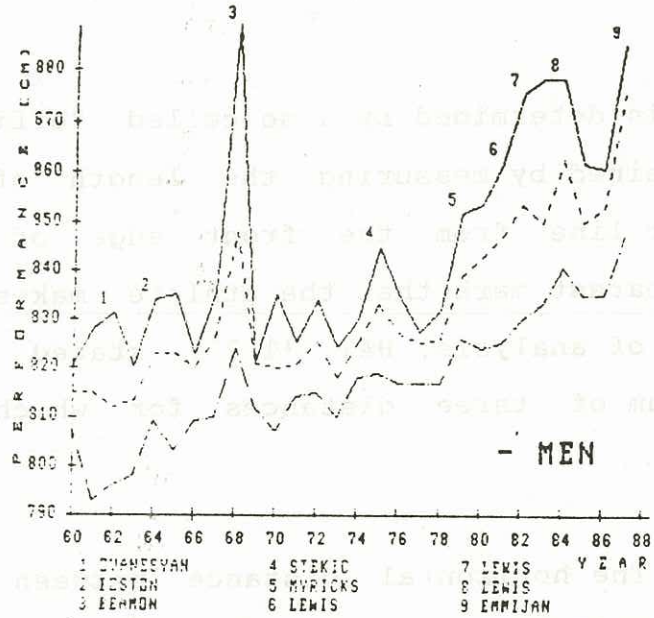
TABLE OF CONTENTS

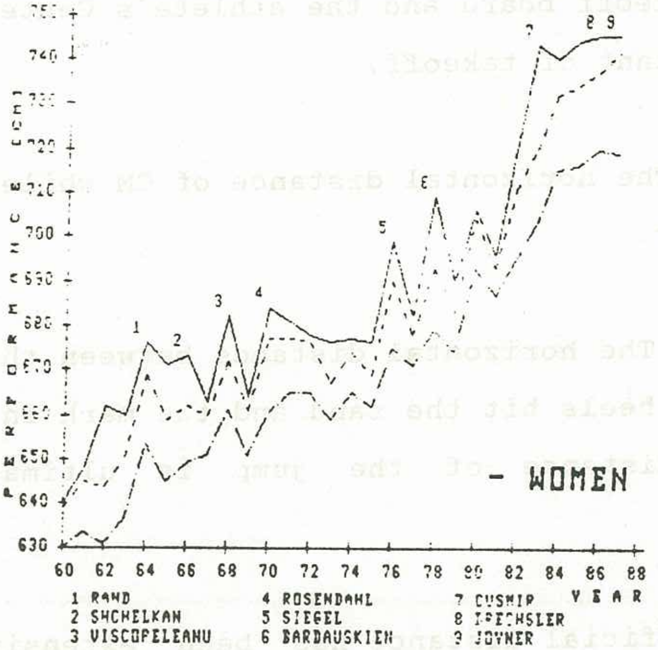
1. INTRODUCTION

The history of improvement for male and female competitors in the long jump reveals quite different trends for the two groups. FIGURES 1 and 2 illustrate the development of the best performances per year (solid line) and also provide mean scores of the best 3 male and 10 female jumpers (dotted line).

While the men`s performance may be characterized as being in the shadow of BEAMON`s fantastic 1968 world record in Mexico, a marked improvement for the women is noted regarding their best jumps as well as the computed trends. With the entrance of LEWIS and EMMIJIAN in long jump competition the men`s performances should markedly improve. Future analysis of the long jump promises to yield interesting results.

FIGURES 1 and 2: Development of performance





2. BIOMECHANICS OF THE LONG JUMP

2.1. DIVISION OF THE EVENT

Long jump performance is determined by a so called "official distance". This is obtained by measuring the length of an imaginary perpendicular line from the front edge of the takeoff board to the nearest mark that the athlete makes in the sand. For purposes of analysis, HAY (1973) stated that the long jump is the sum of three distances for which an athlete is credited:

- Takeoff distance - The horizontal distance between the front edge of the takeoff board and the athlete`s Center of Mass (CM) at the instant of takeoff.

- Flight distance - The horizontal distance of CM while the athlete is in the air.

- Landing distance - The horizontal distance between the CM at the instant the heels hit the sand and the mark in the sand from which the distance of the jump is ultimately measured.

This division of the official distance has been extensively used in discussions and research concerned with techniques of the long jump. One must note that two measures of an

athlete`s performance are commonly used when analysing the long jump: (a) the official distance - the horizontal distance, measured according to the rules governing competition in the event and (b) the effective distance - the horizontal distance of the jump, measured from the toe of the takeoff foot at the instant of takeoff to the nearest mark made by the athlete in the sand. The difference between the two distances indicates the amount which the athlete loses because of poor timing during the run-up.
Other versions concerning the preceding divisions of the official distance are discussed in the literature, but most of them are only modifications of HAY`s proposal.

The magnitude of the takeoff, flight and landing distances, and the relationships between them and the official or effective distance of the jump have been frequently reported. The mean values for the takeoff, flight and landing distances, expressed as percentages of the official distances, for 25 trials by Swiss and West German long jump specialists and decathletes were 3,5%, 88,5% and 8,0%, respectively (HAY 1978). Results of variance analysis published by different authors indicate similar relationships.

In summary, it appears that the flight distance is dominant regarding the percentage contribution to the official distances. Therefore, it is essential to discuss first the biomechanical parameters which influence effective distance and flight distance. The influencing factors for the flight distances are the relative height of CM at takeoff, the takeoff velocity of CM, the takeoff angle and the air resistance. The relative takeoff height is the difference between the heights of CM at takeoff and landing. These heights depend on the vertical position of the segment Center of Mass, that is on the athlete`s body position. The air resistance, of minor influence, is determined by the coefficient of drag, the velocity and the frontal area during flight. While all these parameters change during flight, they must be considered in relation to time.

The most influencing parameters on flight distance are the takeoff velocity and the takeoff angle. These factors are determined by the horizontal and vertical velocity of CM at takeoff. The takeoff velocities are caused by the horizontal and vertical CM`s velocities at touchdown, and the changes of the velocity during the takeoff. The change of velocity is now determined by the average force produced by the athlete, and the takeoff time. These forces are caused by the action of the takeoff leg as well as the swinging effects of the arms and the lead leg.
The initial velocities at touchdown are completely determined by the run-up.

From a practical point of view the long jump consists of four consecutive parts having different biomechanical goals. These parts are:

1. The approach - from the moment the athlete starts towards the board until the instant of touchdown for takeoff. The approach has to produce the initial biomechanical conditions for the subsequent takeoff. It requires the necessary horizontal touchdown velocity of CM.

2. The takeoff - from the instant of touchdown until the instant at which the takeoff foot breaks contact with the ground. The takeoff has to divert and to transfer the approach velocity into takeoff velocity.

3. The flight - from the instant of takeoff until the instant of landing. During the flight the athlete has to prepare for landing by relative movement of the body segments.

4. The landing - from the instant of landing until the athlete`s CM moves ahead of the feet or comes to rest.

2.2. APPROACH

Two goals are identified for the approach:

- Production of maximum speed during the acceleration phase
- Preparation of takeoff during the last strides

Speed

Numerous investigators have reported correlations between measures of the speed of approach and either the official or effective distance of the jump. Because of different methods used for the measurement of speed, most of the data are not comparable. Several investigators measured the horizontal velocity at touchdown. Others measured the "maximum speed", or the average velocity of the last strides or the last meters. Results of the average speed over more than one stride must be lower than the instantanous velocity at takeoff because of the decrease followed by an increase of CM's velocity during each support phase in running. Therefore, the average speed of the last 5 meters is only an indicator for the initial velocity or emerge, which the athlete has for the takeoff action. The inconsistency of the height of correlations between the run-up speed and the official distance in the literature is caused by different run-up speed definitions, different measures and different levels of performance. LUKIN (1949) presented data using 1956 male and 1240 female athletes grouped according to the distance jumped. The correlation coefficients between the approach speed and the length of jump "reveal that initial approach speed is a very important factor", and that the "importance of this factor decreases as results improve". LUKIN interprets these findings to conclude that as strength and overall fitness increase, proper technique becomes more important than running speed. KARAS et. al., (1983) analysed approximately 700 long jump trials of athletes who experienced various types and levels of competition. They obtained results similar to those of LUKIN and reached virtually identical conclusions. For the coach this means that although run-up speed is a crucial factor, the performance differences within a highly qualified homogenous group must be explained by variations in technique.

Several of the investigators, who found a significant correlation between the approach speed and the length of the jump, also reported the corresponding regression equation or gave some indication of the slope of the regression line.

TIUPA et. al., (1982) reported a non-linear regression equation:

$$D = 0.021v^2 + 0.725v - 1.65$$

D = the effective distance of the jump (m) and v = the approach speed (m/s).

SILUYANOV and MAXIMOV (1978) reported the following individual relationships between "jumping distance (D) and run-up speed (v)":

BEAMON	$D = 0.83v$
TER-OVANESIAN	$D = 0.79v$

Regarding the results of poor athletes, they concluded that an improvement in skill mastery is related to a change in the regression line slope as well as an increase in the height of correlation. POPOV (1971) and KARAS, et. al., (1983) stated that an increase in run-up speed of 0.1 m/s was followed by a corresponding increase in distance of jump of 0.08 - 0.10 and 0.12m. These calculations have been supported by the data of NIGG (1974). A very practical approach was developed by SUSANKA/ STEPANEK and JISA (1986). On the basis of measurements in competitions from 1979 to 1984 they concluded that, respecting the mean approach speed during the last meters of run-up, and the length of the jump, zones limiting the dominance of some of the athlete`s dispositions can be assessed by means of inequations of regression lines.

The inequations

$D \leq 1.3636v - 5.71$ (men)

$D \leq 1.227v - 4.93$ (women)

limit the half-plane in which are found the sports performances of the athletes who, during the investigation, had dominant strength. It is also assumed that their jumping technique is good.

The inequations

$D > 1.3636v - 6.09$ (men)

$D > 1.227v - 4.73$ (women)

limit the half-plane in which are found the measurements of the athletes with dominant speed assumptions.

The relations

$D \leq 1.3636v - 5.71$ (men); $D \geq 1.3636v - 6.09$

$D \leq 1.227v - 4.03$ (women); $D \geq 1.227v - 4.73$

limit the central zone which comprise the measurements of the athletes for which there is a relatively uniform distribution of motor abilities.

The athlete's speed decreases over the last 5m of the approach and mainly during the support phase of the second-last stride.

The mean horizontal velocities (CM) for the 12 finalists in the women's long jump at the 1984 Olympic Games (HAY 1985) - 9.24 m/s (third-last), 9.37 m/s (second-last) and 8.82 m/s (last) - indicate that the loss in horizontal velocity occurs during the support phase following touchdown at the end of the penultimate stride.

TABLE 1 summarizes measurements of maximum run-up speed (11 - 6 m) and official distance.

TABLE 1: Maximum run-up speed (11 - 6 m) and official distance of previous studies

		run-up speed (m/s)	official distance (m)
LEWIS, Carl Helsinki 1983	USA	10.9	8.55
DAUTE, Heike Helsinki 1983	GDR	9.7	7.27
MAI, Volker MEJ-Cottbus`86	GDR	9.9	7.99
BUSANOVA, Sofia MEJ-Cottbus`86	BUL	8.8	6.68
HAAF, Dietmar Athens, 1986	FRG	10.4	7.93
HILLE, Patricia Athens 1986	GDR	8.8	6.68

Stride Length

The preparation for takeoff during the last stride may be organized by the stride length. The lengths of the last three strides of the approach have been intensively analysed and discussed in the literature. Numerous studies reported that, for most jumpers, the last stride is shorter than the second last by up to about 0.70 m. For example, NIGG (1974) demonstrated the following mean stride length for the last three strides (D = 7.70 m):

third-last : 2.18m

second-last: 2.42m

last : 2.18m

Similar data are reported by HAY (1979) for male athletes. In 1985, HAY and MILLER published the stride length data of the 12 finalists in the Women`s long jump at the 1984 Olympic Games. The mean length of the last four strides are reported as 2.15m (fourth-last), 2.19m (third-last), 2.24m (second-last), and 2.09m (last). The results for the individual subjects follow fairly well the overall trend of the whole group. For 8 of the 12 subjects the second to last stride was measured as being the longest, while the last one was the shortest of the four strides.

However, researchers have discovered that some athletes have achieved excellent distances with jumps in which the last stride was longer than the second-last (NIGG 1974, POPOV 1971). BEAMON`s world record jump of 8.90 m is reported to have a second-last stride of 2.57 m (POPOV 1971). Finally, NIGG (1974) found a non-significant relationship (r = -0.33) between the ratio of the length of the second-last and last strides, and the effective distance of the jump. These various findings suggest that the importance of the relationship between the length of the last two strides often seems to be exaggerated. The tendency of variations in stride length has to be considered in conjunction with the path of CM and the forward or backward orientation of the body during the last strides when the athlete prepares for the takeoff.

Path of the Centre of Mass

There are marked changes in the height of the athlete`s CM during the final strides of the approach. These changes are intended to facilitate a high vertical velocity at takeoff by keeping the vertical velocity at touchdown as low as possible and by lengthening the vertical path over which the body may be accelerated during the takeoff. The change in the CM height is achieved by lowering the CM during the last two strides of the approach.

Recent findings by NIXDORF and BRÜGGEMANN(1983) indicate a lowering of CM by about 10% of "the approach height" between takeoff into the second-last stride and the following touchdown. They are in general agreement with DIACHKOV (1980), ANDREEV and MIRZAEV (1970) concerning the best time at which to initiate the lowering of the CM which is during the second-to-last contact of the takeoff leg with the ground.

2.3. TAKEOFF

In the running long jump the horizontal velocity of the athlete is reduced during takeoff by 1.0 - 2.0 m/s or more. This indicates a reduction of horizontal velocity of 9.5 - 14% of the approach velocity. This reduction becomes more pronounced when the angle of projection of the body`s CM and the height of jump are increased (POPOV 1971). This result has been supported by the finding of a "high" correlation (r= 0.66) between the magnitude of the decrease in horizontal velocity and the increase in vertical velocity during the takeoff (TIUPA 1982).

Correlation of the horizontal and vertical velocities at takeoff with the distance of the jump have yielded results that appear to be heavily influenced by the nature of the sample. Studies of world-class long jumpers have indicated that the horizontal velocity at takeoff is the dominant influence in determining the distance of the jump. NIGG (1974) has reported correlations between the horizontal and vertical velocity, and the effective distance of the jump as being r = 0.79 and 0.08, respectively. Investigations which use less homogeneous groups and consequently show a greater variability in vertical velocity, (the standard deviation for NIGG`s sample was only 0.04m/s) come to a higher valuation of the vertical velocity component (BALLREICH 1970, KOLLATH 1980). The ratio of the horizontal and vertical velocities at takeoff has been reported to be approximately 2:1 and 3:1, which corresponds to angles of projection takeoff of 26.6 and 18.4 deg., respectively. POPOV (1971) suggested that "it is best to strive for an average projection angle of 20 - 22 deg.". When the angle exceeds 20 - 22 deg., the importance of the approach velocity is increased. When the angle is less than these values, the importance of the force exerted at takeoff increases (POPOV 1971). NIGG (1978) noted that the projection angle decreased with increasing approach velocity. He suggested that this may be because the jumping strength of the faster athletes has approximately the same magnitude as that of the slower ones, and that it is more difficult to jump high with a greater approach velocity. The notion that the optimum angle is near 45 deg. is based on the assumption that the speed of release is constant irrespective of the angle of projection. This assumption is invalid for the long jump because the speed and angle of takeoff are not independent, but negatively correlated. For example, NIGG (1974) found a correlation of r = -0.83. HAY/MILLER (1985) reported a mean takeoff velocity of 8.6 m/s (± 0.25), and a mean angle of takeoff of 18.8 deg. (± 1.8) for the women's final of the 1984 Olympic Games. For elite male long jumpers (HAY et. al., 1984) analysed takeoff velocity ranges from 9.2 m/s to 10.0 m/s (mean:9.5 m/s), and takeoff angles from 18.8 to 20.0 deg., respectively.

Thus, the ratio between the horizontal and vertical takeoff seems to be similar for male and female athletes.

Time of Takeoff

Numerous authors have reported values for the time of takeoff in the long jump. Because of the limited temporal resolution (cinematography with 100 fps) and different operational definitions most of the data should probably be viewed with reservations. The time of takeoff is negatively correlated with the approach velocity (r = -0.43) and with the distance of the jump (r = -0.64) (NIGG 1974). These results suggest that a faster approach lessens takeoff time and results in greater jumping distance. This suggestion corresponds with the thought that, assuming similar geometric conditions, the shorter takeoff time may reduce the amount of decrease of the horizontal velocity.

Path of Centre of Mass

The angle between the line joining the CM to the heel of the takeoff foot and the backward horizontal at touchdown was recorded by FISCHER (1975) between 64 and 69 deg.. For jumps with smaller or larger angles, no good distances have been measured. The corresponding angle at the instant of last ground contact was between 73 and 83 deg.. During the takeoff the athlete`s CM is horizontally and vertically displaced. The vertical displacement of 17 - 25 cm raises the CM to a height at takeoff reported to range from 1.11 - 1.26 m for the 12 women`s long jump finalists at the 1984 Olympic Games (HAY 1985).

The vertical displacement of the CM during the initial impact phase of the takeoff may "demonstrate how well an athlete can tolerate high impact forces and consequently benefit from elastic energy" (LUTHANEN/KOMI 1979). The horizontal displacement, in which the approach velocity is reduced as previously discussed, is reported with values of 80 - 95 cm.

Final Remarks

The purpose of this chapter was to attempt to obtain a scientific understanding of the long jump. From a review of the literature,the authors developed the essential parameters of the event. However, it was not possible to consider all variables. For example, the role of the takeoff leg and lead leg was not considered in the takeoff phase.

All factors measured at the Championships in Rome are based on the parameters defined and discussed in this chapter. They include the most important parameters of the approach (last four strides), takeoff, flight and landing.

3. ANALYSIS OF THE LONG JUMP AT THE WORLD CHAMPIONSHIPS ROME 1987

3.1. METHODS AND PROCEDURES

On September 4 and 5, 1987, twelve female and seventeen male competitors participated in the women`s and men`s long jump finals respectively. Low wind and humidity of about 80% were registered. Temperatures of 19°C and 23°C respectively, offered favorable conditions for the finals.

The competition was filmed with two LOCAM - highspeed cameras in order to provide a three-dimensional analysis of the last four strides, the takeoff, flight and the landing. The cameras were panned in a horizontal plane. The pan shots, referring to the pan angles of the cameras, were controlled by several well defined reference points behind the runway and the pit. These reference markers were digitized with the body landmarks from the films frame by frame for the three-dimensional biomechanical analysis.
The cameras operated at 200 frames per second. Camera speed was controlled by external lightmarks on the film, and the cameras were externally synchronized.

3.2. EVENT SCORECARD

The event scorecard provides general information about the finals, and includes official distances and wind measurements for each trial.

EVENT SCORECARD

Official distance (m)
Wind (m/s)

Time 20:15 - Temp. +23°C
Press 1014mBar - Humidity 77%

Place	No.	Name	Year	Nation	Result	1	2	3	4	5	6
1.	1053	**Lewis Carl**	61	USA	8.67m	8.67m +0.35m/s	8.65m +0.58m/s	8.67m -0.17m/s	8.43m +1.58m/s	X -	8.60m +0.20m/s
2.	949	**Emmiyan Robert**	65	URS	8.53m	8.30m +0.39m/s	X -	X -	8.53m -0.27m/s	X -	X -
3.	587	**Evangelisti Giovanni**	61	ITA	8.38m	X -	8.09m +0.55m/s	8.19m +0.32m/s	7.59m -1.02m/s	X -	8.38m -0.42m/s
4.	1067	**Myricks Larry**	56	USA	8.33m	X -	8.04m +2.30m/s	8.23m +1.15m/s	8.13m -0.57m/s	8.33m -0.99m/s	8.20m -2.40m/s
5.	470	**Hirschberg Jens Uwe**	64	GDR	8.16m	8.16m -0.68m/s	8.04m -0.38m/s	7.97m +1.65m/s	7.85m -0.77m/s	X -	7.95m -0.37m/s
6.	208	**Jefferson Jaime**	62	CUB	8.14m	7.78m -1.26m/s	7.85m -0.45m/s	8.09m +0.50m/s	8.04m -0.89m/s	7.84m -1.03m/s	8.14m +0.17m/s
7.	100	**Amidjinov Vladimir**	63	BUL	8.11m	8.11m -0.36m/s	7.80m +0.16m/s	8.05m +0.51m/s	7.86m -0.74m/s	7.99m +0.28m/s	8.01m +0.35m/s
8.	1023	**Conley Mike**	62	USA	8.10m	X -	8.10m +0.47m/s	X -	X -	X -	X -

9.	973 Layevskiy Sergey 7.89m 7.95m 8.08m -0.79m/s -0.45m/s -0.51m/s	59	URS	8.08m
10.	384 Reski Heiko 7.87m 8.03m X +1.68m/s +0.40m/s -	63	FRG	8.03m
11.	714 Alli Yussuf 7.89m 8.00m 7.79m +0.76m/s -1.98m/s +0.72m/s	60	NGR	8.00m
12.	644 Usui Junichi 7.77m 8.00m 7.62m -1.77m/s +1.92m/s +0.62m/s	57	JPN	8.00m
13.	945 Bobylev Vladimir 7.90m 7.75m 7.78m +2.51m/s +0.86m/s +0.72m/s	66	URS	7.90m
14.	285 Karna Jarmo X 7.80m 7.83m - +0.77m/s +0.50m/s	58	FIN	7.83m
15.	315 Brige Norbert 7.82m X 7.66m -0.45m/s - +0.47m/s	64	FRA	7.82m
16.	717 Emordi Paul X 7.80m 7.68m - -0.17 -0.34m/s	65	NGR	7.80m
17.	892 Krsek Ivo 7.67m 6.81m 7.72m +0.53m/s -0.45m/s -1.19m/s	67	TCH	7.72m

EVENT SCORECARD

Official distance (m) Time 19:32 - Temp. +19°C
Wind (m/s) Press 1013mBar - Humidity 81%

Place	No.	Name	Born	Nat.	1	2	3	4	5	6	Result
1.	639	Joyner-Kersee Jackie	62	USA							7.36m
					6.91m	7.12m	7.36m	6.95m	6.95m	6.99m	
					+0.15m/s	-0.96m/s	+0.31m/s	-0.74m/s	-1.34m/s	-0.54m/s	
2.	555	Belevskaya Elena	63	URS							7.14m
					6.17m	6.81m	6.74m	7.14m	6.92m	6.98m	
					-0.24m/s	+0.30m/s	-1.59m/s	-0.65m/s	-0.74m/s	-0.99m/s	
3.	287	Drechsler Heike	64	GDR							7.13m
					6.91m	7.03m	7.13m	5.62m	-	-	
					-0.30m/s	-0.19m/s	-0.77m/s	-0.69m/s	-	-	
4.	310	Radtke Helga	62	GDR							7.01m
					6.95m	6.56m	7.01m	X	X	6.95m	
					+0.51m/s	-0.17m/s	-0.16m/s	-	-	-0.73m/s	
5.	560	Christiakova Galina	62	URS							6.99m
					6.99m	6.74m	X	X	6.83m	6.80m	
					+0.83m/s	+0.38m/s	-	-	-1.15m/s	-0.34m/s	
6.	604	Valyukevich Irina	59	URS							6.89m
					6.80m	6.41m	6.80m	6.83m	6.66m	6.89m	
					+0.43m/s	+0.17m/s	+0.34m/s	-0.66m/s	-1.68m/s	-0.92m/s	
7.	635	Innis Jennifer	59	USA							6.80m
					6.80m	6.77m	6.72m	X	X	6.51m	
					-0.85m/s	-1.04m/s	+0.66m/s	-	-	-0.89m/s	
8.	7	Boegman Nicole	67	AUS							6.63m
					X	6.41m	6.63m	6.37m	X	6.22m	
					-	-0.79m/s	-0.54m/s	-0.54m/s	-	-0.72m/s	
9.	69	Ninova Liudmila	60	BUL							6.50m
					6.33m	X	6.50m				
					+0.91m/s	-	-0.16m/s				
10.	67	Moneva Silvia		BUL							6.45m
					6.35m	6.45m	6.45m				
					+0.17m/s	-0.34m/s	-0.38m/s				
11.	626	Echols Sheila	64	USA							6.39m
					X	6.39m	X				
					-	-1.00m	-				
12.	154	Demsitz Lene	59	DEN							6.11m
					X	6.11m	X				
					-	-0.81m/s	-				

To judge the best trials from a biomechanical point of view, the authors analysed the longest jumps of the eight best competitors in each final. Only in the case of JOYNER-KERSEE the best trial (7.36 m) was unavailable for analysis. Consequently, her second trial (7.12 m) was analysed. Additionally, the biomechanical analysis includes the data of all the trials by CARL LEWIS.

TABLE 2 presents the first data for the jumps. Four distances are shown:

- The official distance ("Jena Mes.").

- The distance measured on the basis of the authors` three-dimensional biomechanical data ("Mes. Dist.").
  The distance is defined as the horizontal distance between the toe at takeoff and the heel at touchdown in the pit.

- The toe to board distance ("Board").

- The distance between the heel of the athlete and the last visible trace in the sand during landing ("Sand").

The distance measured on the basis of objective biomechanical data is called "effective distance" of the long jump. This distance does not account for losses incurred by failing to hit the board precisely, or when the initial heel contact point is further from the board than the point used for measuring the official distance. Thus, the effective distance constitutes the actual distance from the tip of the takeoff foot to the heel at instant of landing. Hence the effective distance must, by definition, be equal or longer than the officially measured distance. This is true for all but one case (marked by a questionmark in Table 2) where the official result indicates a better jump than measured with biomechanical analysis. The result was carefully re-checked and the authors are confident that their measurement is accurate. Therefore in the following report the officially measured distance in question is excluded and the authors` result (unofficial) is used for further analysis.

The means of the officially measured distances of the best male and female long jumpers in the finals have been calculated with 8.295 m (± 0.21 m) and 6.92 m (± 0.22 m) respectively. These values indicate the best results ever for long jump finals, which have been measured using biomechnical methods. In the men`s competition the mean of the effective distance was 8.395m (± 0.28m), while the "toe-to-board distances" and the "sand distances" were measured with 0.058m (± 0.05m) and 0.114m (± 0.07m) respectively. One can conclude that the precision of the approach was very exact regarding the eight best long jumpers.

For LEWIS, TABLE 2 indicates that in his first jump he cleared 8.84 m (effective distance) and was very close to BEAMON`s 1968 world record. However, in this trial he lost 2 cm on the board and 15cm during landing. In his fourth and sixth jump he showed similar losses during landing. CONLEY and MYRICKS also lost an equal amount of distance during landing. The mean of distance lost during landing is calculated with 0.08m for LEWIS`s jumps. The mean of LEWIS`s "toe-to-board distances" is calculated with 0.03m and indicate the high precision of his run-up.

The data for the women`s finals present mean of the "toe-to-board distance" and the "sand distance" by 0.031m (± 0.03m) and 0.041m (± 0.03m) respectively. The lower "sand distances" of the female jumpers may be determined by the poorer horizontal CM`s velocity during the flight.

The distance of a long jump is determined by the takeoff parameters (takeoff velocity, takeoff angle, CM`s height at takeoff) and the body position during landing (see page D/6 f). For the presentation and discussion of results one must refer to the diagram in CHAPTER 2. This diagram serves to illustrate and define the four consecutive parts of the jump. Thus, separate data are presented for the approach, takeoff, flight and landing.

TABLE 2: Official distance (m), ("Jena Mes.")
Effective distance (m), ("Mes. Dist.")
Loss of distance on board (m)
Loss of distance in sand (m)

Name	Jena Mes.	Mes. Dist.	Board	Sand
Hirschberg	8.16	8.21	0.0	0.05
Conley	8.10	8.29	0.02	0.17
Amidjinov	8.05	8.21	0.08	0.08
Emmiyan	8.53	8.63	0.06	0.04
Myricks	8.33	8.75	0.16	0.26
Evangelisti	8.38 ?	8.01	0.10	0.10
Jefferson	8.14	8.22	0.02	0.06
Lewis (1)	8.67	8.84	0.02	0.15
Lewis (2)	8.65	8.68	0.02	0.01
Lewis (3)	8.67	8.67	0.0	0.0
Lewis (4)	8.43	8.64	0.12	0.09
Lewis (6)	8.60	8.76	0.0	0.16
Christiakova	6.99	7.10	0.05	0.06
Innis	6.77	6.77	0.0	0.0
Boegman	6.41	6.60	0.09	0.10
Joyner-Kers.	7.12	7.14	0.0	0.02
Drechsler	7.03	7.14	0.09	0.02
Radtke	7.01	7.06	0.0	0.05
Belevskaya	7.14	7.21	0.02	0.05
Valyukevich	6.89	6.92	0.0	0.03

3.3. THE APPROACH

Speed

TABLE 3 presents the velocity data for the last strides and the last metres of approach. V1, V2, V3 and V4 indicate the instantaneous velocity of CM at takeoff into the 4th, 3rd, 2nd and the last stride. The last two columns in the table indicate the average speed of the athlete which was measured by photo cells (LB: high barriers) between 11 and 6 m, and 6 and 1 m to the board. The average speed over 5 m must be less than the instantaneous velocity of CM, because in the 5 m interval the athlete realizes more than two strides with minimal two support phases. During each support the athlete`s CM first increases and then decreases horizontal velocity. Therefore,the velocity at the instant of takeoff must be higher than the average speed over several strides. From a biomechanical point of view, the instantaneous velocity of CM at touchdown for takeoff is the most important factor. The measured speeds in columns 5 and 6 are only indicators of the important CM`s velocity. They are presented because of their extremely relevant practical importance. Average speed can be easily measured in the field and during the training process. Therefore, these measurements were included. In comparison with the data presented in chapter 2 the average speed of the finalists in Rome show similar values. LEWIS, for example, demonstrated higher average speed when measured in HELSINKI - 1983.

DAUTE`s (GDR) maximum speed of 9.7 m/s, measured during the first world championships in Helsinki - 1983, was reached only by DRECHSLER with 9.94 m/s.

From TABLE 3,it can be seen that for LEWIS`s jump the maximum CM`s velocity was higher than 11 m/s. Also, when he reached the board, his instantaneous speed of CM was measured at 11.2 m/s. All other participants showed lower velocity.

The female competitors produced CM`s velocities similar to those of HAY`s study which dealt with the finals of the LOS ANGELES GAMES - 1984.

TABLE 3: Approach velocity of CM (m/s)

Horizontal velocity at takeoff into the 4th last stride (v4)
Horizontal velocity at takeoff into the 3rd last stride (v3)
Horizontal velocity at takeoff into the 2nd last stride (v2)
Horizontal velocity at takeoff into the last stride (v1)
Average horizontal speed from 11 to 6 metres before takeoff
Average horizontal speed from 6 to 1 metres before takeoff

Name	v4	v3	v2	v1	11-6	6-1
Hirschberg	-	10.7	10.9	10.7	10.31	10.38
Conley	11.0	10.9	10.9	10.6	10.68	10.64
Amidjinov	10.6	10.8	10.8	10.8	10.58	10.46
Emmiyan	10.5	10.5	10.6	10.3	10.52	10.27
Myricks	10.9	10.8	10.8	10.7	10.74	10.57
Evangelisti	10.8	10.7	10.6	10.4	10.61	10.51
Jefferson	11.1	10.8	11.0	10.6	-	-
Lewis (1)	11.7	11.6	11.8	11.3	-	11.14
Lewis (2)	11.8	11.6	11.9	11.2	11.15	11.02
Lewis (3)	11.7	11.5	11.8	11.2	11.10	10.99
Lewis (4)	11.9	11.7	11.8	11.3	11.12	11.17
Lewis (6)	11.7	11.4	11.9	10.9	11.20	11.17
Christiakova	9.6	9.5	9.8	9.8	9.59	9.48
Innis	9.8	9.7	9.9	9.4	9.54	9.54
Boegman	8.9	9.1	9.2	8.8	8.71	8.88
Joyner-Kers.	9.6	9.5	9.7	9.4	9.25	9.50
Drechsler	10.2	10.2	10.2	9.8	9.94	9.80
Radtke	9.3	9.4	9.6	9.2	9.24	9.17
Belevskaya	10.0	10.0	10.1	10.1	9.54	9.67
Valyukevich	9.6	9.4	9.6	9.6	8.81	9.25

TABLE 4: Speed and instantaneous velocity during the last strides of the approach (mean, standard deviation) in m/s

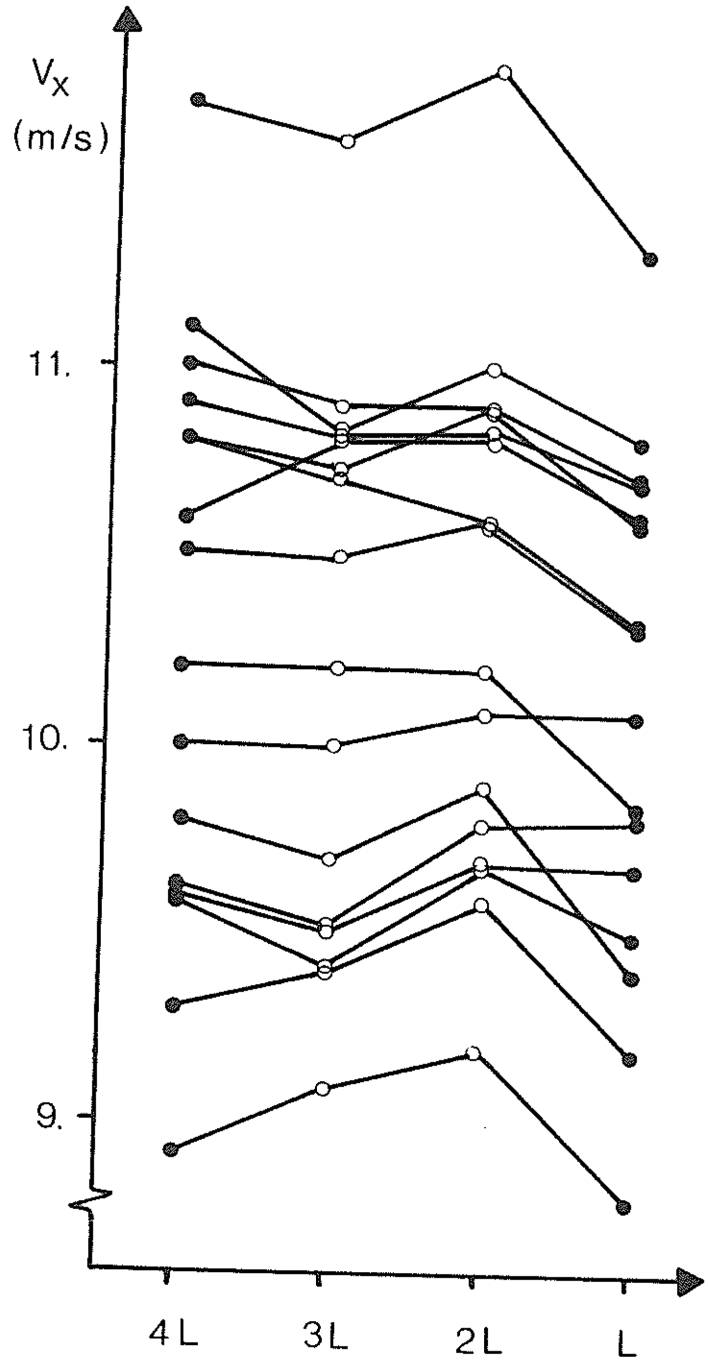
	v4 4L	v3 3L	v2 2L	v1 L	11 - 6 LB	6 - 1 LB
men (n = 8)	10.94 ± 0.37	10.85 ± 0.30	10.93 ±0.35	10.67 ± 0.28	10.57 ± 0.14	10.56 ± 0.26
women (n = 8)	9.63 ± 0.38	9.60 ± 0.33	9.76 ± 0.30	9.51 ± 0.38	9.32 ± 0.39	9.41 ± 0.28
Lewis (n = 5)	11.76 ± 0.08	11.56 ± 0.10	11.84 ± 0.05	11.18 ± 0.15	11.14 ± 0.04	11.10 ± 0.08

In the following section the authors present and discuss only the mean and standard deviation scores in order to obtain an overall view of the long jump. The individual values are presented in APPENDIX "A".

The mean and standard deviation of the horizontal velocity at the instant of takeoff into the last four strides indicates that the variation of the takeoff velocity is susceptible to rhythmic changes (see TABLE 4). In the approach the reduction of horizontal velocity in the third last stride is followed by an increase in the second-last stride. There is a drastic decrease in the last stride (takeoff). This tendency is representative of all the male participants and is especially highlighted in the five trials by LEWIS. For the female jumpers a similar tendency, as shown by the mean scores, has been observed. However, the rhythmic velocity changes are not found for all female finalists. Contrary to this trend are the scores of CHRISTIAKOVA 9.6 - 9.5 - 9.8 - 9.8 m/s, and BELEVSKAYA 10.0 - 10.0 - 10.1 - 10.1 m/s.

To illustrate individual variations with respect to the mean tendency, the individual data of the horizontal velocity during the last strides for the best male and female long jumpers are combined in FIGURE 3.

FIGURE 3: The changes of CM`s velocity during the four last strides



The correlations between the measured velocities and the effective distances are presented in TABLE 5.

TABLE 5: Correlation coefficients with the effective distance

velocity	men (n = 8)	women (n = 8)
v4	.39	.04
v3	.48	-.03
v2	.39	.69 *
v1	.47	.77 *
11 - 6	.33	.62
6 - 1	.48	.70 *

The correlations indicate that only a few parameters reveal the effective distance of the jump. The significant correlations are marked with an asterisk (*).

The authors conclude that the frequently reported overall high correlation between approach velocity and the jump`s distance does not exist in the homogenous group discussed here. The authors found a co-variation of the variables describing the approach velocity and the jumping distance, but they did not find a high significant co-relationship. The same conclusion can be drawn for the individual analysis of LEWIS`s jumps.

Thus, for highly qualified long jumpers, the approach velocity is a very important factor and a necessary condition, but it is not entirely sufficient for a good jump.

The causes for the observed variations in the horizontal velocity during the last four strides are found in the support phases of these strides. The support phases, or more exactly the velocity changes during the stance phases, are determined by three important factors. They are the length of the presupport stride, the position of the body segments at touchdown and takeoff, and the movements of the takeoff leg and the lead leg. Therefore, the authors will discuss the stride lengths, the position of the Center of Mass and the body segments at touchdown and landing, and, last but not least, the body angles of the lead and the takeoff leg during the last four strides.

Stride Length

TABLE 6 contains the stride lengths mean and standard deviation scores for the competitors in the men`s and women`s finals as well as for LEWIS`s five jumps.

TABLE 6: Stride lengths of the four last strides (mean, standard deviation) in m

	4 L	3 L	2 L	L
men (n = 8)	2.18 ± 0.12	2.10 ± 0.16	2.24 ± 0.15	2.01 ± 0.22
women (n = 8)	2.00 ± 0.09	1.93 ± 0.17	2.01 ± 0.11	1.80 ± 0.13
Lewis (n = 5)	2.39 ± 0.05	2.29 ± 0.05	2.47 ± 0.05	1.82 ± 0.04

The frequently reported tendency in the literature (HAY, NIGG, BELBEROW) to lengthen the second-last stride in respect to the third-last and the last stride is confirmed. The lengthening of the second-last stride in comparison to the third-last stride ought to produce a lowering of CM which should continue during the last stride. The reason for a lowering of the CM is the lengthening of the path of acceleration for the takeoff.

The data presented in TABLE 6 reveal a shortening of the last stride in comparison to the second-last stride which is about 10% of the stride length. LEWIS demonstrated extremely higher values in all of his jumps with respect to the stride lengths of three of the last four strides, and in stride length reduction. He lengthened his second-last stride by 0.18m when compared to the third-last stride, and shortened the last stride by 0.65m when compared to the second-last stride!

LEWIS`s extremely high values, when compared to the group data, may be a result of his high horizonzal velocity. With a great reduction of stride length from the second-last into the last stride LEWIS is able to prepare a relatively flat takeoff for flight. This preparation stems largely from the long second-last stride.

EMMIYAN demonstrated the shortest last stride (1.71 m) of the mens finalists. It must be noted however, that his approach speed is much slower than LEWIS`s approach velocity. Also the lengths of the other strides which prepare the takeoff are much shorter than those of LEWIS.

HIRSCHBERG and MYRICKS did not adhere to this discussed tendency. Their stride lengths were measured at 2.21 - 2.42 - 2.45m (HIRSCHBERG) and 2.03 - 2.07 - 2.06 - 2.06m (MYRICKS). The low modulation of their last strides (see FIGURE 3) corresponds with the small changes of the horizontal velocity.

Therefore, the variations of stride lengths seem to be a relevant element to modulate the CM`s velocity during the phase of takeoff preparation.

Flight and Support Times

The previously discussed changes in CM's velocity during the last strides of the approach depend on the stride lengths, and the flight and support times of the strides. The flight time of the stride is defined from the instant of takeoff to the instant of touchdown. This flight follows the support phase of the stride measured from the instant of touchdown to the takeoff of the supporting foot. The individual data are found in the appendix, while the mean and standard deviation scores are located in TABLE 7.

TABLE 7: Flight (FL) and support (ST) times during the last strides (mean, standard deviation) in s

	4L	3L		2L		L	
	FL	ST	FL	ST	FL	ST	FL
men (n = 8)	0.140 ± 0.01	0.091 ± 0.01	0.133 ± 0.009	0.088 ± 0.01	0.132 ± 0.01	0.108 ± 0.01	0.074 ± 0.03
women (n = 8)	0.140 ± 0.007	0.085 ± 0.01	0.139 ± 0.008	0.086 ± 0.007	0.147 ± 0.01	0.094 ± 0.009	0.092 ± 0.01
Lewis (n = 5)	0.142 ± 0.005	0.084 ± 0.003	0.147 ± 0.007	0.081 ± 0.002	0.142 ± 0.005	0.104 ± 0.005	0.066 ± 0.002

Regarding the men`s data, there is a decrease of flight time from the 4th last to the last stride. The support time increases from the 2nd last into the last stride. These data confirm the stride length information. In LEWIS`s jumps the mean of flight times first increases from the 4th last to the 3rd last, comes back in the 2nd last to the amount of the 4th last and then decreases drastically to 66 ms in the last step. The short support times correspond with his high CM`s velocity.

The average flight times of the finals participants decrease from the 3rd last into the 2nd last, and increase to 92 ms in the last stride. The mean of the support time for the womens` last stride is significantly lower than mens` support time. However, the last stride`s flight time is higher in female participants than in male jumpers. The negative correlation between the official distance and the time of flight for the 4th last stride of the approach reported by HAY (1985) for female jumpers, is not indicated in or confirmed by the authors` data. In contrast to the correlation found by data from the 1984 Olympic Games in the women`s final, the authors observe a low positive correlation between the time of flight for the 4th last as well as for the second last stride.

Changes of CM`s Height

The absolute height of CM depends on the position of the body segments and the individual anthropometric data (masses and lengths of segments). To allow a better comparison among the subjects, the authors use only the changes of CM`s height during the support and flight phases and do not discuss the absolute CM`s height. TABLE 8 summarizes the most important information which is based on data from the best jumps of the mens` and womens` finals, and LEWIS`s specially analysed jumps.

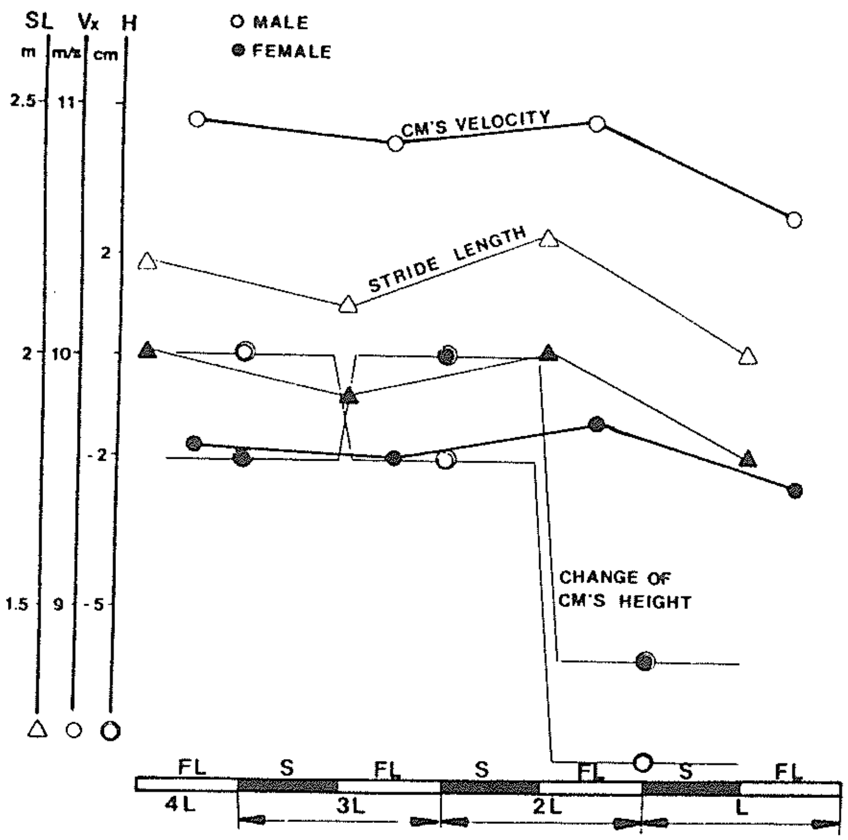
TABLE 8: Change of CM height during flight (FL) and support (ST) phases (mean, standard deviation) in m

	4L	3L		2L		L	
	FL	ST	FL	ST	FL	ST	FL
men (n=8)	-0.05 ±0.02	0.05 ±0.01	-0.03 ±0.01	0.01 ±0.01	-0.07 ±0.02	-0.01 ±0.01	-0.02 ±0.01
	0.0		-0.02		-0.08		
women (n=8)	-0.04 ±0.01	0.02 ±0.01	-0.01 ±0.01	0.01 ±0.01	-0.04 ±0.01	-0.02 ±0.01	-0.02 ±0.02
	-0.02		0.00		-0.06		
Lewis (n=5)	-0.03 ±0.01	0.05 ±0.01	-0.05 ±0.01	0.00 ±0.01	-0.08 ±0.01	0.00 ±0.01	-0.02 ±0.00
	0.02		-0.05		-0.08		

The data show that the most intensive change in CM`s height occurs in the flight phase of the second last stride. Normally, the CM`s height increases during support phases. This can be seen in the stance phase of the 3rd last stride. In the support phases of the second last and the last stride one can observe no (last stride) or very small (2nd last stride) CM`s sink. Therefore, the authors conclude that a lowering of CM`s height already begins in the stance phase of the 2nd last stride.

The authors developed FIGURE 4 as a means of summarizing the previously discussed data regarding takeoff preparation during the last four strides.

FIGURE 4: Takeoff preparation during the last four strides



Body Position at Touchdown and Takeoff

The position of athlete's body can be represented by the angle between a line from the tip of the foot or heel, and the CM and the horizontal axis. These angles, measured at the instant of touchdown and takeoff, indicate the amount of backward and forward body lean during the last strides and are called body lean angles.

As a check for the horizontal CM's position at touchdown and takeoff for each stride during the takeoff preparation, the authors chose the angle between the CM and the heel at touchdown; and the CM and the tip of the foot at takeoff, respectively, to the horizontal axis. These angles gave preference to the absolute CM's position because of the comparability of subjects with different anthropometric data. Values less than 90° represent the backward lean at touchdown and forward lean at takeoff. This confirms that the lower body lean angle at touchdown follows the higher decrease of run-up velocity. The lower angle at takeoff indicates the higher increase of the horizontal CM's velocity during the pushing phase of support. These angles representing the forward lean are also found in the above discussed rhythm of takeoff preparation. The differences from the 2nd last to the last stride especially indicate that changes of body position are found in the touchdown and in the takeoff.

When analysing the data, the authors found no radical step to step changes in the fourth, third and second last stride. However, in the last stride there was a radical variation in the athletes` kinematics. The backward lean decreased from the 2nd last to the last stride at touchdown from 86.2 to 77.8 degrees (men finalists), and the forward lean increased from 62.9 to 59.0 degrees. This tendency is not found in a proportionate number of the women`s finalists. The reason may be due to the techniques of DRECHSLER, RADKE, BELEVSKAYA and VALYUKEVICH. These female jumpers increase the body lean angle at touchdown from the 2nd last to the last stride. This action, in contrast to the other female finalists, corresponds with the female jumpers who exhibit minor velocity changes in the takeoff preparation phase.

TABLE 9: Body lean angles at takeoff (TO) and touchdown (TD) of the four last strides (mean, standard deviation) in degrees

	4L	3L		2L		L	
	TO	TD	TO	TD	TO	TD	TO
men (n=8)	63.6 ± 1.7	85.3 ± 3.3	62.9 ± 2.6	86.2 ± 2.9	62.9 ± 2.6	77.8 ± 2.9	59.0 ± 3.1
women (n=8)	64.3 ± 1.7	86.7 ± 2.2	65.4 ± 2.2	85.0 ± 2.3	65.7 ± 2.6	83.6 ± 4.8	61.6 ± 2.1
Lewis (n=5)	60.7 ± 0.7	86.3 ± 1.2	65.0 ± 0.9	87.4 ± 1.8	64.1 ± 1.5	77.3 ± 2.4	60.2 ± 0.9

Body Angles at Touchdown and Takeoff

In the literature two types of techniques are found: the takeoff leg is brought into contact with the ground, or the lead leg is moved for takeoff. Regarding the last strides of the run-up consisting of support and flight phases, the authors consider each support phase as a takeoff. Therefore, the techniques of the the takeoff leg as well as of the lead leg for each support, are discussed.

Takeoff leg: The most widely supported technique advocates that the foot is brought to the ground in a backward sweeping, or powering movement. This action is known as a so called active landing. It reduces the forward horizontal velocity of the foot at impact and thus, the resulting braking reaction evoked from the ground. This active landing assists in minimizing the loss in horizontal velocity during the takeoff.

The second technique advocates a locking placement of the foot and is believed to facilitate the energy transfer of the swinging body segments in the early support phase.

The described backward-sweeping or locking may be represented by a bended or extended knee of the takeoff leg at touchdown. Therefore, the angle of the knee joint is chosen to discuss the technique of the supporting leg used for takeoff in the last strides.

TABLE 10 illustrates that each athlete in all takeoff preparation strides began the support phases by bending the knee of the takeoff leg. The mean scores of the male and female jumpers do not differ, but the data in paranthesis point out that the range of the angle data are extremely high.

The values measured at the instants of takeoff indicate that the knee is not completely extended. The data for the last two strides especially illustrate the flexed takeoff knee. This loss of the full extended takeoff leg corresponds with the very short flight times of these strides. LEWIS markedly demonstrates the active landing and the not fully extended knee angle at takeoff.

Lead leg: Little has been published in the biomechanical literature concerning how the swing of the lead leg contributes to the CM's velocity changes during takeoff. From a practical point of view, preference is given to a flexed knee of the lead leg which reduces the moment of inertia of the leg, or to a nearly extended knee which lengthens the pendulum. Therefore, the authors analysed the data to determine if world-class athletes use a short and quick lead leg action or a long pendulum during the takeoff preparing strides.

TABLE 10: Angle of the knee joint of takeoff leg at touchdown (TD) and takeoff (TO) (mean, (maximum,minimum)) in degrees

	4L	3L		2L		L	
	TO	TD	TO	TD	TO	TD	TO
men (n=8)	163 (155,173)	152 (138,164)	162 (144,169)	150 (143,155)	150 (131,162)	145 (137,152)	147 (136,163)
women (n=8)	160 (156,164)	154 (144,172)	160 (151,167)	151 (140,166)	154 (142,164)	147 (137,156)	143 (134,155)
Lewis (n=5)	156 (149,160)	156 (153,158)	143 (137,147)	151 (146,156)	137 (134,148)	146 (139,152)	132 (128,140)

TABLE 11 indicates a similar tendency for the male and female finalists. While the knee angle of the lead leg at touchdown increases from the 3rd last, the second last to the last stride, the angle at takeoff increases from the second last to the last stride. The data point out that, in the last stride the technique of the long pendulum is used. In the 4th, 3rd and 2nd last steps athletes seem to prefer the flexed lead leg. This was a frequent practice used by LEWIS which was observed in his five analysed jumps.

TABLE 11: Angle of the knee joint of the lead leg at touchdown (TD) and takeoff (TO) (mean, (maximum,minimum)) in degrees

	4L	3L		2L		L	
	TO	TD	TO	TD	TO	TD	TO
men (n=8)	67 (61,77)	39 (33,45)	68 (52,77)	48 (37,54)	62 (44,78)	56 (41,72)	115 (77,14[illegible]
women (n=8)	73 (64,86)	37 (32,42)	76 (64,91)	43 (36,49)	68 (60,76)	52 (38,73)	112 (74,15[illegible]
Lewis (n=5)	64 (57,72)	36 (33,43)	55 (52,57)	55 (49,61)	68 (64,81)	62 (51,68)	140 (120,15[illegible]

3.4. TAKEOFF

Velocity and angle of projection

During takeoff, the athlete transfers the initial velocity into the takeoff velocity. This is, as previously discussed, the most important factor for obtaining distance in the long jump.

TABLE 12 includes the individual CM`s velocity data for the analysed jumps. The takeoff velocity in the run-up direction is indicated with "vx", and "vz" symbolizes the vertical takeoff velocity. The letters "vy" represent the horizontal velocity component perpendicular to "vx". Negative values of "vx" indicate that the athlete flies to the left side.

The angle of projection is given with alpha, and the direction angle is expressed with beta.

TABLE 12: Velocities vx, vy, vz, v of CM at takeoff in m/s
Angles of projection alpha (xz-plane), beta (xy-plane) at takeoff in degrees

Name	vx	vy	vz	v	alpha	beta
Hirschberg	9.1	0.1	3.1	9.6	18.8	0.7
Conley	8.6	-0.1	3.3	9.5	20.6	-0.4
Amidjinov	9.1	0.1	3.1	9.6	18.9	0.7
Emmiyan	8.5	-0.3	4.0	9.4	24.9	-2.1
Myricks	9.0	-0.2	3.6	9.7	22.1	-1.4
Evangelisti	8.8	0.1	3.3	9.4	20.3	0.4
Jefferson	8.7	-0.7	3.5	9.4	22.0	-4.7
Lewis (1)	9.9	0.3	3.2	10.4	17.7	1.9
Lewis (2)	9.2	0.9	3.4	9.8	20.2	5.7
Lewis (3)	8.9	0.9	3.5	9.6	21.5	5.5
Lewis (4)	8.8	1.1	3.5	9.5	21.6	7.3
Lewis (6)	9.2	1.0	3.3	9.9	19.8	6.3
Christiakova	8.3	-0.1	3.1	8.8	20.3	-0.7
Innis	8.2	-0.1	3.0	8.7	20.3	-0.7
Boegman	7.6	0.3	3.0	8.1	22.0	2.2
Joyner-Kers.	7.9	0.3	3.2	8.5	22.1	1.8
Drechsler	9.1	0.1	2.5	9.4	15.6	0.5
Radtke	7.9	-0.4	3.1	8.5	21.4	-2.9
Belevskaya	8.4	0.1	3.0	8.9	19.6	0.4
Valyukevich	7.8	0.0	3.1	8.4	21.9	-0.2

The mean of the horizontal takeoff velocity is calculated with 8.96 m/s (±0.41) for the male, and 8.15 m/s (±0.44) for the female group. LEWIS reached 9.2 m/s in his jumps (± 0.38, n=5) and was able to use his excellent run-up speed. The average vertical takeoff velocity was measured with 3.39 m/s (±0.28) for the men, 3.0 m/s (±0.2) for the women and 3.38 m/s (±0.11, n=5) for LEWIS.

The often discussed relationship between the run-up velocity and the takeoff velocity was proven by the correlation analysis. The results of these calculations also indicate that in a group of high level athletes as analysed in this study, there are differences in the ability to transfer the initial approach energy into takeoff velocity. The following correlation coefficients have been calculated:

	effective distance	horizontal touchdown velocity (initial velocity for takeoff)
horizontal takeoff velocity	.44 .55	.56 .69
vertical takeoff velocity	.41 .47	.86* .88*

(The coefficients calculated for the male finalists are found on the first line, those for the female jumpers on the second line.)

One must be cautious in interpreting these correlations because they are not especially high. The sample is also small.

Changes of CM`s Velocity

During takeoff, the horizontal CM`s velocity decreases while vertical velocity increases. The reduction of horizontal and resultant velocity is calculated for the male and female competitors as well as for LEWIS`s five trials.
TABLE 13 presents the mean and range scores. In the authors` sample, the data reveal a decrease of horizontal velocity during takeoff from 0.7 to 2.3 m/s. The height of velocity reduction indicates no significant correlation with the effective distance of the jump.

TABLE 13: Reduction of horizontal and resultant CM`s velocity at takeoff (mean, (maximum,minimum)) in m/s

	Δ vx	Δ v
men (n=8)	-1.71 (-1.4, -2.0)	-1.05 (-0.9, -1.2)
women (n=8)	-1.36 (-0.7, -1.8)	-0.85 (-0.4, -1.2)
Lewis (n=5)	-1.98 (-1.4, -2.3)	-1.34 (-0.9, -1.8)

Body Angles at Touchdown and Takeoff

The angles of body lean, as well as the knee angles of the takeoff leg and the lead leg, were measured at instants of touchdown and takeoff.

TABLE 14: Angles of body lean and of the knee joint at touchdown (TD) and takeoff (TO) (mean, (maximum,minimum)) in degrees

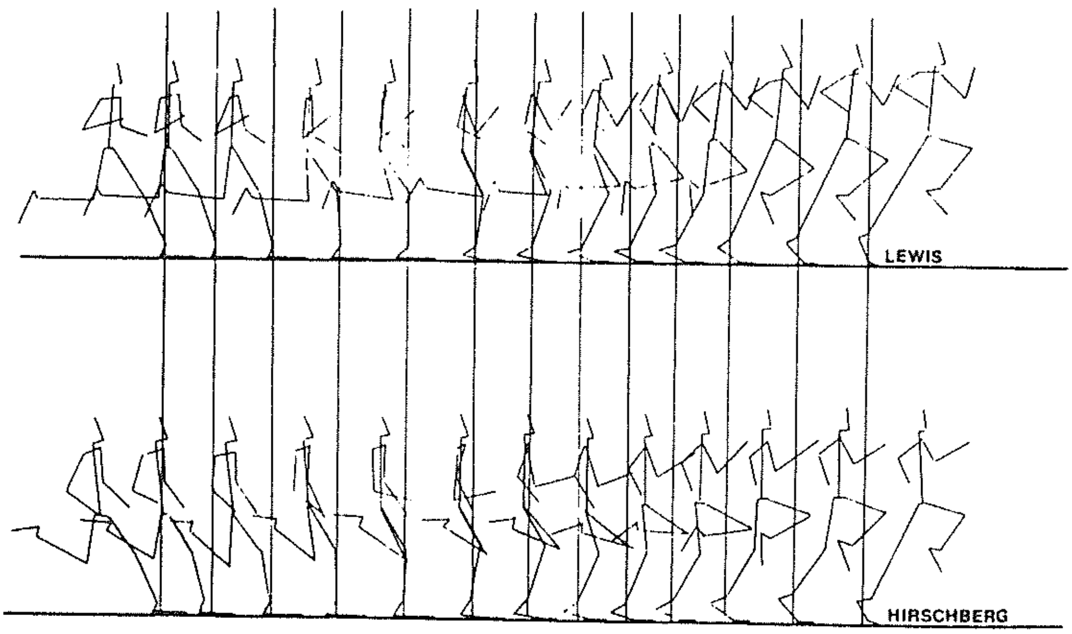
	Angle of body lean		Knee angle			
			takeoff leg		lead leg	
	TD	TO	TD	TO	TD	TO
men	64.5	74.4	166.9	177.7	88.9	74.7
(n=8)	(60,68.8)	(72,76.8)	(160,176)	(170,180)	(57,116)	(59,102)
women	67.1	78.1	165.8	174.3	77.8	72.3
(n=8)	(63.7,71.6)	(76.2,80.3)	(162,171)	(167,177)	(64,86)	(46,96)
Lewis	65.3	75.0	168.9	176.4	109.6	85.2
(n=5)	(62.3,68.7)	(74,75.6)	(167,170)	(172,180)	(104,110)	(66,103)

The data for the body lean indicate that athletes with a high approach velocity use lower body lean angles when compared to those having low running speed. This was especially noted for the female finalists. The observed angles correspond with those reported in the literature.

The knee angle of the takeoff leg does not differ for the analysed groups. At touchdown the knee joint is not completely extended however, the joint angle seems to be in a straight position at takeoff. The data regarding the knee angle of the lead leg demonstrate that there are different techniques for the swinging action of this segment. The individual data point out that several athletes use the leg as a relatively long pendulum at the beginning of the takeoff phase. Other jumpers bend the knee joint to decrease the leg`s moment of inertia thereby increasing the speed of the leg. LEWIS, for example, begins his takeoff with lead leg knee angles of more than 100 degrees, and uses the leg as a relatively long pendulum. With this technique his horizontal lead leg velocity is comparatively high compared to the other athletes, and it contributes to the high takeoff velocity of CM.
Conversely, the angular velocity of the lead leg decreases and contributes to a total angular momentum of the body which produces a forward rotation with respect to the transverse axis during flight. The slide figure graphics (see FIGURE 5) illustrate the results and allows one to compare LEWIS`s takeoff technique with the takeoff of HIRSCHBERG who demonstrated the flexed lead leg technique.

The results of the data from the analysed parameters describing takeoff techniques lead the authors to conclude that, regarding highly qualified athletes, it is impossible to advocate just one technique for the transition of approach energy into the flight. This means that a knowledge of the takeoff (based on the presented data as well as a review of the literature) is not sufficient to create an overall valid theory for this often improved skill. In order to obtain a more comprehensive understanding concerning the factors which limit takeoff techniques more data, comparable to that contained in this study, must be analysed. Such studies are a vital source of primary information in helping athletes to maximize their physiological capabilities.

FIGURE 5: Takeoff techniques of LEWIS and HIRSCHBERG



3.5. FLIGHT AND LANDING

As previously discussed, the flight depends on the takeoff velocity of CM, the takeoff angle and the relative CM`s height at the instant of takeoff. These data are logically presented in the chapter titled "TAKEOFF".

During the flight, the analysed athletes used modified versions of the often reported "hang", "stride" or "hitch-kick" techniques to prepare an optimal body position for the landing.

In all analysed jumps, the authors found a slight forward rotation after takeoff which is consistent with the data on angular momentum during long jumps flight reported in BALLREICH and BRÜGGEMANN (1986). In preparing for the landing, the athletes produce segmental angular momentum about the transverse axis through the CM using the arms and the legs depending on the chosen technique.

For quantitative analysis, the data appear to have been based on the technique which propels the athlete forward from the marks in the sand at the instant of landing. The landing distance and the landing height are not sufficient to estimate the technique of landing. The analysis conducted during the world championships indicates that there are very different styles. The purpose of this report was not to present a detailed analysis of landing techniques, but to provide an overview of the most important factors in the long jump. Therefore the authors report the athletes` landing in slide figures. For all athletes, the authors chose the same view using the compute graphic. FIGURES 5 and 6 include the landings of the analysed jumps.

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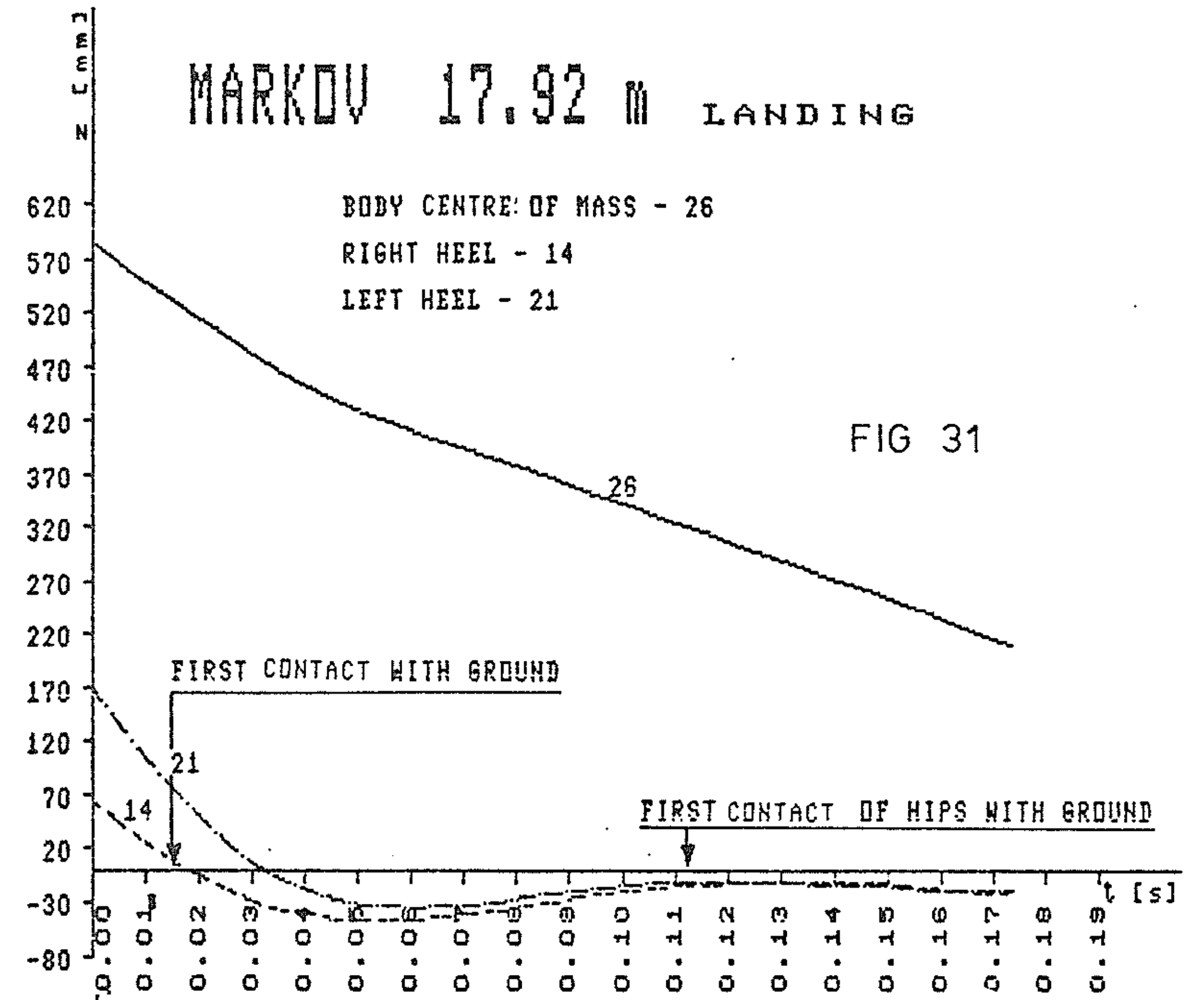

FIG 31

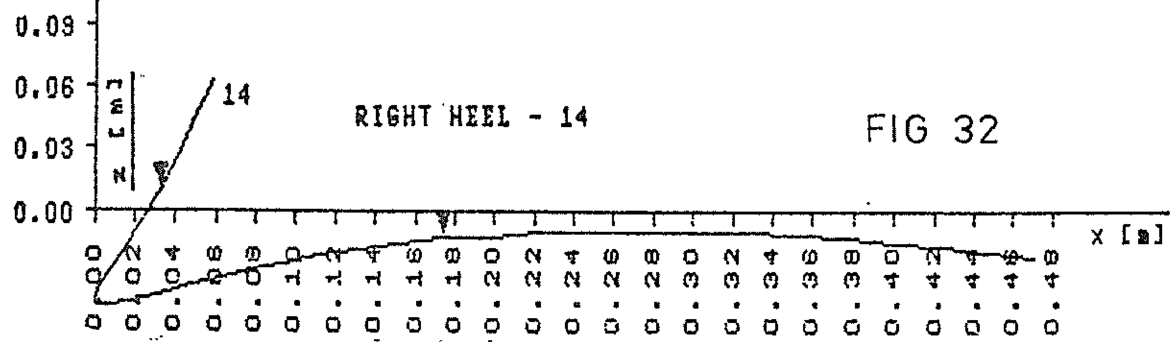

FIG 32

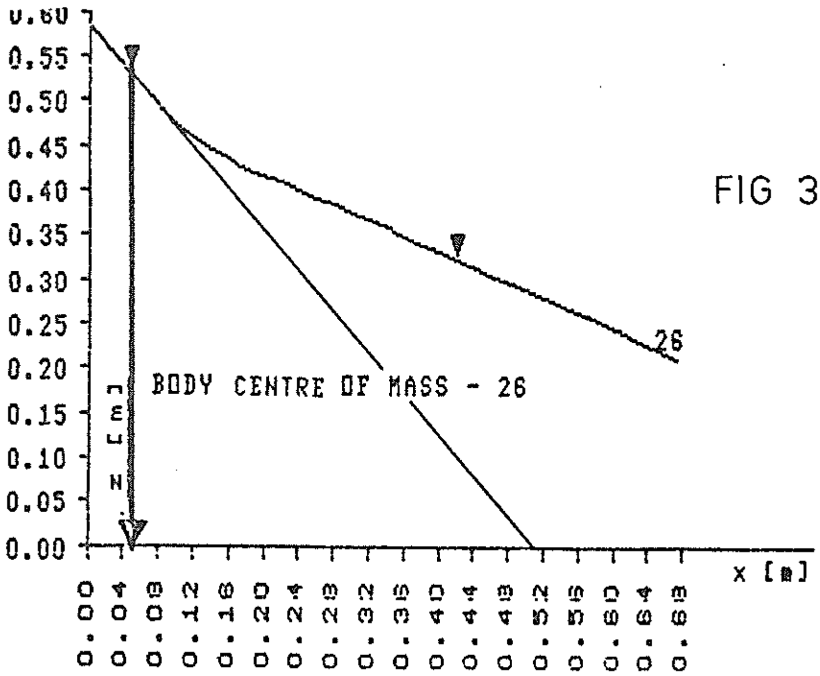

FIG 33

The following is the survey of data for basic evaluation of the triple jump technique :

Angle parameters:	1^{st}TO	2^{nd}TO	3^{rd}TO	Expected trend
ATD_A	111	112	113	114 - 115
ABT_{TD}	-55	-60	-54	
ABT_{TO}	94	96	100	103
ATO	67	60	63	
IFA	13.9	13.3	21.5	

Time data and par. of CM path :	1^{st}TO	2^{nd}TO	3^{rd}TO	Expected trend
h_{TD}	0.96	0.97	0.95	below the 1 m limit
h_{TO}	1.11	1.12	1.13	lifting
S_y	- 0.04	0.02	0.02	minimization
S_z	0.16	0.14	0.19	lifting increase in 3rd TO
d_{LH}	0.38	0.48	0.40	
d_{TO}	0.62	0.61	0.50	
t_v	0.05	0.067	0.07	
t_a	0.054	0.064	0.09	
t_{1-3}	0.12	0.15	0.17	

Velocity components:	1^{st}TO	2^{nd}TO	3^{rd}TO	Expected trend
v_{xTD}	10.2	9.3	8.0	increase
v_{yTD}	0.5	0.5	0.2	minimization
v_{zTD}	- 0.8	- 2.4	- 2.25	decrease
v_{TD}	10.2	9.5	8.3	increase
v_{xTO}	9.7	8.3	6.6	increase
v_{yTO}	- 0.6	- 0.4	0.23	minimization
v_{zTO}	2.3	1.9	2.7	increase 2nd & 3rd TO
v_{TO}	10.0	8.7	7.0	increase

Arm swing

There are two basic variants of arm swing technique :

1. The double arm swing in all the three takeoffs which is difficult to do.
2. The more natural the running-circular swing (RCS) - natural running swing (NRS) - and double arm swing action (DSA).

Technical corrections should be made in the preparatory phases of training; never in the competition period or just before the most important event of the year.

Tinkering with technique during competition results in impaired performance and instability in all trials as evidenced by the performance of Procenko.

The final was affected by the awkward interruption caused by the opening of victory ceremony. An admirable ability of psychological resilience and concentration was displayed by the bronze medallist Sakirkin. Owing to the victory ceremony, he had to interrupt four of his six trials.

The prevailing wind direction was along the run-up. The wind was utilized above all by Taiwo, Bouschen and Procenko. They all achieved their best results with excessive wind support (over 3.5 m/s).

6. Conclusions

Biomechanical analyses of the best triple jumpers can be used for laying down some of the conditions for reaching top performance levels and pointing to the development trends in technical execution.

The speed potential of triple jumpers now significantly approximates that of long jumpers.

A top level triple jumper should be able to reach average speeds of 10.4 m/s and higher (minimum 10.1 - 10.2 m/s) in the section 6 - 1 m before the takeoff line.

The pre-takeoff rhythm also approximates that of the long jump. It involves:

- increase of stride frequency, at least in the penultimate stride;
- reduction of the flight path of body CM (which can be achieved by varying lenghts of the last stride);
- minimization of the downward path of body CM in the flight phase of the last stride;
- lowering of the height of body CM before takeoff to below the 1m limit.

The technical execution of the takeoffs differs significantly between athletes. Takeoff technique should be in accordance with the tendency to minimize losses of horizontal velocity, and with the demand for the efficient linking of the body CM trajectory in the support and flight phases of the jump.

Taking into account the run-up speed before the 1st TO, losses of horizontal velocity should not exceed 12% in the step, and 16% in the jump.

Losses of horizontal velocity in the support phases should not exceed 10% in the 1st TO, and 12% in the 2nd and 3rd TO.

At the same time, the components of velocities v_y, v_z at the instant of touchdown, and v_y in the course and at the instant of takeoff should be minimized.

The optimum ratio of the lenghts of jumps is difficult to determine because of the differences in the individual abilities of each athlete. A certain limit of ratios (or rather the lenght of the hop and step) does exist and should not be exceeded, because that would make maximum performance impossible.

There are various technical patterns which can help athletes to get beyond the 18 m limit. The following ratios of lenghts seem to be quite realistic: 36.0 : 30.5 : 33.5%, (6.50 + 5.50 + 6.00 m), or 34.5 : 31.0 : 34.5% (6.20 + 5.60 + 6.20).

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8. Symbols and abbreviations used in the Report

D_O	- official performace (m)
D_L	- lost distance (distance between takeoff-line and the toe of the takeoff-foot) (m)
D_E	- effective distance - $D_O + D_L$ (m)
d_1	- length of hop (m)
d_2	- length of step (m)
d_3	- length of jump (m)
d_{LH}	- horizontal distance of the heel from body CM at landing (m)
d_{TO}	- horizontal distance of body CM from the toe at takeoff (m)
S_y	- lateral deviation of body CM (m)
S_z	- vertical lift of body CM, i.e. $h_{TO} - h_{TD}$ (m)
h_{TD}	- height of body CM at landing (m)
h_{TO}	- height of body CM at the instant of takeoff
H_B	- body height (m)
t_v	- time from moment of landing to moment of vertical (s)
t_a	- time from moment of landing to moment of amortization (maximum bend of knee-joint) (s)
t_1	- duration of first takeoff (s)
t_2	- duration of second takeoff (s)
t_3	- duration of third takeoff (s)
T_1	- duration of hop (support and flight phases) (s)
T_2	- duration of step (support and flight phases) (s)
T_3	- duration of jump (support and flight phases) (s)
T	- duration of triple jump ($T_1+T_2+T_3$) (s)
v_{xTD}	-horizontal component of the velocity of body CM at landing (m/s)
v_{yTD}	- lateral component of the velocity of body CM at landing (m/s)
v_{zTD}	- vertical component of the velocity of body CM at landing (m/s)
v_{TD}	- resulting velocity of body CM at landing (m/s)
v_{xTO}	- horizontal compotent of the velocity of body CM at takeoff (m/s)
v_{yTO}	- lateral component of the velocity of body CM at takeoff (m/s)
v_{zTO}	- vertical component of the velocity of body CM at takeoff (m/s)
v_{TO}	- resulting velocity of body CM at takeoff (m/s)

ATD_A	- angle of landing vis-a-vis heel (degrees)
ATD_B	- angle of landing vis-a-vis toe (degrees)
AKJTD	- angle of takeoff-leg knee at landing (degrees)
AKJv	- angle of takeoff-leg knee at moment of the vertical (degrees)
AKJa	- angle of takeoff-leg knee at moment of amortization (maximum bend of knee joint) (degrees)
AKJTO	- angle of takeoff-leg knee at takeoff (degrees)
ABTTD	- angle between thighs at landing (degrees)
ABTTO	- angle between thighs at takeoff (degrees)
ATO	- takeoff angle (degrees)
IFA	- initial flight angle (degrees)
w	- wind velocity (m/s)
v_1	- mean approach-run velocity 11-6 m before takeoff line (m/s)
v_2	- mean approach-run velocity 6-1 m before takeoff line (m/s)
f_{n-2}	- mean stride frequency (stride per second) in the third step before takeoff line f_{n-2}
f_{n-1}	- mean stride frequency in the penultimate run-up step
f_n	- mean stride frequency in the last run-up step

N_S	- number of run-up strides
N_T	- number of trial
RL	- right leg
LL	- left leg
RA	- right arm
LA	- left arm

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BIOMECHANICAL ANALYSIS OF THE TRIPLE JUMP

Sušanka, P.; Jurdík, M.; Koukal, J.; Krátký, P.; Velebil, V.

Contents

1. Introduction

The overall performance level of the triple jump competition at the II World Championships in Athletics was the highest ever recorded. Led by the European record of Christo Markov of Bulgaria (17.92 m) the average length of the best jumps of the top eight finalists was 17.44 m and a distance of 17.23 m was required to qualify for the finals.

FINAL **31/8 - 16.40**

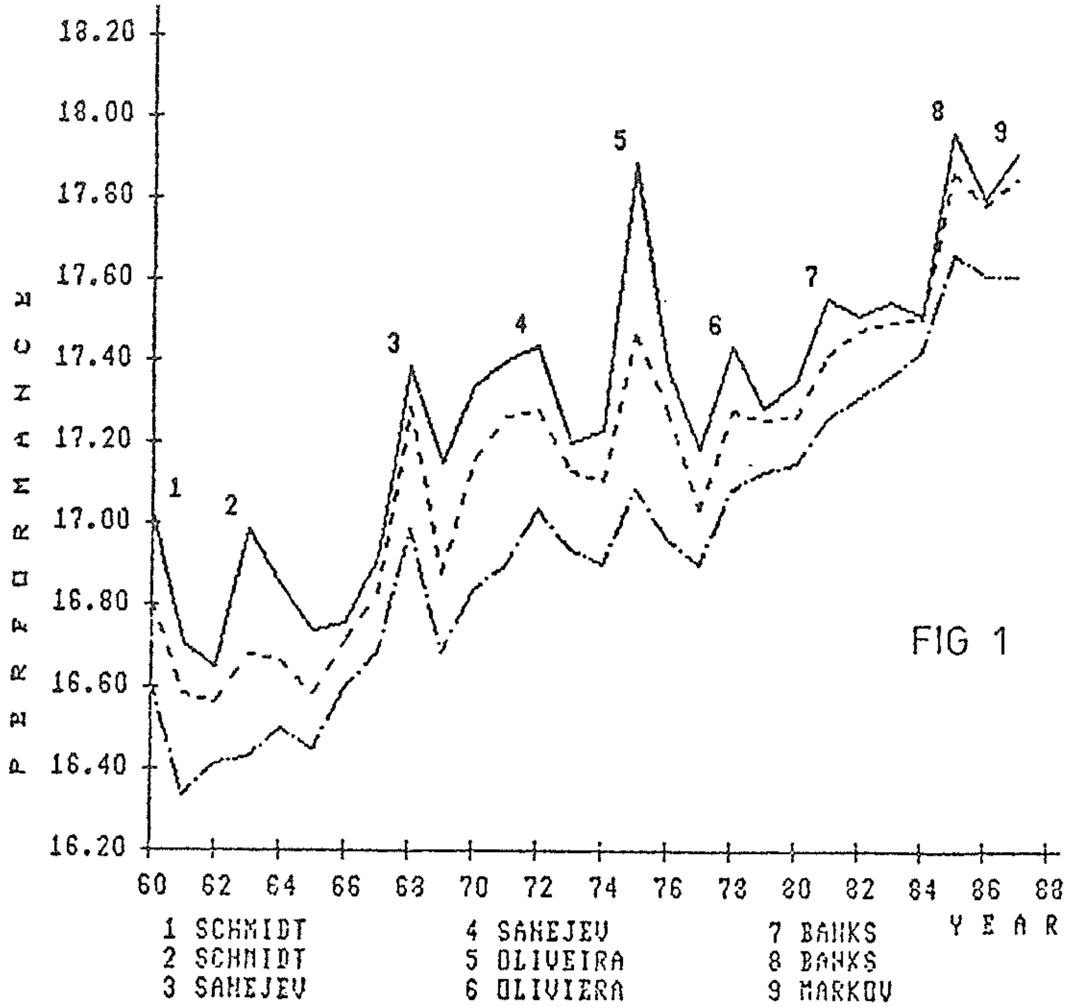
1.	117	Markov Christo							65	BUL	17.92 CR
			17.70	17.73	X	17.92	X	X			
			+2.14	+1.81	+0.00	+1.57	+0.00	+0.00			
2.	1023	Conley Mike							62	USA	17.67
			17.34	17.37	X	17.65	X	17.67			
			+4.32	+1.89	+0.00	+0.91	+0.00	-1.00			
3.	991	Sakirkin Oleg							66	URS	17.43
			17.03	17.36	17.31	X	17.29	17.43			
			-2.21	+1.41	+2.71	+0.00	+1.26	+1.34			
4.	970	Kovalenco Aleksandr							66	URS	17.38
			17.38	X	X	X	16.81	16.99			
			-1.00	+0.00	+0.00	+0.00	+2.13	+0.17			
5.	761	Pastusinski Jacek							64	POL	17.35
			17.27	17.20	17.13	17.28	17.35	17.26			
			+0.81	+0.38	+0.40	-0.21	+1.66	-0.77			
6.	724	Taiwo Joseph							59	NGR	17.29
			17.29	X	17.09	16.82	16.96	X			
			+3.81	+0.00	+1.72	+0.78	-0.17	+0.00			
7.	354	Bouschen Peter							60	FRG	17.26
			X	17.26	X	17.08	16.73	16.72			
			+0.00	+3.58	+0.00	-0.44	+1.58	-0.17			
8.	990	Protsenko Oleg							63	URS	17.23
			X	X	17.23	X	X	16.30			
			+0.00	+0.00	+3.83	+0.00	+0.00	+0.23			
9.	51	Elliott Norbert							62	BAH	16.79
			X	X	16.79	—	—	—			
			+0.00	+0.00	+1.84	+0.00	+0.00	+0.00			
10.	903	Slanar Ivan							61	TCH	16.69
			X	16.69	16.26	—	—	—			
			+0.00	+0.88	-0.36	+0.00	+0.00	+0.00			
11.	577	Badinelli Dario							60	ITA	16.63
			16.63	16.40	16.48	—	—	—			
			+0.50	-1.66	+1.65	+0.00	+0.00	+0.00			
12.	751	Hoffmann Zdzislaw							59	POL	16.58
			16.49	X	16.58	—	—	—			
			+1.51	+0.00	+1.83	+0.00	+0.00	+0.00			
	645	Yamashita Norifumi							62	JPN	DNC

Ore/Time 19:19 — Temp.: +26 °C
Press.: 1017 mBar — Umidità/Humidity: 57%

Recent development of the event (including the 1st World Championships - Helsinki 1983) has proved that triple jumpers are improving their motor abilities, in particular the ability of reaching top run-up velocity.

That, above all, has influenced the performance level of the past years with its clearly rising trend (see Fig. 1). The goal of reaching 18 m in the near future seems to be quite realistic.

Diagram of performance development:



Top-level results are based on optimum training in the final phase before the most important competition and on performance stability throughout the year.

Even the slightest variation in performance determines the final placement, especially among the best 20 triple jumpers.

Improved results changed the order of competitors to higher then their table position held before the Championships (Markov, Sakirkin, Pastusinski, Bouschen, Elliot). On the other hand losses of performance exceeding 2% predetermined the athletes' failure.

TABLE 1

WORLD LIST 1987 (at 15th October 1987) TRIPLE JUMP MEN

17.92	+1.6	Christo	Markov	65	BUL	1	Roma WCh	3108	1.	+0.11
17.87		Mike	Conley	62	USA	1	San Jose TAC	2706	2.	-0.20
17.77	+1.0	Alexandr	Kovalenko	66	URS	1	Brjansk NC	1807	4.	-0.39
17.65	+1.0	Alexandr	Jakovlev	57	URS	1	Moskva Znam	0606	R	
17.61	+0.6	Oleg	Procenko	63	URS	1	Praha EP/A	2806	8.	-0.38
17.53		Al	Joyner	60	USA	Q	San Jose TAC	2606	R	
17.49		Willie	Banks	56	USA	-	San Jose TAC	2706	N	-1.12
17.48	+1.9	Jorge	Reyna	63	CUB	1	Habana	2702	-	
17.45	+1.9	Alexandr	Leonov	62	URS	1	Soči	2405	R	
17.43	+1.4	Oleg	Sokirkin	66	URS	3	Roma WCh	3108	3.	+0.06
17.36		Ray	Kimble	53	USA	1	Modesto S&W	0905	R	
17.35	+1.7	Jacek	Pastusinski	64	POL	5	Roma WCh	3108	5.	+0.20
17.32		Charlie	Simpkins	63	USA	Q	San Jose TAC	2606	N	-0.98
17.25	+2.0	Ivan	Slanař	61	CS	1	Bratislava PTS	1306	10.	-0.56
17.24	+1.0	Frank	Rutherford	64	BAH	Q	Baton Rouge NCAA	0406	N	-1.25
17.24	-0.5	Volker	Mai	66	GDR	1	Neubrandenburg	1106	-	
17.23	-0.6	Nikolaj	Musijenko	59	URS	3	Brjansk NC	1807	R	
17.22	+1.7	Vasif	Asadov	65	URS	2	Soči	2405	R	
17.22	-0.3	Vladimir	Černikov	59	URS	1	Novosibirsk	1608	R	
17.20		Peter	Bouschen	60	FRG	1	Düsseldorf	0706	7.	+0.06
17.19		Robert	Cannon	58	USA	6	San Jose TAC	2706	R	
17.18		Zdzislaw	Hoffmann	59	POL	1	Bydgoszcz	0108	12.	-0.60
17.15		Boris	Chochlov	58	URS	3	Čeljabinsk	0208	R	
17.12	+0.6	John	Dodoo	60	GHA	1	Nairobi AfrG	0908	N	-0.64
17.11	-0.3	Igor	Lapšin	63	URS	2	Bratislava PTS	1306	R	
17.11		Djordje	Kožul	63	YUG	2	Göteborg EP/B	2806	N	-0.74
17.10		Gennadij	Valjukevič	58	URS	4	Čeljabinsk	0208	R	
17.10		Vladimir	Zubrilin	63	URS	5	Čeljabinsk	0208	R	
17.09	+1.8	Joseph	Taiwo	59	NGR	-	Roma WCh	3108	6.	+0.36
17.07	+0.6	Kerry	Harrison	65	USA	2	Zagreb WUG	1707	R	
17.05		Arne	Holm	61	SWE	3	Göteborg EP/B	2806	N	-1.29

Wind Assisted:

17.60w		Willie	Banks	56	USA	2	San Jose TAC	2706
17.59w		Charlie	Simpkins	63	USA	3	San Jose TAC	2706
17.42w		Kerry	Harrison	65	USA	1	Lawrence	1804
17.39w		Ray	Kimble	53	USA	1	San Jose Jenn II.	3005
17.38	+2.8	Vjačeslav	Bordukov	59	URS	1	Moskva	1608
17.29	+3.9	Joseph	Taiwo	59	NGR	6	Roma WCh	3108
17.26	+3.6	Peter	Bouschen	60	FRG	7	Roma WCh	3108

↑ 1 (wind column) ↑ 2 (placement column) ↑ 3 ↑ 4

1 - WIND

2 - PLACEMENT IN THE CONTENTS

3 - PLACEMENT IN THE II WC

R - REDUCED RANKING LISTS

N - DID NOT PASS THE QUALIFICATION II WC

4 - DIFFERENCE BETWEEN THE PERFORMANCE AT THE II WC AND THE BEST PERFORMANCE 1987

2. Biomechanics of the Triple Jump

Since 1978 our studies have focused on investigating the development of the triple jump technique of top-level athletes. Based on this work we can describe the biomechanical factors at each phase of the jump and note the developmental changes which have clearly influenced the overall improvement in performance.

The performance in the triple jump depends on the approach velocity, the technical execution of the takeoffs and the choice of the suitable ratio of the hop, step, and jump.

The following factors are necessary for the optimum effectiveness of the triple jump technique :

1. Minimum loss of horizontal velocity;
2. Minimum variation range of the velocity v_y (movements in the frontal plane);
3. Optimum flight course characterized by minimum necessary height of the CM parabola;
4. Optimum linking of the CM functional trajectory courses in the transition between support and flight phases;
5. Technical execution of the landing, without loss in jump length.

The event can be divided into these elements : a) run-up, b) hop, c) step, d) jump.

The Run-up

Run-up speed is a major factor in determining the initial flight velocity of the hop, step and jump (STARZYNSKI 1962, TAN ENG YOON 1971, KREJER 1978, 1980, RAČKOV 1980, SUŠANKA 1979, 1983, 1984, ARNOLD 1985, KOUKAL and SUŠANKA 1986). As in the long jump, the approach run can be characterized by a) the number of strides, b) run-up speed c) stride frequency and d) pre-takeoff rhythm. The figures in this data compare to a considerable extent to the data for the long jump, the few differences occur only in the last phase of the approach. In the last three strides of the run-up, triple jumpers do not lower their body CM as much as the long jumpers, because the hop takeoff launches them at a smaller initial flight angle.

The difference in run-up speed between triple and long jumpers has decreased. The average run-up speed of the last 2-3 strides before takeoff (6 - 1 m before the takeoff line) in the best triple jumpers is 10.4 - 10.6 m/s.

The Hop

Athletes usually use their stronger leg to takeoff for the hop, chiefly because the following takeoff must be from the same leg. This phase is crucial for the success of the entire triple jump. The takeoff leg lands on the takeoff board as actively as possible, pushing downward and backward from above (a "pawing" movement). In the first part of the support phase the leg is flexed, in the second part it is extended vigorously, its movement being completed throughout the takeoff into the flight phase. Meanwhile the swinging leg, together with the arms, performs a long and fast action, vigorously checked before the end of the takeoff, with the aim of transferring the momentum of the swinging extremities to the other parts of the body.

After completing the takeoff action, the takeoff leg is flexed under the pelvis, moving forward and upward until the thigh is almost parallel to the ground. Now, preparation starts for the next takeoff.

Perfomance model prerequisites:

- run-up speed v_x in excess of 10.5 - 10.6 m/s;
- minimum v_z (vertical velocity) at the instant of touchdown: -0.4 - 0.6 m/s;
- velocity losses v_x not to exceed 4 - 5 % of primary velocity;
- lowering of CM before first take-off under 1 m even in athletes with body height over 185 cm;
- less CM lift and greater forward shift of CM (in the direction of movement) at the instant of takeoff, consequently a smaller flight angle 13 - 15^{o} ;
- both the development trends and our previous findings have proved that the optimum hop length is ca. 36% of the entire triple jump - or 35% if the athlete can minimize the differences in the lengths of the hop, step and jump (ca. 0.3 m).

The Step

The step is the most difficult and, with most athletes, the shortest phase of the triple jump. The takeoff for the step is performed in a way similar to the hop, with a pawing motion, but the horizontal velocity is lower, and use of the swinging legs should be made to minimize further loss of the horizontal speed (in Helsinki 1983, Conley 9,65 m/s, Marinec 9.1 m/s - Sušanka et. al. 1984). As soon as the takeoff has been completed, the athlete is in the starting position for the third takeoff.

In the final part of the flight phase the knee of the swinging leg rises, while the takeoff leg moves backwards for a powerful swing leading to the third takeoff which should again be performed as a pawing motion.

Perfomance model prerequisites:

- velocity v_x at touchdown for the takeoff 9.4 - 8.8 m/s minimum;
- velocity v_z (vertical) at touchdown for the takeoff should not exceed 2.8 m/s.

  This demand is closely related with the position of CM at the instant of touchdown and with the parameters at the instant of the previous takeoff.
- lowering of CM at the instant of touchdown to ca 1 m, forward shift of the sole by 0.5-0.7 m;
- loss of forward velocity v_x during the takeoff rises but should not exceed 6-11%;
- velocity v_x at the instant of the takeoff should exceed 8.0 m/s;
- velocity of initial flight (resulting velocity-vector) v should exceed 8.4 m/s;
- vertical velocity v_z should not exceed 2.0 to 2.1 m/s because of the resulting reduction of the initial flight angle (under 14°);
- height of body CM (h_{TO}) is less than in the first and third takeoff;
- forward shift of CM with regard to takeoff place by ca 0.55- 0.7 m.

The Jump

The last phase of the triple jump is executed much like the long jump; the difference is that here the horizontal velocity at the touchdown has dropped by 2.5 - 3.5 m/s to 7.5 - 8.5 m/s (KREJER 1980, SUŠANKA et. al. 1984, 1986). In the flight phase, the triple jumpers use any of the three techniques : the float, the hang and the hitchkick or a combination of the hang and the hitchkick. Another feature in which the jump differs from the long jump is in the action of the arms (most triple jumpers use double-arm action).

Perfomance model prerequisites:

- velocity v_x at the touchdown for takeoff 8.8 m/s to minimum 8.3 m/s;
- velocity v_z (vertical) at the touchdown for takeoff should not exceed -2.5 m/s.

  This demand (similarly in the second takeoff) is closely related with the position of CM at the instant of touchdown and with the parameters at the instant of the preceding takeoff.
- lowering of CM at the instant of touchdown to ca 1 m or less. A forward shift of the sole 0.5-0.7 m;
- velocities v_y in the frontal plane (right angle to movement) should be minimal, approximating zero;
- loss of forward velocity v_x during takeoff, compared with the first and second takeoff, rises again, ranging between 25- 30%;

- velocity v_x at the instant of takeoff should exceed 5.8 m/s;
- initial flight velocity (resulting velocity vector) v_0 should exceed 6.8 m/s;
- vertical velocity v_z should markedly exceed (unlike the preceding takeoff) 2.0 m/s. It can approximate the same vertical velocity as in the long jump takeoff, i.e. in excess of 3 m/s. This results in an increase of the initial flight angle to 20-25°;
- forward shift of CM at the instant of takeoff should not change markedly. The height of body CM (h_{TO}) should exceed 1.15 m, but obviously also depends, apart from the technical execution of the jump, on body height and other anthropometric factors.

3. Methods and Procedure

The analysis has been focused on the following characteristics of technical execution of the triple jump:

- run-up data,
- geometric data of takeoffs,
- velocity losses in the course of the triple jump,
- relation between lengths and time data in hop, step and jump,
- arms swing,
- landing data.

In addition to 3-D film analysis, videoanalysis and measurement of average velocities of run-up by photocells were used for data collection. Some data can be measured by two(or three) different methods and in those cases one method was used to check the accuracy of measurements taken by another.

For our biomechanical analysis of the triple jump, the 3-dimensional kinematographic method, with 2 cameras rotating round their vertical axes, was used. They were used to record the final 3 preparatory steps plus the triple jump itself. This scope of field allows analysis of locomotion over a stretch of about 28m. Placing both cameras on tripods limited the rotation of the cameras (and thus the deviations of the shot image) in relation to the x-axis. The scope-angle was chosen so that from both cameras, a motion in the object field over 4 - 6 m was taken.The placing of the cameras is shown in Fig. 2A. PHOTOSONICS 500 cameras with a frequency of 200 frames per second were used.

On the basis of film analysis, the 3-dimensional coordinates are calculated in the following 2 steps.

In the first step, the angular distance of the momentary optical axis of the object-lens and separate anthropometric points in relation to the reference target are fixed, on the basis of coordinates calculated from separate frames. The position of the reference target is fixed in the absolute /i.e. real/ system of coordinates which is parallel with the runway (Fig. 2A), by direct measurement on the spot in the stadium. The angles in question are used for calculating the projection of anthropometric points into the vertical reference (projection) plane which includes the reference targets. This plane is identical for both cameras as well as for the projection.

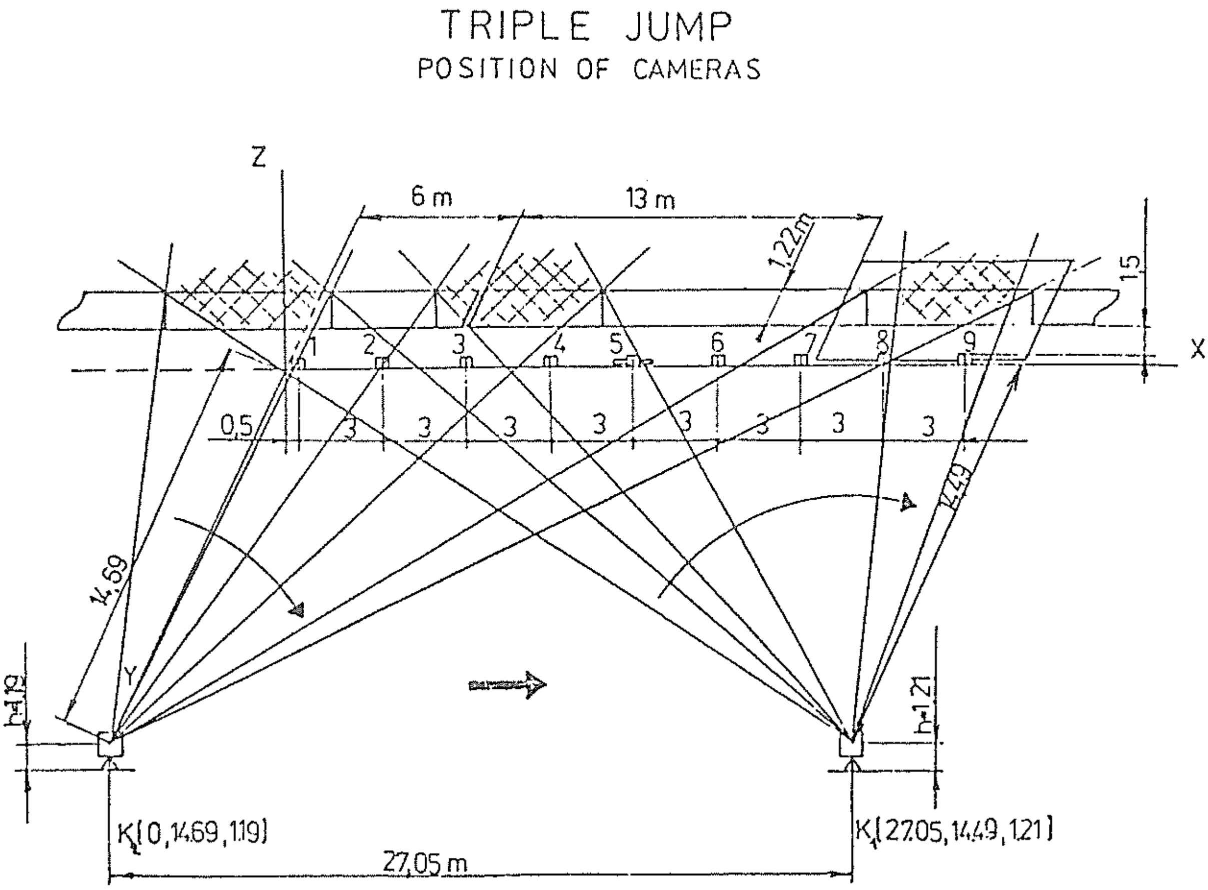


FIG 2A

In the second step - by means of the projections of anthropometric points and coordinates of both cameras mentioned above (positioned by means of a theodolite with regard to the runway and reference targets) the 3-dimensional coordinates are calculated as intersection points of rays .

The vertical coordinates were smoothed before starting the calculation and horizontal coordinates were projected into the reference plane.

Futher data have been obtained from the videorecording of finals. The recordings were made by 3 Betamovie cameras fixed on tripods placed at right angles to and 0.6 and 11 m from the takeoff line. All 3 cameras shot the complete course of separate trials from the beginning of the approach until the landing. From these recordings the distance and time data of hop, step and jump were obtained. The distance data were received by means of marks placed by us along both sides of the runway at the sections 5.50-6.00-6.50 m and 10.50-11.00-11.50-12.00 m from the takeoff line (Fig. 2B).

LOCATION OF PHOTOCELLS AND CONTROL MARKS

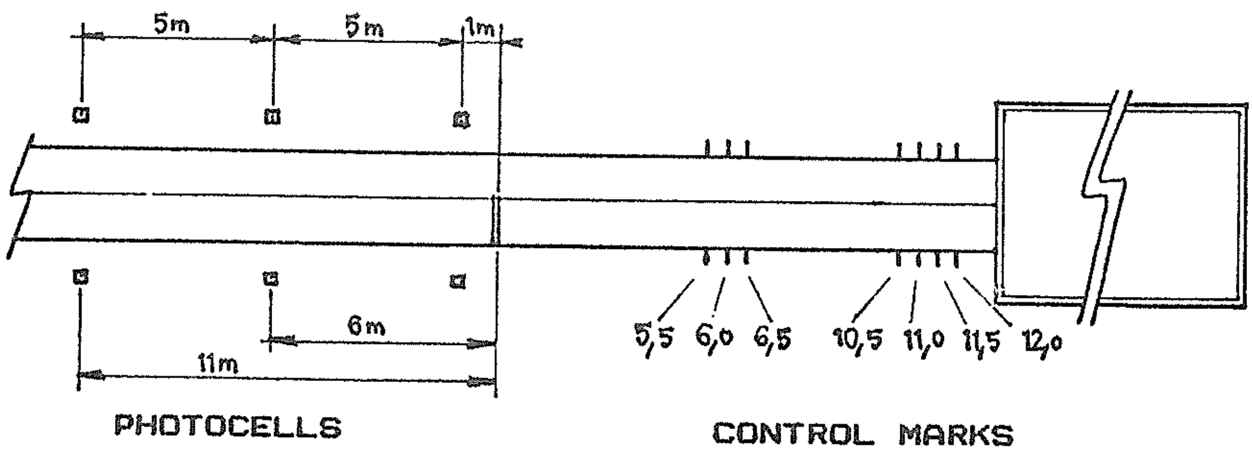


FIG 2B

The lengths of separate triple jump components were registered with accuracy ±0.05m in the following way:

Hop - from the toe (not from the takeoff line) at the first takeoff - to the toe at the first landing;
Step - from the toe at the second takeoff - to the toe at the second landing;
Jump - the sum of the lengths of the lost distance, the hop and the step was subtracted from the sum of lengths of the lost and official distance.

The accuracy of the data obtained from the videorecordings has been checked and also corroborated by the film analysis.

Time parameters of hop, step and jump were obtained in three ways:
- from the videorecording with an inserted digital time (for the purpose of the fast information only);
- from the film shot at 200 f/s;
- by means of space kinematography.

Run-up speed was measured in the normal way - by means of 3 photo-cell gates placed at the distance 1, 6 and 11 m before the takeoff line. Such a placement of photo-cells enables registration of the average run-up speed within two sections - 11-6 m (v_1) and 6-1 m (v_2) before the takeoff line.

A list of the symbols and abbreviations used in the text and the tables can be found at the end of the Report. To make orientation in the tables easier, the values are marked in graphs in the respective tables.

4. Biomechanical Analysis of the Triple Jump - Rome 1987

This Report is presented in relation to the elements of the jump. The biomechanical fundamentals of each element will be presented followed by the measured parameters and the results including interpretation of the analysed jumps.

4.1 Initial Phase - Approach run

The run-up in the triple jump, much as in the long jump, can be characterized by:
- number of running strides (N_S),
- run-up speed (v_1, v_2, v_{XTD}),
- rhythm of pre-takeoff strides (f_{n-2}, f_{n-1}, f_n).

The number of run-up strides used by the WC finalists ranged between 17 and 23; 5 competitors used an odd number and 8 athletes an even number of strides (Fig. 3A -N).

Most athletes started their run-up from the standing position, only Pastusinski, Badinelli and Slanař used the moving start.

It is interesting to note that two of them showed inaccuracies in excess of 0.14 m (Table 15) in their longest attempts.

4.1.1. Run-up speed

High run-up speed is the basic condition for achieving top performances, even in the triple jump - a technically demanding event. Our measurements of the Rome final fully confirmed this.

Information about average run-up speeds (v_1, v_2) was compared with the values of the horizontal component of instantaneous velocity (v_{xTD}) at touchdown for the first takeoff, obtained by means of 3-D film analysis. Instantaneous velocity was 0.1 - 0.2 m/s lower. This can be illustrated by the example of some of the finalists:

	v_1 [m/s]	v_2 [m/s]	v_{xTD} [m/s]
Markov	10.26	10.62	10.40
Conley	10.31	10.37	10.20
Pastusinski	10.06	10.20	10.10
Taiwo	9.86	10.08	10.00

The finalists can be grouped on the basis of mean run-up speed over the section 6 - 1 m before takeoff line, as follows:

I. v_2 over 10.40 m/s: Markov (17.70 - 17.92 m), Conley (17.65 - 17.67m), Kovalenko (17.38).

II. v_2 within the range of 10.20 - 10.40 m/s: Pastusinski (17.13 - 17.28 m), Bouschen (16.72 - 17.28 m), Procenko (16.30 and 17.23 m), Elliot (16.79), Badinelli (16.40 - 16.63 m).

III. v_2 within the range of 9.90 - 10.20 m/s; Sakirkin (17.31 - 17.43 m), Taiwo (16.82,17.09,17.29m), Slanar (16.26 and 16.69 m).

IV. v_2 below 9.90 m/s; Hoffmann (16.49 and 16.58 m).

Markov and Conley managed to translate high speed in the final phase of the run-up (Table 3) into good performance, unlike Kovalenko, Pastusinski, Badinelli and Procenko. Sakirkin and Taiwo had very good results despite lower run-up speed. The slowest of the finalists were Slanar and Hoffmann: this clearly affected their performances.

A comparison of our measurements from Helsinki 83 and Rome 87 (Tables 2 and 3) reveals that, with the exception of Sakirkin, Taiwo, Procenko and Hoffmann, the Rome finalists achieved a higher v_1 speed 11-6 m before the takeoff line (an average of 0.2 m/s).

In the second section (6 - 1 m before the takeoff line), higher v_2 speeds were achieved by four athletes in Helsinki. This seems to indicate that triple jumpers have been trying to achieve a smoother build-up of run-up speed, this providing better conditions for pre-takeoff adjustment.

Three of the athletes (Conley, Bouschen and Hoffmann) took part in both finals. While Conley and Bouschen displayed similar run-up speed, Hoffmann, the champion in Helsinki, was notably slower in Rome.

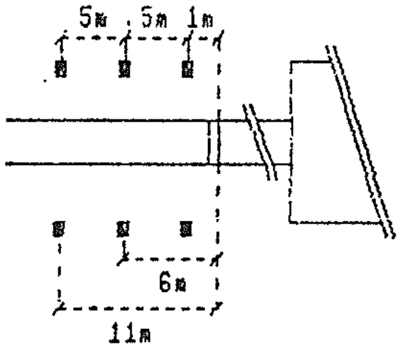
RUN-UP VELOCITIES - 1st WC-HELSINKI 1983

Name	N_T D_o	v_{11-6}	v_{6-1}	wind	II.MS P	II.MS PL
HOFFMANN	4 17,18 5 17,35 6 17,42	9,26 9,49 9,63	10,25 9,60 10,10	1,1 -0,2 0,6	16,58	12
BANKS	1 17,08 2 16,72 3 17,18	9,77 9,75 9,84	10,75 10,06 10,78	0,8 0,7 0,4	16,37	Q/19/
AGBEBAKU	6 17,18	10,40	10,37	1,4	15,66	Q/27/
CONLEY	2 16,91 3 17,13 5 17,05	10,48 9,84 9,75	10,78 10,59 10,55	3,3 1,6 -0,9	17,67	2

PL - placing
Q - performance in qualification

TABLE 2

MARKOV BUL



	D	NS	V1	V2	W
→ F	17.70	23	10.27	10.55	2.14
→ F	17.92	23	10.26	10.62	1.57
V	17.73	23	10.35	10.46	1.81

D - PERFORMANCE(m)
NS - NUMBER OF RUN-UP STEPS
V1 - RUN-UP SPEED 11-6m (m/s)
V2 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)

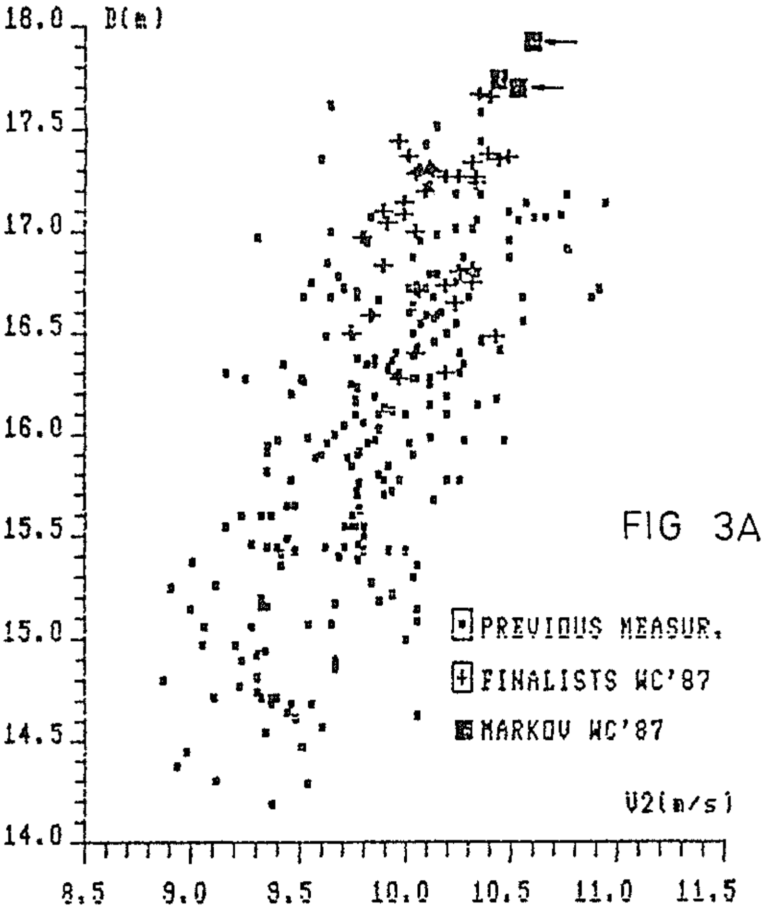


FIG 3A

CONLEY USA

F - FILMING ANALYSIS

V. - VIDEO ANALYSIS

	D	NS	V1	V2	W
→ F	17.65	20	10.35	10.42	0.91
→ F	17.67	20	10.31	10.37	-1.00
V	17.34	20	10.35	10.33	4.32
V	17.37	20	10.33	10.50	1.89

D - PERFORMANCE(m)
NS - NUMBER OF RUN-UP STEPS
V1 - RUN-UP SPEED 11-6m (m/s)
V2 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)

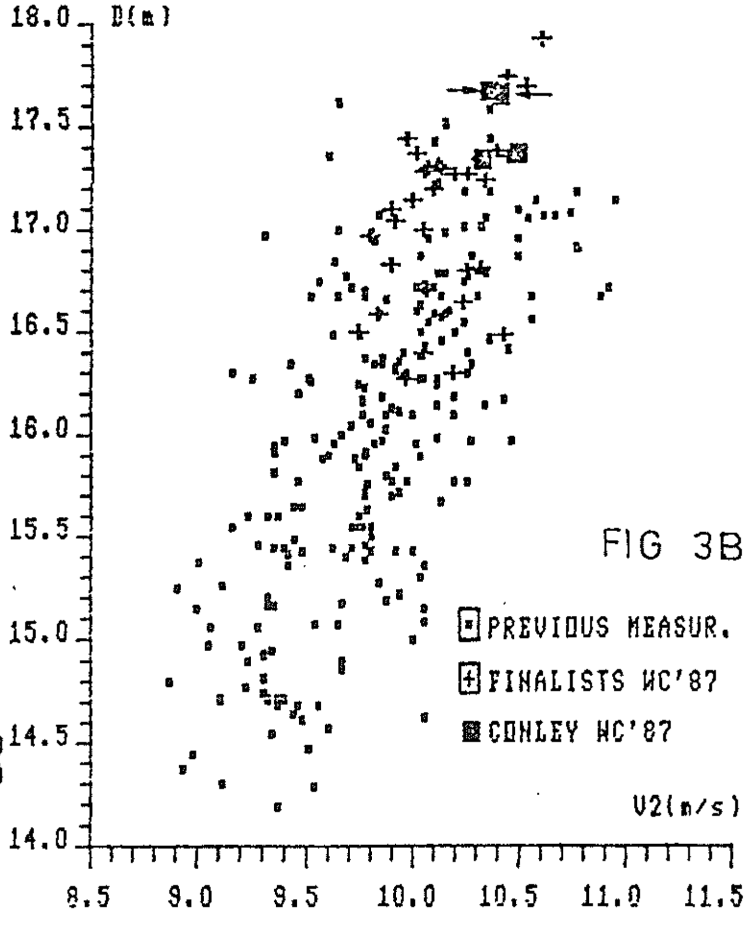
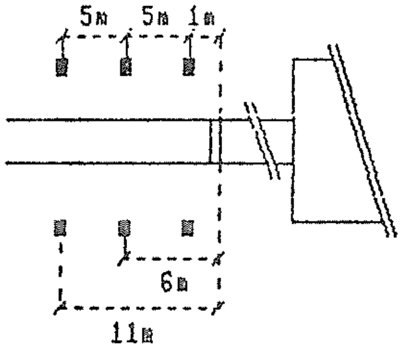


FIG 3B

SAKIRKIN URS



	D	NS	V1	V2	W
F	17.03	17	9.42	9.92	-2.21

D - PERFORMANCE(m)
NS - NUMBER OF RUN-UP STEPS
V1 - RUN-UP SPEED 11-6m (m/s)
V2 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)

V	17.36	17	9.54	10.02	1.41
V	17.31	17	9.67	10.12	2.71
V	17.29	17	9.47	10.14	1.26
V	17.43	17	9.62	9.98	1.34

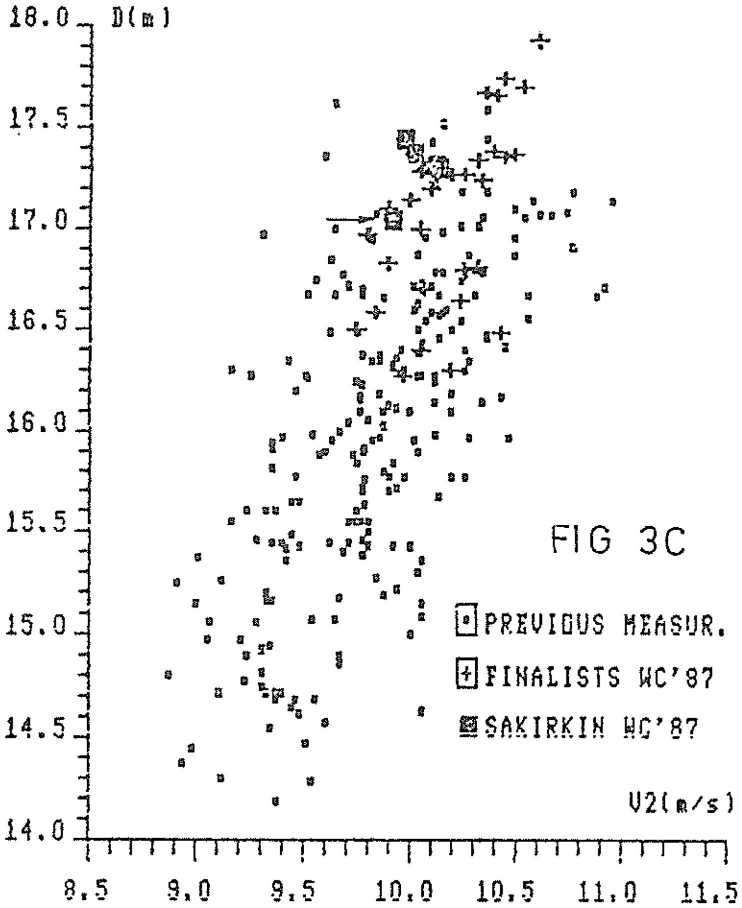


FIG 3C

KOVALENKO URS

F - FILMING ANALYSIS

V - VIDEO ANALYSIS

	D	NS	V1	V2	W
F	17.38	18	10.14	10.40	-1.00

D - PERFORMANCE(m)
NS - NUMBER OF RUN-UP STEPS
V1 - RUN-UP SPEED 11-6m (m/s)
V2 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)

V	16.81	18	9.94	10.33	2.13
V	16.99	18	9.82	10.06	0.17

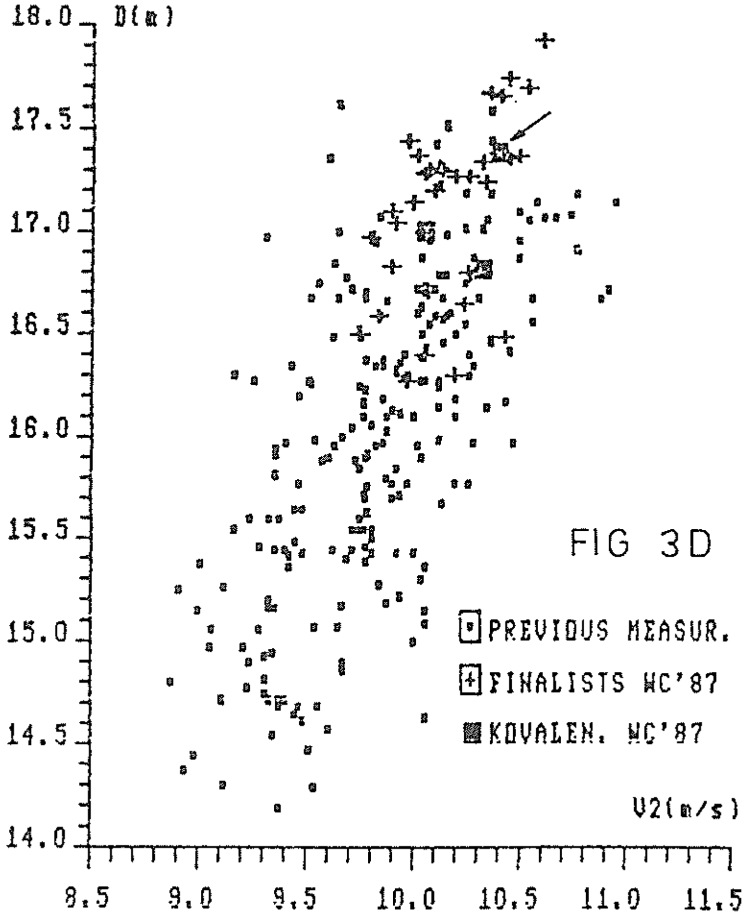


FIG 3D

TIME CHARACTERISTICS OF RUN-UP

/STRIDE FREQUENCY IN THREE LAST STEPS AND RUN-UP VELOCITY/

TABLE 3

Name	N_T	D_E	f_{n-2}	f_{n-1}	f_n	v_{11-6}	v_{6-1}	wind
MARKOV	1	17,81	4,35	4,55	5,00	10,27	10,55	2,14
	3	x	3,85	4,55	5,00	10,42	10,53	
	4	17,96	4,17	4,55	4,76	10,26	10,62	1,57
	5	x	3,70	4,55	5,00	10,40	10,55	
CONLEY	1	17,37	5,00	4,76	5,00	10,35	10,33	4,32
	4	17,72	4,54	4,54	5,00	10,35	10,42	0,91
	5	x	4,54	4,16	5,26	10,66	10,06	
	6	17,70				10,31	10,37	-1,00
SAKIRKIN	1	17,18	4,54	4,54	4,76	9,42	9,92	-2,21
	4	x	4,35	4,35	4,76	9,60	9,77	
KOVALENKO	1	17,40	4,00	4,35	5,55	10,14	10,40	-1,00
	4	x	4,00	4,35	5,26	9,84	10,00	
	6	17,11				9,82	10,06	0,17
PASTUSINSKI	1	17,45	4,00	4,35	5,00	10,22	10,27	0,81
	6	17,34				10,06	10,20	-0,77
TAIWO	1	17,47	4,35	4,76	5,26	9,86	10,08	3,81
BOUSCHEN	1	x		4,16	5,00	10,20	10,20	
	2	17,34	4,54	4,35	5,26	10,29	10,35	3,58
	5	16,83	4,35	4,00	5,00	10,08	10,33	1,58
	6	16,84				10,02	10,20	-0,17
PROCENKO	1	x	4,16	3,85	4,54	9,52	9,84	
	4	x	4,00	4,35	4,76	9,94	10,31	
	6	16,33				9,80	10,20	0,23
ELLIOT	1	x	4,54	4,00	4,76	10,00	10,18	
SLANAŘ	1	x	4,54	4,54	5,00	10,20	9,84	
BADINELLI	1	16,75	4,35	4,35	5,55	10,00	10,25	0,50
HOFFMANN	1	16,61	4,54	4,54	5,55	9,69	9,75	1,51
	2	x	4,16	4,16		9,49	9,92	
YAMASHITA	1	x	4,35	4,35	5,00	10,04	10,18	

N_T - Number of trial

D_E - Effective distance /m/

f_{n-2} - Frequency in third step from takeoff /number per second/

f_{m-1} - Frequency in penultimate run-up step /number per second/

f_n - Frequency in last run-up /number per second/

v_{11-6} - Average run-up velocity 11-6m from takeoff board /m/s/

v_{6-1} - Average run-up velocity 6-1m from takeoff board /m/s/

4.1.2. Stride frequency

Basic information concerning the stride rhythm during the run-up can be obtained from the stride frequency. We concentrated only on the final part of the run-up.

By means of film analysis we fixed the duration of the last three strides of the run-up (sum of the support and flight phases of each stride). The timed data were computed into the number of strides per second (f_{n-2} = stride frequency in the third step before takeoff, f_{n-1} = the same in penultimate step of the run-up, f_n = the same in the last step of the run-up).

Triple jumpers tend towards modifying the rhythm of the last three strides by increasing stride frequency. This means that the duration of the last three strides is successively reduced. This can be proved by watching top - level athletes. (Table 3)

Four athletes from among the 13 finalists in Rome clearly increased stride frequency in the last three strides, reducing the duration of the strides (Markov, Kovalenko, Pastusinski and Taiwo for instance had stride frequency of 4.35 - 4.55 - 5.00 strides per second).

1st WORLD JUNIOR CHAMPIONSHIP - ATHENS 1986

Name	N_T	D_E	f_{n-2}	f_{n-1}	f_n	v_{11-6}	v_{6-1}	wind
PARIGIN	3	16,84	4,08	4,00	4,16	9,73	10,16	0,95
LOPEZ	2	16,82	4,34	4,16	4,34	9,88	10,10	1,95
DIMITROV	2	16,38	4,54	4,54	4,16	9,43	9,80	1,10
DU	1	16,09	4,54	4,16	5,00	9,88	10,06	1,35
MRŠTÍK	5	15,97	4,00	4,00	4,54	9,40	9,56	0,70

TABLE 4

The others had an equal frequency in the second and third stride, and a higher rate in the last one (Sakirkin, Slanar, Badinelli, Hoffmann and Yamashita, for instance 4.35 - 4.35 - 4.76 strides per second respectively). A decrease in stride frequency in the penultimate stride (for instance 4.54 - 4.16 - 5.26 strides per second) was found with the rest of the finalists (Conley, Bouschen, Procenko and Elliot).

All the finalists of the II WC had a higher frequency in the last stride before takeoff than in the third stride before takeoff. The same thing cannot be said about the juniors category. Most of the juniors athletes have not fully mastered the technique of preparing for the takeoff. A clear indication is an example from the 1st WJC (Table 4). The variability of the stride frequency is notably higher both in each individual athlete's trial and between each of the athletes. This is also true for the characteristics for run-up (stride frequency in three last steps and run-up velocity).

4.1.3. Pre-takeoff rhythm

From the pre-takeoff rhythm and its changes we can judge the importance of technique modifications of the final phase of the approach run.

There is evidence for the close dependence of the external and internal characteristics of the movement.

A detailed time-analysis of the last three run-up strides, focused on the duration of the support and flight phases, revealed the following facts:

- duration of support phases is equal (Bouschen, Procenko, Elliot, Yamashita) or is increased (Markov, Conley, Pastusinski, Taiwo, Sakirkin, Slanar, Badinelli); uneven data were found with Kovalenko and Hoffmann;
- duration of flight phases of the finalists is gradually reduced (Markov, Sakirkin, Kovalenko, Pastusinski, Taiwo, Slanar, Badinelli, Hoffmann, Yamashita), or is in correspondence with the rhythm: medium, longest, shortest (Conley, Bouschen, Procenko, Elliot).

The execution of the last three strides for the jumpers in the triple jump final approximated the pre-takeoff rhythm of long jumpers. At touchdown, the jumper in the last two strides is near to the vertical moment position(Kovalenko, Pastusinsky, Slanar). Badinelli, Conley, Taiwo, Pastusinski and Yamashita displayed uncompleted takeoffs, as a result of a reduction of the flight phases of the pre-takeoff strides.

Except for Slanar, no other athlete reduced the running speed just before the first takeoff through the rhythmical modification of the last strides (in the section 6 - 1 m before the takeoff line). See Table 3. The fact that the run-up speed increases until the first takeoff was proved both in Helsinki and Rome. Even so it cannot be said that all the competitors fully exploit their maximum speed. For instance Conley, a finalist at Rome both in the triple and long jump, reached in the triple jump an average speed 0.2 m/s lower than in long jump.

4.2. Geometric data of takeoffs

In this section time and trajectory characteristics of body CM and angle parameters of all three takeoffs are presented.
The data are:

- body CM position at touchdouwn and takeoff and its trajectory during interaction with the ground;
- distance of the perpendicular from the suppport point (defined by the position of the heel or toe) at the instant of touchdown and takeoff;
- angles of touchdown, takeoff and initial flight;
- takeoff time ;
- horizontal distance from CM to takeoff toe.

In this report we present the following additional data concerning each takeoff:

- sideward deviations of body CM and CM of limbs during takeoff;
- vertical changes in body CM positions and CM of limbs during takeoff;
- functional course of changes in the knee-joint angle (AJK) during takeoff;
- functional course of the thighs angle (ABT) during takeoff;
- time and angle data in the moment of vertical (the body CM is located exactly over the CM of the takeoff foot) and in the momet of the amortization (the greatest flexion at the knee joint of the takeof leg).

This information was obtained by the three-dimensional side projection (Figs 4, 11, 18A to C), projection into elevation (Figs 5, 12, 19 A-C) and projection into the ground plan (Figs 6. 13 20 A to C). They show the execution of takeoffs and facilitate visual judgement (together with Fig. 8 A to G) of the sideward deviations of body CMs of limbs, which may affect the dynamic stability of the jumper.

4.2.1. First take off (Hop)

The body CM at the instant of touchdown is, in all athletes below the 1 m level. Pastusinski is the only exception (his 201 cm make him very tall indeed). The highest value of body CM-elevation was in Sakirkin's hop: 0.21 m. This also was the longest hop in the set of values concerned (6.45 m); initial flight angle 16.8 ^{o}.

Ground projection of the takeoff (Fig. 6 A to C) the CMs of limbs (LL, RL, LA, RA) and the body CM (26) (Fig. 8 A, B, C, D, F, K, G) reveal graphically the level of takeoff execution. Next to Sakirkin's hop, Conley and Kovalenko had an efficient takeoff in the hop. That is shown by the shift of body CM and CM of the takeoff leg in the dircetion of the x-axis (i.e. in the direction of the hop). During takeoff, only minimal sideward/frontal deviation 0 - 2 (max. 3) cm between these CMs was observed.

Conversely, in Taiwo's, Bouschen's and Elliot's takeoffs, significant sideward deviations occurred. Taiwo and Elliot probably became aware of takeoff inaccuracy in flight. Following poor takeoffs athletes usually try to keep the dynamic balance by compensatory movements of the extremities. The sideward deviation of the takeoff-leg CM and the body CM (26) rises to 5 - 8 cm and even more. In some cases the athlete has to compensate for the loss of stability in the flight phase.

In all cases observed the lifting of CM starts just before the end of knee flexion (before the instant of amortisation). At this moment, or, rarely, near this point, the thigh position starts changing (the swinging leg thigh passes the thigh of the takeoff leg). The lift of the CM of the swinging leg starts before the end of the amortization phase.

In most trials, in the hop, the instant of the vertical position (body CM is above the centre of the takeoff foot) is identical with the instant of amortization (Table 6 AKJ_a, AKJ_v, and Table 5 - t_v, t_a). The only exception is Kovalenko: the instant of the vertical was reached by 0.015 s sooner.

The angle-magnitudes between the thighs at the instant of touchdown and takeoff, ABT_{TD}, ABT_{TO}, show the extent of the action of the swinging leg in takeoff.

In the hop Pastusinski (Table 6) was the most active of all the finalists; but his takeoff was the slowest of all (takeoff time t_1 = 0.135 s).

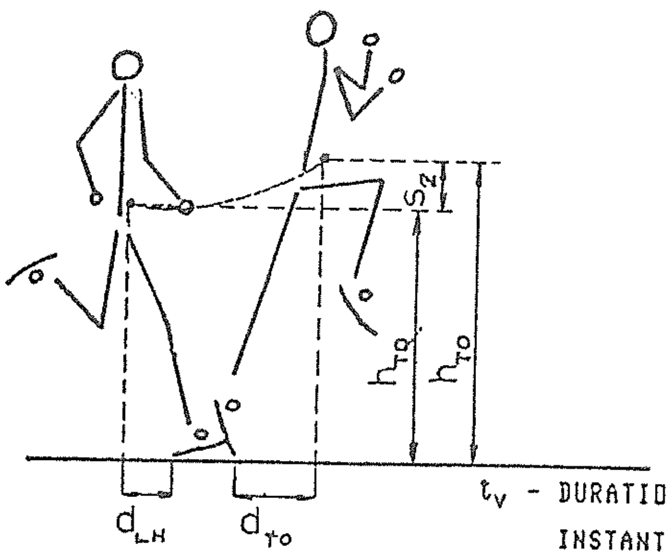
Takeoff times range between 0.1 - 0.135 s. The smallest touchdown angle - ATD_A was measured in Conley, Bouschen (107°) and Taiwo (110°). This correlates with the shortest forward shift of the sole at touchdown (d_{LH}) in Conley (0.31 m) and Taiwo (0.34 m). Together with Bouschen, they also had the shortest hop length. The forward shift of the body CM in front of the takeoff-spot clearly influences the takeoff angle.

Shortest horizontal distance between the body CM and the toe of the takeoff foot was measured in Markov (0.39 m) and Taiwo (0.37 m); conversely, these two have the largest takeoff angle (70°). The initial flight angle ranges between 13 - 14°. Only Sakirkin (16.8°) and Elliot (12.3°) differ from the others.

TIME DATA AND TRAJECTORY CHARACTERISTIC OF BODY CM - 1ST TAKEOFF (HOP)

	D_o	D_E	d_1	H_B	h_{TD}	h_{TO}	S_y	S_z	d_{LH}	d_{TO}	t_v	t_a	t_1
MARKOV	17.92	17.96	6.54	185	0.96		-0.08		0.40	0.39	0.055	0.05	0.11
CONLEY	17.67	17.70	6.11	186	0.96	1.12	-0.02	0.16	0.31	0.54	0.05	0.055	0.12
SAKIRKIN	17.03	17.18	6.45	183	0.90	1.11	-0.04	0.21	0.36	0.47	0.05	0.055	0.12
KOVALENKO	17.38	17.40	6.17	181	0.96		0.00		0.40	0.57	0.05	0.065	0.115
PASTUSINSKI	17.26	17.34	6.40	201	1.02	1.20	0.00	0.18	0.45	0,55	0.05	0.05	0.135
TAIWO	17.29	17.43	6.03	180	0.97	1.08	-0.05	0.11	0.34	0.37	0.05	0.055	0.105
BOUSÇHEN	17.26	17.34	5.78	181							0,045	0,045	0,10
ELLIOTT	x			183	0.93	1.05	-0.14	0.12	0.42	0.45	0.055	0.06	0.12

TABLE 5



t_v - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE MOMENT OF VERTICAL [s]

t_a - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE INSTANT OF AMORTIZATION [s]

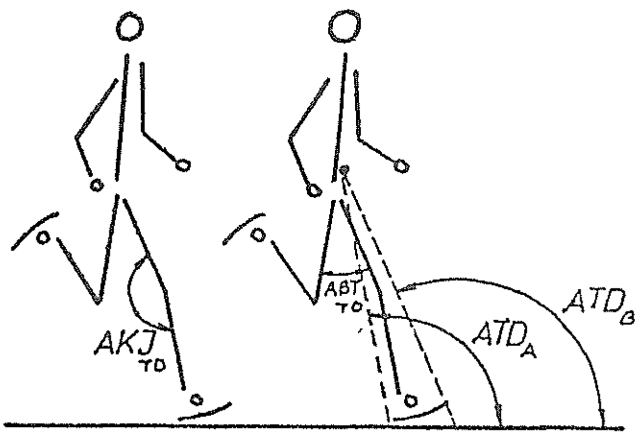
t_1 - DURATION OF THE HOP [s]

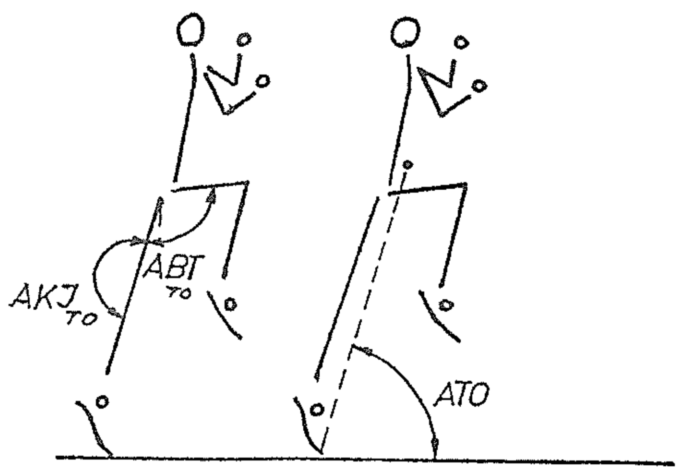
TABLE 6

ANGLE PARAMETERS - 1ST TAKEOFF (HOP)

	D_o	D_E	d_1	ATD_A	ATD_B	AKJ_{TD}	AKJ_A	AKJ_V	AKJ_{TO}	ABT_{TD}	ABT_{TO}	ATO	IFA
MARKOV	17.92	17.96	6.54	112	124	161	148	148	172	-58	91	70	14.1
CONLEY	17.67	17.70	6.11	107	121	153	130	130	157	-53	92	63	14.0
SAKIRKIN	17.03	17.18	6.45	111		152	134	135	156	-60	83	66	16.8
KOVALENKO	17.38	17.40	6.17	113	124	158	129	132	157	-62	95	66	13.3
PASTUSINSKI	17.26	17.34	6.40	113	126	156	139	139	170	-53	111	64	13.0
TAIWO	17.29	17.47	6.03	110	122	150	133	133	155	-54	82	70	13.6
BOUSCHEN	17.26	17.34	5.78	107		155	141	141		-44	112		
ELLIOTT	X			114	126	159	135	138	160	-58	82	67	12.3

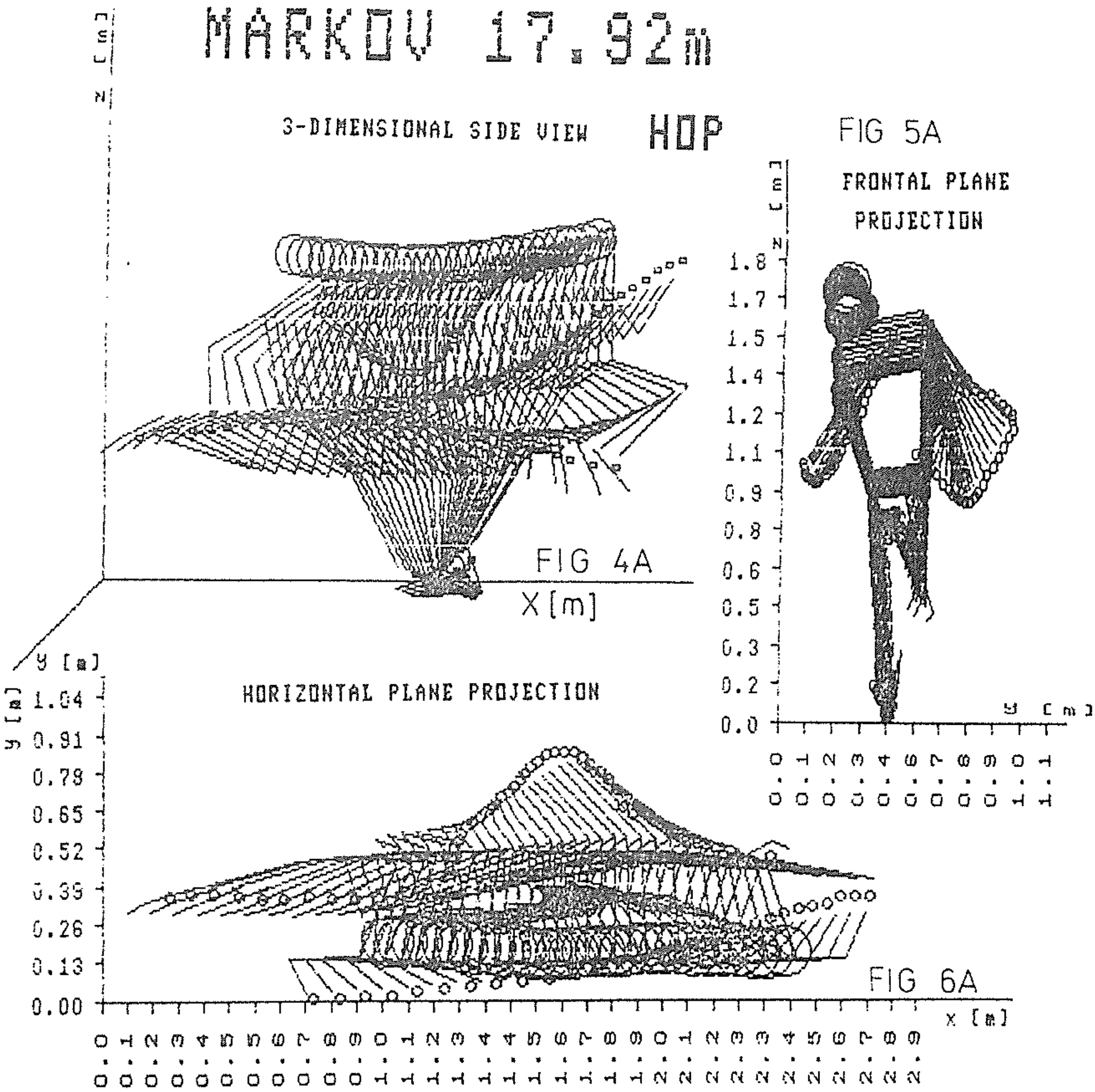
THE ANGLES AKJ_{TD}, AKJ_A, AKJ_V, AKJ_{TO} (DESCRIPTION SEE FIG.)
ARE LIMITED BY CONNECTING LINES OF THE CENTERS OF ROTATION IN HIP,
KNEE AND ANGLE JOINTS.
THE QUESTION IS ABOUT SPACE ANGLE, WHICH, IN EXTENSION OF KNEE JOINT,
DOES NOT REACH 180°(0°).
THE ANGLE BETWEEEN THE AXIS OF FEMUR AND TIBIA IS GREATER THAN ANGLE
DEFINED ABOVE (DIFFERENCE IN PLANE PROJECTION CCA (5)
IN SPACE PROJECTION 8-12)





AKJ_A - ANGLE AT KNEE JOINT
AT THE AMORTIZATION [°]

AKJ_V - ANGLE AT KNEE JOINT
AT THE VERTICAL MOMENT [°]



3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
133	0.02	26	5224	-108	1091
143	0.07	26	5772	-127	1075
155	0.13	26	6403	-171	1184

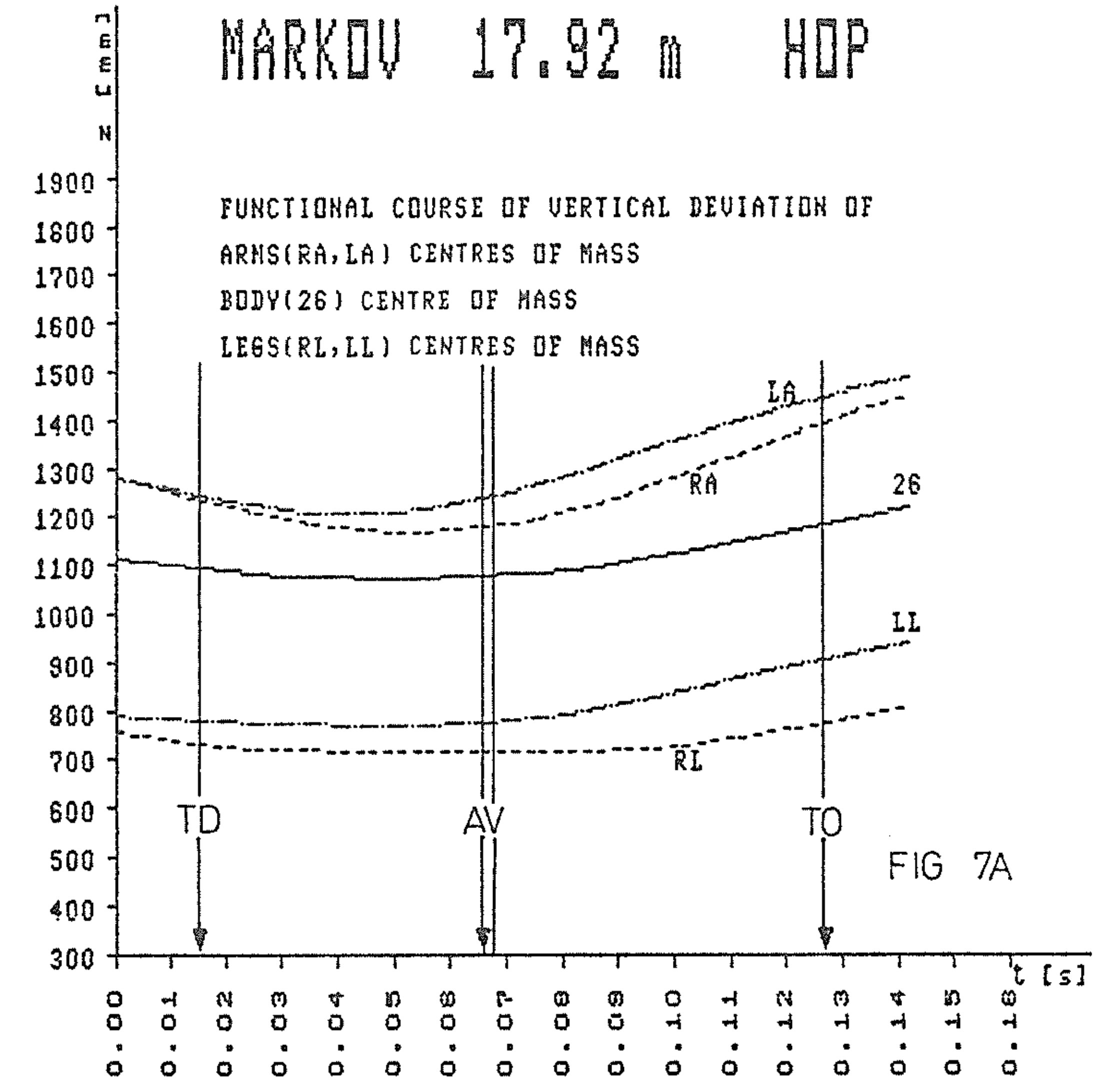

MARKOV 17.92 m HOP
Z [mm]
FUNCTIONAL COURSE OF VERTICAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS
LA
RA
26
LL
RL
TD
AV
TO
t [s]

FIG 7A

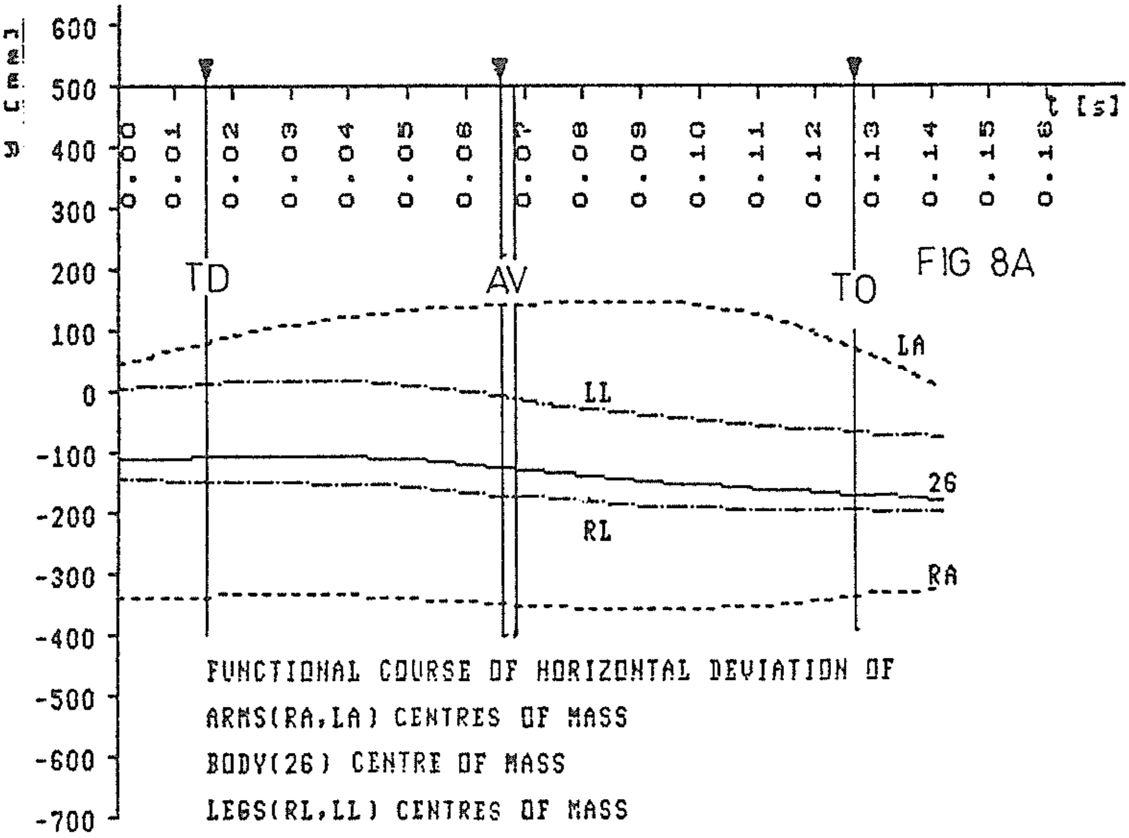

y [mm]
t [s]
TD
AV
TO
LA
LL
26
RL
RA
FUNCTIONAL COURSE OF HORIZONTAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS

FIG 8A

CONLEY 17.67 m

HOP

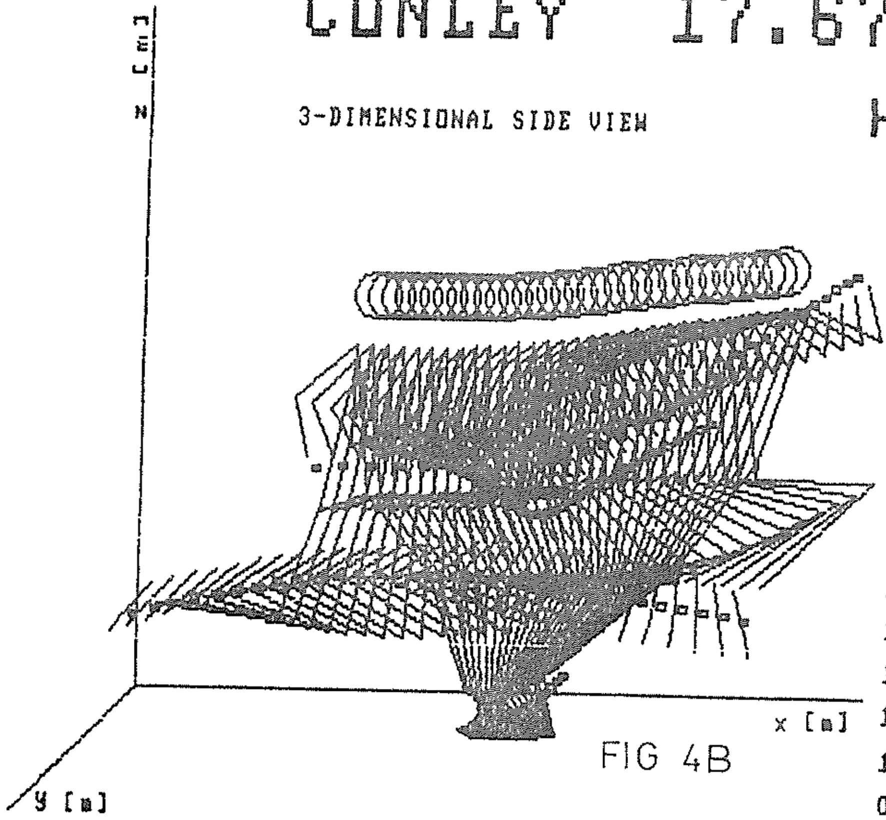


FIG 4B

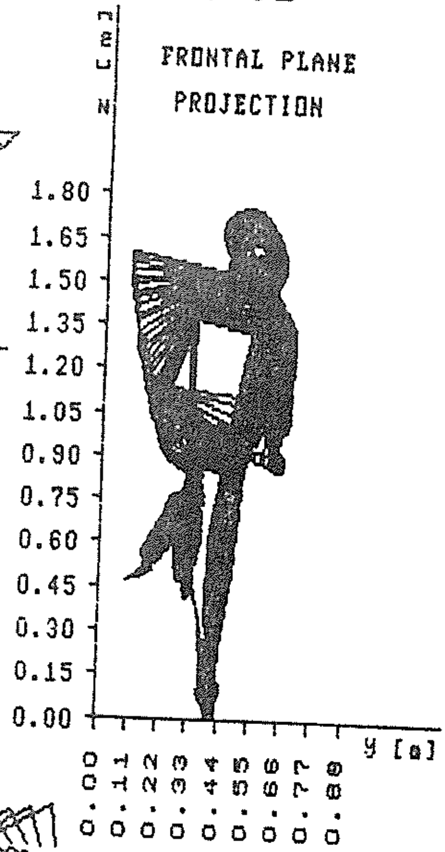


FIG 5B

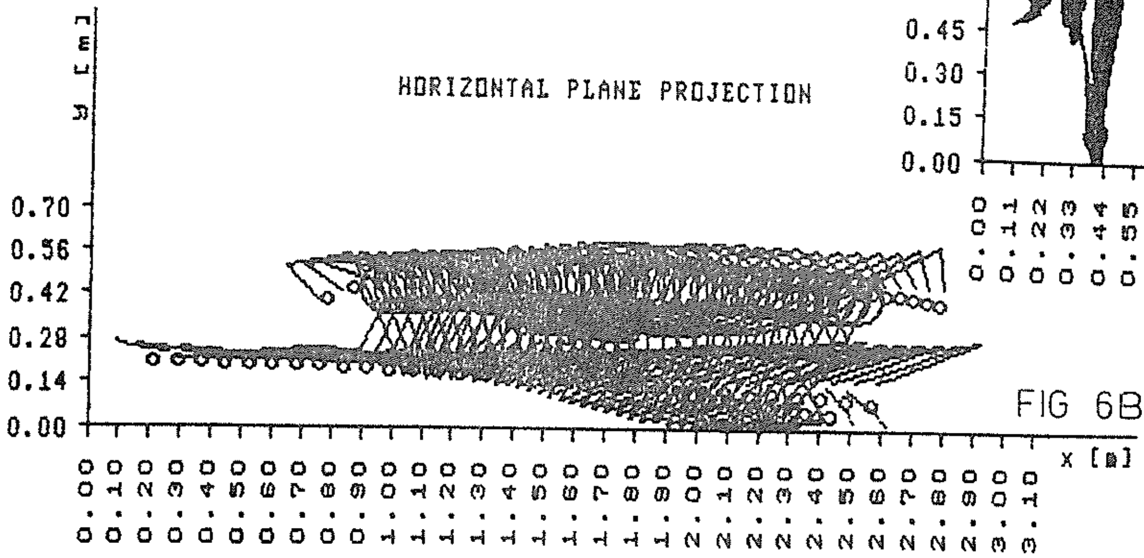


FIG 6B

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
120	0.02	26	5417	-292	962
131	0.07	26	5954	-284	976
144	0.14	26	6594	-311	1120

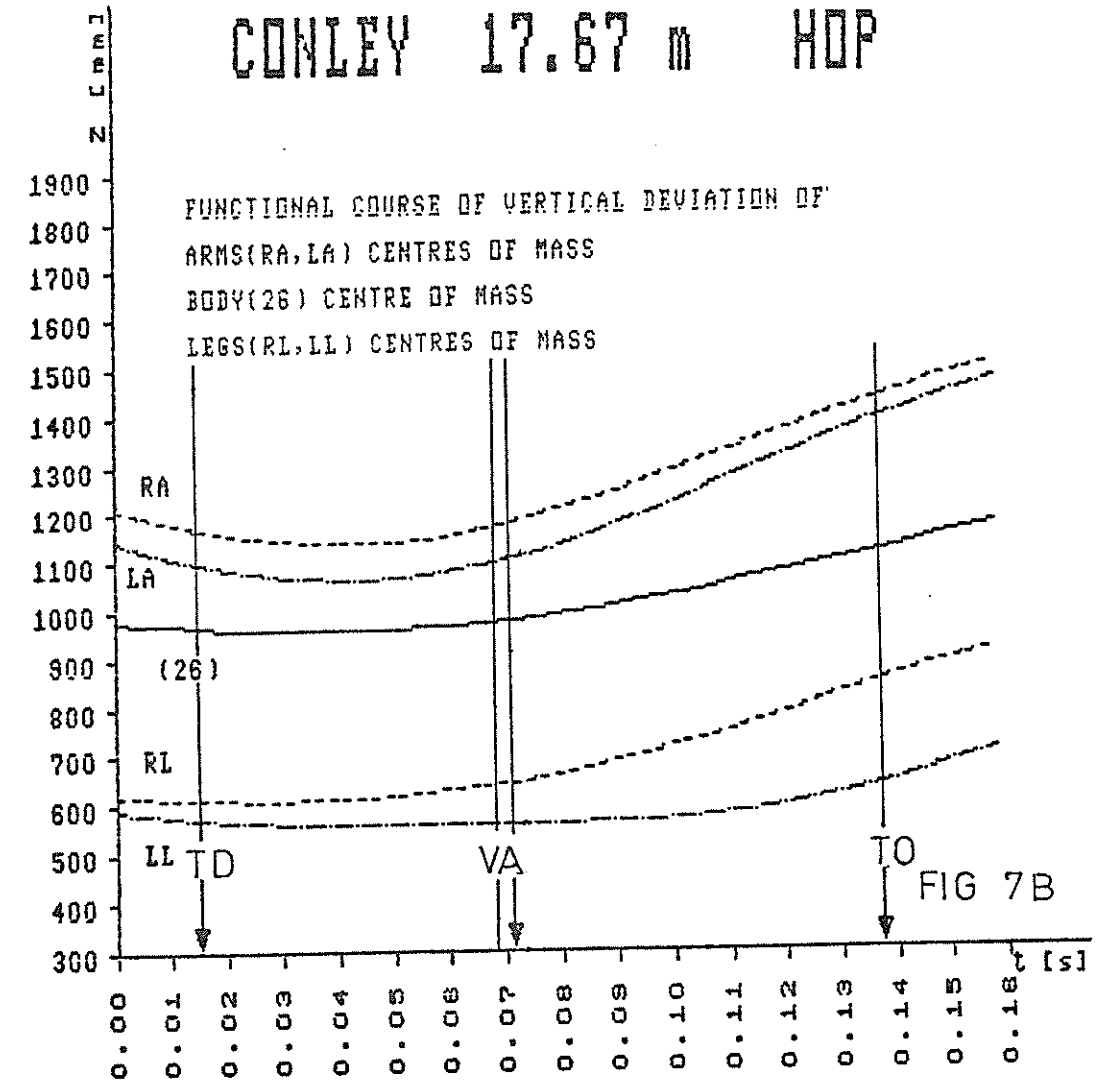

CONLEY 17.67 m HOP
Z [mm]
FUNCTIONAL COURSE OF VERTICAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
RA
LA
(26)
RL
LL
TD
VA
TO
t [s]
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16

FIG 7B

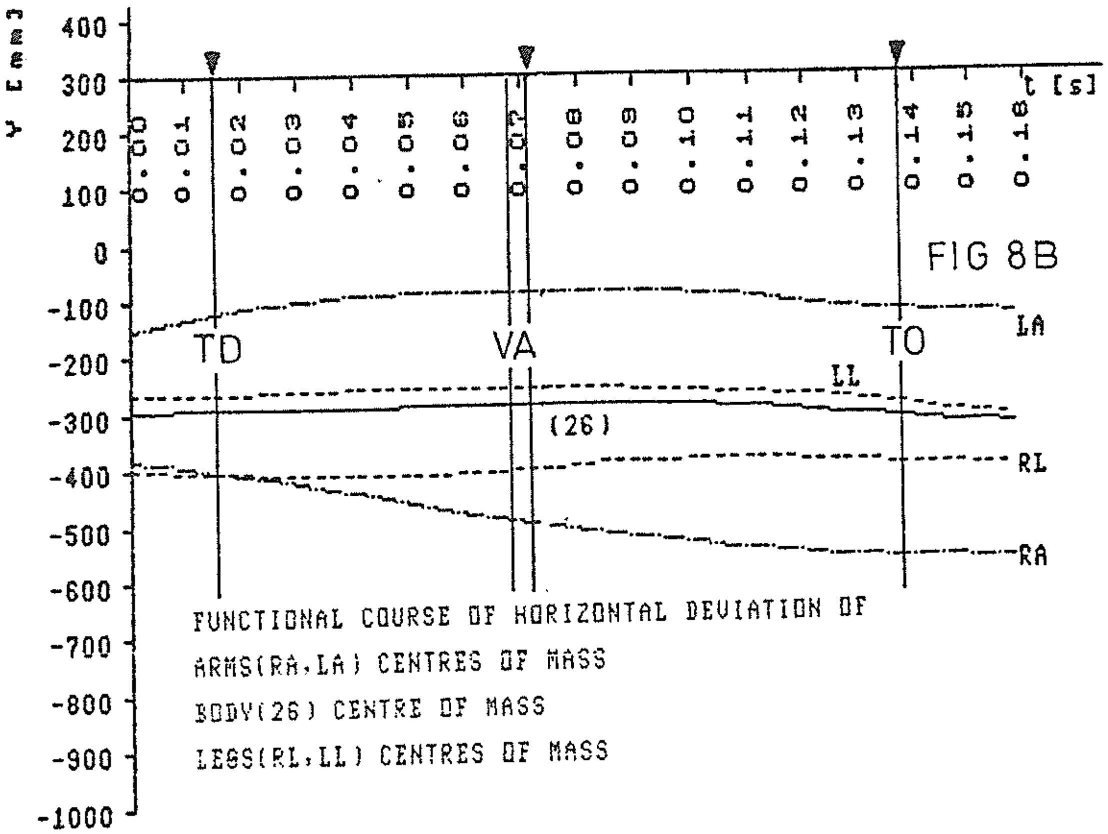

Y [mm]
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
t [s]
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
TD
VA
TO
LA
LL
(26)
RL
RA
FUNCTIONAL COURSE OF HORIZONTAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS

FIG 8B

SAKIRKIN 17.03 m

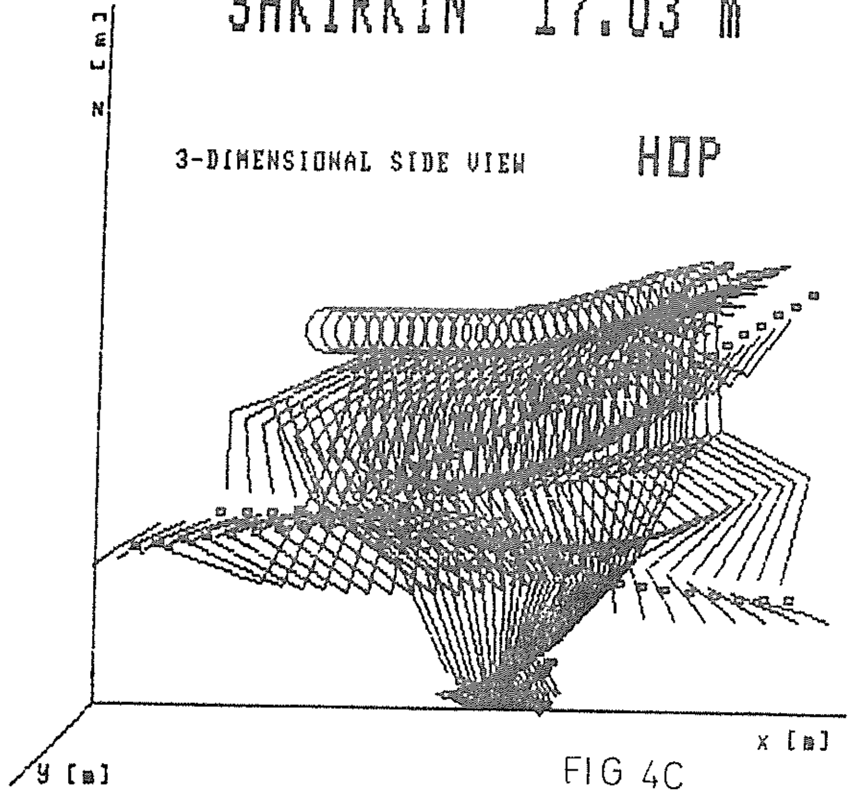


FIG 4C

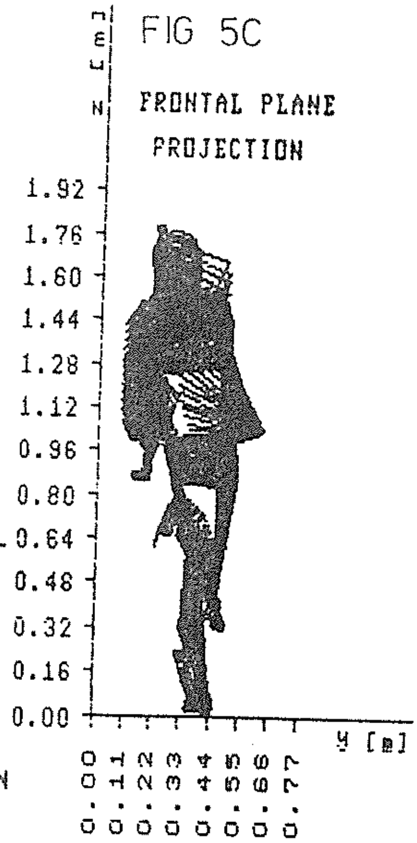


FIG 5C

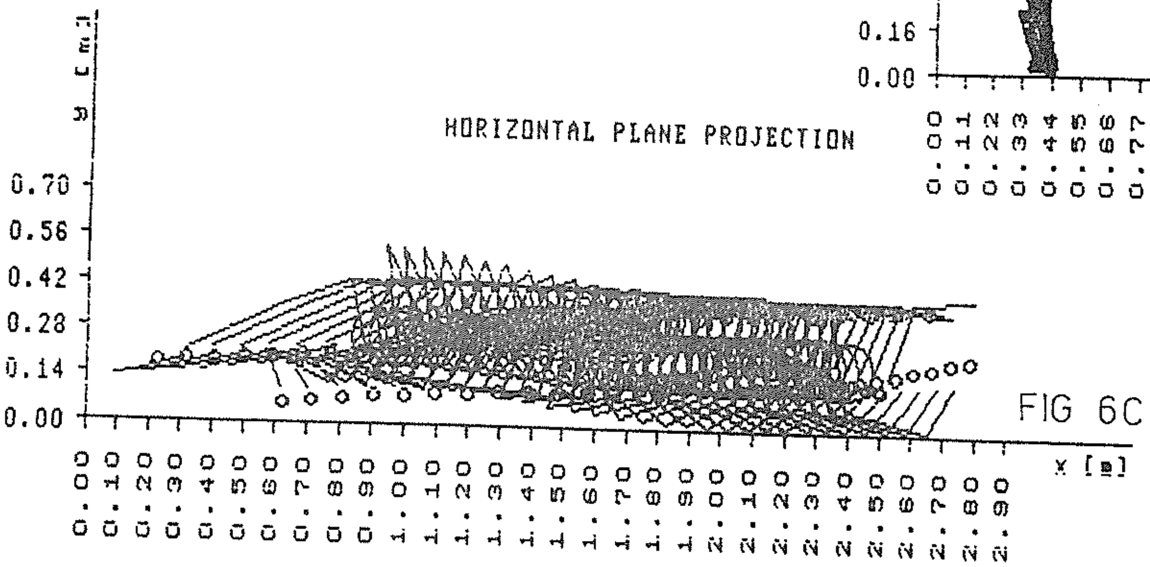
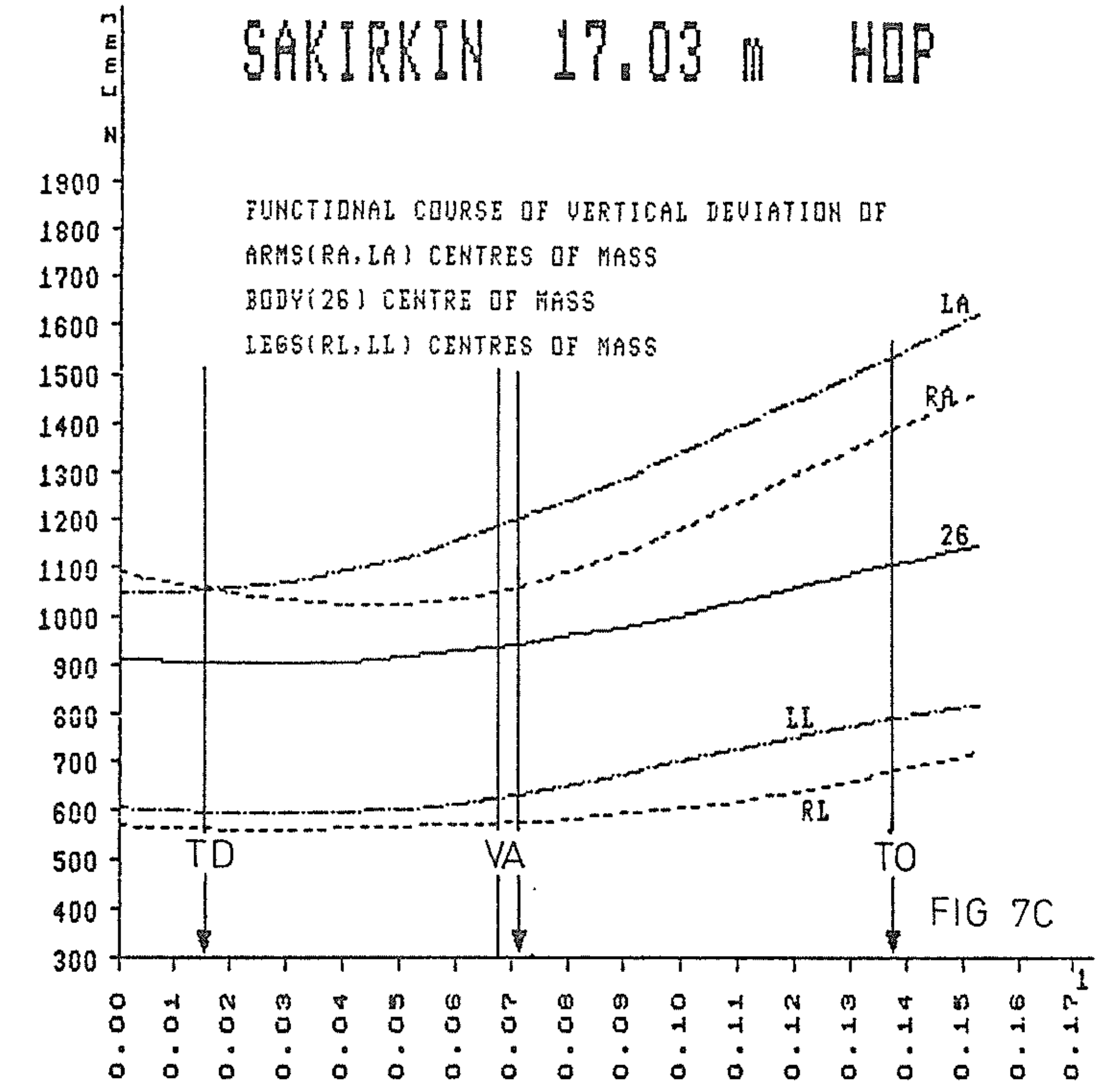


FIG 6C

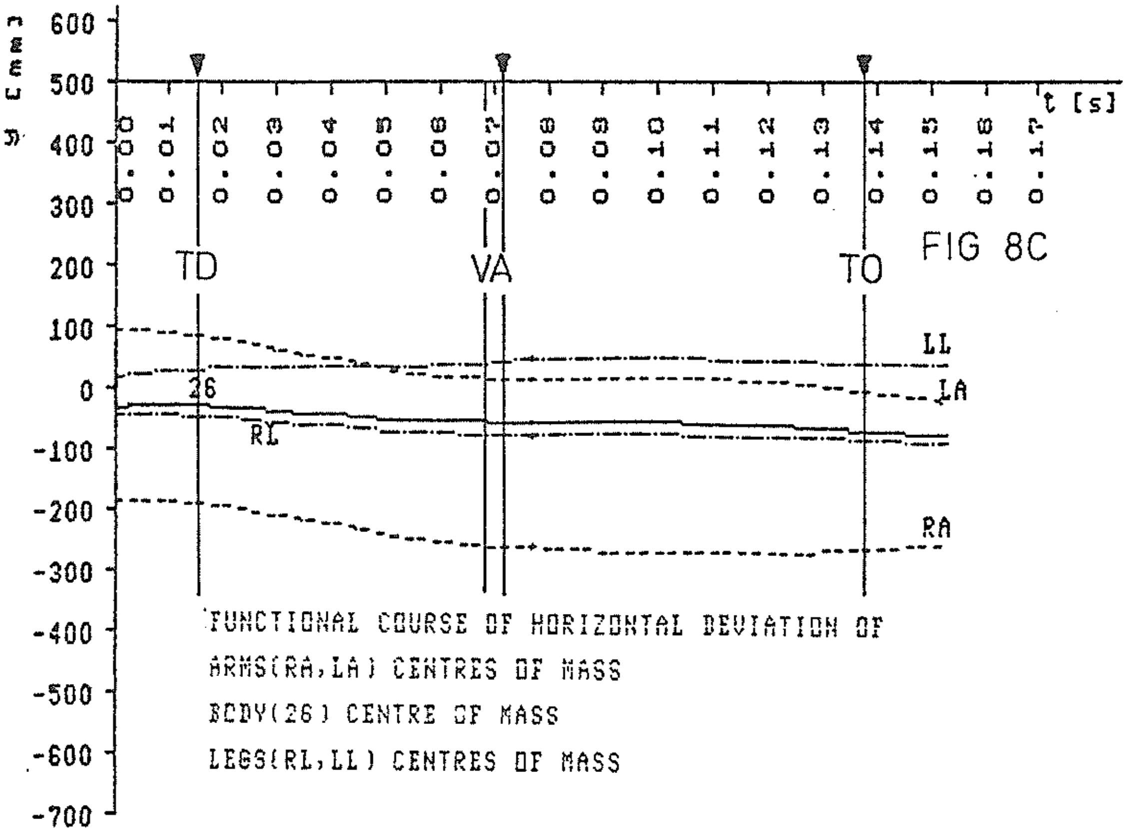
3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
126	0.02	26	5182	-31	903
137	0.07	26	5807	-57	941
150	0.14	26	6411	-71	1106



Z [mm]
SAKIRKIN 17.03 m HOP
FUNCTIONAL COURSE OF VERTICAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS
LA
RA
26
LL
RL
TD
VA
TO
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17

FIG 7C



y [mm]
t [s]
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17
TD
VA
TO
LL
LA
26
RL
RA
FUNCTIONAL COURSE OF HORIZONTAL DEVIATION OF
ARMS(RA,LA) CENTRES OF MASS
BODY(26) CENTRE OF MASS
LEGS(RL,LL) CENTRES OF MASS

FIG 8C

4.2.2. Second takeoff (Step)

The height of body CM at the instant of touchdown ranges in most jumpers between 0.94 - 0.96 m, again with the exception of Pastusinski (1.04 m) and Taiwo (1.01 m). The mean touchdown angle (Table 8) is greater than in the first and third takeoffs. This corresponds with the longer horizontal distance of body CM from the heel of the takeoff leg at the instant of touchdown. The maximum forward shifts at the instant of touchdown are 0.23 to 0.24 m longer than in the other takeoffs.

The elevation of both particular and total body CM in Markov still starts before the instant of amortization, while in others it starts later on.

In most of the second takeoffs the moment of amortization (AKJ_a = min.) occurs after the moment of the vertical. The time-lag between both moments is evident in Sakirkin (0.02 s) and Kovalenko (0.015 s). Markov and Taiwo repeat the course of the first takeoff, i.e. the synchronization of the moments of the vertical and amortization ($AKJ_a = AKJ_v$ and $t_a = t_v$). In Bouschen's case the observed moments follow each other in reverse order.

The extent of the movement of the swinging leg increases in all the athletes except Markov. This is more evident in Sakirkin, Kovalenko, Bouschen and Pastusinski.

The minimum changes of the takeoff-leg knee flexion in Markov correspond with the minimum downward shift of the CM in the amortization phase and with the reduced takeoff time.

The greatest sideward deviations (S_y) were found in the second takeoff - indicating the difficulties of mastering this triple jump phase properly.

The highest elevation of the CM achieved in the takeoff-course (0.19 m) is 2 to 3 cm lower than in the other takeoffs.

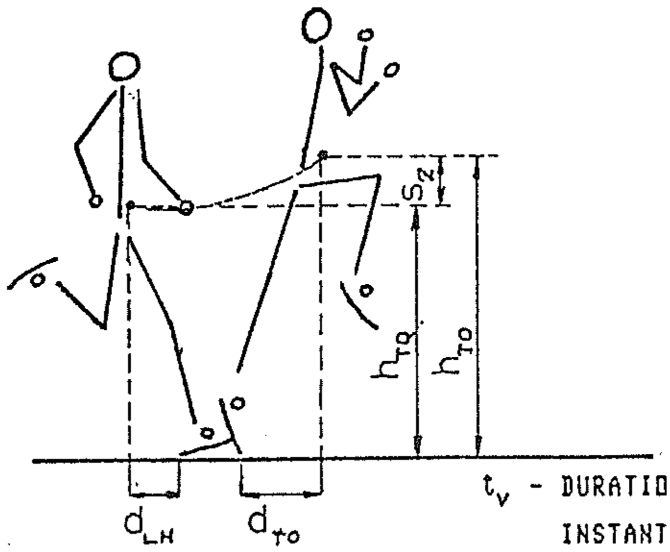
The horizontal forward shift of the body CM, in relation to the takeoff spot undoubtedly increases (variation range 0.47 -0.69 m).

The support time is also extended (first takeoff 0.10 - 0.135 s, second takeoff 0.135 - 0.18 s). That goes for the time necessary for reaching the vertical moment (first takeoff - 0.045 - 0.055 s, second takeoff - 0.05 - 0.075 s) and the amortization (first takeoff 0.045 - 0.065 s, second takeoff 0.05 - 0.09 s). Average takeoff angle 59.6^{o}; initial flight angle 13.3^{o}.

TIME DATA AND TRAJECTORY CHARACTERISTIC OF BODY CM - 2ND TAKEOFF (STEP)

	D_o	D_E	d_2	H_B	h_{TD}	h_{TO}	S_y	S_z	d_{LH}	d_{TO}	t_v	t_a	t_2
MARKOV	17.92	17.96	5.30	185	0.96	1.10	-0.01	0.14	0.32	0.66	0.05	0.05	0.135
CONLEY	17.67	17.70	5.52	186	0.94		-0.03		0.65	0.68	0.075	0.075	0.155
SAKIRKIN	17.03	17.18	5.15	183	0.96		-0.06		0.37	0.63	0.075	0.055	0.15
KOVALENKO	17.38	17.40	5.58	181	0.94		0.09		0.68	0.53	0.07	0.055	0.14
PASTUSINSKI	17.26	17.34	5.22	201	1.04	1.15	0.07	0.11	0.51	0.69	0.08	0.09	0.18
TAIWO	17.29	17.43	5.42	180	1.01	1.13	0.04	0.12	0.42	0.53	0.065	0.065	0.145
BOUSCHEN	17.26	17.34	5.70	181	0.94	1.13	0.03	0.19	0.44	0.47	0.065	0.06	0.135
ELLIOTT	X		6.04	183	0.94	1.08	0.03	0.14	0.48	0.69	0.055	0.065	0.165

TABLE 7



t_v - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE MOMENT OF VERTICAL [s]

t_a - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE INSTANT OF AMORTIZATION [s]

t_2 - DURATION OF THE STEP [s]

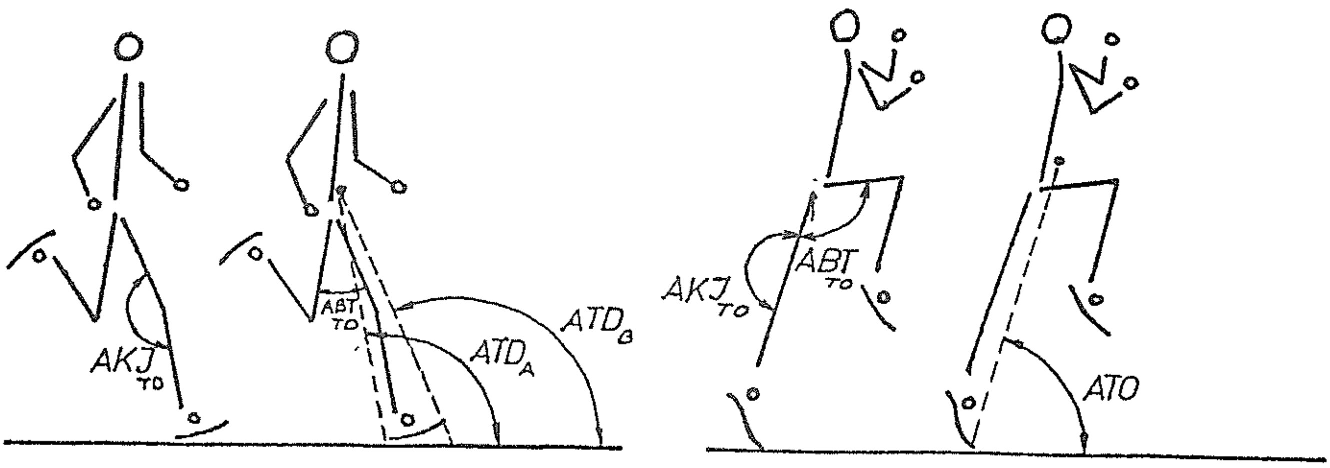
TABLE 8 ANGLE PARAMETERS - 2ND TAKEOFF (STEP)

	D_o	D_E	d_2	ATD_A	ATD_B	AKJ_{TD}	AKJ_A	AKJ_V	AKJ_{TO}	ABT_{TD}	ABT_{TO}	ATO	IFA
MARKOV	17.92	17.96	5.30	108	120	159	151	151	168	-58	91	58	13.2
CONLEY	17.67	17.70	5.52	109		164	134	136	165	-57	93	57	10.0
SAKIRKIN	17.03	17.18	5.15	111		159	125	129	167	-63	98	58	14.2
KOVALENKO	17.38	17.40	5.58	112		160	138	140	172	-69	93	61	
PASTUSINSKI	17.26	17.34	5.22	116	127	158	121	122	165	-63	108	58	15.5
TAIWO	17.29	17.47	5.42	112	124	159	140	140	168	-54	87	63	15.6
BOUSCHEN	17.26	17.34	5.70	115	127	161	139	140		-67	97	66	
ELLIOTT	X			112	128	165	125	133	164	-46	100	56	11.0

THE ANGLES AKJ_{TD}, AKJ_{A}, AKJ_V, AKJ_{TO} (DESCRIPTION SEE FIG.) ARE LIMITED BY CONNECTING LINES OF THE CENTRES IN ROTATION OF HIP, KNEE AND ANGLE JOINTS.

THE QUESTION IS ABOUT SPACE ANGLE, WHICH IN EXTENSION OF KNEE JOINT DOES NOT REACH 180° (0°).

THE ANGLE BETWEEEN THE AXIS OF FEMUR AND TIBIA IS GREATER THAN ANGLE DEFINED ABOVE (DIFFERENCE IN PLANE PROJECTION CCA (5) IN SPACE PROJECTION 8-12)



AKJ_A - ANGLE AT KNEE JOINT AT THE AMORTIZATION [°]

AKJ_V - ANGLE AT KNEE JOINT AT THE VERTICAL MOMENT [°]

MARKOV 17.92 m

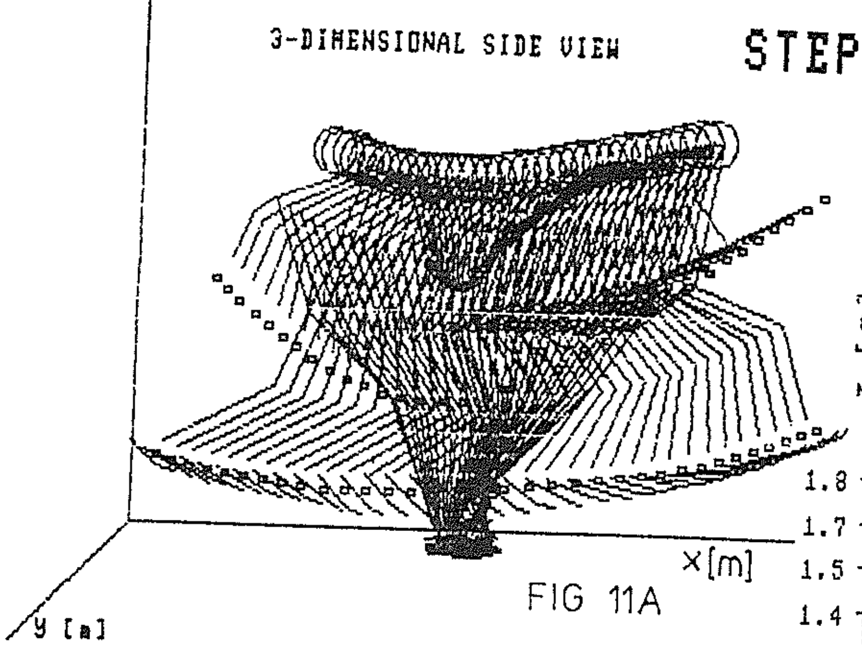
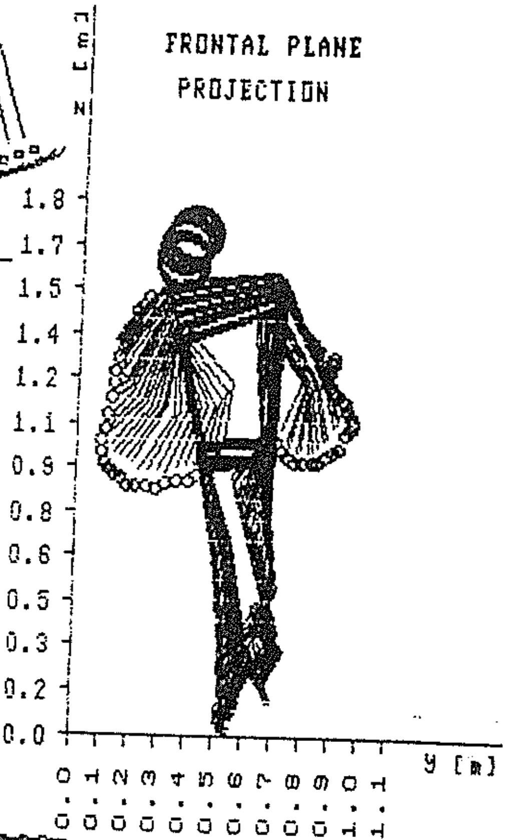


FIG 11A

FIG 12A



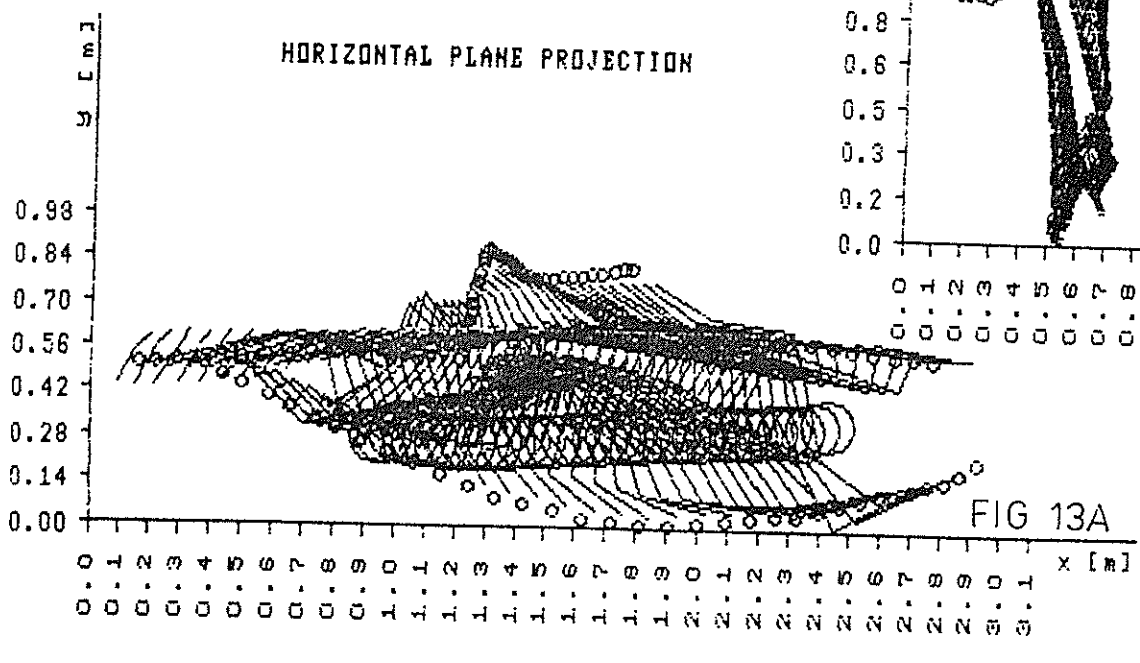


FIG 13A

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
269	0.02	26	11895	-179	960
279	0.07	26	12358	-166	976
296	0.15	26	13116	-190	1096

MARKOV 17.92 m STEP

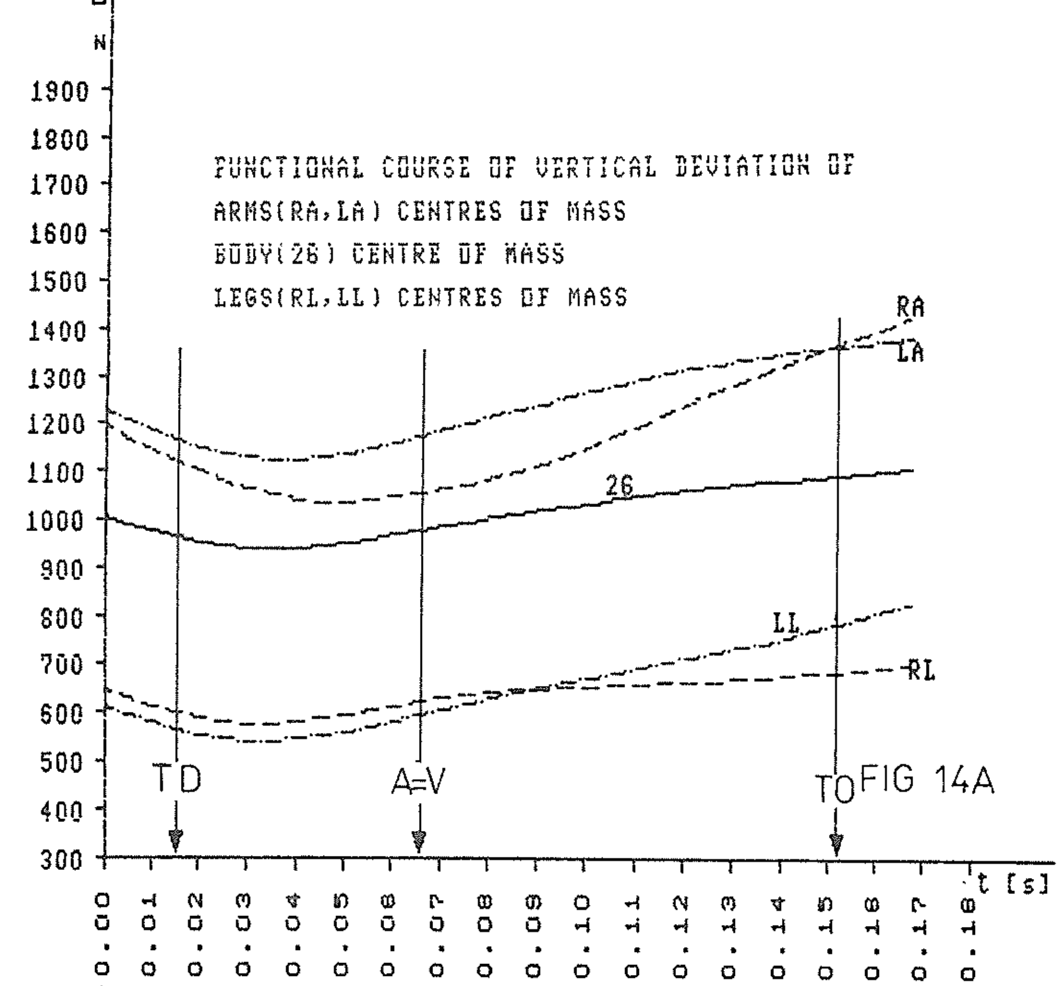


FIG 14A

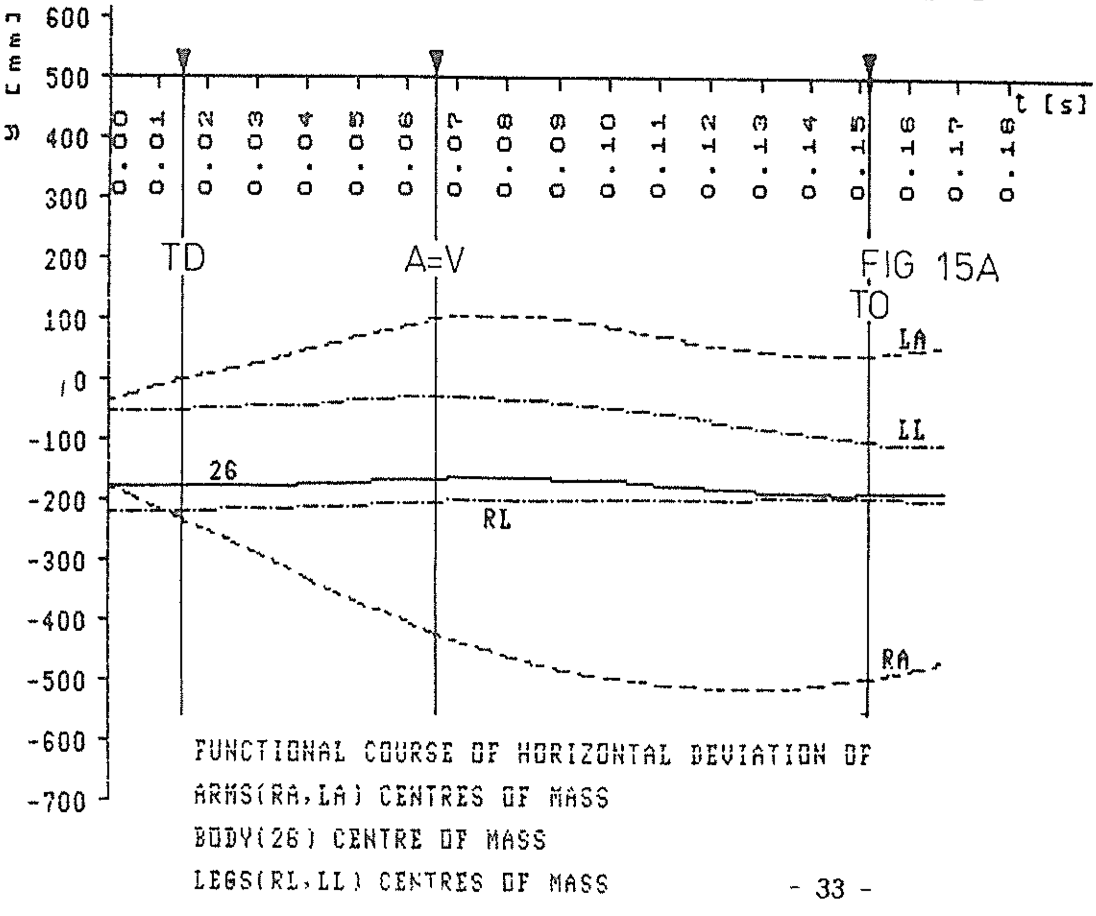


FIG 15A

CONLEY 17.67 m

STEP

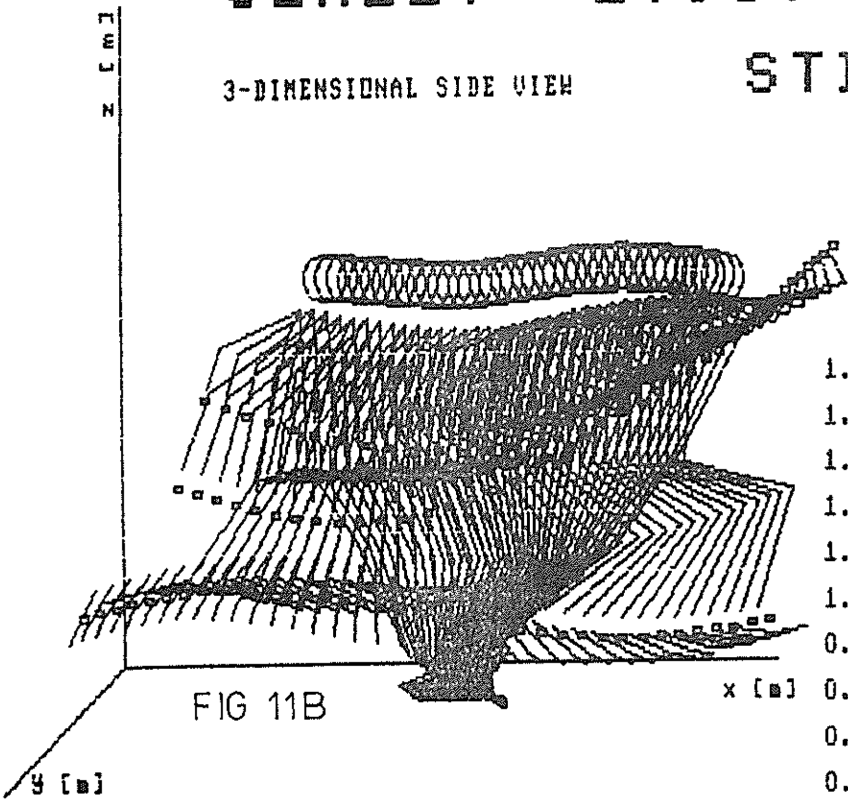


FIG 11B

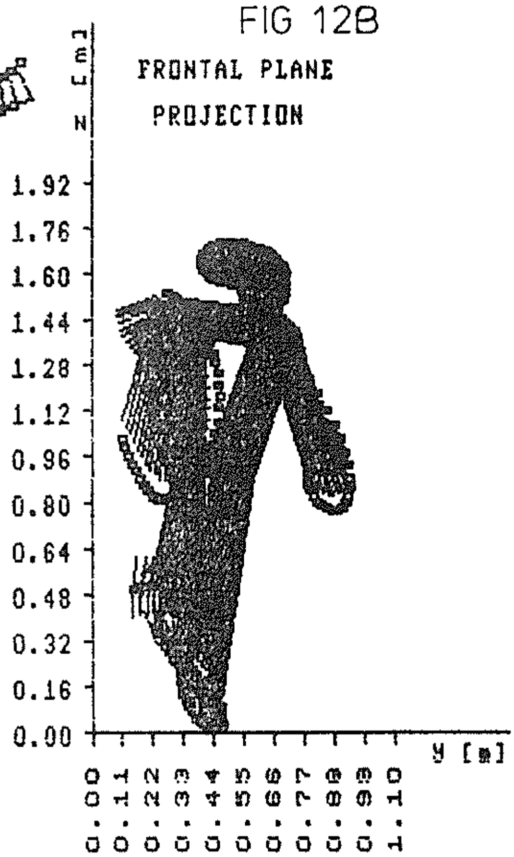


FIG 12B

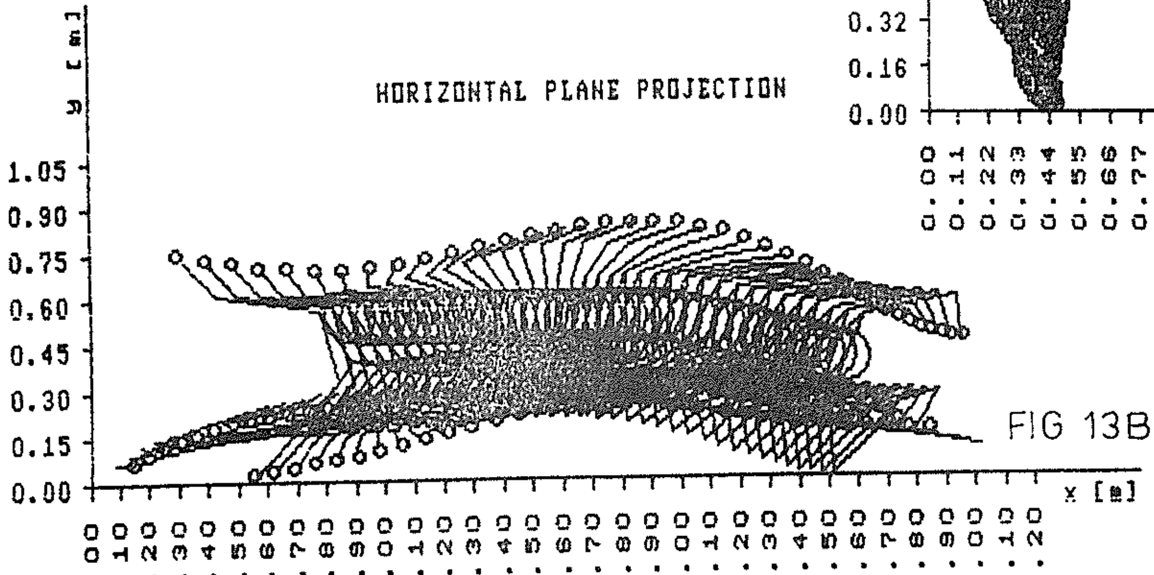


FIG 13B

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
240	0.02	26	11409	-322	943
255	0.09	26	12082	-251	902
271	0.17	26	12824	-349	1043

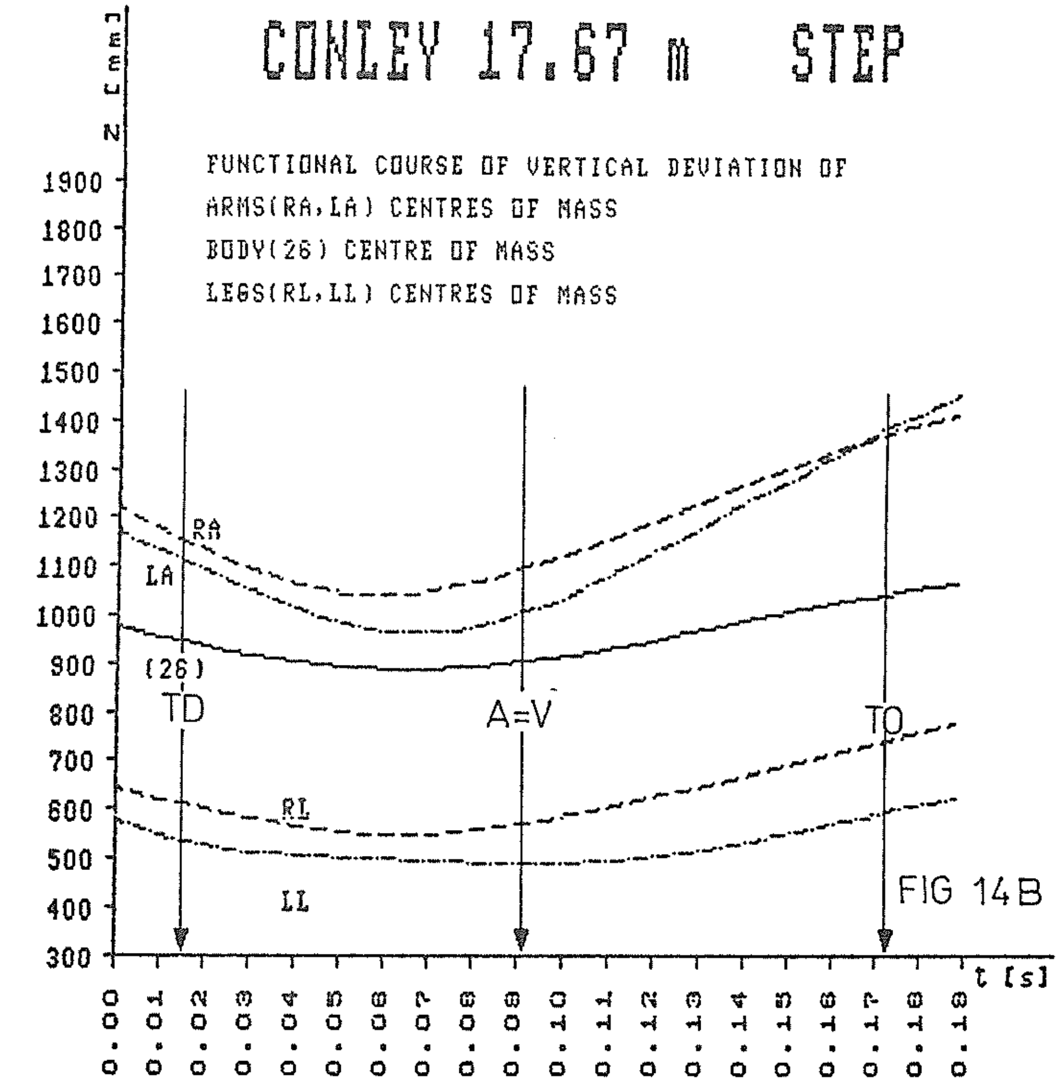


FIG 14B

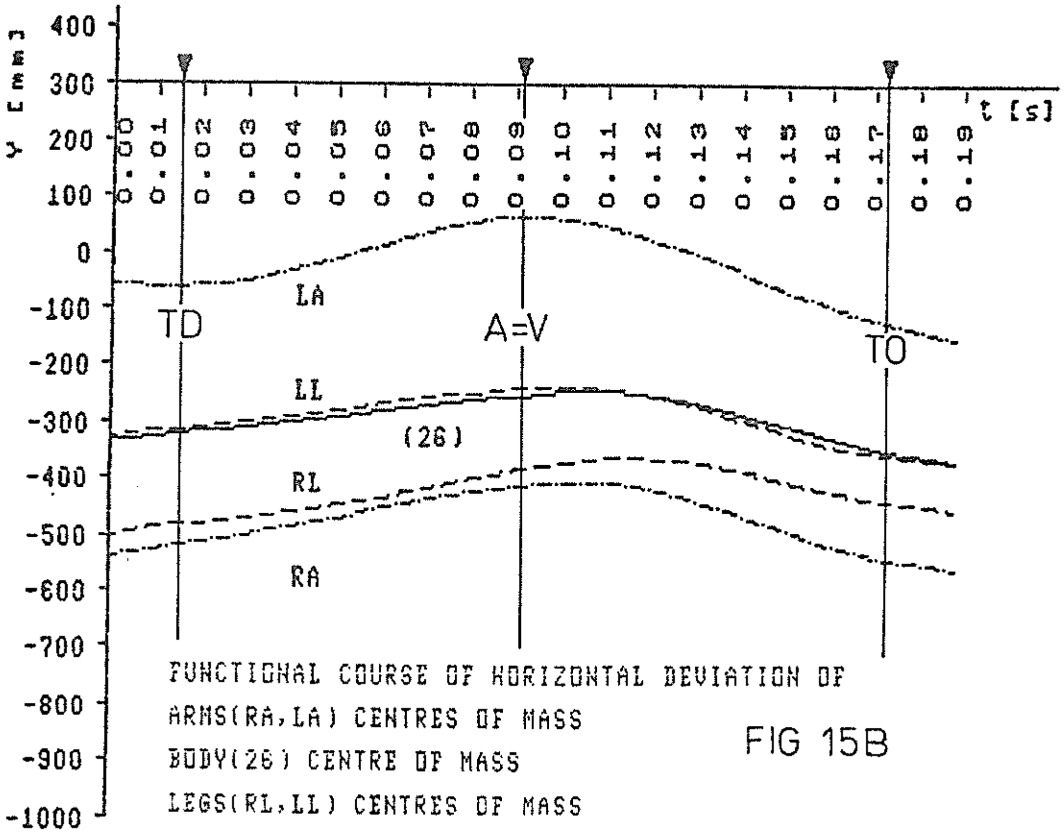


FIG 15B

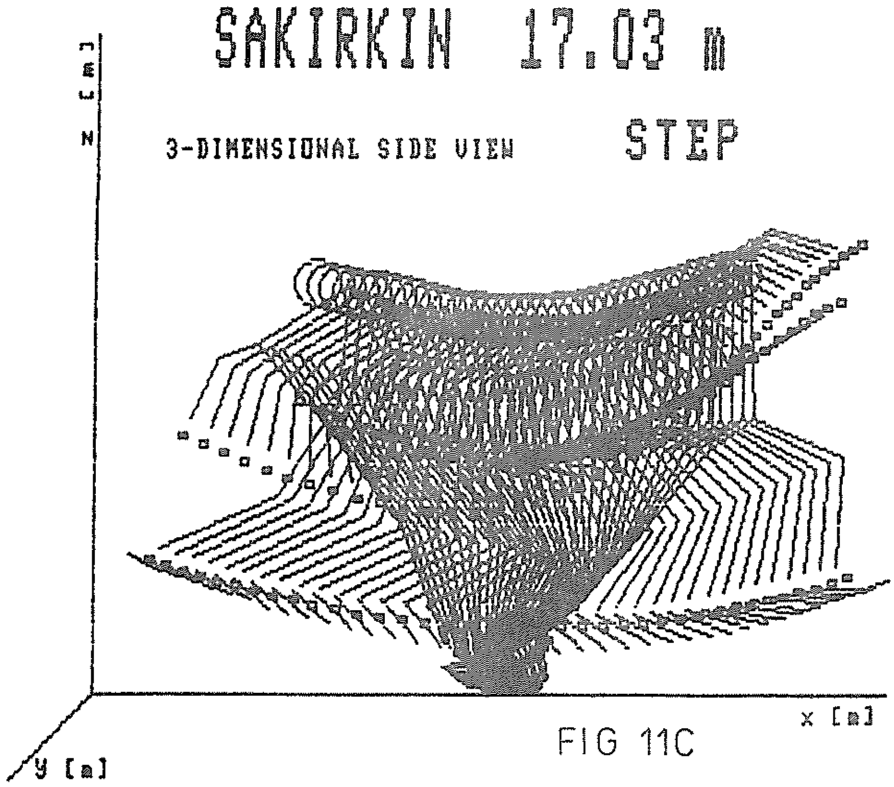
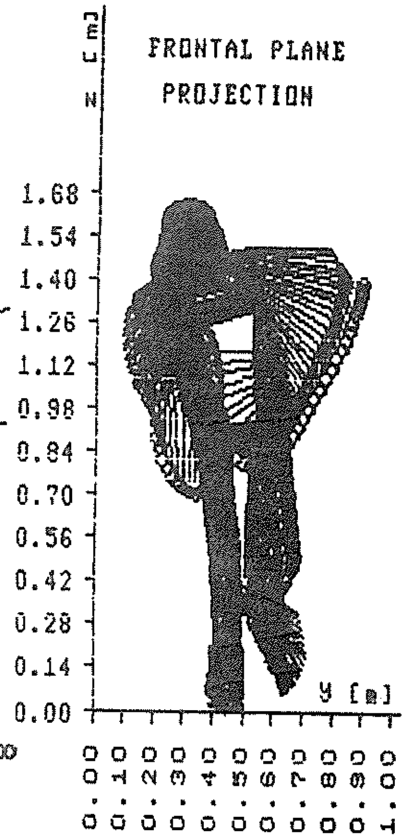


FIG 11C

FIG 12C



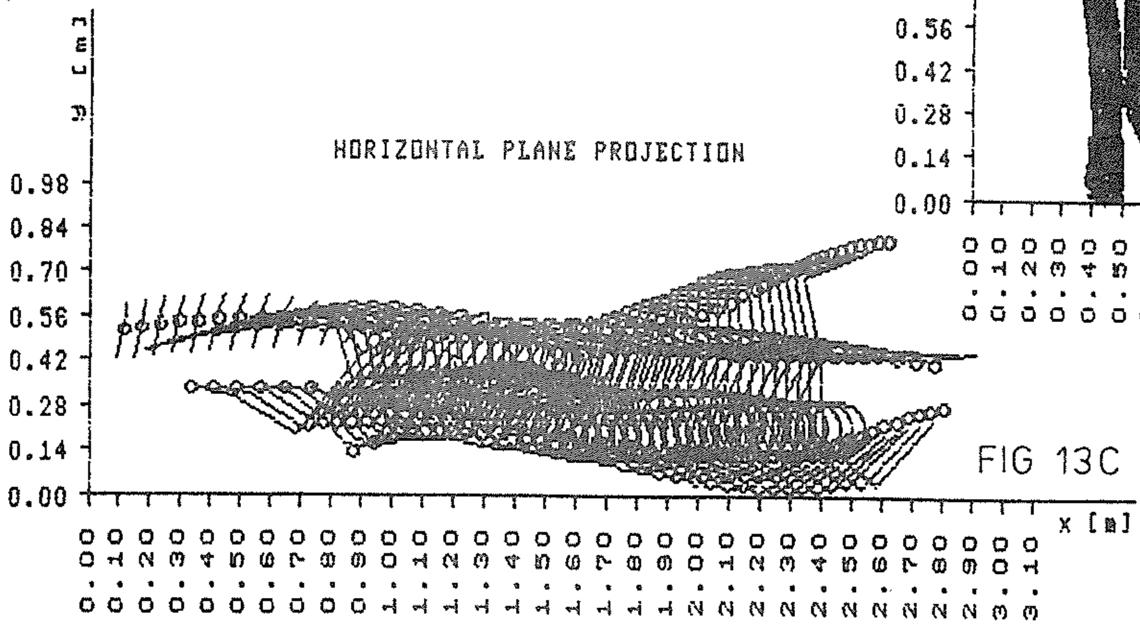


FIG 13C

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
267	0.02	26	11640	67	961
282	0.09	26	12367	0	895
298	0.17	26	13028	9	1051

SAKIRKIN 17.03 m STEP

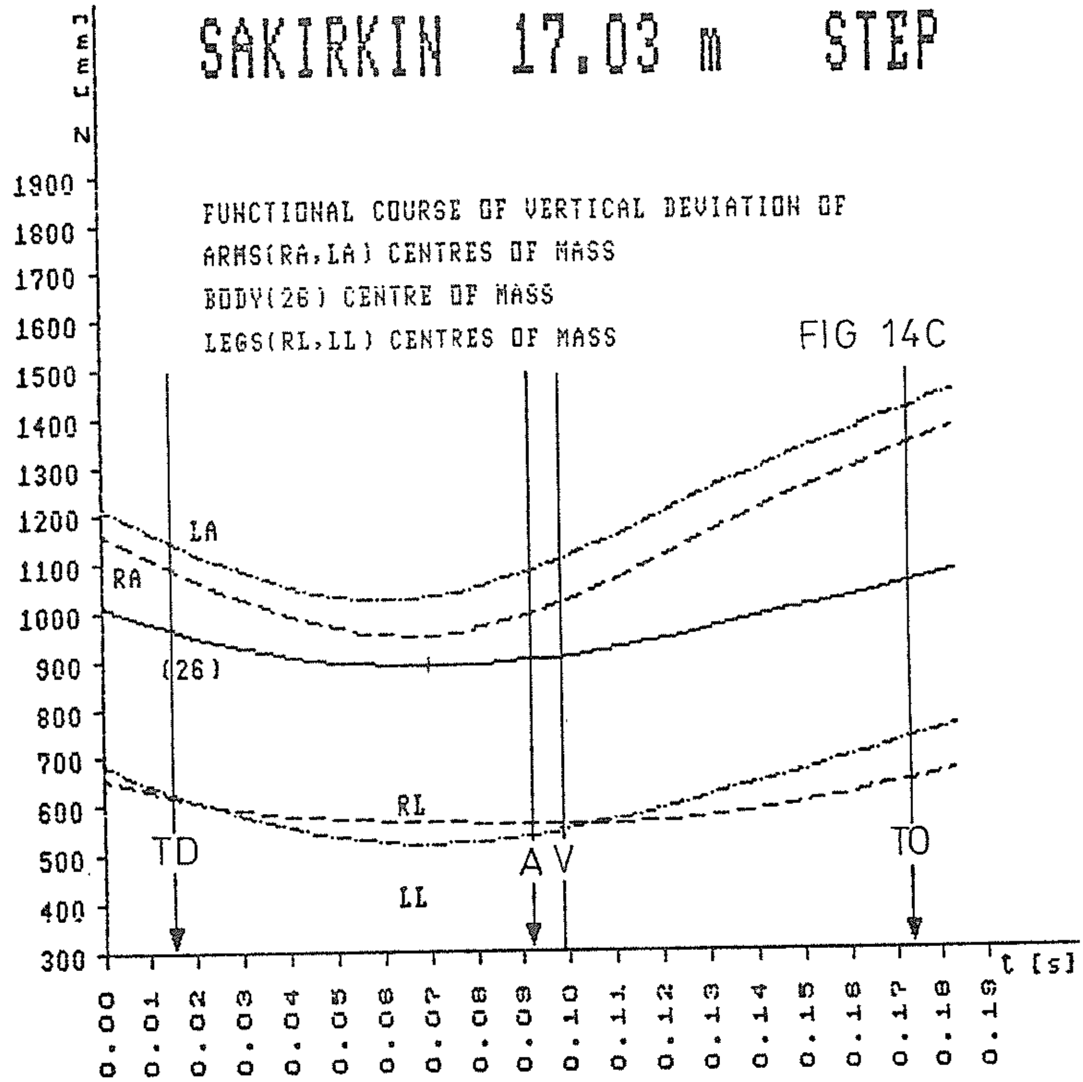


FIG 14C

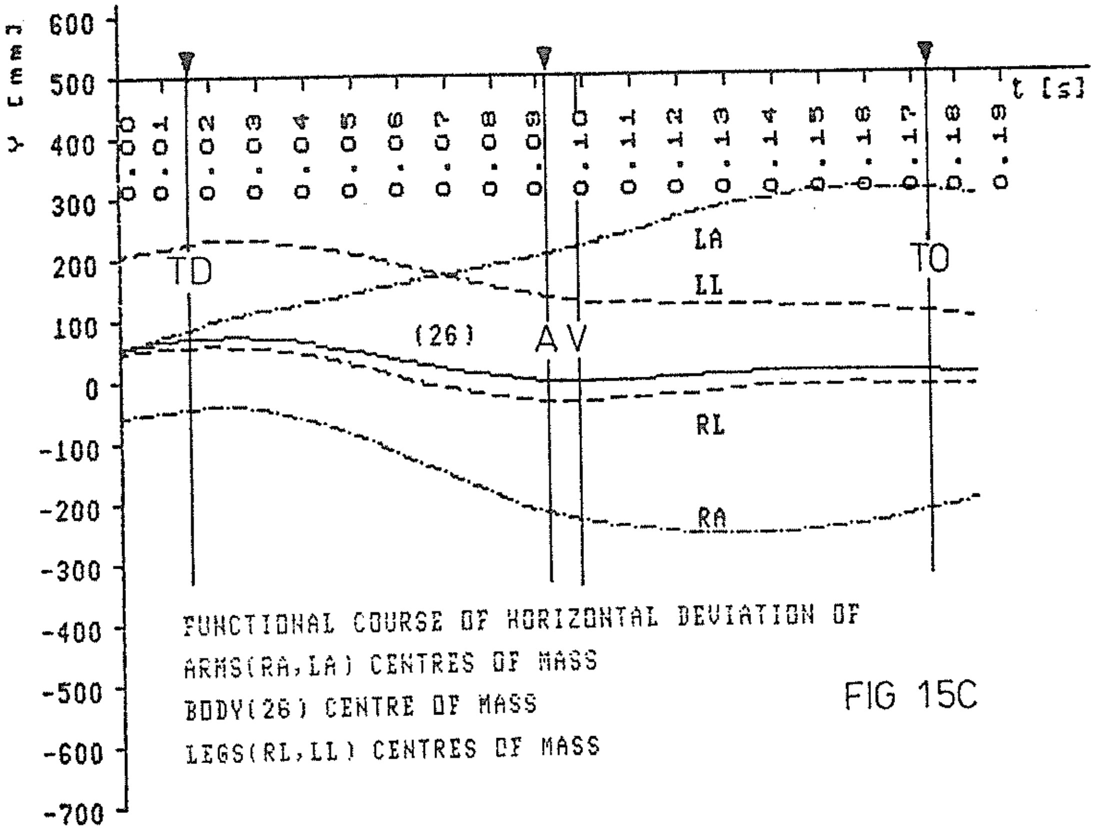


FIG 15C

4.2.3. Third takeoff (Jump)

The CM, in 6 of the jumpers concerned, is situated, at the instant of the touchdown, below the 1 m limit. The variation range of the CM height at the instant of touchdown - 0.92 m (Markov) - 1.02 (Bouschen).

No marked differences of touchdown angle from the preceding takeoffs (111 - 115^{o}) were found.

The same is true of the horizontal distance between body CM and the takeoff spot (heel). In relation to the movement direction of the body CM in ground projection (Fig. 22 A, B, D, E, G, K), technically efficient takeoff was executed by Conley, Kovalenko, Taiwo, Bouschen and Elliot. The sideward deviation of the takeoff leg CM in all these jumpers did not exceed 2 to 3 cm.

Both Pastusinski and Bouschen start the lift of the total CM and CM of the limbs roughly at the moment of amortization (Fig. 21 E, G).

The time lag of the moment of amortization behind the moment of the vertical 0.015 - 0.02 s (for the first time even in Markov -0.02 s), (Table 9), is evident in all the jumpers.

The largest extent of the swinging leg movement was found in Markov, Kovalenko and Pastusinski.

Compared with the preceding takeoffs, the variation range of the takeoff-time tends to increase (0.145 - 0.195 s). The mean takeoff angle is smaller (63^{o}) than in the first takeoff (66^{o}) and - as could be expected - greater than the mean angle of the 2nd takeoff (60^{o}). The magnitude of the initial-flight angle is markedly increased (first takeoff - 13.9^{o}; second takeoff 13.3 ^{o}; third takeoff 21.6^{o}).

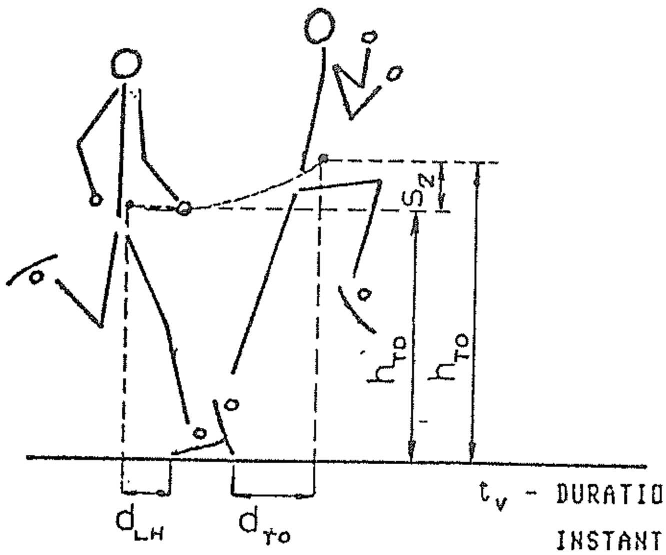
The third takeoff was poorer in the cases of Sakirkin and, particularly, Pastusinski (Figs 22 C, 22 E). The deviation of the CM from prior movement direction is quite clear. The sideward shift of the takeoff limb and the body CM is 7 - 9 cm.

Markov, too, had some technical problems in the last takeoff (Fig. 22 A), and had to even out the takeoff - course by means of sideward movements of the legs (sideward deviation 7 - 8 cm). In other parameters he differed from the others so much that, despite the above problem, he had the longest jump (6.12 m). Markov was the only jumper to keep up the tendency observed in the 1st and 2nd takeoffs. He starts the lift of the body CM and CM of the limbs before reaching the moment of amortization (Fig. 21 A), benefiting the other factors of the takeoff and providing the conditions for the longest jump.

TIME DATA AND TRAJECTORY CHARACTERISTIC OF CM - 3RD TAKEOFF (JUMP)

	D_o	D_E	d_3	H_B	h_{TD}	h_{TO}	S_y	S_z	d_{LH}	d_{TO}	t_v	t_a	t_3
MARKOV	17.92	17.96	6.12	185	0.92	1.14	-0.04	0.22	0.36	0.53	0.065	0.085	0.16
CONLEY	17.67	17.70	6.07	186	0.93	1.14	0.07	0.21	0.43		0.08	0.095	0.195
SAKIRKIN	17.03	17.18	5.58	183	0.93		-0.02		0.36	0.42	0.065	0.08	0.15
KOVALENKO	17.38	17.40	5.65	181			0.03		0.40	0.53	0.07	0.075	0.16
PASTUSINSKI	17.26	17.34	5.72	201	1.00	1.17	0.01	0.17	0.41	0.55	0.08	0.105	0.19
TAIWO	17.29	17.43	6.02	180	0.93	1.10	0.02	0.17	0.44	0.56	0.065	0.095	0.165
BOUSCHEN	17.26	17.34	5.86	181	1.02	1.13	0.01		0.40	0.49	0.065	0.08	0.145
ELLIOTT	X		5.03	183	0.94	1.10	0.04	0.16	0.39	0.44	0.07	0.09	0.165

TABLE 9



t_v - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE MOMENT OF VERTICAL [s]

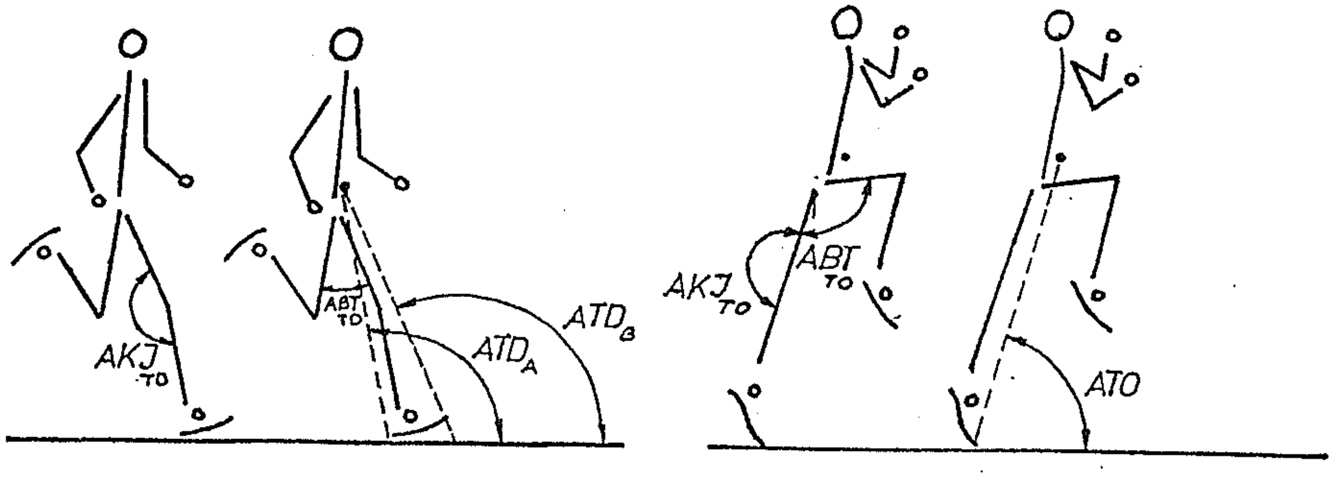
t_a - DURATION OF THE PHASE FROM THE TOUCHDOWN INSTANT TILL THE INSTANT OF AMORTIZATION [s]

t_3 - DURATION OF THE JUMP [s]

TABLE 10 ANGLE PARAMETERS - 3RD TAKEOFF (JUMP)

	D_o	D_E	d_3	ATD_A	ATD_B	AKJ_{TD}	AKJ_A	AKJ_V	AKJ_{TO}	ABT_{TD}	ABT_{TO}	ATO	IFA
MARKOV	17.92	17.96	6.12	111	126	164	144	145	171	-56	107	65	
CONLEY	17.67	17.70	6.07	114	124	157	119	120	165	-62	97	59	17.7
SAKIRKIN	17.03	17.18	5.58	111		161	144	145	173	-62	85	69	23.4
KOVALENKO	17.38	17.40	5.65	114	127	156	127		168	-63	112	52	21.4
PASTUSINSKI	17.26	17.34	5.72	112	125	160	122	127	158	-54	108	65	20.0
TAINO	17.29	17.47	6.02	115	127	158	124	127	163	-49	100	63	23.5
BOUSCHEN	17.26	17.34	5.86	111	123	159	134	137	161	-44	95	66	23.0
ELLIOTT	X			113	125	164	135	136	173	-45	95	68	21.3

THE ANGLES AKJ_{TD}, AKJ_a, AKJ_V, AKJ_{TO} (DESCRIPTION SEE FIG.)
ARE LIMITED BY CONNECTING LINES OF THE CENTRES OF ROTATION IN HIP, KNEE AND ANGLE JOINTS.
THE QUESTION IS ABOUT SPACE ANGLE, WHICH IN EXTENSION OF KNEE JOINT DOES NOT REACH 180° (0°).
THE ANGLE BETWEEEN THE AXIS OF FEMUR AND TIBIA IS GREATER THAN ANGLE DEFINED ABOVE (DIFFERENCE IN PLANE PROJECTION CCA (5) IN SPACE PROJECTION 8-12)



AKJ_A - ANGLE AT KNEE JOINT AT THE AMORTIZATION [°]

AKJ_V - ANGLE AT KNEE JOINT AT THE VERTICAL MOMENT [°]

MARKOV 17.92 m

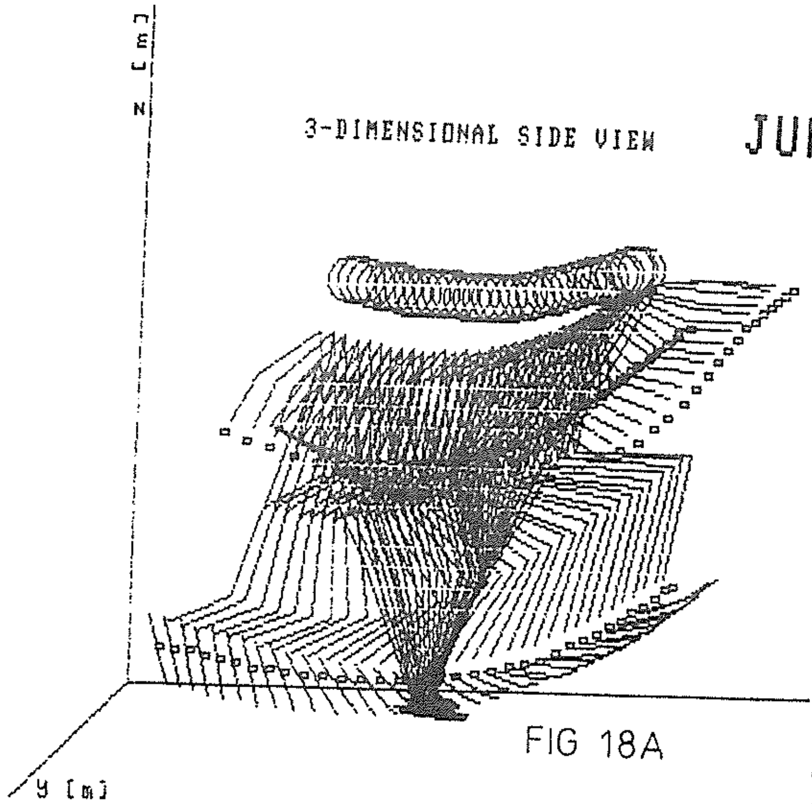


FIG 18A

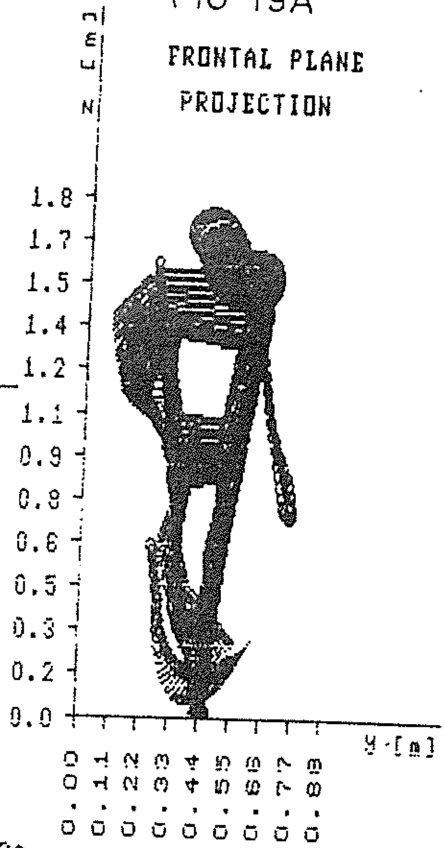


FIG 19A

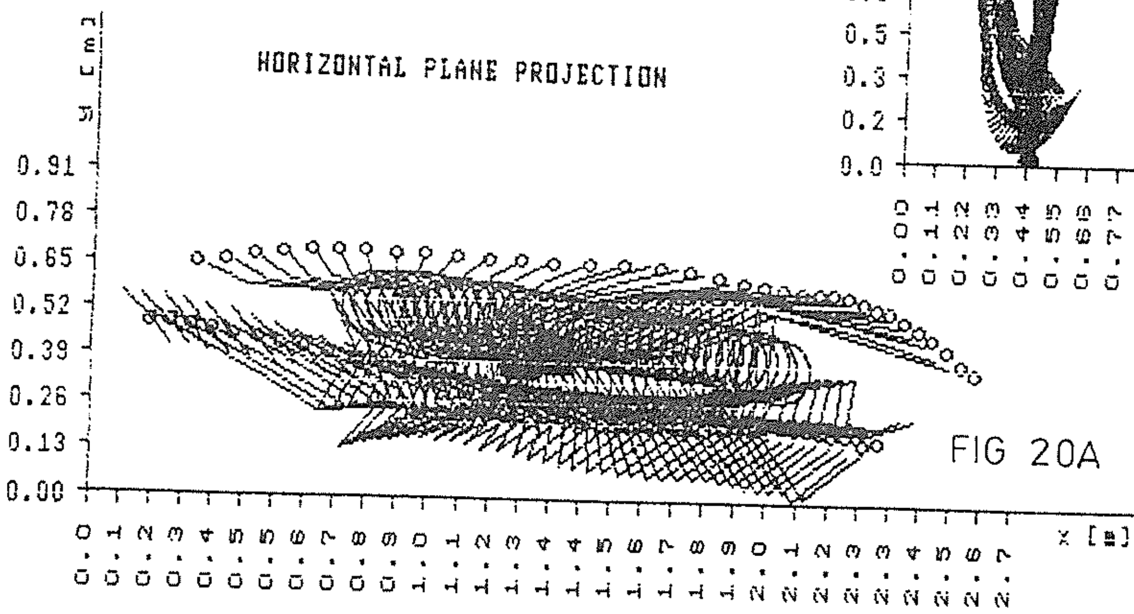


FIG 20A

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
389	0.02	26	17196	-211	921
406	0.10	26	17869	-201	919
421	0.18	26	18329	-216	1141

MARKOV 17.92 m JUMP

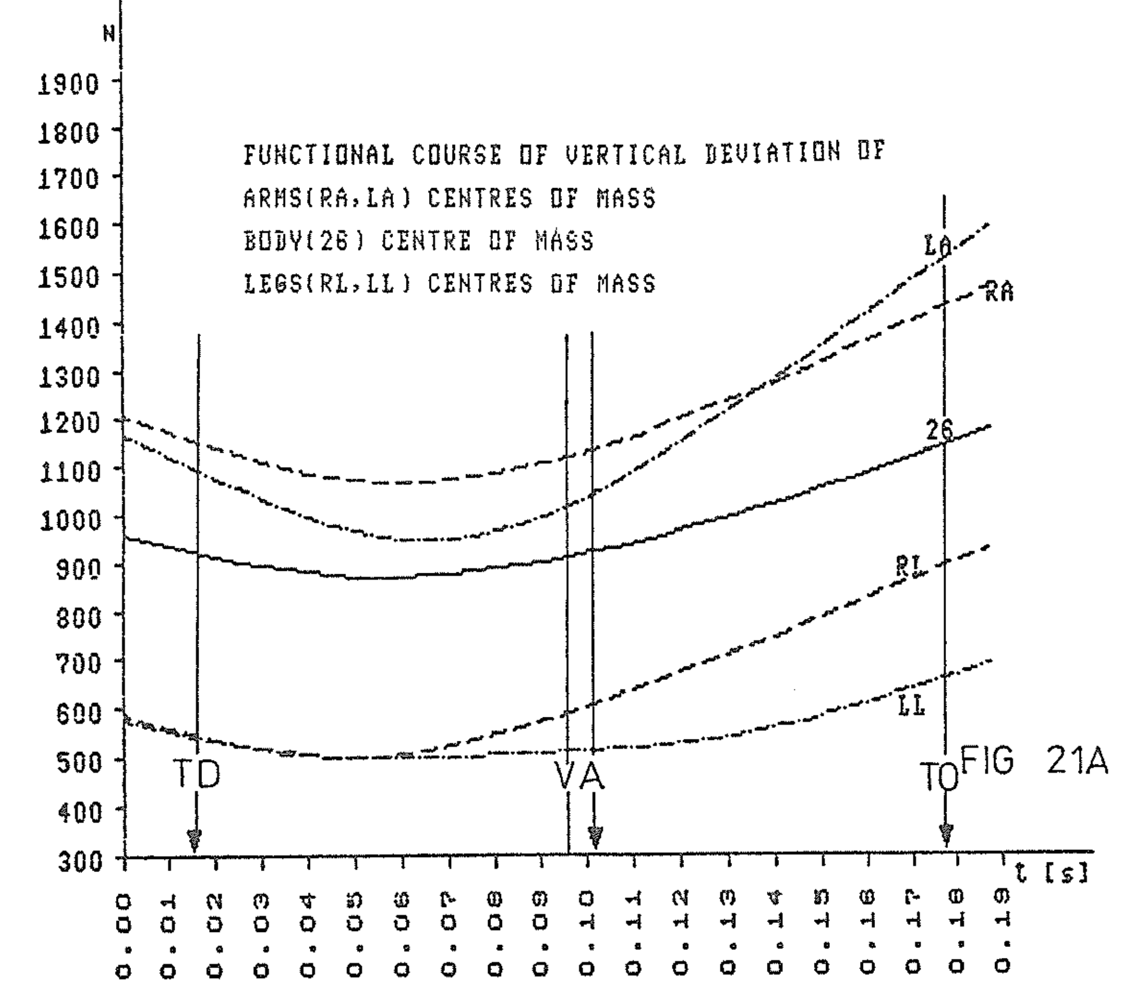


FIG 21A

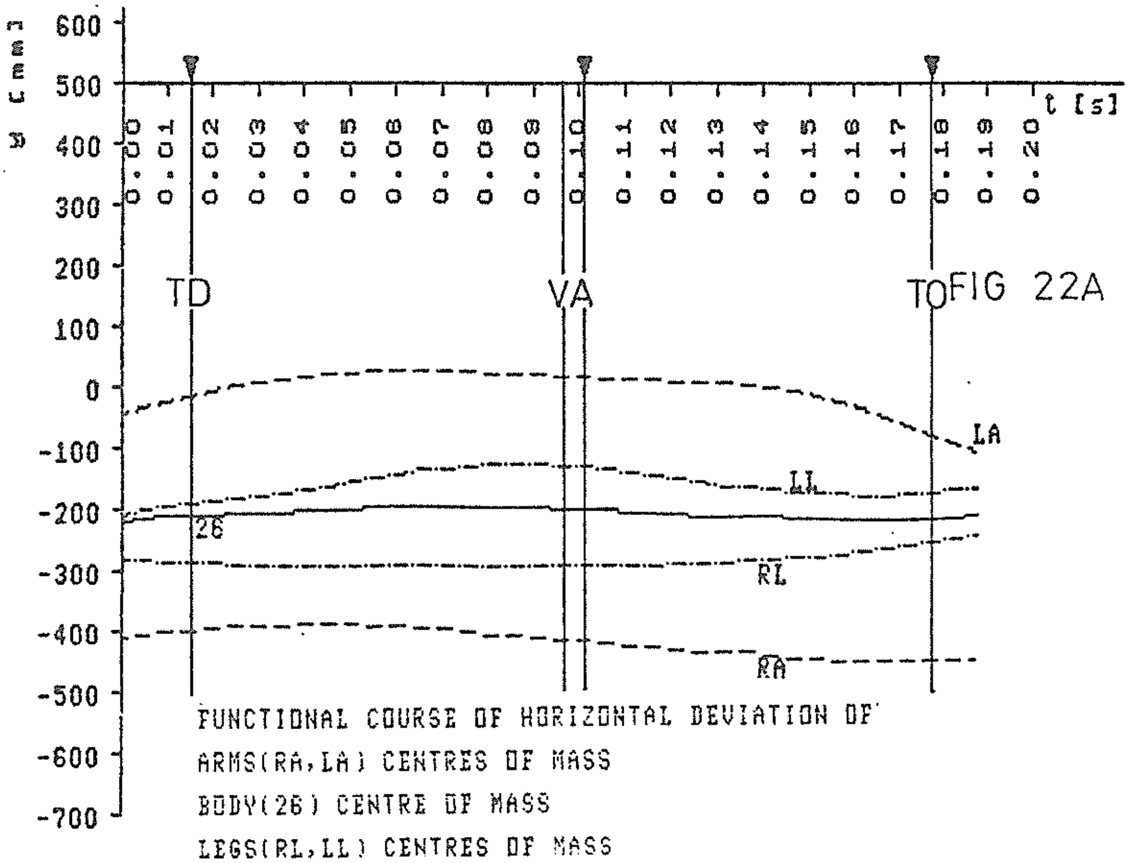


FIG 22A

CONLEY 17.67 m JUMP

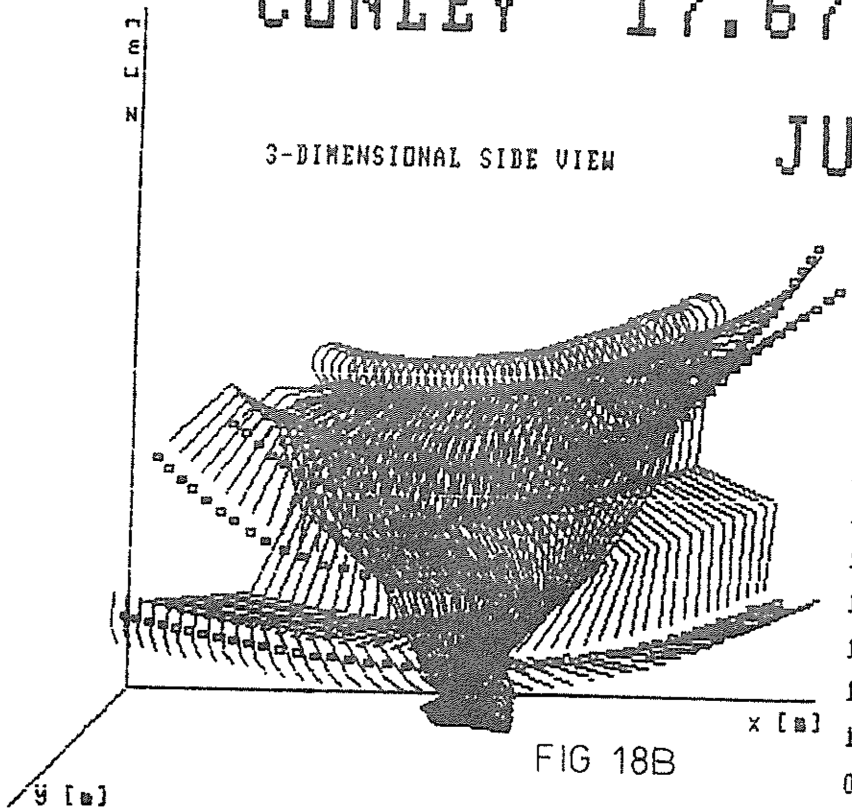
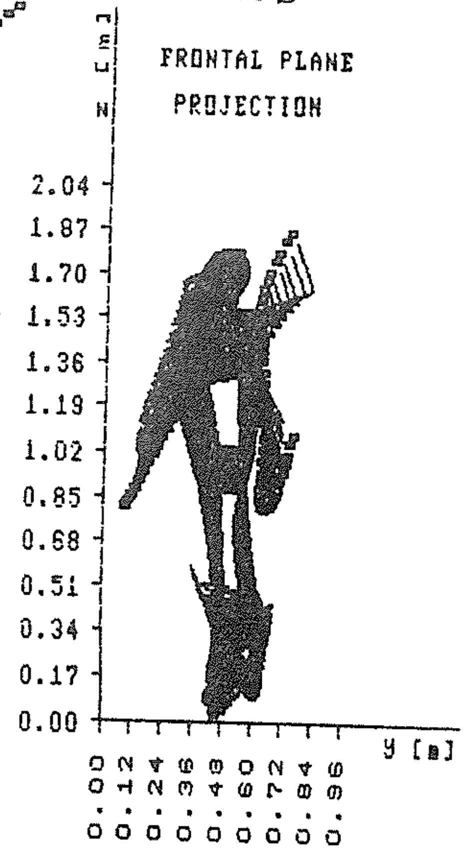


FIG 18B

FIG 19B



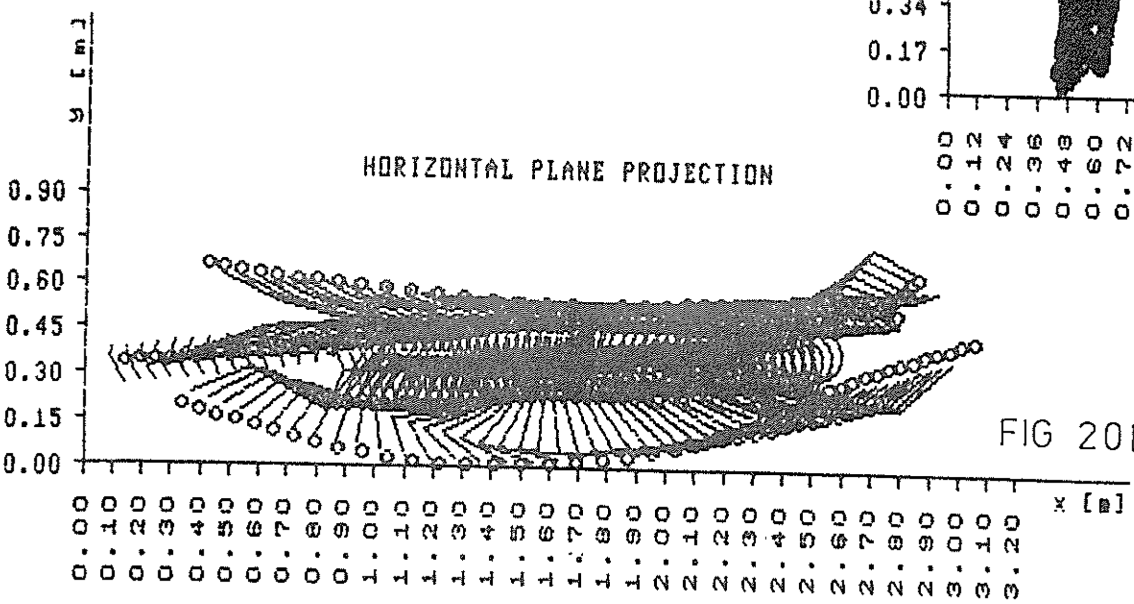


FIG 20B

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
363	0.02	26	16896	-300	933
382	0.11	26	17631	-284	902
402	0.21	26	18356	-233	1141

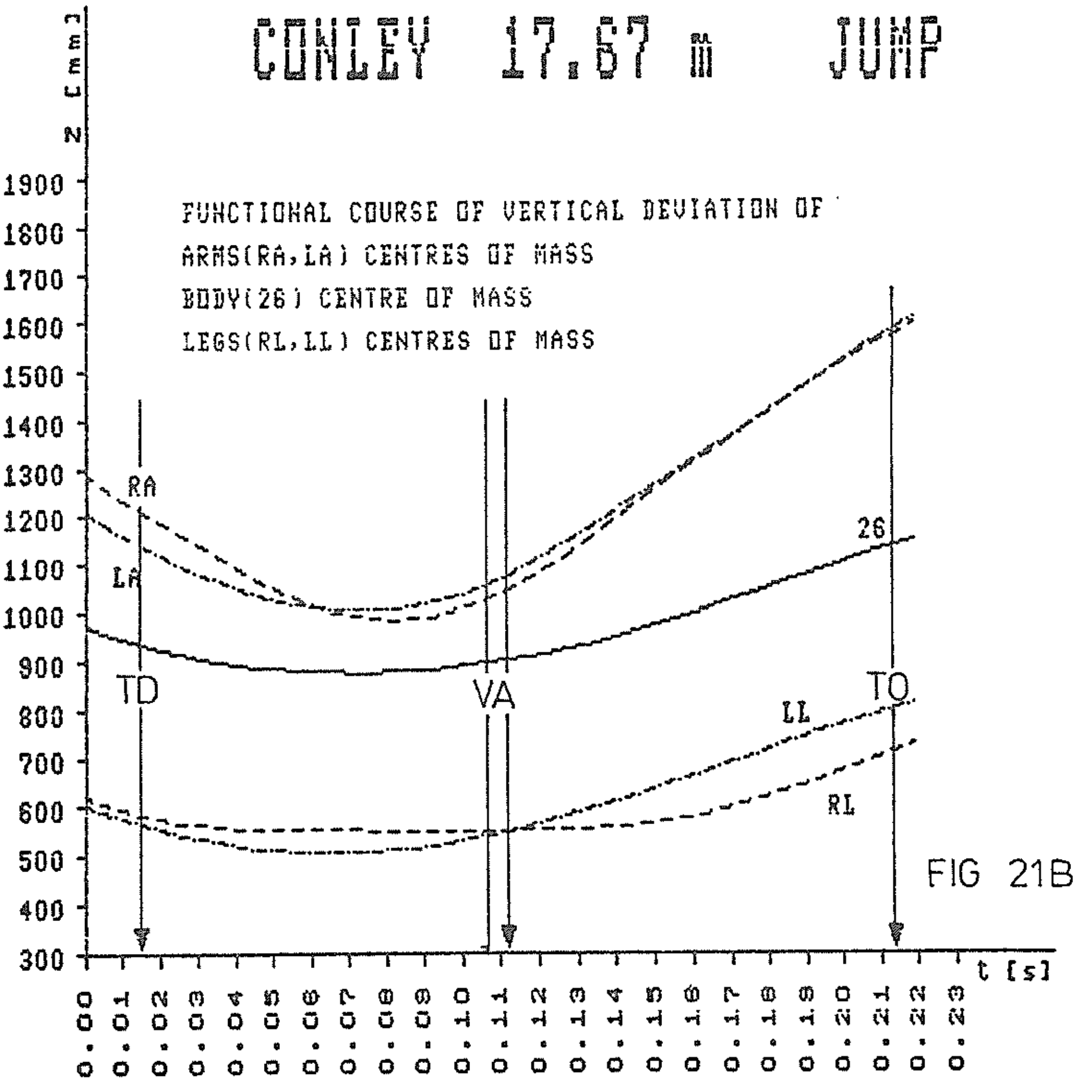


FIG 21B

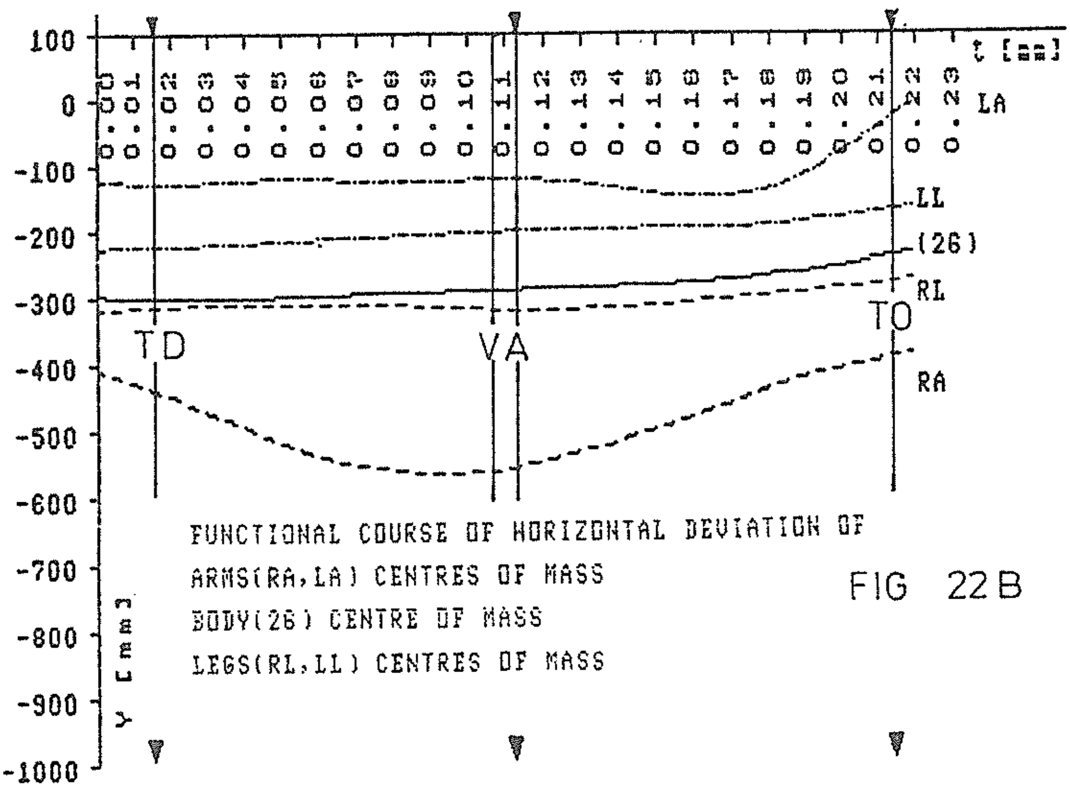


FIG 22B

SAKIRKIN 17.03 m

3-DIMENSIONAL SIDE VIEW JUMP

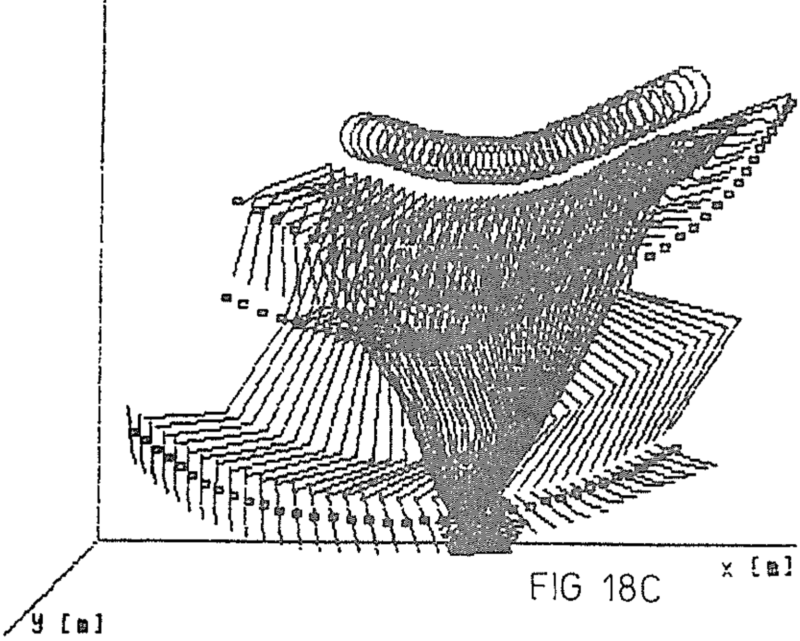


FIG 18C

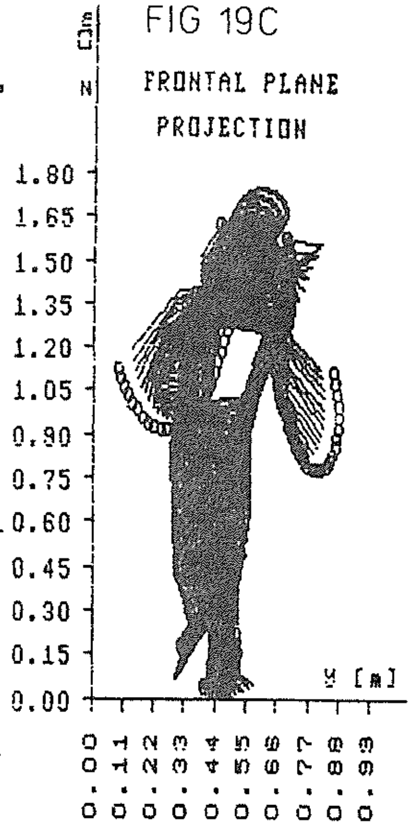


FIG 19C

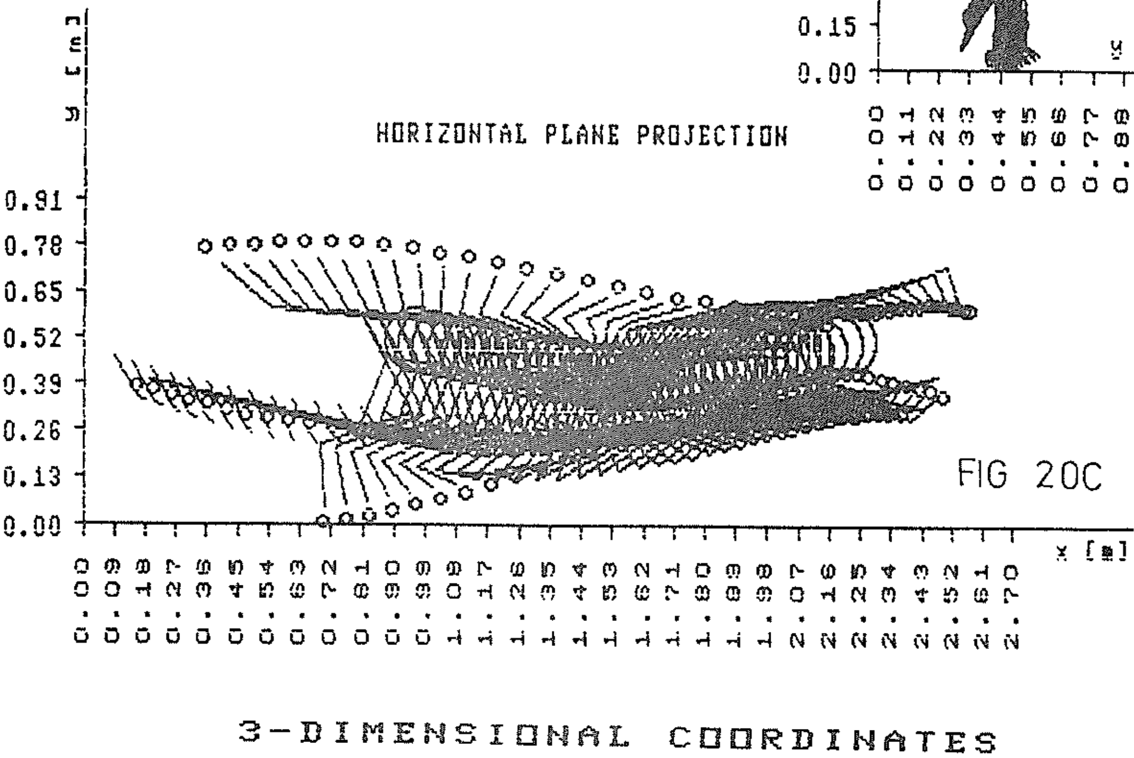


FIG 20C

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
391	0.02	26	16881	-39	931
407	0.10	26	17472	-66	887
422	0.17	26	17919	20	1071

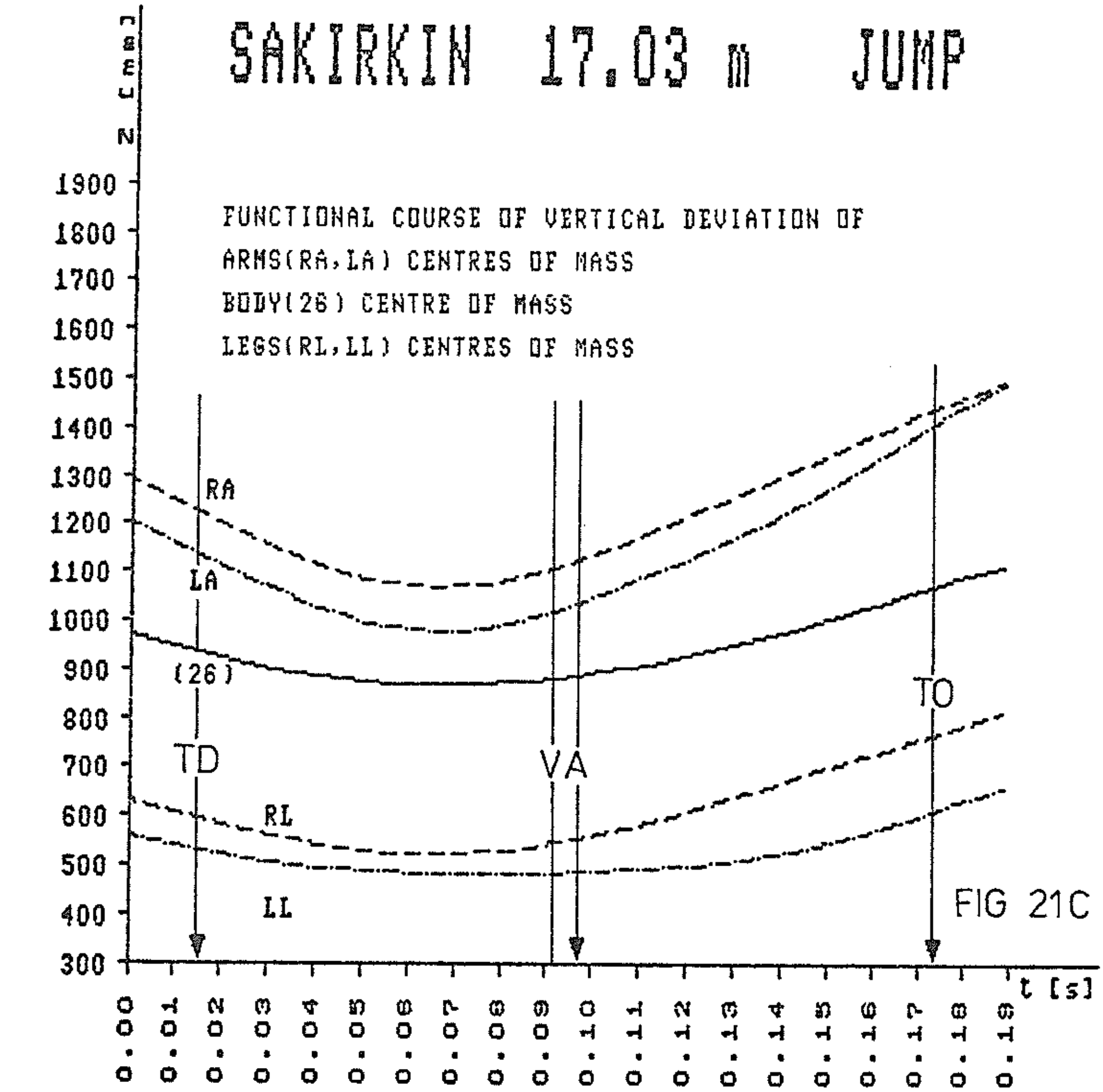


FIG 21C

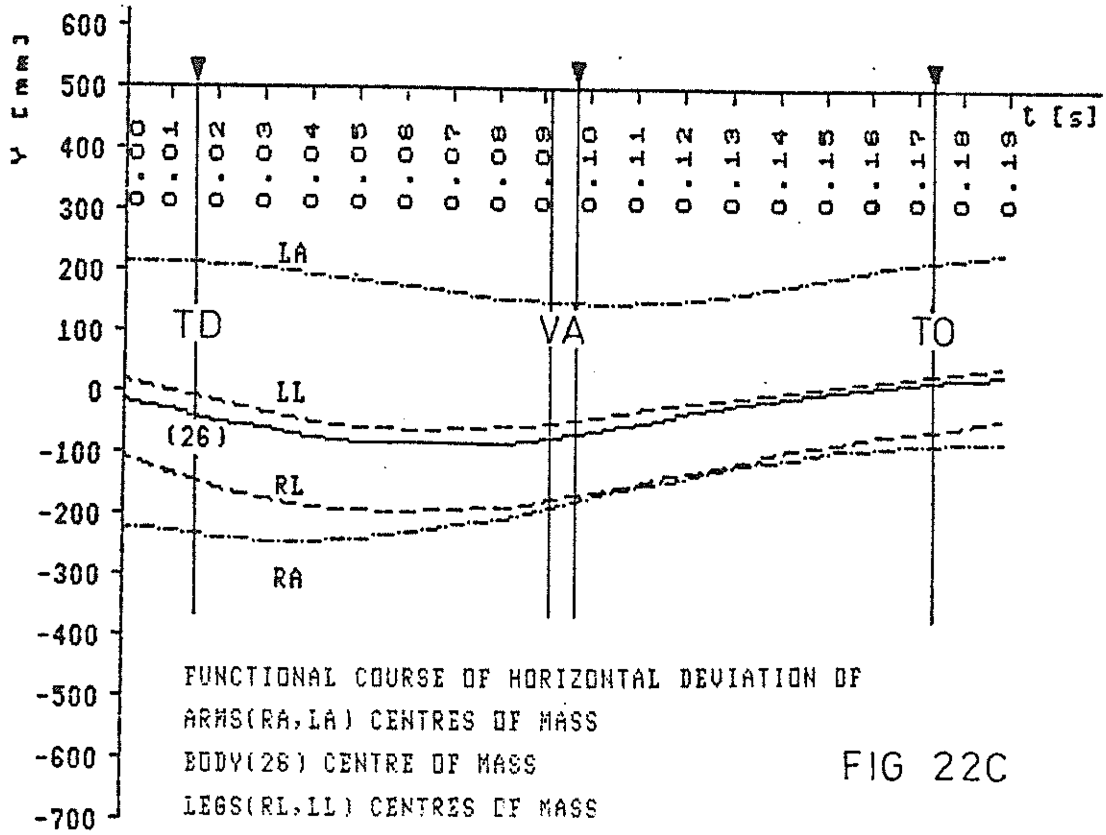


FIG 22C

4.2.4. Arms swing

Optimum arms swing action helps the athlete a) to maintain maximum horizontal velocity in the course of the triple jump, b) to increase vertical velocity in separate takeoffs and c) to maintain dynamic balance in flight and support phases. Information about this element of triple jump technique was obtained by means of film analysis. For basic evaluation of arm swing technique videorecord can be used.

The finalists of the II WC used two kinds of arms action - (1) the running swing action (RSA) and (2) the double arm swing action (DSA). There are two variants of the reciprocal running swing - (a) natural rumning swing (NRS) and modified running-circular swing (RCS) with circular movement of the relatively extended arm on the side of the swinging leg. With respect to utilizing the mobility of the swinging arms, double arm action is more efficient. It obviously requires a higher level of movement coordination. Incorrect execution can cause loss of stability in flight phase. The most natural combination of swing movements in the triple jump is the variant RCS - NRS - DSA.

In Rome it was used by Markov, Slanar and Hoffmann. However the most frequent variant was the one with the double arm swing in hop step and jump (Kovalenko, Taiwo, Procenko, Elliot, Badinelli).

The other athletes used the following techniques:

RCS - DSA - DSA (Conley, Pastusinski)
RCS - NRS - NRS (Bouschen, Yamashita)
DSA - NRS - DSA (Sakirkin)

Suprisingly, even elite competitors change their arm swing pattern in their top performance period. Conley only in the takeoff for the hop (at Helsinki 83 he used the double arm swing in all takeoffs), and Procenko in all three takeoffs (eight weeks before the II WC, at the European Cup meeting in Prague he used the reciprocal arm swing exclusively). Such striking changes, before the most important competition of the year seem to be irrational.

4.3. Velocity components in takeoffs

The results of measurements and analyses make it possible to lay down the basic conditions of efficient execution of the takeoffs, depending on the geometry of movement.

1. Minimization of velocity components
   - v_y at the instant of touchdown,
   - v_z at the instant of touchdown,
   - v_y at the instant of takeoff.

2. Minimum losses of horizontal velocity v_x in takeoffs.
3. Maximum run-up speed - 10.4 m/s (minimum 10.1 - 10.2 m/s).

The ratio of horizontal and vertical velocity components in the course of the takeoffs indicates that the characteristic relations of these values cannot be determined. This is probably due to the difference in run-up speeds and to individual technique patterns.

Losses of the horizontal velocity component (Tables 11, 12, 13) are factors of considerable significance.

a/ Losses of horizontal velocity in the course of the support phases averaged 10% in the first, and 12% in the second and third takeoffs.

	Hop	Step	Jump
Markov	0.3 m/s (10%)	0.7 m/s (11%)	-----
Conley	0.3 m/s (10%)	1.5 m/s (12%)	1.6 m/s (12.5%)
Pastusinski	0.3 m/s (10%)	2.1 m/s (12.7%)	1.3 m/s (12%)

b/ The mean gradual reduction of the horizontal velocity at the instant of touchdown in the second and third takeoffs is 13% and 16%.

	Step	Jump
Markov	1.7 m/s (12.5%)	-----
Conley	1.8 m/s (12%)	3.8 m/s (16%)
Pastusinski	2.5 m/s (13.2%)	4.0 m/s(16.5%)

c/ The corresponding mean values at the instant of takeoff for the hop, step and jump are: 5.9%, 20.8% and 36.2%.

	Hop	Step	Jump
Markov	0.5 m/s (4.8%)	2.1 m/s (20.2%)	------
Conley	0.3 m/s (2.9%)	1.8 m/s (17.6%)	3.8 m/s (37.3%)
Pastusinski	0.3 m/s (3.1%)	2.5 m/s (24.7%)	4.0 m/s (39.6%)

The rise of vertical velocity v_z (Tables 11, 12 and 13) ranges within 2.0 - 2.8 m/s in the first, 1.4 - 2.4 m/s in the second and 2.0 - 3.0 m/s in the third takeoff.

The level of velocity v_y has significant influence on the dynamic stability of the jumper. Excessive rates may cause undesirable rotation in successive phases of the triple jump. The optimum values v_y for the takeoff should range between 0 ± 0.6 m/s. The variation range in the trials concerned was $v_y = 0 \pm 1.5$ m/s.

VELOCITY COMPONENTS - 1ST TAKEOFF (HOP)

	D_o	D_E	d_1	V_{xTD}	V_{yTD}	V_{zTD}	V_{TD}	V_{xTO}	V_{yTO}	V_{zTO}	V_{TO}
MARKOV	17.92	17.96	6.54	10.4	0.0	-1.3	10.5	10.1	-0.9	2.5	10.5
CONLEY	17.67	17.70	6.11	10.2	0.0	-0.5	10.2	9.9	-0.7	2.4	10.2
SAKIRKIN	17.03	17.18	6.45						-0.3	2.8	
KOVALENKO	17.38	17.40	6.17	10.2	0.0	-0.8	10.6	9.8	-0.2	2.3	10.1
PASTUSINSKI	17.26	17.34	6.40	10.1	1.3	-0.6	10.3	9.8	-1.4	2.2	10.2
TAIWO	17.29	17.47	6.03	10.0	0.9	-0.8	10.1	9.6	0.0	2.2	9.4
BOUSCHEN	17.26	17.34	5.78								
ELLIOTT	X			10.1	0.6	-1.0	10.2	9.6	-0.5	2.0	9.5

TABLE 11

VELOCITY COMPONENTS - 2ND TAKEOFF (STEP)

	D_o	D_E	d_1	V_{xTD}	V_{yTD}	V_{zTD}	V_{TD}	V_{xTO}	V_{yTO}	V_{zTO}	V_{TO}
MARKOV	17.92	17.90	5.30	9.9	0.0	-2.5	9.4	8.3	0.0	1.9	8.6
CONLEY	17.67	17.70	5.52	9.9	0.7	-1.9		8.4	-1.5	1.4	8.7
SAKIRKIN	17.03	17.18	5.15	9.0	0.7	-2.8	9.5	8.0	-0.2	2.0	8.3
KOVALENKO	17.38	17.40	5.58								
PASTUSINSKI	17.26	17.34	5.22	9.7	1.2	-2.1		7.6	0.0	2.1	
TAIWO	17.29	17.47	5.42	8.7	1.2	-2.3	9.1		-0.4	2.4	9.0
BOUSCHEN	17.26	17.34	5.70	9.6	-0.2	-2.9	10.0	9.3	0.0		
ELLIOTT	X				-0.4	-2.4			-0.4	1.8	

TABLE 12

VELOCITY COMPONENTS - 3RD TAKEOFF (JUMP)

	D_o	D_E	d_1	V_{xTD}	V_{yTD}	V_{zTD}	V_{TD}	V_{xTO}	V_{yTO}	V_{zTO}	V_{TO}
MARKOV	17.92	17.96	6.12		0.3	-2.1			0.2	3.4	7.0
CONLEV	17.67	17.70	6.07	8.0	0.0	-2.0	8.3	6.4	1.1	2.0	6.8
SAKIRKIN	17.03	17.18	5.58		-1.5	-2.1		6.5	0.7	2.8	7.2
KOVALENKO	17.38	17.40	5.65	7.9	0.2	-2.2	8.2	6.9	-0.3	2.7	7.4
PASTUSINSKI	17.26	17.34	5.72	7.4	0.9	-2.0	7.8	6.1	-0.6	2.2	6.6
TAIWO	17.29	17.47	6.02	8.2	0.5	-2.4	8.5	6.9	0.4	3.0	7.5
BOUSCHEN	17.26	17.34	5.86	8.1	0.4	-2.9	8.8	7.0	-0.3	3.0	
ELLIOTT	X			8.0	0.8	-2.3	8.4	6.2	0.6	2.4	6.7

TABLE 13

V_{XTD} - HORIZONTAL VELOCITY AT THE INSTANT OF TOUCHDOWN
V_{YTD} - LATERAL VELOCITY AT THE INSTANT OF TOUCHDOWN
V_{ZTD} - VERTICAL VELOCITY AT THE INSTANT OF TOUCHDOWN
V_{TD} - VELOCITY AT THE INSTANT OF TOUCHDOWN
V_{XTO} - HORIZONTAL VELOCITY AT THE INSTANT OF TAKEOFF
V_{YTO} - LATERAL VELOCITY AT THE INSTANT OF TAKEOFF
V_{ZTO} - VERTICAL VELOCITY AT THE INSTANT OF TAKEOFF
V_{TO} - VELOCITY AT THE INSTANT OF TAKEOFF

4.4. Length relationship of the Hop, Step and Jump

The relationship between the lengths of the hop, step and jump phases of the triple jump has been evaluated since the beginning of the technical development of the event. While on cinder and clay runways the tracing of takeoff points was easy, synthetic surfaces make it necessary to use film or video-recordings.

The ratio of the hop, step and jump is typical of variations in the technique of the triple jump at the first WC Helsinki 1983, 4 types of technical execution can be determined (Table 14):

COMPARISON OF HOP, STEP AND JUMP LENGHTS
1st WC - HELSINKI 1983

TABLE 14

Name	N_T D_L	D_E	d_1	d_2	d_1+d_2	d_3	%
HOFFMANN	4 0,34	17,52	6,68	5,66	12,34	5,18	38,1:32,3:29,6
	5 0,10	17,45	6,52	5,68	12,20	5,25	37,4:32,5:30,1
	6 0,04	17,46	6,59	5,75	12,34	5,12	37,7:32,9:29,4
BANKS	1 0,16	17,24	5,74	4,99	10,73	6,51	33,3:28,9:37,8
	2 0,04	16,76	5,86	5,08	10,94	5,82	35,0:30,3:34,7
	3 0,14	17,32	5,85	5,24	11,09	6,23	33,8:30,2:36,0
AGBEBAKU	6 0,09	17,27	6,04	5,45	11,49	5,78	35,0:31,5:33,5
CONLEY	2 0,40	17,31	5,88	5,50	11,38	5,93	33,8:32,0:34,2
	3 0,36	17,49	6,02	5,64	11,66	5,83	34,4:32,2:33,4
	5 0,15	17,20	5,80	5,83	11,63	5,57	33,7:33,9:32,4

1. Almost equal length of hop and jump 580 - 610 cm and step 520 - 540 cm; percentage pattern 35.5:30.5:35.0.
2. Markedly longest hop (over 650 cm), very long step (over 560 cm) and very short jump (under 530 cm), percentage pattern 38.0:32.0:30.0.
3. Shorter hop (570 - 590 cm), short step (500 -520 cm) and markedly longest jump (over 630 cm), percentage pattern 34.0:30.0:36.0.
4. Almost equal lengths of hop, step and jump (within 560 - 600 cm), percentage pattern 34.0:32.5:33.5.

Findings from the II WC in Rome have not produced such differences as in Helsinki. In accordance with the percentage pattern of their best performances, athletes can be classed in six groups:

1.	36.5 : 30.0 : 33.5	(Markov, Pastusinski)
2.	34.5 : 31.5 : 34.5	(Conley, Taiwo, Elliot)
3.	38.0 : 30.0 : 32.0	(Sakirkin, Hoffmann)
4.	35.5 : 32.0 : 32.5	(Kovalenko, Procenko)
5.	33.5 : 33.0 : 33.5	(Bouschen)
6.	36.0 : 29.0 : 35.0	(Badinelli, Slanar)

From this survey and from the data presented in Table 15 it follows:

a/ Most competitors had the longest hop in their best trials;
b/ For all competitors, without exception, the step was the shortest of the three phases.

None of the athletes used the extreme version used by the winner of the WC in Helsinki.

The findings mentioned above and the measurements undertaken at important events in 1987 (Bruno Zauli European Cup and E. R. Memorial in Prague) reveal a tendency towards a higher utilization of run-up speed. It is manifested in the "checked" length of the hop, and in an effort to maintain the horizontal speed until the third takeoff. The length of the step depends on the technical execution of the hop and continues to be the most variable part of the triple jump for most jumpers.

We believe that 18 m can be achieved by several variations of technique. The athletes who stand the best chance are those with percentage patterns of 36.0 : 30.5 : 33.5 (6.50 + 5.50 + 6.00 m, i.e. Markov) and 34.5 : 31.0 : 34.5 (6.20 + 5.60 + 6.20 m, i.e. Conley).

COMPARISON OF HOP, STEP AND JUMP LENGTHS - ROME 1987

TABLE 15

Name, country	D_O	D_L	D_E	d_1	d_2	d_1+d_2	d_3	%
MARKOV	17,70	0,11	17,81	6,55	5,35	11,90	5,90	36,8:30,0:33,1
BUL	17,73	0,00	17,73	6,45	5,55	12,00	5,73	36,4:31,3:32,3
	17,92	0,04	17,96	6,54	5,30	11,84	6,12	36,4:29,5:34,1
CONLEY	17,34	0,03	17,37	5,98	5,40	11,38	5,99	34,4:31,1:34,5
USA	17,37	0,14	17,51	6,14	5,45	11,59	5,92	35,1:31,1:33,8
	17,65	0,07	17,72	6,17	5,30	11,47	6,25	34,8:29,9:35,3
	17,67	0,03	17,70	6,11	5,52	11,63	6,07	34,5:31,2:34,3
SAKIRKIN	17,03	0,15	17,18	6,45	5,15	11,60	5,58	37,5:30,0:32,5
URS	17,36	0,09	17,45	6,74	4,85	11,59	5,86	38,6:27,8:33,6
	17,31	0,07	17,38	6,62	5,23	11,85	5,53	38,1:30,1:31,8
	17,29	0,06	17,35	6,64	5,07	11,71	5,64	38,3:29,2:32,5
	17,43	0,18	17,61	6,71	5,22	11,93	5,68	38,1:29,6:32,3
KOVALENKO	17,38	0,02	17,40	6,17	5,58	11,75	5,65	35,5:32,1:32,5
URS	16,81	0,11	16,92	5,96	4,92	10,88	6,04	35,2:29,1:35,7
	16,99	0,12	17,11	6,13	4,86	10,99	6,12	35,8:28,4:35,8
PASTUSINSKI	17,27	0,18	17,45	6,26	5,29	11,55	5,90	35,9:30,3:33,8
POL	17,20	0,02	17,22	6,22	5,38	11,60	5,62	36,1:31,2:32,6
	17,13	0,00	17,13	6,10	5,52	11,62	5,51	35,6:32,2:32,2
	17,28	0,14	17,42	6,56	4,98	11,54	5,88	37,7:28,6:33,8
	17,35	0,05	17,40	6,45	4,92	11,37	6,03	37,1:28,3:34,7
	17,26	0,08	17,34	6,40	5,22	11,62	5,72	36,9:30,1:33,0
TAIWO	17,29	0,18	17,47	6,03	5,42	11,45	6,02	34,5:31,0:34,5
NGR	17,09	0,12	17,21	5,72	5,28	11,00	6,21	33,2:30,7:36,1
	16,82	0,08	16,90	5,88	5,45	11,33	5,57	34,8:32,2:33,0
	16,96	0,08	17,04	6,06	5,39	11,45	5,59	35,6:31,6:32,8
BOUSCHEN	17,26	0,08	17,34	5,78	5,70	11,48	5,86	33,3:32,9:33,8
FRG	17,08	0,12	17,20	6,02	5,45	11,47	5,73	35,0:31,7:33,3
	16,73	0,10	16,83	6,07	5,28	11,35	5,48	36,1:31,4:32,6
	16,72	0,12	16,84	6,19	5,20	11,39	5,45	36,8:30,9:32,4
PROCENKO	17,23	0,09	17,32	6,10	5,48	11,58	5,74	35,2:31,6:33,1
URS	16,30	0,03	16,33	6,01	5,44	11,45	4,83	36,8:33,3:29,6
ELLIOT	16,79	0,23	17,02	5,93	5,21	11,14	5,88	34,3:30,6:34,5
BAH								
SLANAŘ	16,69	0,04	16,73	6,04	4,91	10,95	5,78	36,1:29,3:34,5
TCH	16,26	0,12	16,38	5,97	4,68	10,65	5,73	36,4:28,6:35,0
BADINELLI	16,63	0,12	16,75	6,14	4,61	10,75	6,00	36,7:27,5:35,8
ITA	16,40	0,14	16,54	6,14	4,41	10,55	5,99	37,1:26,7:36,2
	16,48	0,24	16,72	5,72	5,10	10,82	5,90	34,2:30,5:35,3
HOFFMANN	16,49	0,12	16,61	6,27	4,73	11,00	5,61	37,7:28,5:33,8
POL	16,58	0,09	16,67	6,34	5,06	11,40	5,27	38,0:30,4:31,6

P - Performance

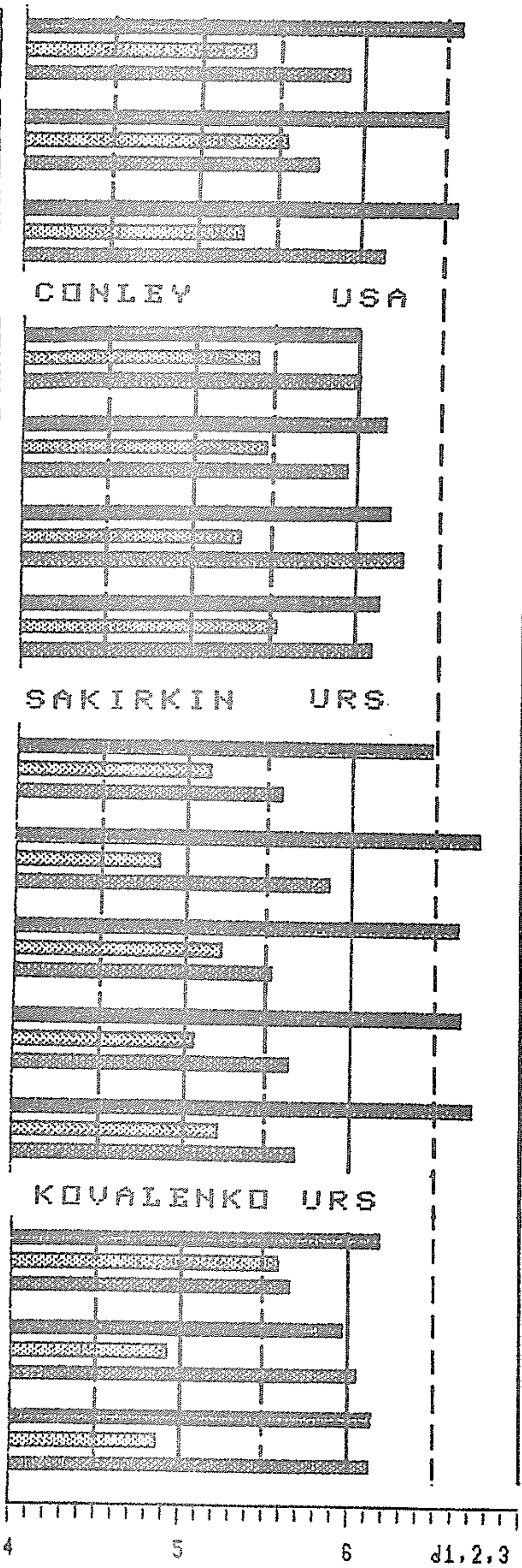
D_L - Lost distance

D_E - Effective distance

$d_{1,2,3}$ - Lengths of hop, step and jump

d_1+d_2 - Hop+step length

% - Percent pattern



Athlete	Trial	Result	DL	DE	d1,2,3	%	T1,2,3	T
Christo MARKOV BUL	1 TRIAL	17.70	0.11	17.81	6.55	36.8%	0.69	
					5.35	30.0%	0.62	
					5.90	33.1%	0.83	2.14
	2 TRIAL	17.73	0.00	17.73	6.45	36.4%	0.68	
					5.55	31.3%	0.68	
					5.73	32.3%	0.88	2.24
	4 TRIAL	17.92	0.04	17.96	6.54	36.4%	0.68	
					5.30	29.5%	0.61	
					6.12	34.1%	0.92	2.21
Mike CONLEY USA	1 TRIAL	17.34	0.03	17.37	5.98	34.4%	0.60	
					5.40	31.1%	0.61	
					5.99	34.5%	0.84	2.05
	2 TRIAL	17.37	0.14	17.51	6.14	35.1%	0.60	
					5.45	31.1%	0.64	
					5.92	33.8%	0.89	2.13
	4 TRIAL	17.65	0.07	17.72	6.17	34.8%	0.62	
					5.30	29.9%	0.61	
					6.25	35.3%	0.88	2.11
	6 TRIAL	17.67	0.03	17.70	6.11	34.5%	0.61	
					5.52	31.2%	0.63	
					6.07	34.3%	0.87	2.11
Oleg SAKIRKIN URS	1 TRIAL	17.03	0.15	17.18	6.45	37.5%	0.69	
					5.15	30.0%	0.64	
					5.58	32.5%	0.87	2.20
	2 TRIAL	17.36	0.09	17.45	6.74	38.6%	0.75	
					4.85	27.8%	0.60	
					5.86	33.6%	0.87	2.22
	3 TRIAL	17.31	0.07	17.38	6.62	38.1%	0.71	
					5.23	30.1%	0.62	
					5.53	31.8%	0.82	2.15
	5 TRIAL	17.29	0.06	17.35	6.64	38.3%	0.73	
					5.07	29.2%	0.60	
					5.64	32.5%	0.82	2.19
	6 TRIAL	17.43	0.18	17.61	6.71	38.1%	0.74	
					5.22	29.6%	0.67	
					5.68	32.3%	0.85	2.26
Alex. KOVALENKO URS	1 TRIAL	17.38	0.02	17.40	6.17	35.5%	0.65	
					5.58	32.1%	0.63	
					5.65	32.5%	0.86	2.14
	5 TRIAL	16.81	0.11	16.92	5.96	35.2%	0.60	
					4.92	29.1%	0.56	
					6.04	35.7%	0.88	2.04
	6 TRIAL	16.99	0.12	17.11	6.13	35.8%	0.64	
					4.86	28.4%	0.56	
					6.12	35.8%	0.92	2.12

FIG 25

DL LOST DISTANCE(m)
DE EFFECTIVE DISTANCE(m)

HOP -d1 (m)
STEP-d2 (m)
JUMP-d3 (m)

T1,2,3 -DURATION OF PHASES
T - DURATION OF T.JUMP(s)

4.4.1. Time characteristics of Hop, Step and Jump

Data concerning the duration of the separate takeoffs t_1, t_2 , t_3 (Table 16) may contribute to a greater accuracy in the technical evalution of the triple jump. When analyzing the support phases of the hop, step and jump we also recorded the time in which the jumpers reached the moment of the vertical t_v (the body CM is located exactly over the CM of the takeoff foot) and the moment of the amortization t_a (the greatest flexion angle at the knee joint of the takeoff leg has been reached).

The data in Tables 5, 7 and 9 were obtained by space kinematography and the data in Table 16 by the time-analysis of trials recorded by HS cameras (f = 200 frames/sec). A comparison of our data with other data from literature reveals that the duration of the takeoff support phases is reduced in the step and jump. Rule of thumb evaluation of the technical execution of the takeoffs may profit from the use of their total time. In the successful trials of the finalists it was less than 0.45 s. The mean value in 29 trials analysed is 0.43 s. Average takeoff times of the athletes mentioned above were: hop 0.117s, step 0.149 s and jump 0.161 s.

The duration of the flight phase depends on the initial flight angle and velocity. It is affected by losses of the horizontal velocity and by the vertical-velocity component.

These relations can be seen, among others, in the 4th trials of Markov (D_E = 17.96) and Conley (D_E = 17.72); Markov had higher run-up speed (0.2 m/s); his hop was longer by 37 cm and shorter by 0.1 s. Both jumpers had a step of 5.30 m, but Conley's flight phase was shorter (by 0.1 s). The flight phase of Conley's jump was shorter too (0.02 s), although he jumped 13 cm farther than Markov.

The athletes mentioned above represent the two most effective variants of the triple jump.

TIME CHARACTERISTIC OF HOP STEP, JUMP

	N_T	D_E	HOP $S-t_1$	HOP F	STEP $S-t_2$	STEP F	JUMP $S-t_3$	JUMP F	TRIPLE S	TRIPLE F	JUMP S+F
MARKOV	1	17,81	10	58	13	49	14	69	37	176	213
	3	x	12	54	14	49	15	73	41	176	217
	4	17,96	11	59	14	47	16	73	40	180	220
	5	x	12	59	14	47	16	73	42	179	221
CONLEY	1	17,37	11	49	16	44	17	68	44	161	205
	4	17,72	12	49	16	45	16	72	44	166	210
	5	x	12	47	17	43	17	72	46	162	208
	6	17,70	12	49	15	48	19	69	45	167	212
SAKIRKIN	1	17,18	12	60	15	49	15	72	41	182	223
	4	x	12	58	15	50	15	67	42	175	217
KOVALENKO	1	17,40	11	52	14	49	16	69	41	170	211
	4	x	12	49	15	46	15	68	42	163	205
	6	17,11	12	52	15	42	14	78	41	172	213
PASTUSINSKI	1	17,45	14	48	16	49	16	72	46	169	215
	6	17,34	13	53	18	47	19	69	50	169	219
TAIWO	1	17,47	11	52	14	52	17	73	43	176	219
	6	x	12	52	17	44	19	74	48	170	218
BOUSCHEN	1	x	11	49	13	58	14	62	38	169	207
	2	17,34	10	47	13	56	15	69	38	172	210
	5	16,83	11	51	14	48	16	73	41	172	213
	6	16,84	11	555	13	51	15	70	39	176	215
PROCENKO	1	x	11		15	47	19	66	45		
	4	x	12	52	15	41	16	71	43	164	207
	6	16,33	11	51	16	51	17	52	44	154	198
ELLIOT	1	x	12	52	16	44	17	71	46	166	212
SLANAR	1	x	15	54	17	44	16	76	48	174	222
BADINELLI	1	16,75	12	55	14	41	15	71	41	167	208
HOFFMANN	1	16,61	12	56	16	43	16	71	44	170	214
YAMASHITA	1	x	12	56	14	46	15	65	41	167	208

TABLE 16

N_T - Number of trial

D_E - Effective distance /m/

S - Duration of support phases of hop, step, jump (t_1, t_2, t_3) and the whole triple jump /$s.10^{-2}$/

F - Duration of flight phases of hop, step, jump and the whole triple jump /$s.10^{-2}$/

4.5. Final Phase - Landing

The trajectory of the body CM (26) intersects, in theoretical elongation of its descending part, the plane of the landing area 0.5m farther, in relation to the actual landing spot.

The triple jumper is able to complete the landing manoeuvre, transferring all the parts of the body beyond the spot of the first contact with the sand (Figs 28 - 30).

The rapid drop of both legs in the final phase of the flight may result in slight backward motion in the pit (Fig. 32).

The film analysis of landing technique (Figs 28-33) makes it possible to assess losses reducing the total length of jump; that may be caused by:

a/ premature leg landing,
b/ contact with the sand by another part of the body.

Markov, Conley and Sakirkin performed, in analysed trials, landing without losses.

On the contrary Kovalenko, Pastusinski, Bouschen, Taiwo and Elliott touched the sand also with another part of the body. The average loss of jump length was 0.15 m.

All above mentioned jumpers had, in analysed trials, a premature leg landing.

5. Discussion

The number of measurements made in Rome is insufficient for determining the interdependence between run-up speed and performance, or the contribution of technique and dynamic strength of the lower extremities to the performance.

Nomograms, of the kind plotted for the long jump, cannot be provided without additional analyses and statistical data-processing of large amounts of information.

Our recommendation to trainers is to watch the run-up speed both in competitions and in training. The methodology, and equipment for measurements, (described in section 3.), both fairly cheap and simple, are normally easily available.

Some generalizations can be made on the basis of 3-D analyses of the geometry of movements as described above. Using this information and assisted by a videorecorder, a coach can correct technical execution of the triple jump.

FINAL PHASE - LANDING

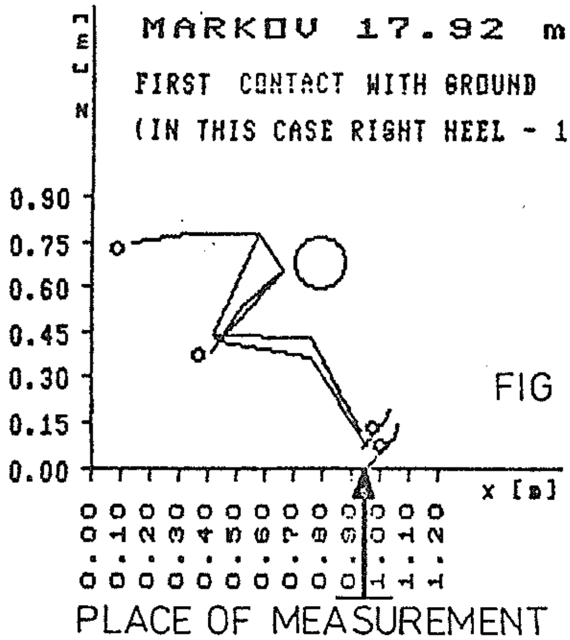


FIG 28

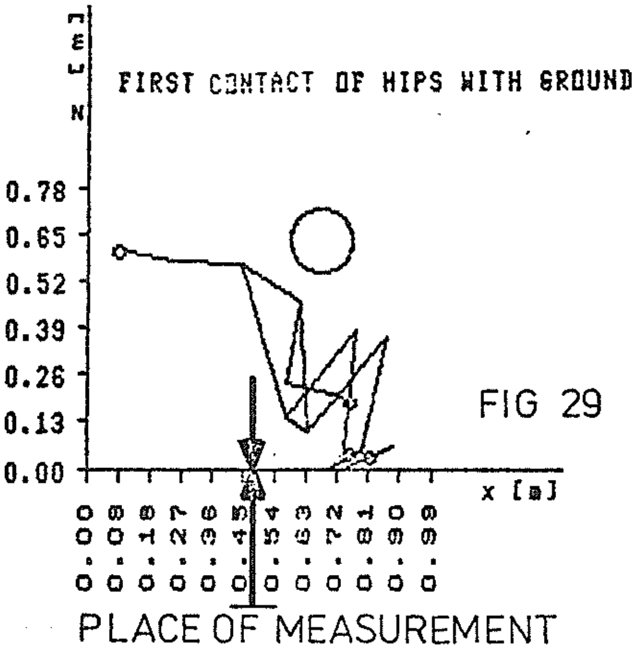


FIG 29

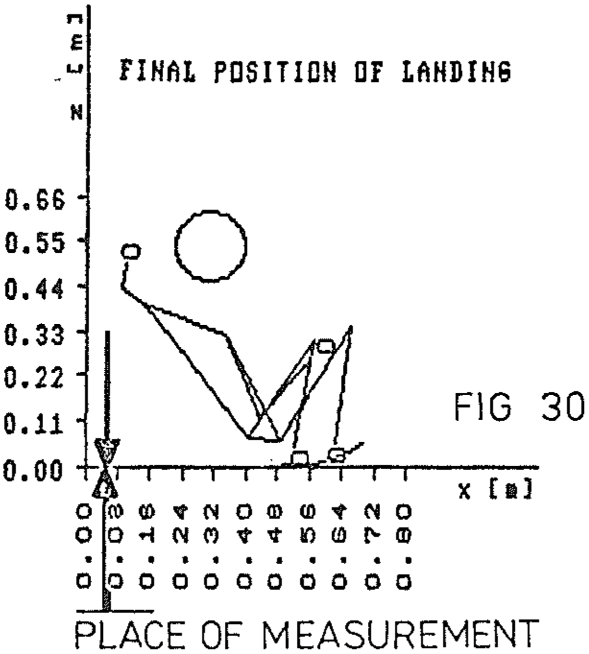


FIG 30

G

BIOMECHANICAL ANALYSIS OF THE HIGH JUMP

Ritzdorf, W.; Conrad, A.

The authors wish to express their thanks to
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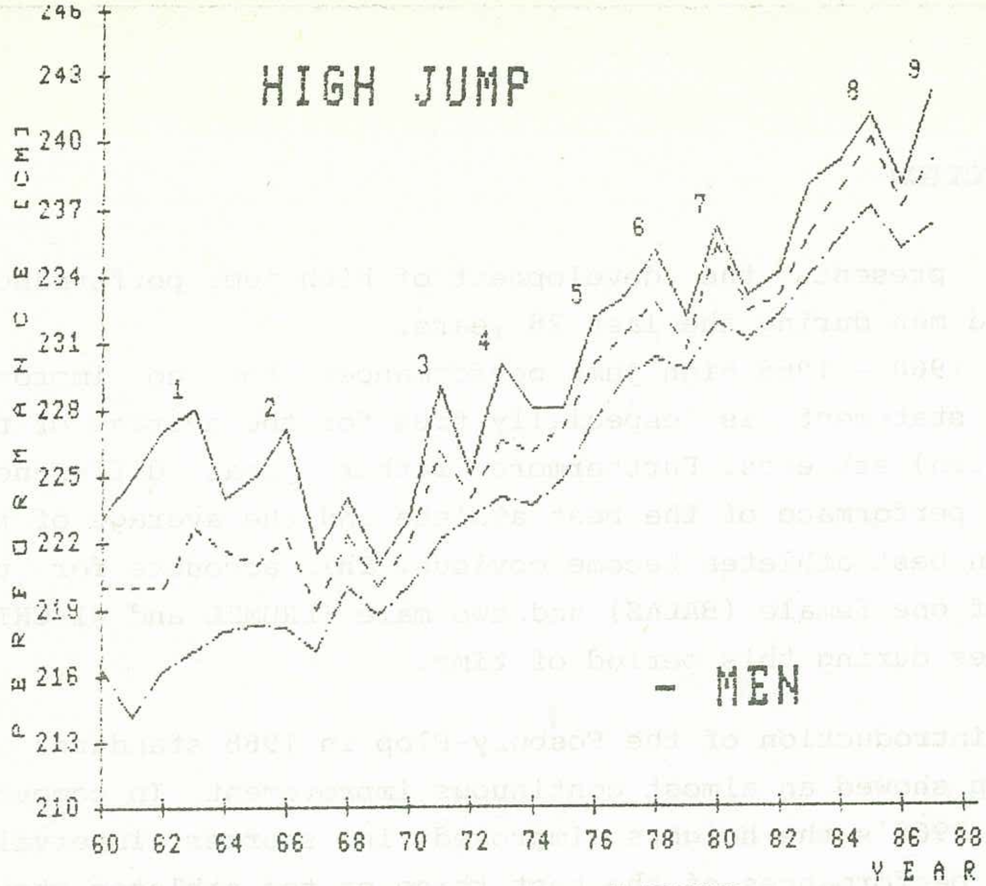
CONTENTS

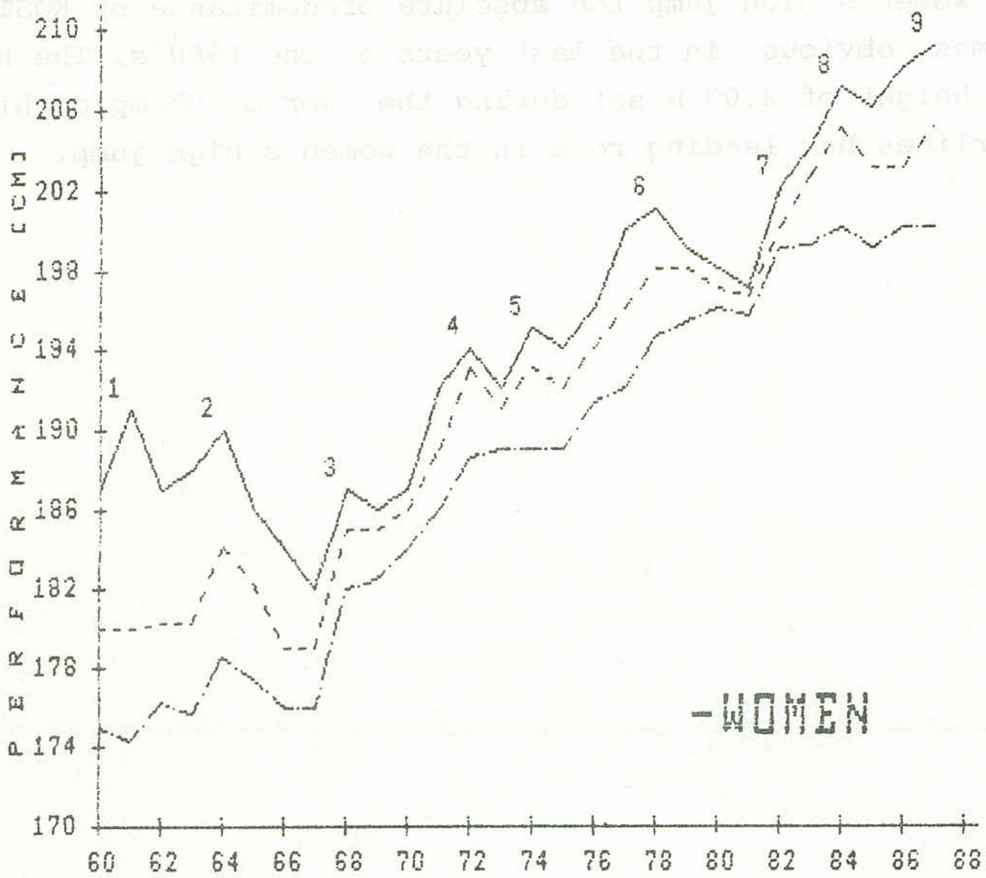
1. INTRODUCTION

Figure 1 presents the development of high jump performances for women and men during the last 28 years.
In the years 1960 - 1968 high jump performances show no improvement. This statement is especially true for the average of the best three (ten) athletes. Furthermore rather great differences between the performace of the best athlete and the average of the three and ten best athletes become obvious. This accounts for the dominance of one female (BALAS) and two male (BRUMEL and NI CHIH-CHIN) athletes during this period of time.

With the introduction of the Fosbury-Flop in 1968 standards in the high jump showed an almost continuous improvement. In comparison with the 1960's the heights improved in shorter intervals. The average performances of the best three or ten athletes show a closer connection to that of the best high jumper. While this tendency remains the same in the men's competition up to the present time, in the women's high jump the absolute predominance of KOSTADINOWA becomes obvious in the last years of the 1980's. The new world record height of 2.09 m set during the World Championships in Rome underlines her leading role in the women's high jump.



1 BRUMEL
2 NI CIIHCHIN
3 MATZDORF
4 STONES
5 STONES
6 YASHCHENKO
7 WESSIG
8 PAKLIN
9 SJOEBERG



1 BALAS
2 BALAS
3 SCHMIDT
4 BLAGOJEVA
5 WITSCHAS
6 SIMEONI
7 MEYHARTH
8 ANDONOVA
9 KOSTADINOVA

2. BIOMECHANICS OF THE HIGH JUMP

2.1. Division of the event

From a practical point of view the high jump may be considered to consist of three consecutive parts:

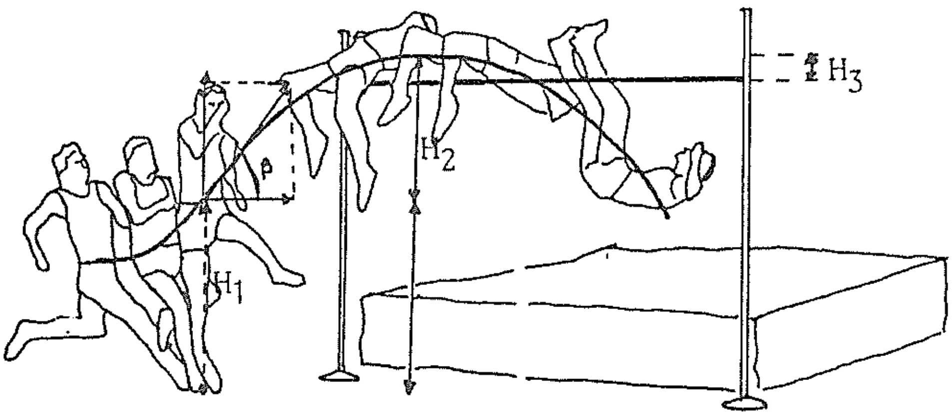
1. the approach - from the moment the athlete starts towards the bar until the instant of touchdown (TD) for takeoff

2. the takeoff[1] (TO) - from the instant of touchdown until the instant at which the takeoff foot breaks contact with the ground (the instant of takeoff)

3. the flight - from the instant of takeoff until the instant of landing; the landing in the high jump is not a performance-relevant phase.

From a biomechanical point of view, HAY (1973) stated that the takeoff and the flight in the high jump could be separated into three partial heights.

Fig. 2: Partial heights in the high jump



1 The terms "touchdown" and "takeoff" are often used to refer to the instants of touchdown and takeoff. The term "takeoff" may thus be used to refer either to an instant in time or to a period of time, depending on the context.

- takeoff height - the height of the athlete's centre of mass (CM) at the instant of takeoff;
- height of CM flight - the difference between maximum height of athlete's CM during the flight and the takeoff height;
- height over the bar - the vertical distance between the height of CM flight and the height of the bar.

Because of the great importance of the approach, we chose a combined procedure of practical and biomechanical points of view in our studies.

The takeoff height is almost independent of the approach. It is determined by anthropometric parameters like body segment masses, segment lengths and the location of centres of mass in the segments, as well as by the body angles at the instant of takeoff.

In addition to the resultant takeoff height the following parameters determinating the takeoff-height are considered in our studies:

- knee angle of the takeoff leg at TO
- angle of lead leg thigh at TO
- angle of trunk position at TO.
- angle of forward/backward and inward lean at TO

From a biomechanical point of view, the CM height of flight is strictly dependent on the vertical CM velocitiy at takeoff. The vertical takeoff velocity itself is determined by the vertical impulse, the vertical CM velocity at touchdown and the mass of the jumper.

Practically, the vertical impulse may be influenced by the approach, the conditions at TD, the vertical path of CM during TO and the support time. In the approach, during the last two steps until the moment of TD the following parameters are determined:

- support and flight times
- stride lengths and frequencies
- path of CM
- angle of run-up
- horiziontal, vertical and resultant velocities.

Concerning the TO itself the following are considered:

- support time
- distance from the bar
- vertical path of CM
- angle of takeoff
- body-segment and body-position angles at TD and TO
- horizontal, vertical and resultant velocities.

In this way relevant parameters of performance may be quantified.

The height over the bar depends on the orientation of the segments crossing the bar. According to DAPENA (1980) it is highly influenced by the angular momentum of the whole body about the transverse axis through the athlete's CM.
We determine the difference between maximum CM height and the height of the bar.

2.2. Review of literature and previous findings

Because of the difficulty of correctly measuring this three dimensional event, we can only review and discuss a few biomechanical articles, which present three dimensional data (DAPENA 1980a, b, VAN GHELUWE/DOMINCK 1979).

Three dimensional analysis is required for a full and correct analysis of the high jump, especially because of the curved run-up and the rotations on three axes. Results of 2-D analysis must be interpreted with care.
Our own data relies mainly to the following events:

- World Junior Championships, Athens 1986
- European Champinonships, Stuttgart 1986
- International High Jump Meeting Women, Wörrstadt 1985, 1986.

In the following chapter we discuss the parameters in the rank order of their appearance, i.e. first approach, than takeoff.

2.2.1. Approach

2.2.1.1. Times

Tab. 1 shows the results of selected jumps during the European Championships 1986 (for further information see New Studies in Athletics 4/1986):

Tab. 1: Support and flight-times of last three strides

Name	HB	3ST	3FLT	2ST	2FLT	LST	LFLT	TOST
Kostadinowa Stefka	2.00+	--	--	0.06	0.13	0.11	0.09	0.10
Issaewa Swetlana	1.96-	--	--	0.12	0.12	0.14	0.11	0.14
Turtschak Olga	1.96-	--	--	0.16	0.14	0.18	0.09	0.16
Redetzky Heike	1.90-	--	--	0.14	0.22	0.12	0.04	0.14
Paklin Igor	2.34+	--	--	0.16	0.10	0.19	0.05	0.17
Maltschenko Sergej	2.31+	0.12	0.17	0.13	0.09	0.18	0.06	0.15
Thränhardt Carlo	2.28+	0.16	0.16	0.20	0.11	0.16	0.06	0.17
Mögenburg Dietmar	2.28+	0.13	0.15	0.12	0.15	0.14	0.06	0.15

The results show the general tendency to decrease flight times in the last strides and thus confirm former data (see Athens report). In coaching practice this is interpreted as a predominant running activity in the last strides with minimal loss in horizontal velocity.

2.2.1.2. Stride lengths

There is a general consensus in the coaching literature that a typical rhythm obtained by lengthening the penultimate stride and shortening the 3rd to last and takeoff strides, prevails in the high jump. Because of a pronounced active foot plant with the heel making the first ground contact, the strides look somewhat dragged.

Quantitative data are given by DAPENA (1980a). The lengthening of the penultimate stride mentioned above was not found in all jumpers. The reported stride lengths vary from 1.55 m - 2.11 m for the 3rd to last, 1.57 m - 2.11 m for the penultimate and 1.62 m - 2.10 m for the last stride.

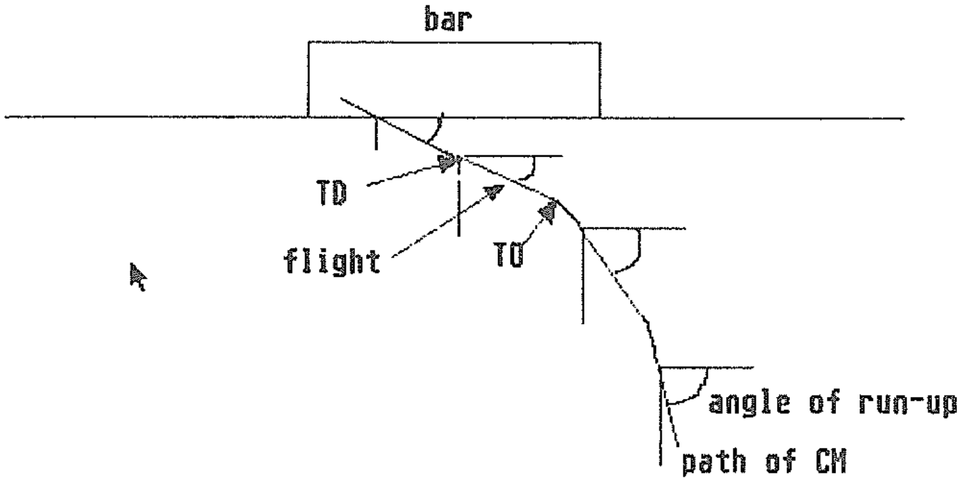
Our own data does not confirm these findings. All medallists in the mentioned championships show a shortening of penultimate stride compared with the third to last. The last stride is either shortened again (Men's medallists Stuttgart, three medallists Athens, Kostadinova) or lengthened (Issaewa, Turtschak, three medallists Athens). The stride frequencies generally increase during the last steps, and thus confirm the predominant running activity.

2.2.1.3. Path of CM

Vertical changes of CM heights during support phases were found to be minimal. There is a moderate tendency to decreasing heights at TD in the last three steps. In most cases TD height is minimal for the takeoff. An overhead point of view illustrates the horizontal path of CM, i.e. the run-up angle (see Fig. 3).

Run up angles show a decreasing tendency in the last steps (DAPENA 1980a) with a wide range of individual differences even in the last step. Data measured are between 22° and 63° in the last step. Therefore individual changes should be interpreted with care.

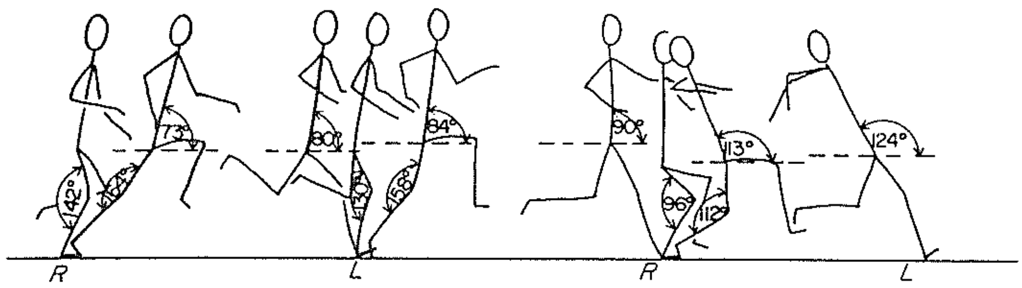
Fig. 3: Run-up angle



2.2.1.4. Body-segment and body-position angles

Concerning the body-segment angles the knee-angle is of special interest. The analysis of this angle in the support leg illustrates that, for the penultimate step, most athletes touch the ground with a nearly straightened leg. For most athletes the values are greater than 160°. Maximum amortisation angles are in the order of 150°, with the important exception of Paklin (132°). In the last step TD angles are on the order of 150°-160°, while angles at maximum amortisation differ from 140° (Kostadinova) to less than 120° (Paklin, Issaewa, all junior medallists in Athens except Müller). In general minimal knee angles are reached in the amortisation phase of the last step and not in the takeoff. These must be interpreted in their meaning for the preparation of the takeoff. In excellent jumpers minimal knee angles in the last step are not necessarily combined with a decrease of horizontal velocity.

Fig. 4: Angles of body lean



Additionally all athletes show a marked inward lean according to their run-up speed and angle.

2.2.1.5. Velocity

Data on the horizontal component of the CM velocity in the run-up were reported by ADDACHI et al. (1973), NIGG et al. (1974) and DAPENA (1980a). The values ranged from 4.50 m/s - 7.90 m/s.

NIGG et al. (1974) measured the projected velocity for Dwight Stones as 6.80 m/s. Knowing that the final run-up angle is 37°, DAPENA (1980a) calculated a total horizontal velocity of 8.50 m/s for Stone's jump. Considering the methods used and the frame rate, the calculated velocity for Stones' jump seems to be over-estimated.
Our own data from the men's final during the European Championships are presented in Tab. 2.

Tab. 2: Horizontal velocity of CM during approach

Name	HB	3.letzter Schritt	2.letzter Schritt	letzter Schritt	Absprung
Kostadinowa Stefka	2.00+	--	6.07	5.65	3.33
Issaewa Swetlana	1.96-	--	5.67	5.55	4.44
Turtschak Olga	1.96-	--	5.38	6.02	4.19
Redetzky Heike	1.90+	--	5.84	5.92	4.86
Paklin Igor	2.34+	--	7.67	7.88	3.65
Maltschenko Sergej	2.31+	7.18	7.17	6.53	4.08
Thränhardt Carlo	2.28+	7.52	7.62	7.35	4.27
Mögenburg Dietmar	2.28+	8.06	8.31	7.92	4.48

For Sotomayor's winning jump at the World Junior Championships 8.4 m/s for the penultimate step and 8.2 m/s for the last step were measured.
Corresponding data for the women are between 6.4 and 7.8 m/s.

To sumarize: there is no clear tendency in the run-up-speed-ratio in the last two steps. Slight decreases in velocity can be found as well as slight increases.

2.3. Takeoff

2.3.1. Support time

The takeoff time is partially determined by the action of the lead segments. Takeoffs with running arm action and bent lead leg (flop 1) are characterized by shorter takeoff times (120 ms - 200 ms) than those takeoffs with double arm and straight lead leg action (flop 2) (170 ms - 230 ms) (NIGG 1974, HAY 1975, VIITASALO et al. 1982).

Although a significant correlation between time of takeoff and height of flight was not reported by any author, there is a tendency among today's world's best athletes towards rather short support times. Our own data of the mentioned events show support times between 120 (Kostadinova) and 190 ms (Sotomayor), with most athletes between 150 and 170 ms. This requires enormous reactive strength and high acceleration of the lead leg and the arms in the takeoff.

2.3.2. Path of centre of mass

According to former studies, the vertical path over which the CM can be accelerated during takeoff shows a maximum trend. NIGG (1974) reported positive correlations between the vertical rise of CM during TO and the height of flight analysing several jumps of D. Stones. The values ranged from 0.38 to 0.48 m. Corresponding values of our own studies range from 0.41 to 0.46 m (men) and 0.31 to 0.39 m (women) for Stuttgart's medallists. Athens' results are in the same order, except Sotomayor with 0.61 m. This wide range of CM-motion was combined with a quite long support time as mentioned above. Our own statistical analysis does not confirm the general tendency of a positive correlation between vertical rise of CM and the height of the flight.
Large differences were found for the toe to bar distance at takeoff. They ranged from 0.55 m (Kostadinova, Wörrstadt 2.03 m), 0.69 m (Paklin, Stuttgart 2.34 m) to more than 1.20 m (Sotomayor, Mögenburg, Tränhardt).

2.3.3. Angles

The knee angle, as the most important body segment angle, generally ranges from 165° to 175° at TD, with the exception of Paklin (155°). Maximum amortisation angles differ from 140° to 155° and thus confirm coaching literature. Surprisingly, no athlete in our studies was able to completely straighten the lead leg at the moment of TO. Body position angles show a marked backward lean at TD and moderate inward leans. This confirms findings of DAPENA (1980b) who found very small lateral deviation of the CM (max. 7°) during the takeoff.

"This implies that during the takeoff phase there was very little centripetal force applied on the athlete or centrifugal force applied by the athlete on the ground. Thus the claim made in previous theoretical literature that centrifugal force plays an important role during the takeoff does not appear to be justified" (DAPENA 1980a, 41).

Characteristic angles of TO were found to be smaller than 50°. DAPENA reported takeoff angles of 40-48°. The takeoff angles of Kostadinova were measured as 45°. Only Paklin and Sotomayor reached angles greater than 50° (51°, 52°).

2.3.4. Velocities

During the takeoff the horizontal velocity of the athletes is reduced by 2.30 m/s - 3.70 m/s (DAPENA 1980a). The reduction seems to be quite constant for each athlete. The analysis of several jumps of Kostadinova shows results similar to those of DAPENA. She reduced the horizontal velocity by 2.3 m/s - 2.4 m/s in each of her succesful trials. Corresponding values for the men range from 3.5 m/s to 4.2 m/s in worldbest ahtletes.

The vertical velocity at TO, which strictly determines the flight height of the CM, ranges from 4.0 m/s to 4.5 m/s in men and 3.8 m/s to 4.0 m/s in women. Only Kostadinova was measured with a vertical takeoff velocity of more than 4.0 m/s.
These velocities produce flight heights of 0.75 to 1.02 m.

To highlight: the vertical takeoff-velocity is the resultant parameter that is determined by many technical parameters as discussed above as well as by athletic parameters. Therefore it cannot be influenced and changed directly.

3. METHODS AND PROCEDURES

For both high jump finals at the world championships the participating athletes were filmed with three LOCAM highspeed filmcameras synchronized at a nominal speed of 150 fps. While the womens' event was taken with fixed cameras, the male athletes were filmed with horizontally panning cameras. For each method the positioning of known reference marks in the object area was necessary to enable 3D-analysis. For reasons of comparison of the data of both competitions, both applied methods guarantee compatible results.

A number of factors made it impossible to analyse the best trial for each participant. Therefore it became unavoidable that we analysed jumps over lower heights or failures.

4. ANALYSIS OF THE HIGH JUMP FINALS AT THE II WC IN ATHLETICS

4.1. Event Scorecard

	1.80	1.85	1.90	1.83	1.96	1.99	2.02	2.04	2.06	2.08	2.09
S.KOSTADINOWA	-	o	o	-	o	o	o	xxo	xo	-	xo
T.BYKOWA	-	o	o	o	o	o	o	o	xx	x	
S.BEYER	o	o	o	o	o	xo	xxx				
S.COSTA	o	o	o	o	o	xx	x				
L.KOSITSINA	-	o	o	xxo	o	xxx					
H.REDETZKY	-	o	o	o	xo	xxx					
S.ISSAEVA	o	o	o	o	xxx						
L.RITTER	-	o	xo	o	xxx						
L.AVDEENKO	-	xo	o	o	xxx						

	2.10	2.15	2.20	2.25	2.29	2.32	2.35	2.38	2.40
P.SJOEBERG	-	-	-	o	-	o	o	o	xxx
I.PAKLIN	-	-	o	o	xo	o	xo	xxo	xxx
G.AVDEENKO	-	-	-	o	o	o	xxo	xxo	xxx
D.MÖGENBURG	-	-	-	o	o	o	o	x	xx
C.SAUNDERS	-	-	o	o	-	o	xxx		
S.MATEI	-	-	o	xxo	o	o	x	xx	
J.ZVARA	-	o	o	o	o	xxo			
C.THRÄNHARDT	-	-	-	o	o	xxx			

4.2. Results of the biomechanical analysis

In the following numerical and graphical presentation of the results special abbreviations are used. In detail they have the following meanings:

CM	- centre of mass
HB	- height of bar
TD	- touch down; first contact with the ground
AM	- amortisation: in general in combination with the smallest knee angle
TO	- takeoff; moment of last contact with the ground
2nd last	- penultimate stride or penultimate flight time in the run-up
2TD	- touch down in the penultimate stride
2AM	- amortisation in the penultimate stride
2TO	- takeoff in the penultimate stride
1TD	- touch down in the last stride
1AM	- amortisation in the last stride
1TO	- takeoff in the last stride

Tab. 3: Partial height according to the HAY-model (m)

	Bar	H1	H2	H3
S.KOSTADINOWA	2.09+	1.18	1.01	0.10
T.BYKOWA	2.04+	1.18	0.93	0.07
S.BEYER	2.02-	1.10	0.86	0.06
S.COSTA	2.02-	1.18	0.97	0.13
L.KOSITSINA	1.96+	1.24	0.70	-0.02
H.REDETZKY	1.96+	1.21	0.82	0.07
S.ISSAEVA	1.96-	1.24	0.67	-0.05
L.RITTER	1.93-	1.17	0.91	0.15
P.SJOEBERG	2.38+	1.37	1.17	0.16
I.PAKLIN	2.38+	1.45	1.08	0.15
G.AVDEENKO	2.38+	1.43	1.07	0.12
D.MÖGENBURG	2.38-	1.42	1.10	0.14
C.SAUNDERS	2.32+	1.28	1.10	0.06
S.MATEI	2.32+	1.24	1.30	0.22
J.ZVARA	2.32-	1.43	1.03	0.14
C.THRÄNHARDT	2.29+	1.43	1.02	0.16

Tab. 3 shows the attempts that were analysed (+ = clearance, - = failure). H1, H2 and H3 refer to the above mentioned biomechanical model (HAY 1973).

H1 (takeoff height) and H2 (height of flight) will be discussed later. H3 (height over the bar) illustrates that it seems to be very difficult to clear the bar with a height of CM less than the height of the bar. While only L.KOSITSINA was succesful with a negative H3 value. S.COSTA and D.MÖGENBURG fail although they raised their CM more than 10 cm over the bar's height.

Tab. 4: Support times (s)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	0.120	0.133	0.140
T.BYKOWA	2.04+	0.140	0.133	0.167
S.BEYER	2.02-	0.127	0.133	0.153
S.COSTA	2.02-	0.127	0.133	0.153
L.KOSITSINA	1.96+		0.173	0.140
H.REDETZKY	1.96+	0.140	0.127	0.167
S.ISSAEVA	1.96-	0.147	0.160	0.160
L.RITTER	1.93-	0.160	0.167	0.153
P.SJOEBERG	2.38+	0.140	0.147	0.160
I.PAKLIN	2.38+	0.147	0.180	0.180
G.AVDEENKO	2.38+	0.167	0.193	0.180
D.MÖGENBURG	2.38-	0.133	0.147	0.147
C.SAUNDERS	2.32+	0.147	0.153	0.160
J.ZVARA	2.32-		0.220	0.227
S.MATEI	2.32+	0.140	0.140	0.127
C.THRÄNHARDT	2.29+	0.147	0.153	0.160

Tab. 5: Flight times (s)

	HB	2nd last	last
S.KOSTADINOWA	2.09+	0.093	0.087
T.BYKOWA	2.04+	0.153	0.047
S.BEYER	2.02-	0.133	0.067
S.COSTA	2.02-	0.133	0.060
L.KOSITSINA	1.96+		0.080
H.REDETZKY	1.96+	0.187	0.047
S.ISSAEVA	1.96-	0.087	0.067
L.RITTER	1.93-	0.087	0.073
P.SJOEBERG	2.38+	0.153	0.060
I.PAKLIN	2.38+	0.133	0.047
G.AVDEENKO	2.38+	0.120	0.040
D.MÖGENBURG	2.38-	0.160	0.060
C.SAUNDERS	2.32+	0.100	0.033
J.ZVARA	2.32-		0.073
S.MATEI	2.32+	0.133	0.080
C.THRÄNHARDT	2.29+	0.120	0.073

Fig. 4: Support times.

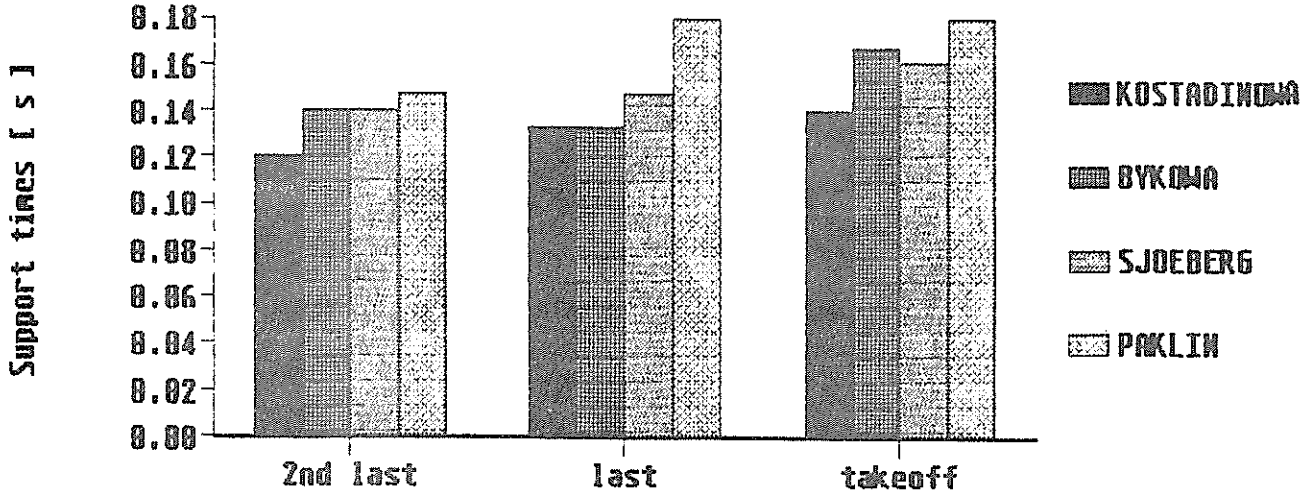


Fig. 5: Flight Times.

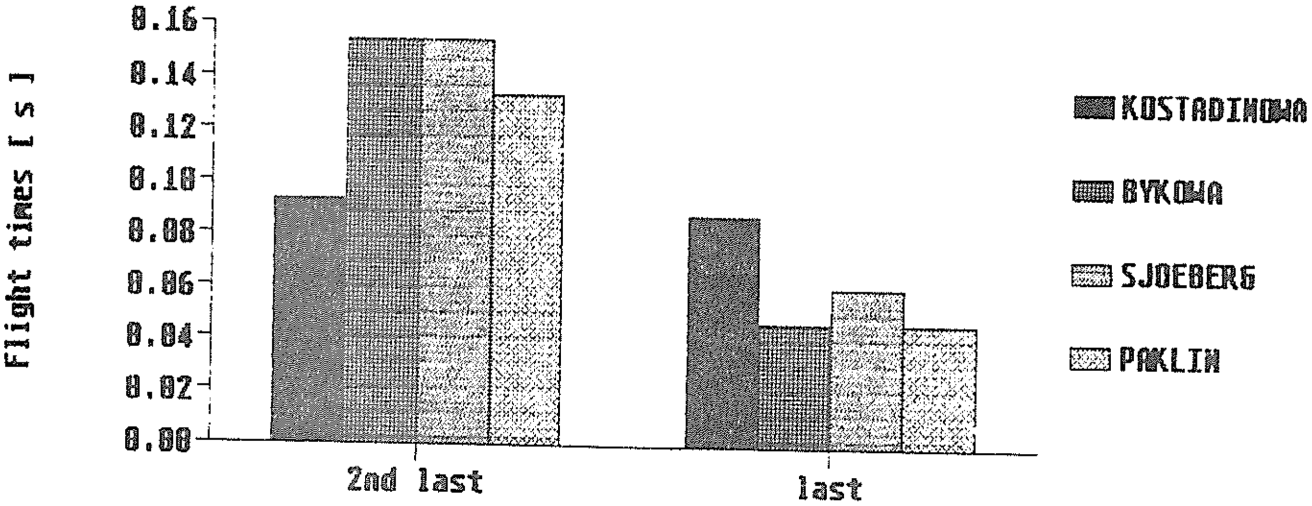


Table 4 in general presents increasing support times during the last two strides of the approach and the takeoff. This indicates the intention to lengthen the acceleration phase in order to reduce the horizontal velocity as little as possible in preparation for the takeoff.

The takeoff time itself trends to be minimal for the best female athletes. The results of the male competitors however do not necessarily confirm this supposition. The rather short takeoff times with the enormous reaction forces acting upon the athlete may account for the activation of reactive muscle forces. A clear exception can be found in the takeoff performance of J.ZVARA. He may be described as a FLOP 2 jumper. This technique with straight lead leg and double arm action is generally combined with longer takeoff times.

In connection with increasing support times, the flight times show an inverse tendency. As mentioned above this can be interpreted as a high running activity.
Thus stride frequency should also keep increasing to underline this interpretation.

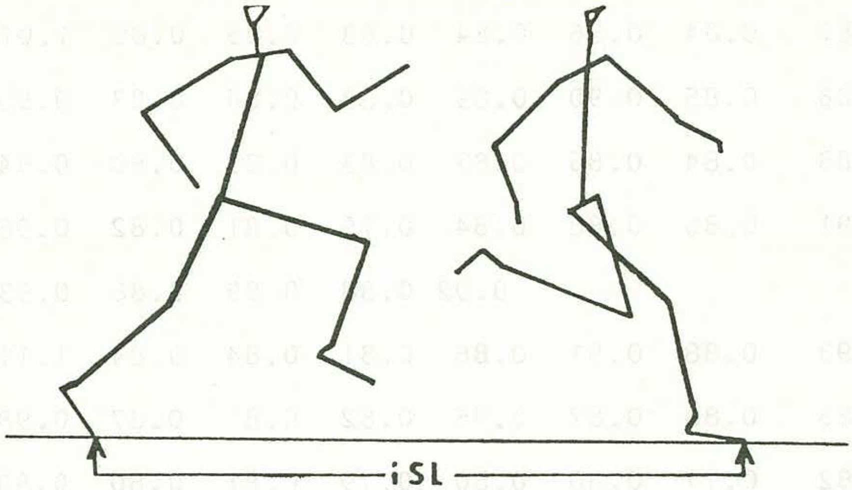
Tab. 6: Stride frequency (S/s)

	HB	2nd last	last
S.KOSTADINOWA	2.09+	4.69	4.54
T.BYKOWA	2.04+	3.44	5.55
S.BEYER	2.02-	3.84	5.00
S.COSTA	2.02-	3.84	5.18
L.KOSITSINA	1.96+		3.95
H.REDETZKY	1.96+	3.05	5.74
S.ISSAEVA	1.96-	4.27	4.40
L.RITTER	1.93-	4.04	4.16
P.SJOEBERG	2.38+	3.41	4.83
I.PAKLIN	2.38+	3.57	4.40
G.AVDEENKO	2.38+	3.48	4.29
D.MÖGENBURG	2.38-	3.41	4.43
C.SAUNDERS	2.32+	4.04	5.37
J.ZVARA	2.32-		3.41
S.MATEI	2.32+	3.66	4.54
C.THRÄNHARDT	2.29+	3.74	4.42

Tab. 7: Stride length (m)

	HB	2nd last	last
S.KOSTADINOWA	2.09+	1.76	2.01
T.BYKOWA	2.04+	2.07	1.61
S.BEYER	2.02-	1.83	1.66
S.COSTA	2.02-	1.95	1.61
L.KOSITSINA	1.96+		1.67
H.REDETZKY	1.96+	2.20	1.73
S.ISSAEVA	1.96-	1.34	1.75
L.RITTER	1.93-	1.27	2.45
P.SJOEBERG	2.38+	2.25	1.95
I.PAKLIN	2.38+	2.44	2.18
G.AVDEENKO	2.38+	2.53	2.04
D.MÖGENBURG	2.38-	2.49	2.03
C.SAUNDERS	2.32+	1.98	1.83
J.ZVARA	2.32-		2.13
S.MATEI	2.32+	2.32	2.07
C.THRÄNHARDT	2.29+	2.00	2.17

Fig. 6: Stride length (m)



In the womens' competition the method of lengthening or shortening the last two strides may be regarded as individual preference. On the other hand the male athletes - with the exception of C.THRÄNHARDT - shorten the last stride as compared with the penultimate one. This obviously depends on their rather short flight times in the last stride in addition to the active foot plant for takeoff.

Tab. 8: Heights of CM at TD, AM and TO (m)

	HB	TD	AM	TO	TD	AM	TO	TD	AM	TO
S.KOSTADINOWA	2.09+	0.87	0.84	0.86	0.84	0.83	0.85	0.85	1.01	1.18
T.BYKOWA	2.04+	0.88	0.85	0.90	0.89	0.83	0.84	0.83	0.95	1.18
S.BEYER	2.02-	0.88	0.84	0.86	0.87	0.83	0.83	0.80	0.94	1.10
S.COSTA	2.02-	0.91	0.86	0.88	0.84	0.79	0.81	0.82	0.98	1.18
L.KOSITSINA	1.96+				0.92	0.88	0.89	0.88	0.93	1.24
H.REDETZKY	1.96+	0.93	0.88	0.91	0.86	0.81	0.84	0.84	1.11	1.21
S.ISSAEVA	1.96-	0.85	0.83	0.87	0.85	0.82	0.87	0.87	0.98	1.24
L.RITTER	1.93+	0.82	0.77	0.80	0.80	0.79	0.81	0.80	0.89	1.17
P.SJOEBERG	2.38+	1.04	1.00	1.04	1.00	0.95	0.97	0.96	1.10	1.37
I.PAKLIN	2.38+	0.96	0.92	0.95	0.92	0.90	0.91	0.91	0.94	1.45
G.AVDEENKO	2.38+	0.98	0.93	1.00	0.97	0.95	0.99	0.98	1.04	1.43
D.MÖGENBURG	2.38-	1.04	0.99	1.00	0.98	0.95	0.98	1.01	1.14	1.43
C.SAUNDERS	2.32+	0.91	0.86	0.90	0.88	0.84	0.86	0.85	0.96	1.28
J.ZVARA	2.32-				0.89	0.83	0.89	0.89	1.04	1.43
S.MATEI	2.32+	0.89	0.85	0.89	0.85	0.83	0.88	0.86	0.96	1.24
C.THRÄNHARDT	2.29+	1.15	1.11	1.13	1.08	1.03	1.05	1.01	1.08	1.43

Fig. 7: Vertical path of CM (KOSTADINOWA - BYKOWA)

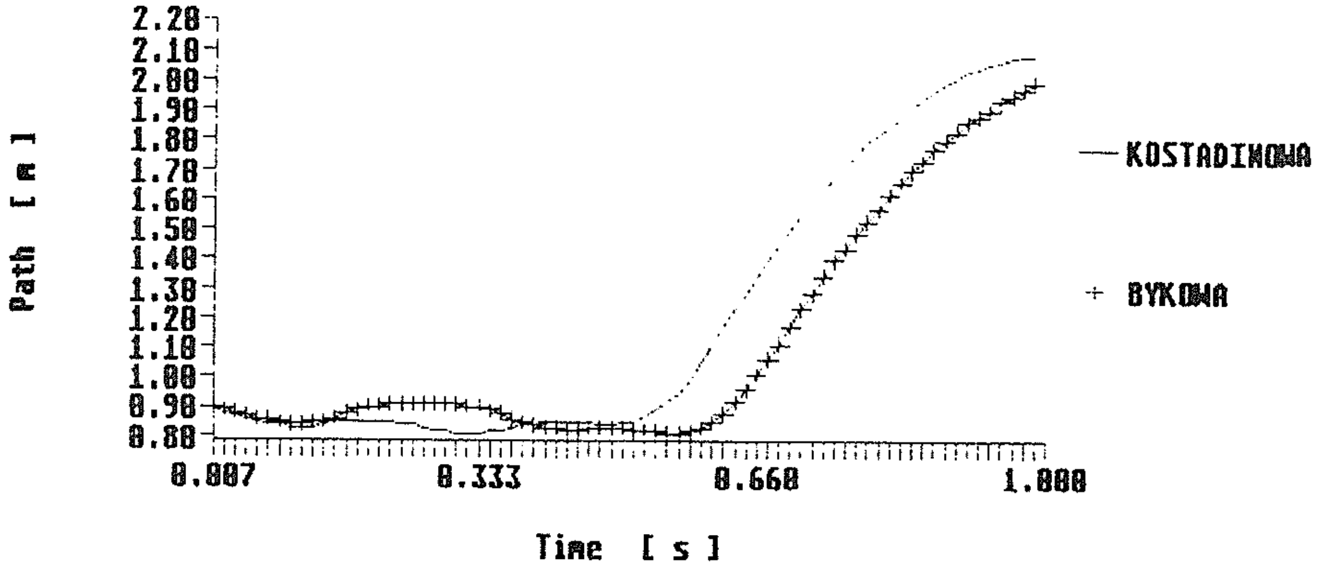
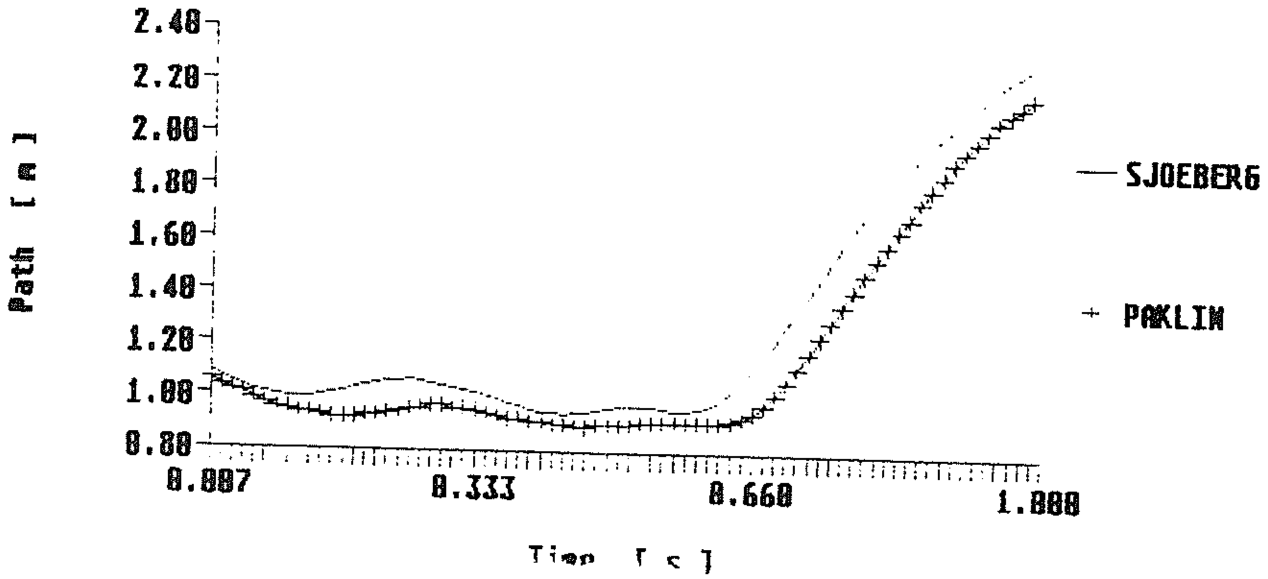


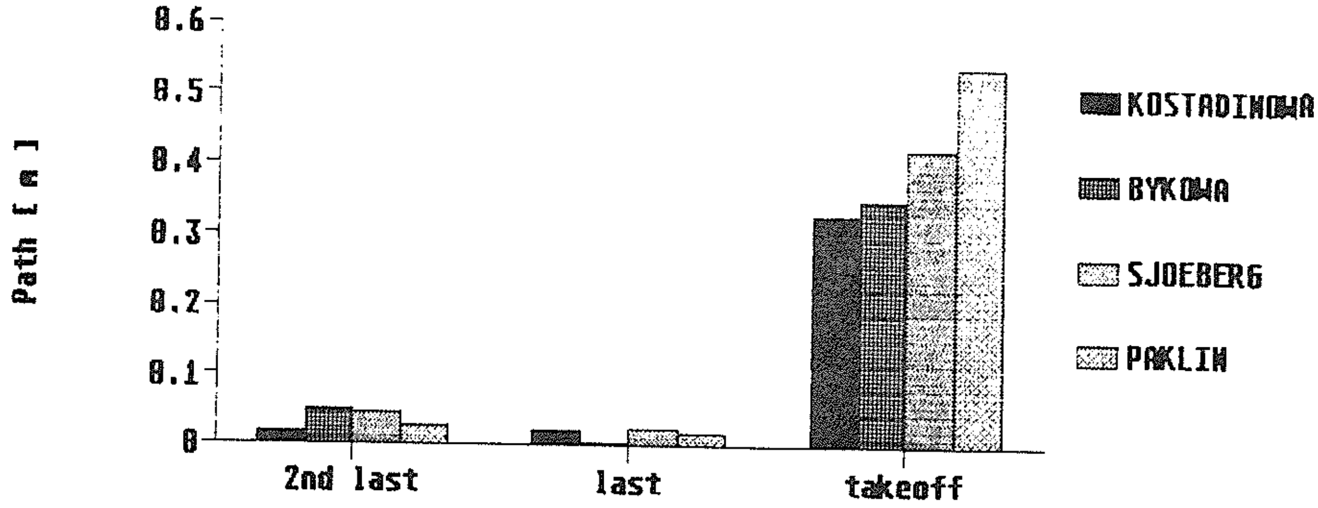
Fig. 8: Vertical path of CM (SJOEBERG - PAKLIN)



Tab. 9: Vertical path of acceleration (m)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	0.02	0.02	0.33
T.BYKOWA	2.04+	0.05	0.00	0.35
S.BEYER	2.02-	0.02	0.00	0.30
S.COSTA	2.02-	0.02	0.01	0.36
L.KOSITSINA	1.96+		0.02	0.36
H.REDETZKY	1.96+	0.04	0.03	0.37
S.ISSAEVA	1.96-	0.03	0.06	0.37
L.RITTER	1.93-	0.03	0.02	0.37
P.SJOEBERG	2.38+	0.04	0.02	0.42
I.PAKLIN	2.38+	0.03	0.02	0.54
G.AVDEENKO	2.38+	0.06	0.04	0.45
D.MÖGENBURG	2.38-	0.01	0.02	0.41
C.SAUNDERS	2.32+	0.04	0.01	0.43
J.ZVARA	2.32-		0.05	0.54
S.MATEI	2.32+	0.05	0.05	0.38
C.THRÄNHARDT	2.29+	0.02	0.02	0.42

Fig. 9: Vertical path of acceleration



In general the CM-height continues to decrease during the last two strides of the approach with a minimum at AM in the last step. During takeoff itself CM reaches its lowest position at the moment of TD. Consequently the CM can be accelerated positively during the entire time of takeoff. The absolute height of CM depends on the individual anthropometric segment lengths and the inward lean of the athlete in connection with his angle of run-up. Thus the absolute height H1 - as described above - must be regarded as an individual parameter that may hardly be compared interindividually.

Confirming former findings, the vertical path of the CM during takeoff does not follow a maximum trend for the Rome finalists. In connection with the short takeoff times this can be regarded as a logical consequence. Concerning the winners of both competitions, S.KOSTADINOWA and P.SJOEBERG, their vertical paths of the CM lie below the average of all finalists in their group.

Tab. 10: Angle of run-up (degrees)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	49	41	25
T.BYKOWA	2.04+	53	43	35
S.BEYER	2.02-	47	40	38
S.COSTA	2.02-	54	42	35
L.KOSITSINA	1.96+		12	14
H.REDETZKY	1.96+	48	34	22
S.ISSAEVA	1.96-	17	17	12
L.RITTER	1.93-	46	40	31
P.SJOEBERG	2.38+	60	51	43
I.PAKLIN	2.38+	38	23	23
G.AVDEENKO	2.38+	61	55	43
D.MÖGENBURG	2.38-	59	48	44
C.SAUNDERS	2.32+	46	37	36
J.ZVARA	2.32-		43	34
S.MATEI	2.32+	53	42	34
C.THRÄNHARDT	2.29+	48	42	39

Fig. 10: Angle of run-up

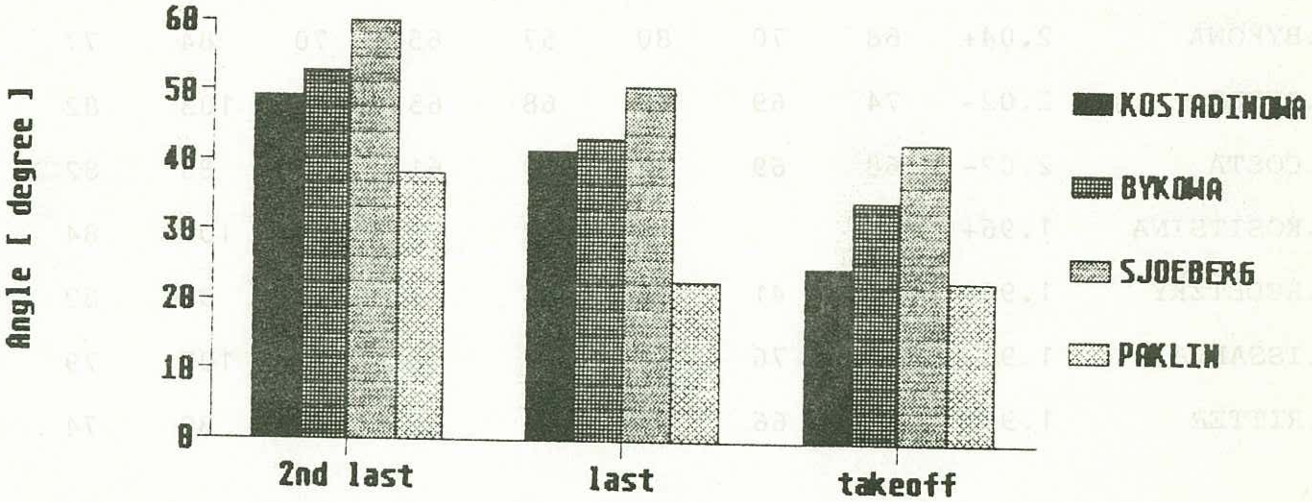
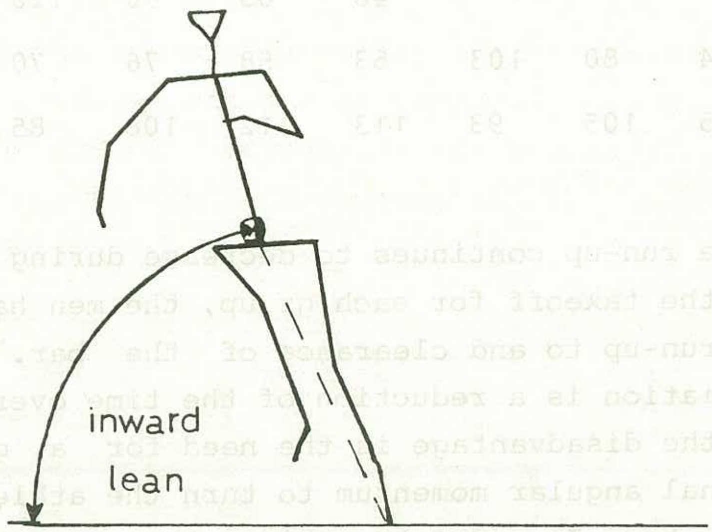


Fig. 11: Angle of inward lean



Tab. 11: Inward lean at TD, AM and TO (degrees)

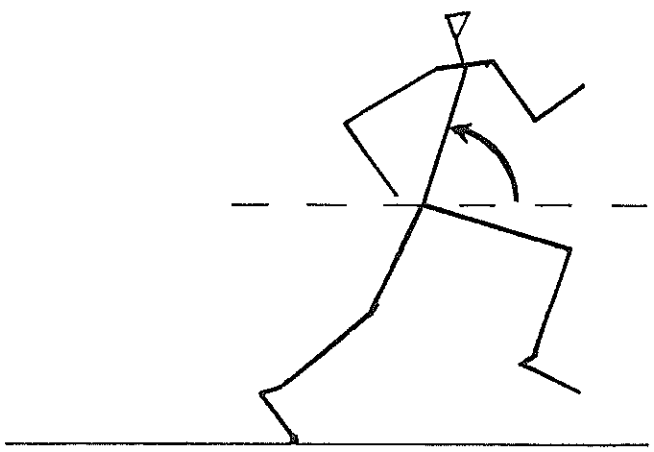
	HB	TD	AM	TO	TD	AM	TO	TD	AM	TO
S.KOSTADINOWA	2.09+	61	63	74	53	60	63	71	76	81
T.BYKOWA	2.04+	68	70	80	57	65	70	84	77	84
S.BEYER	2.02-	74	69	68	68	65	65	103	82	88
S.COSTA	2.02-	68	69	77	59	61	67	83	82	88
L.KOSITSINA	1.96+				92	77	60	107	84	89
H.REDETZKY	1.96+	72	41	73	56	55	57	94	82	87
S.ISSAEVA	1.96-	90	76	68	87	78	65	107	79	86
L.RITTER	1.93+	60	66	79	64	67	60	80	74	84
P.SJOEBERG	2.38+	83	69	60	80	67	55	138	79	86
I.PAKLIN	2.38+	71	80	104	69	73	88	86	66	82
G.AVDEENKO	2.38+	103	62	51	91	70	48	135	98	95
D.MÖGENBURG	2.38-	82	66	61	94	69	49	127	84	90
C.SAUNDERS	2.32+	76	65	95	50	60	72	82	75	85
J.ZVARA	2.32-				48	65	56	126	80	88
S.MATEI	2.32+	74	80	103	53	58	76	70	66	79
C.THRÄNHARDT	2.29+	105	105	93	113	112	108	85	92	83

While the angle of the run-up continues to decrease during the last two strides and the takeoff for each group, the men have a predominantly "steeper" run-up to and clearance of the bar. The advantage of this variation is a reduction of the time over the bar. On the other hand, the disadvantage is the need for a greater amount of longitudinal angular momentum to turn the athlete's body backward towards the bar. In order to achieve this amount of angular momentum, the run-up angle to the bar is drastically reduced during the last strides. Combined with an adequate inward lean the athlete manages the turn of the body without reducing the vertical impulse. Again, both winners show an enormous conversion of their run-up angles, nearly 20° within the last two strides.

Furthermore, a small radius is always accompagnied by an inward lean adequate to overcome the centrifugal forces that act upon the athlete. Thus, the tighter the run-up angles, the greater the amount of inward lean. The values for S.KOSTADINOWA, P.SJOEBERG, G.AVDEENKO and D.MÖGENBURG confirm this assumption.

During the time of takeoff the centrifugal forces finally contribute to the production of angular momentum about the transversal axis through the athlete's CM.

Fig. 12: Angle of foreward/backward lean



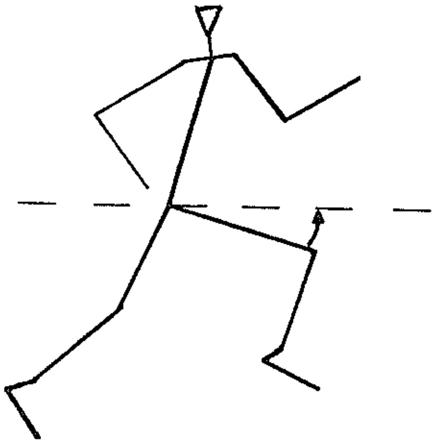
Tab. 12: Foreward/backward body lean at TD, AM and TO (degrees).

	HB	TD	AM	TO	TD	AM	TO	TD	AM	TO
S.KOSTADINOWA	2.09+	86	86	90	91	92	97	107	91	92
T.BYKOWA	2.04+	85	90	93	101	93	95	103	96	92
S.BEYER	2.02-	97	91	95	93	96	94	102	94	93
S.COSTA	2.02-	81	80	91	93	78	93	97	90	99
L.KOSITSINA	1.96+				93	91	98	98	99	97
H.REDETZKY	1.96+	74	83	88	83	81	97	98	89	90
S.ISSAEVA	1.96-	93	88	94	94	95	105	106	103	99
L.RITTER	1.93+	65	74	80	79	79	87	93	91	99
P.SJOEBERG	2.38+	100	115	125	100	104	115	126	104	94
I.PAKLIN	2.38+	81	71	78	84	86	100	106	103	99
G.AVDEENKO	2.38+	105	99	129	105	107	117	123	110	98
D.MÖGENBURG	2.38-	98	109	120	102	120	123	110	99	92
C.SAUNDERS	2.32+	86	69	72	70	84	95	100	92	95
J.ZVARA	2.32-				79	95	106	112	98	94
S.MATEI	2.32+	72	65	72	81	84	90	103	90	87
C.THRÄNHARDT	2.29+	86	82	90	91	83	98	104	102	94

Tab. 13: Angle of lead leg thigh at TO (degrees)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	-33	-20	-8
T.BYKOWA	2.04+	-37	-30	-7
S.BEYER	2.02-	-22	-27	-2
S.COSTA	2.02-	-23	-30	-10
L.KOSITSINA	1.96+		-49	-30
H.REDETZKY	1.96+	-28	-35	-2
S.ISSAEVA	1.96-	-48	-43	-35
L.RITTER	1.93-	-27	-27	-6
P.SJOEBERG	2.38+	-32	-51	7
I.PAKLIN	2.38+	-22	-34	-4
G.AVDEENKO	2.38+	-35	-61	2
D.MÖGENBURG	2.38-	-24	-82	10
C.SAUNDERS	2.32+	-39	-25	-14
J.ZVARA	2.32-		-33	24
S.MATEI	2.32+	-36	-19	-3
C.THRÄNHARDT	2.29+	-32	-33	9

Fig. 13: Angle of lead leg thigh



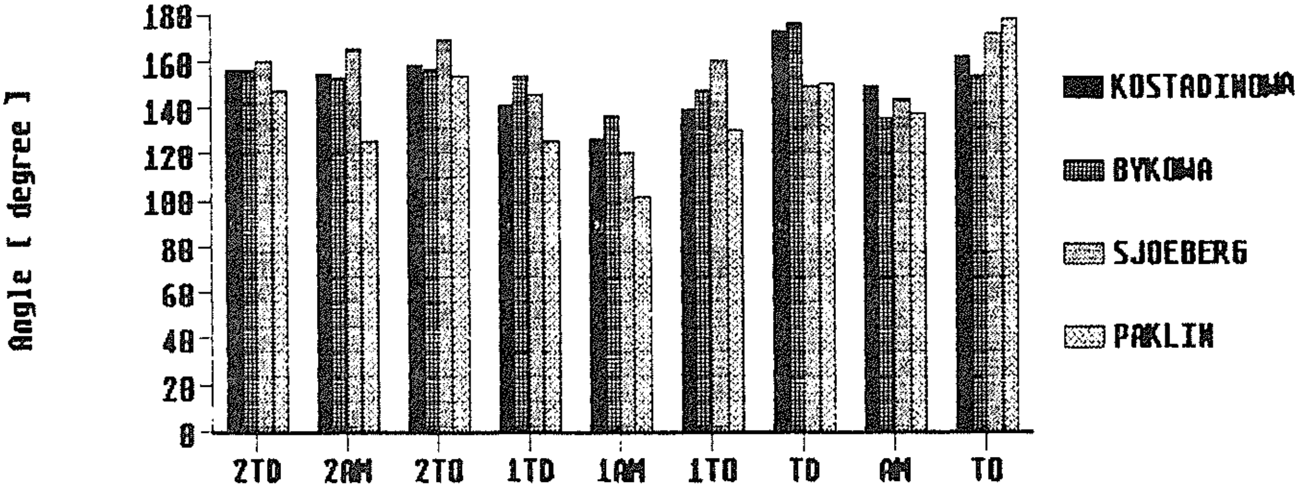
The position of the trunk during the last strides implies an increasing backward lean to prepare for the takeoff. This behaviour becomes necessary in order to achieve a sufficient vertical impulse. During takeoff itself in most cases the trunk rotates foreward until it reaches a nearly upright position.

The absolute angle of the lead leg becomes interesting when considering the final takeoff. A high lead leg (positive values for lead leg thigh) influences the takeoff height (H1) positively. Generally one may assume a profitable range of the lead leg thigh angle at about a horizontal orientation (values about 0°). Regarding the angles for the Rome finalists it may be stated that the position of the lead leg is not a relevant factor.

Tab. 14: Knee angle of the support leg at TD, AM and TO (degrees)

	HB	TD	AM	TO	TD	AM	TO	TD	AM	TO
S.KOSTADINOWA	2.09+	156	154	158	141	126	139	172	149	161
T.BYKOWA	2.04+	156	152	156	153	136	147	176	135	153
S.BEYER	2.02-	174	155	156	155	110	120	171	148	157
S.COSTA	2.02-	163	152	166	146	144	144	155	144	160
L.KOSITSINA	1.96+				137	121	146	155	141	168
H.REDETZKY	1.96+	170	159	165	155	133	145	176	141	146
S.ISSAEVA	1.96-	153	147	135	135	127	143	168	143	169
L.RITTER	1.93+	167	150	144	127	107	144	165	151	168
P.SJOEBERG	2.38+	159	165	168	145	120	159	149	143	171
I.PAKLIN	2.38+	147	125	153	125	101	130	150	137	177
G.AVDEENKO	2.38+	164	142	162	144	96	143	164	129	141
D.MÖGENBURG	2.38-	171	147	167	150	133	159	158	150	175
C.SAUNDERS	2.32+	141	139	142	139	113	137	163	134	167
J.ZVARA	2.32-				158	101	128	164	132	165
S.MATEI	2.32+	146	127	153	146	111	148	167	150	172
C.THRÄNHARDT	2.29+	147	143	148	142	124	143	163	144	175

Fig. 14: Knee angle of the support leg at TD, AM and TO



Regarding the knee angles of the support leg during run-up the observer may be astonished about the small amount of bending of the leg. In view of the high running velocity combined with the corresponding reaction forces this can only be explained with enormous muscle forces acting against gravity. In contrast to the penultimate stride, the last stride contains a rather strong bending of the support leg. Minimal knee angles are found in AM of this support phase and not in takeoff. This is one reason for the very short flight phase between last stride and takeoff. Furthermore the reduction of the CM-height can partially be explained by this behaviour. The TD for takeoff ensues with a rather straightened leg, thus confirming the above mentioned active foot plant. The following amortisation should be kept minimal, as comparison with the best athletes confirms. The fact that some male athletes bend their support legs more than women jumpers may support the assumption that men jump more forcefully, while women use reactive muscle potentials. The small amount of knee flexion may be a criterion for knee extensor potential and partially for good performance in high jumping. The FLOP 2 technician - J.ZVARA - however shows a smaller knee angle in order to lengthen the vertical path of acceleration of CM.

Surprisingly, even the best athletes do not succed in straightening their leg at the moment of takeoff. This contributes to the quantity of the takeoff height (H1). On the other hand one may doubt if it is reasonable to straighten completely the takeoff leg, taking into account the small amount of muscle force in this range of knee angle and the high vertical takeoff velocities. This can also explain the difference in this parameter between women and men.

Tab. 15: Horizontal velocity (m/s)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	7.8	7.5	3.8
T.BYKOWA	2.04+	7.1	6.8	3.2
S.BEYER	2.02-	6.4	7.2	4.5
S.COSTA	2.02-	6.6	6.7	4.2
L.KOSITSINA	1.96+		5.7	3.4
H.REDETZKY	1.96+	6.5	6.8	3.9
S.ISSAEVA	1.96-	5.4	5.8	3.5
L.RITTER	1.93-	7.0	7.6	3.5
P.SJOEBERG	2.38+	7.2	7.2	3.6
I.PAKLIN	2.38+	8.5	6.9	3.3
G.AVDEENKO	2.38+	8.4	7.8	3.2
D.MÖGENBURG	2.38-	8.0	8.0	4.3
C.SAUNDERS	2.32+	7.6	6.9	3.3
J.ZVARA	2.32-		6.1	2.6
S.MATEI	2.32+	7.8	7.1	3.8
C.THRÄNHARDT	2.29+	7.3	7.1	3.9

Fig. 15: Horizontal velocity (KOSTADINOWA - BYKOWA)

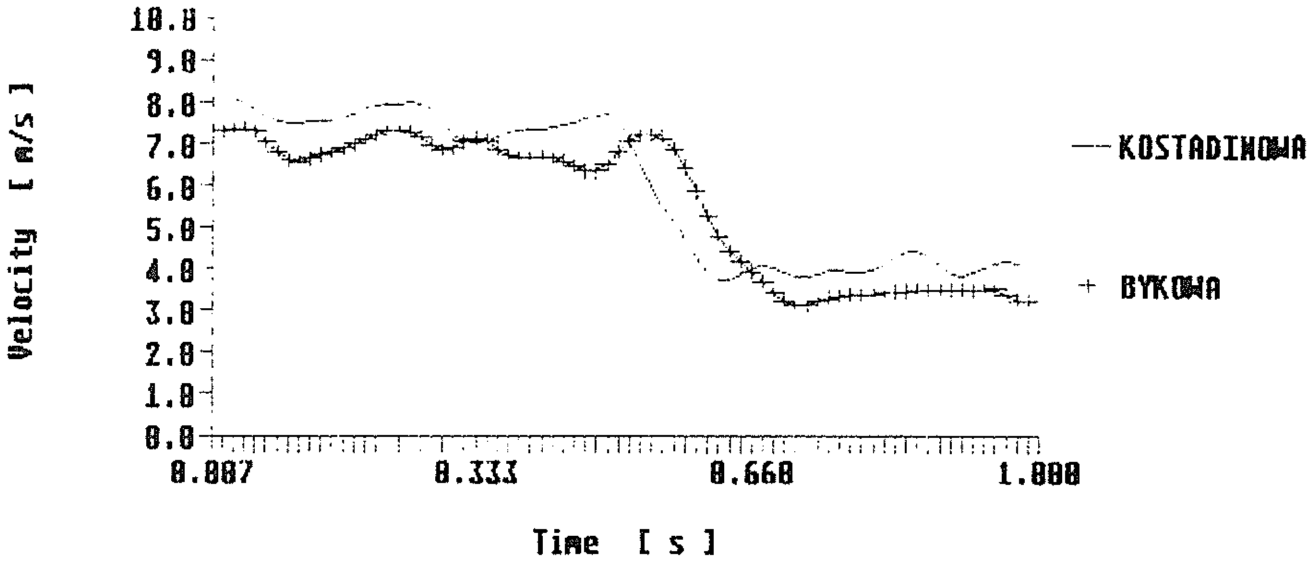
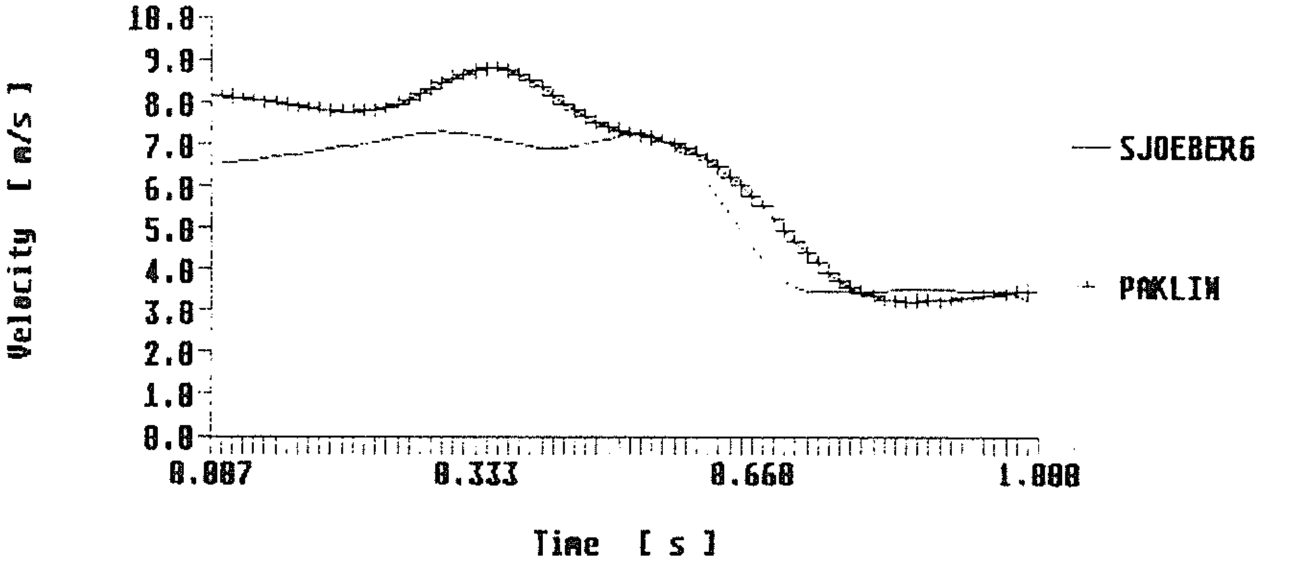


Fig. 16: Horizontal velocity (SJOEBERG - PAKLIN)



Tab. 16: Change of horizontal velocity (m/s)

	HB	last	takeoff
S.KOSTADINOWA	2.09+	-0.37	-3.65
T.BYKOWA	2.04+	-0.25	-3.66
S.BEYER	2.02-	0.83	-2.73
S.COSTA	2.02-	0.07	-2.43
L.KOSITSINA	1.96+		-2.30
H.REDETZKY	1.96+	0.32	-2.88
S.ISSAEVA	1.96-	0.46	-2.35
L.RITTER	1.93-	0.62	-4.13
P.SJOEBERG	2.38+	-0.01	-3.55
I.PAKLIN	2.38+	-1.58	-3.61
G.AVDEENKO	2.38+	-0.55	-4.62
D.MÖGENBURG	2.38-	-0.06	-3.69
C.SAUNDERS	2.32+	-0.65	-3.62
J.ZVARA	2.32-		-3.44
S.MATEI	2.32+	-0.76	-3.32
C.THRÄNHARDT	2.29+	-0.25	-3.20

The horizontal velocity of CM during approach was regarded as one important parameter that influences the takeoff and thus the height of the flight (H2). Therefore it should be found reasonable to assume that the better athletes would have a faster approach. To some extent the Rome finalists do so but there is no absolutely clear tendency.

In regard to horizontal velocity it may be stated that, in most cases, a reduction is found in the penultimate to last stride. In order to minimize the loss of kinetic energy this reduction should be kept minimal. The further acceleration during the last stride however seems to be unfavourable for the preparation for the takeoff (reduction of CM-height) as the example of L.RITTER illustrates.

During the takeoff horizontal velocity should be drastically reduced and converted into vertical velocity. Of course, this depends on the distance of the takeoff from the bar and the run-up angle, but finally the horizontal part of the resultant velocity vector does not play the most important role.

So the change in horizontal velocity can be regarded as a relevant factor of high jump performance. Tab. 16 reflects the greatest changes for the best athletes. Especially in the womens' competition S.KOSTADINOWA and T.BYKOWA but also L.RITTER show enormous reductions of velocity.

Tab. 17: Vertical velocity at TD (m/s)

	HB	2nd last	last
S.KOSTADINOWA	2.09+	-0.63	-0.41
T.BYKOWA	2.04+	-0.77	-0.36
S.BEYER	2.02-	-0.47	-0.68
S.COSTA	2.02-	-0.92	-0.08
L.KOSITSINA	1.96+		-0.49
H.REDETZKY	1.96+	-1.16	-0.19
S.ISSAEVA	1.96-	-0.60	-0.31
L.RITTER	1.93-	-0.42	-0.39
P.SJOEBERG	2.38+	-0.97	-0.39
I.PAKLIN	2.38+	-0.83	-0.37
G.AVDEENKO	2.38+	-0.80	-0.40
D.MÖGENBURG	2.38-	-0.92	-0.00
C.SAUNDERS	2.32+	-0.62	-0.34
J.ZVARA	2.32-		-0.36
S.MATEI	2.32+	-0.94	-0.61
C.THRÄNHARDT	2.29+	-0.95	-0.83

Tab. 18: Change of vertical velocity (m/s)

	HB	2nd last	last
S.KOSTADINOWA	2.09+	1.07	4.87
T.BYKOWA	2.04+	0.87	4.63
S.BEYER	2.02-	0.45	4.78
S.COSTA	2.02-	1.43	4.44
L.KOSITSINA	1.96+		4.19
H.REDETZKY	1.96+	1.43	4.21
S.ISSAEVA	1.96-	0.94	3.93
L.RITTER	1.93-	0.75	4.61
P.SJOEBERG	2.38+	1.17	5.17
I.PAKLIN	2.38+	0.92	4.97
G.AVDEENKO	2.38+	0.80	4.98
D.MÖGENBURG	2.38-	1.72	4.64
C.SAUNDERS	2.32+	0.61	4.98
J.ZVARA	2.32-		4.85
S.MATEI	2.32+	1.12	5.66
C.THRÄNHARDT	2.29+	0.84	5.29

The vertical impulse during takeoff was mentioned to be the most relevant factor for a good performance in high jump. Neglecting the athlete's mass the change of vertical velocity may be equated with the vertical impulse. Then the vertical velocity at TO may be determined as the sum of (negative) vertical velocity at TD and the change of vertical velocity.

$$Vz(TO) = Vz(TD) + \Delta Vz$$

For a constant change of vertical velocity the vertical velocity at TO increases with decreasing vertical velocity at TD. Therefore the vertical velocity at TD should be kept minimal as Tab. 17 presents.

For example S.BEYER: In spite of her good change of vertical velocity she only realizes an average takeoff velocity because of her great negative velocity at TD.

Vertical velocity at TO finally must be regarded as the predominant aim for the high jumper and as a consequence of the activities taking place during the takeoff.

Tab. 19: Vertical velocity at TO (m/s)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	0.29	0.44	4.45
T.BYKOWA	2.04+	0.73	0.10	4.27
S.BEYER	2.02-	0.83	-0.02	4.10
S.COSTA	2.02-	0.39	0.51	4.37
L.KOSITSINA	1.96+		0.29	3.70
H.REDETZKY	1.96+	0.67	0.27	4.02
S.ISSAEVA	1.96-	0.25	0.34	3.62
L.RITTER	1.93-	0.43	0.33	4.22
P.SJOEBERG	2.38+	0.53	0.20	4.78
I.PAKLIN	2.38+	0.48	0.09	4.60
G.AVDEENKO	2.38+	0.37	0.00	4.58
D.MÖGENBURG	2.38-	0.65	0.79	4.64
C.SAUNDERS	2.32+	0.36	-0.01	4.64
J.ZVARA	2.32-		0.36	4.49
S.MATEI	2.32+	0.36	0.18	5.06
C.THRÄNHARDT	2.29+	0.23	-0.11	4.47

Tab. 20: Resultant velocity (m/s)

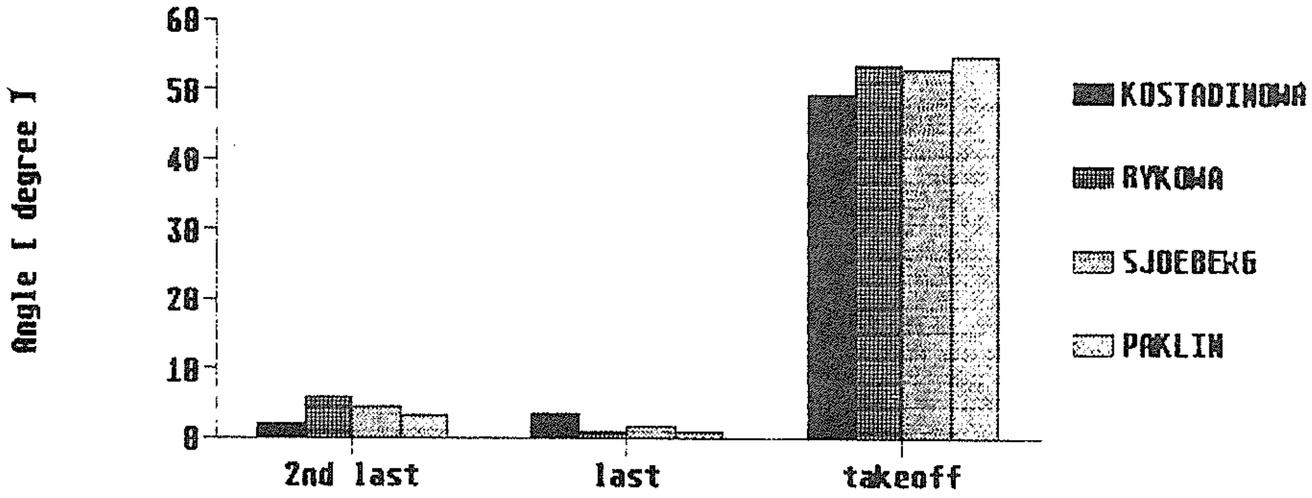
	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	7.86	7.50	5.88
T.BYKOWA	2.04+	7.14	6.85	5.32
S.BEYER	2.02-	6.45	7.22	6.08
S.COSTA	2.02-	6.61	6.69	6.08
L.KOSITSINA	1.96+		5.75	5.05
H.REDETZKY	1.96+	6.53	6.81	5.62
S.ISSAEVA	1.96-	5.38	5.84	5.02
L.RITTER	1.93-	6.99	7.60	5.46
P.SJOEBERG	2.38+	7.20	7.17	6.00
I.PAKLIN	2.38+	8.48	6.89	5.65
G.AVDEENKO	2.38+	8.36	7.80	5.58
D.MÖGENBURG	2.38-	8.08	8.01	6.32
C.SAUNDERS	2.32+	7.58	6.92	5.70
J.ZVARA	2.32-		6.08	5.20
S.MATEI	2.32+	7.86	7.09	6.31
C.THRÄNHARDT	2.29+	7.34	7.09	5.93

The vertical velocity strictly determines the height of the flight. The resultant velocity is the sum of the horizontal and vertical vectors of velocity. It may be interpreted without knowledge of the two velocity components and thus indicates the takeoff angle.
Again the example of S.BEYER illustrates that her resultant velocity is even greater than S.KOSTADINOWA's but is primely influenced by the horizontal component. So the result is a smaller takeoff angle and not a greater height of flight as Tab. 21 shows.

Tab. 21: Takeoff angle (degree)

	HB	2nd last	last	takeoff
S.KOSTADINOWA	2.09+	2	3	49
T.BYKOWA	2.04+	6	1	53
S.BEYER	2.02-	7	0	42
S.COSTA	2.02-	3	4	46
L.KOSITSINA	1.96+		3	47
H.REDETZKY	1.96+	6	2	46
S.ISSAEVA	1.96-	3	3	46
L.RITTER	1.93-	4	3	51
P.SJOEBERG	2.38+	4	2	53
I.PAKLIN	2.38+	3	1	55
G.AVDEENKO	2.38+	3	0	55
D.MÖGENBURG	2.38-	5	6	47
C.SAUNDERS	2.32+	3	0	55
J.ZVARA	2.32-		3	60
S.MATEI	2.32+	3	1	53
C.THRÄNHARDT	2.29+	2	-1	49

Fig. 19: Takeoff angle

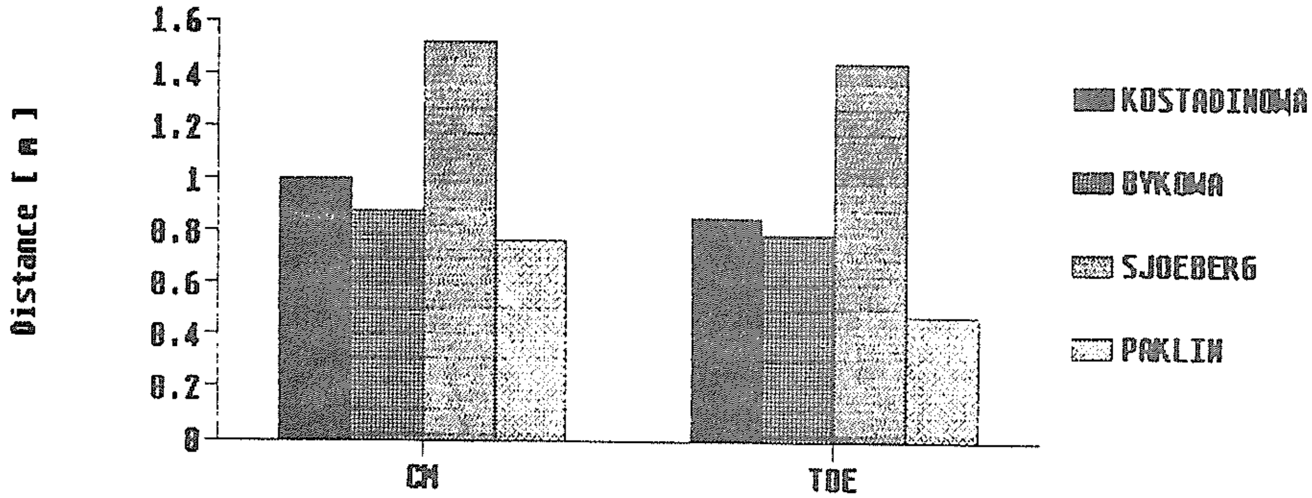


The angle of takeoff gives an impression of the flight's steepness within the plane of motion. Greater takeoff angles imply the predominance of vertical velocity in comparison to horizontal velocity. Tab. 21 shows takeoff angles that lie between 45° and 60°. The fact that J.ZVARA takes off with the greatest angle of takeoff is not further surprising. The so called FLOP 2 always shows extremely low horizontal takeoff velocities in relation to the vertical takeoff velocity and therefore enables great takeoff angles.

Tab. 22: Distance from the bar (m)

	HB	CM	TOE
S.KOSTADINOWA	2.09+	1.00	0.85
T.BYKOWA	2.04+	0.87	0.79
S.BEYER	2.02-	1.04	1.02
S.COSTA	2.02-	1.20	1.16
L.KOSITSINA	1.96+	0.48	0.44
H.REDETZKY	1.96+	0.89	0.83
S.ISSAEVA	1.96-	0.43	0.44
L.RITTER	1.93-	0.85	0.75
P.SJOEBERG	2.38+	1.52	1.44
I.PAKLIN	2.38+	0.76	0.48
G.AVDEENKO	2.38+	0.88	0.99
D.MÖGENBURG	2.38-	0.72	0.74
C.SAUNDERS	2.32+	0.63	0.62
J.ZVARA	2.32-	0.85	0.82
S.MATEI	2.32+	1.04	0.91
C.THRÄNHARDT	2.29+	1.06	1.22

Fig. 21: Distance from the bar



In connexion with the distance from the bar and the angle of run-up during takeoff it becomes interesting to know if the maximum height of the flight is achieved when the CM is crossing the bar. This would be an optimal behaviour while anything different from that would be unfavourable for the bar clearance.

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H

BIOMECHANICAL ANALYSIS OF THE POLE VAULT

Gros, H.J.; Kunkel, V.

POLE VAULT

TABLE OF CONTENTS

1. INTRODUCTION

Performance in the men's pole vault competition over the past years has been characterized by a remarkable increase in the heights cleared. FIGURE 1 depicts this trend. The top curve (marked "A") shows the best world performance for each year. The two curves below represent the mean values for the best three (B) and the best ten (C) vaulters respectively. This gives an indication of the performance differences among the world's best pole vaulters. In 1987, ten vaulters cleared heights of 5.80 meters or more. The top three vaulters were BUBKA (6.03), DIAL (5.96) and GATAULIN (5.90).

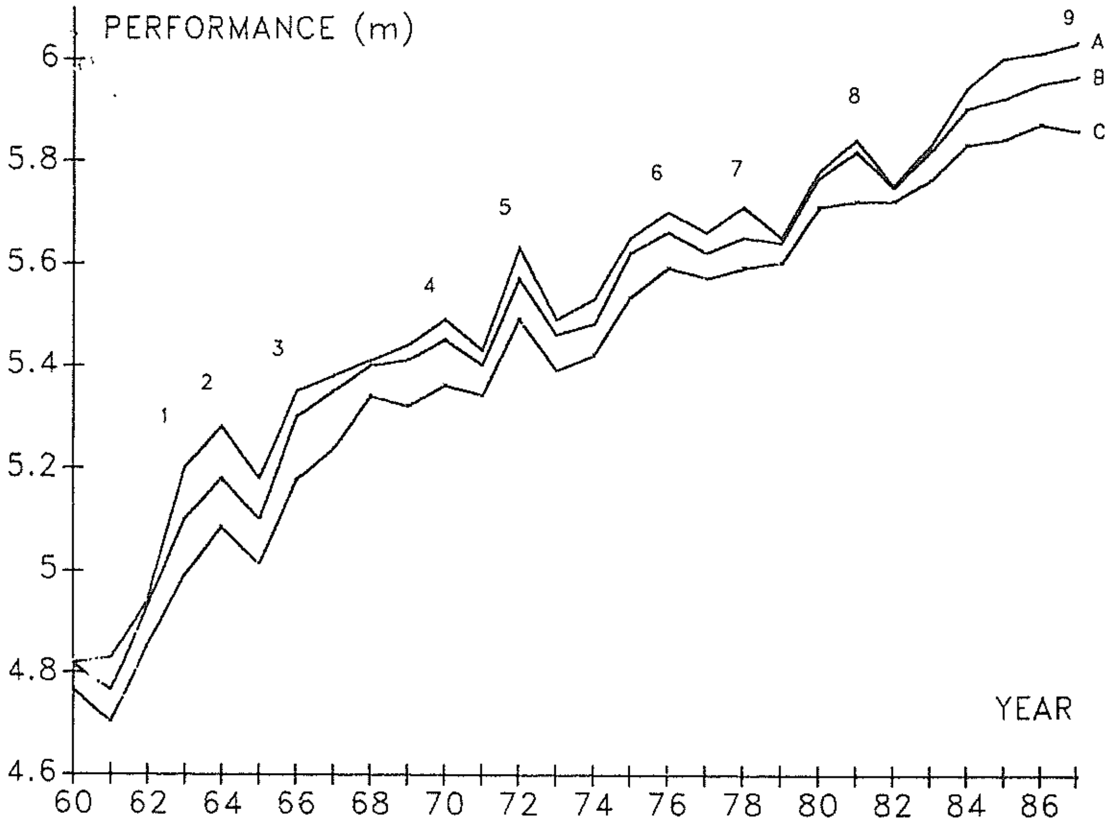


FIGURE 1: Progression of performance in the pole vault

LEGEND:

1 PENNEL	2 HANSEN	3 PENNEL
4 PAPANICOLAOU	5 SEAGRAN	6 ROBERTS
7 TULLY	8 VOLKOV	9 BUBKA

2. BIOMECHANICS OF THE POLE VAULT

This report attempts to summarize some results of recent biomechanical research on the pole vault. Phases of the vault, functions of the phases and underlying mechanical principles are presented not only in an effort to provide the coach with background information about the event, but also to elicit comments and suggestions for future research from coaches and athletes.
The graphs shown in this chapter were developed using data obtained from the analysis of S. Bubka's winning vault (5.85 m).
The terminology and abbreviations used are consistent throughout the report. Referring to FIGURES 2 - 5 will greatly facilitate understanding and interpreting the data presented in chapter three.

2.1 DIVISION OF THE EVENT

For the purpose of this report the pole vault is subdivided into five distinct phases:

1. *the approach* includes the initial acceleration and the pole plant up to the touchdown of the takeoff foot;

2. *the take-off* is defined as the time where the take-off foot is in contact with the ground;

3. *the first phase on the pole* is defined as the time from the end of the take-off to the maximum pole bend (MPB);

4. *the second phase on the pole* lasts from MPB until the vaulter leaves the pole (PR);

5. *the free flight phase* begins as the vaulter leaves the pole and ends as the vaulter touches the landing pit.

2.2 THE APPROACH

In the run-up (approach) phase the vaulter must generate an optimum level of kinetic energy (i.e. a high horizontal velocity) and prepare for the planting of the pole. Depending on the pole carrying technique, the maximum velocity with the pole is approximately 0.8 to 1.2 m/s lower than in a "free" run-up. The decrease is caused by the necessity to counteract the moment caused by the pole. This forward rotating moment becomes larger with increasing grip height and decreases as the angle between the pole and the horizontal axis is increased.

The vaulter in the run-up (as compared to a sprint run) assumes a more upright body position - the decelerating force in the contact phase increases, stride length and/or frequency decrease and account for the reduced velocity.

Thus, the difference between the velocities in run-ups with and without the pole (which can be easily measured with photocells during a training session) is a good indicator of the efficiency of the carrying technique. Small differences indicate good technique and improvements should be sought by increasing the maximum sprint speed. Conversely, large differences are indicative of poor adaptation to the pole carriage. Carrying the pole close to the vertical axis is not necessarily a good solution since the plant has to be initiated much earlier. Thus, it becomes increasingly difficult to hit the box and, furthermore, cross-winds may affect the pole more.

In good vaults the velocity of the center of mass (CM) increases throughout the plant prep phase to as much as 9.7 m/s or more. This is facilitated by a "moment-free" lowering of the pole which enables the vaulter to increase stride frequency, thus more than compensating for the observed reduction in stride length. Generally, the penultimate stride is the longest of the last four strides. The CM is slightly lowered in this stride. By shortening the last stride most vaulters raise the CM into the takeoff phase thus facilitating a smooth transition from the horizontal run-up to the take-off velocity at 15 to 18 degrees.

McGINNIS (1987) reports mean data obtained from the analysis of

16 vaults in the range of 5.50 to 5.81 m. He measured 2.2 m for the penultimate stride, 2.04 m for the last stride (which gives a stride length ratio of 0.93) and velocities of 9.43 and 9.57 m/s respectively.

2.3 THE TAKE-OFF

During the short take-off (between 0.08 and 0.12 sec.) the athlete must generate sufficient vertical impulse while minimizing the loss in horizontal velocity and, at the same time, bring the body into a good position for the energy transfer to the pole.

FIGURE 2 shows Bubka's CM velocities throughout the vault. The phases are indicated through the vertical lines (TO - takeoff, MPB - maximum pole bend, PS - pole straight, PR - pole release, HP - highest point).

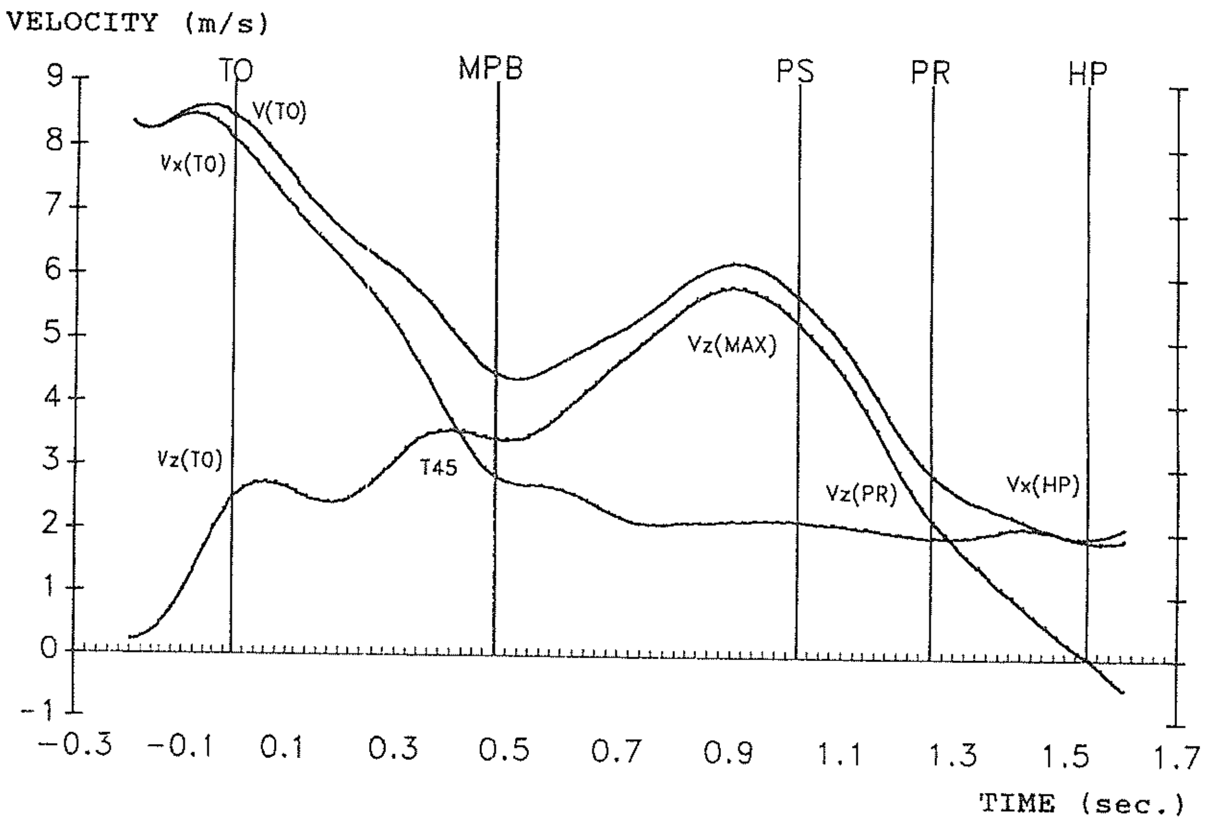


FIGURE 2: Resultant velocity (V) of Bubka's center of mass and the horizontal (Vx) and vertical (Vz) components.

The vaulter's horizontal CM velocity (Vx) decreases during take-off due to the braking force in the first part of the take-off. Simultaneously, the generated vertical impulse accelerates the CM to a vertical takeoff velocity [Vz(TO)] of 2.2 m/s. Vx(TO) may be up to 2 m/s lower than the velocity in the last run-up stride. Bubka, however,manages to reach a Vx(TO) of 8.3 m/s. McGINNIS (1987) reports a mean Vz(TO) of 2.43 m/s and a mean Vx(TO) of 7.57 m/s.

The vaulter's body position at takeoff is another crucial factor. The general consensus is that the top hand should be roughly in line with the toe of the takeoff foot at TO. A vaulter who is "under" is not able to generate sufficient vertical impulse and will lose more horizontal velocity. However, placing the takeoff foot slightly forward in relation to the top hand might be beneficial since the pre-bend of the pole is positively influenced. If the vaulter jumps into the pole (i.e. his takeoff leg leaves the ground before the pole touches the box) his vertical velocity will be smaller, and chances are that the pole will "sag". In both cases the planting angle of the pole, which should be as large as possible for a smooth transition into the vertical motion, will suffer. Analyses of two vaults resulting in the breaking of the pole just after MPB suggest that small takeoff angles (around 11 - 12 deg.) are a factor contributing to the overloading and failure of the pole. The angle of the pole at takeoff [AP(TO)] is approximately 29 to 30 degrees. It is influenced by grip height, anthropometrical factors and, of course, body position.

The second function of the takeoff, as mentioned above, is to bring the body into a good position for an efficient energy - transfer to the pole. As grip heights increase this becomes increasingly important. The active energy transfer phase can be defined as the time when the pole is planted and the take-off foot is on the ground. An efficient energy transfer with minimal losses requires the vaulter to be as rigid as possible. "Giving" in the shoulder (usually caused by insufficient resistance of the lower arm and little pre-tension in the shoulder girdle) or sagging in the lumbar spine cause energy dissipation into the body and potential injury. Hence, a hyperlordosis of the lumbar spine must be prevented through contraction of the appropriate muscle groups. This does not imply that all energy dissipated into the body is lost. Energy used to pre-stress muscles and tendons may be recovered during the first phase on the pole. The "rigid" vaulter also applies larger bending moments to the pole and thus reduces the compressive load required to bend the pole. This helps ensure efficient energy transfer, and minimizes the high impact forces transmitted to the vaulter via the pole. Please look at FIGURE 3, showing the energy curves for Bubka's vault. The total energy at take-off [Etot(TO)] is a measure of the vaulter's potential. It is the sum of Epot(TO), the potential energy at take-off, which depends on body mass and CM height, and the total kinetic energy [Ekin(TO)]. To facilitate inter-individual comparison, energy is often expressed in Joule/Kg. McGINNIS reports mean values of 33 J/Kg [Ekin(TO)].

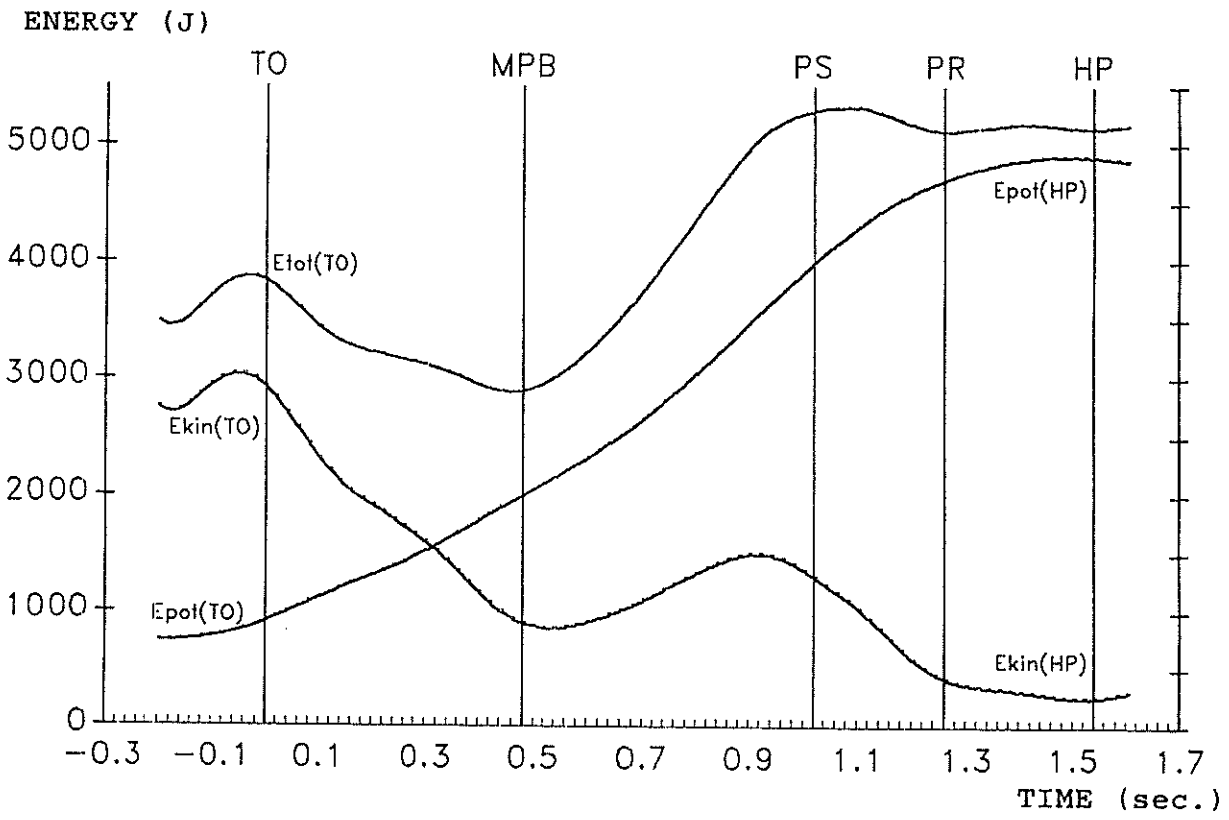


FIGURE 3: Kinetic energy (Ekin), potential energy (Epot) and total energy of the vaulter (Etot).

2.4 FIRST PHASE ON THE POLE

A number of terms are used to describe the action of the vaulter on the pole. Since terms like "long swing", "short pendulum" are either hard to define or are defined in a rather arbitrary way, let us consider what happens from the time the vaulter leaves the ground to maximum pole bend (MPB). Look at FIGURE 2 once more. The horizontal velocity keeps decreasing steadily to a minimum of about 2 m/s and remains constant throughout the vault. Ideally V(x) should be just sufficient to clear the bar. Values of about 1 m/s have been measured. The vertical velocity increases and exceeds V(x) at the time T45, which occurs before MPB. This means that the CM moves upwards at an angle greater than 45 degrees after T45 and before MPB.

The movement of the pole is best described by a graph of the pole deflection (i.e. the reduction in chord length), the angle of the pole to the horizontal axis, and the angular velocity (AVP) of the pole chord. This information is summarized in FIGURE 4. In Bubka's vault the angle of the pole chord (AP) increases from 29 to 60 degrees at MPB [AP(MPB)]. At the same time the chord length keeps decreasing to a low value of 3.83 m [CL(MIN)] at MPB. McGINNIS (1987) reports a mean minimum chord length of 3.4 m occurring 0.48 sec. after takeoff. The dip in the energy curve (Etot) in FIGURE 3 is the result of the energy being stored as strain energy in the pole during this phase.

The angular velocity of the pole chord in Bubka's vault increases rapidly, reaches a first maximum [AVP(MAX)] and stays fairly high until after MPB. Other vaulters in this study show a marked drop between the two peaks which means that the chord does not rotate smoothly about the box. However, more data is required to assess the relevance of this finding.

2.5 SECOND PHASE ON THE POLE

In the second phase on the pole the implement straightens again (see FIGURE 4) and returns most of the energy stored in the form of kinetic energy to the vaulter. This kinetic energy is in turn transformed into potential energy which is equivalent to raising the CM. In FIGURE 2 you notice a marked increase in vertical velocity to 6.2 m/s. This value is considerably higher than the Vz(MAX) reported in the literature (McGINNIS: 5.04 m/s). The corresponding increase in E(kin) can be seen in FIGURE 3.

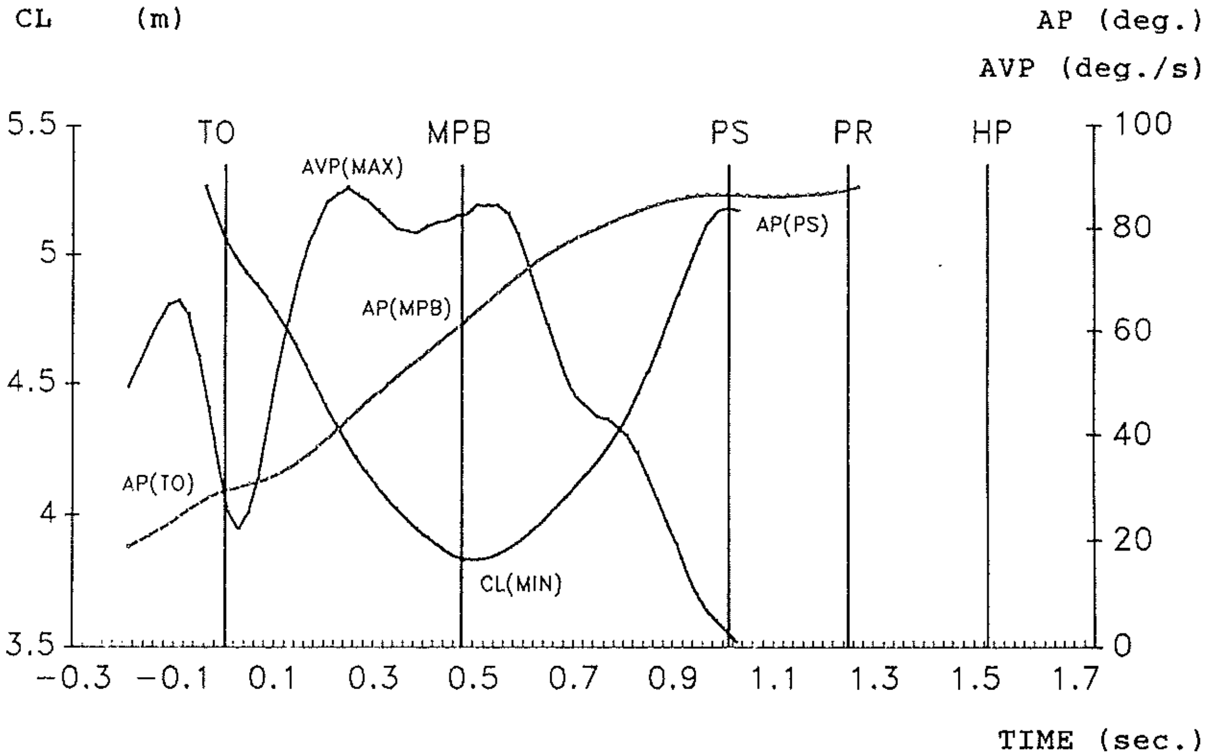


FIGURE 4: Angle of the pole chord to the horizontal (AP in degrees), angular velocity of the pole chord (AVP in degrees/sec.) and chord length (CL in m).

The pole chord rotates to 87 degrees at PS. The vaulter can speed up the straightening of the pole by applying a negative bending moment (i.e. push with the upper hand and pull with the lower hand) in this phase. This however, requires an extreme rock-back position in the beginning in order to avoid premature reversal of the direction of rotation caused by a gravitational moment acting on the vaulter if his CM is not below the top hand. This can be best demonstrated with the data presented in FIGURE 5. The moment of inertia (ICM) of the vaulter with respect to his CM is a measure for the mass distribution. The reduction of ICM approximately 0.3 sec. into the vault marks the instant when the suspended body starts to tuck. The moment of inertia reaches its lowest value (i.e. the tuck is tightest) after MPB (at t=0.61 sec.). The angular momentum of the vaulter [L(MAX)] reaches its maximum value at t=0.35 sec. Because of the rotation of the pole chord the angular momentum decreases and finally becomes negative. This happens earlier if the CM is in front of the top hand (due to the gravitational moment mentioned above). Thus TL-, the time when the direction of rotation is reversed, is a very important parameter. TL- occurs at t=0.86 sec. in Bubka's vault - a value that compares very favourably with the TL- of 0.78 sec. reported by McGINNIS.

While the chord approaches the vertical the vaulter extends his body through the "J" and "I" position (see the increased moment of inertia in FIGURE 5). This movement should be performed backward/upward to avoid premature dropping of the legs and body. However, the direction of rotation will and must reverse during this phase since a certain amount of angular momentum is necessary for the bar clearance. This change must occur while the vaulter is on the pole since angular momentum is constant during the flight phase. Angular momentum for the clearance should be created as late as possible and be as low as possible.

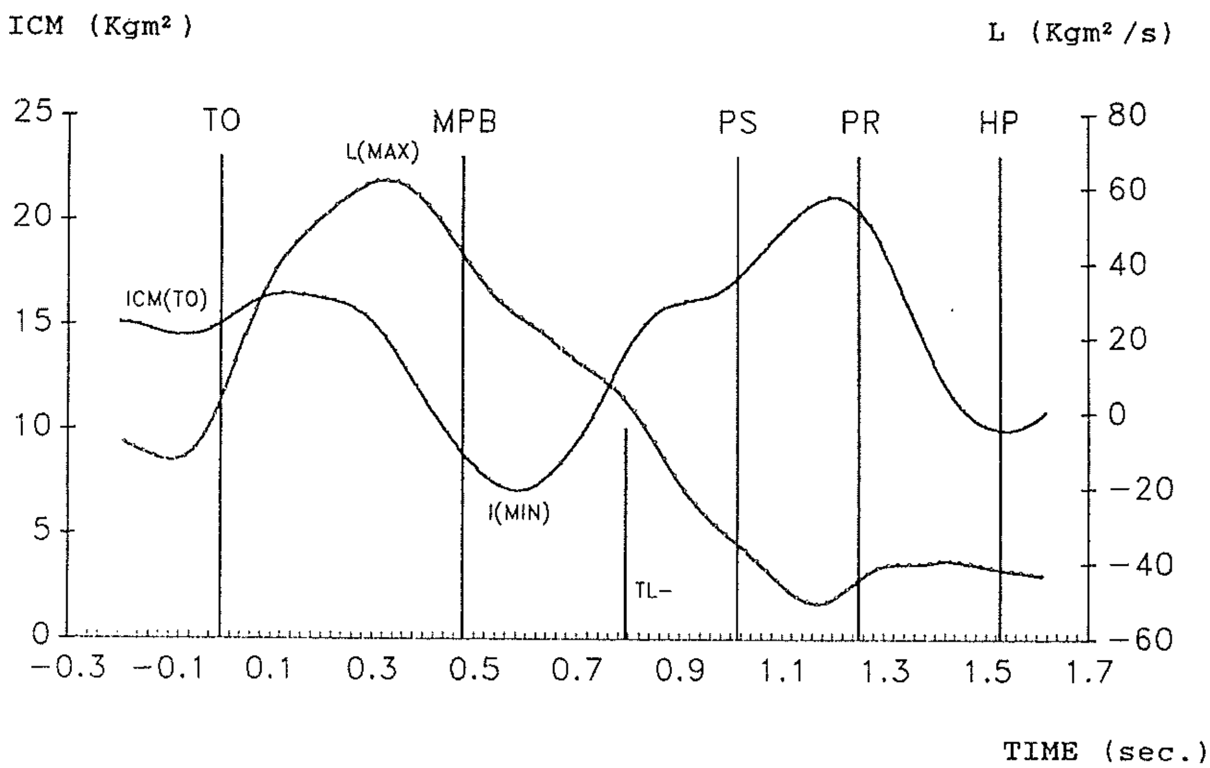


FIGURE 5: Moment of inertia about the center of mass (ICM) and angular momentum (L).

2.6 FREE FLIGHT PHASE

As the vaulter leaves the pole (PR) the flight parabola of his CM is determined by the velocity and height of the CM and by the angle of projection. Angular momentum and horizontal velocity are constant. The only thing a vaulter can do now, is to bring his body into a favourable position with respect to the bar. This means that the high point of the flight curve should be above the bar while successive clearance is executed. "Successive clearance" means that as few body parts as possible are above the bar at any time while all other segments are as far below the bar as possible. Deviations from this pattern (e.g. vigorous movements of body parts) may help "save" a vault at submaximum heights but is detrimental to the athletes maximum performance.

3. SUMMARY OF FINDINGS – ROME 1987

3.1 METHOD AND PROCEDURES

Three LOCAM highspeed cameras were used to film the pole vault finals. The cameras were set up as follows:

Camera 1 (C1) was set so that the optical axis intersected the plane of motion at right angles at a point 4 m back from the end of the planting box. The distance between C1 and the middle of the runway was 37.8 m. C1 was panned to record the approach, take-off and first phase on the pole. The size of the object field was 5 m to reduce errors inherent in the data analysis.

Camera 2 (C2) was set so that the optical axis intersected the plane of motion at right angles at a point 1 m back from the end of the box. The distance to the plane of motion was 37.5 m. C2 was panned vertically, covering the rockback, second phase on the pole and free flight phase.

Both cameras, operating at 150 F/s, were synchronized and had a built-in timing light generator to determine the precise frame rate. They were set 1.7 m above the level of the runway.
Markers were placed along the runway and on the standards to allow reconstruction of the X and Z coordinates from the panned shots. Panning was controlled through a videocamera mounted on the highspeed cameras.

Camera 3 was mounted in the stands directly in line with the runway. It was also panned vertically and used to provide additional information where the motion could not be clearly seen from the side view cameras, and to allow 3-D analysis.
Camera and marker positions were adjusted using surveying equipment.

The best vault of the eight top ranked athletes was chosen for analysis. Due to a technical problem the approach parameters for Bubka's winning vault could not be determined. Thus, the data for his second vault is reported. In all parameters associated with the actual vault, data for Bubka's vaults clearing 5.70 and 5.85 m are reported.

The films were digitized and analyzed using specialized software capable of eliminating the pan, linking the coordinates obtained from C1 and C2, and computing the required parameters.
It must be noted that although the working conditions in Rome were excellent in general, part of the approach was obscured by judges and members of the press. Therefore not all parameters could be obtained. This missing data is marked "--" in the tables.

This report does not include a full interpretation of the data. However, a few comments are made and printed in italics to denote that these remarks are of an interpretative nature. The reader is asked to refer to chapter two, "Biomechanics of the Pole Vault" for a more detailed description of the data reported in chapter three. FIGURES 2 - 5 and the corresponding text make reference to most parameters chosen for inclusion in this report.

One limitation of this report must be clearly stated: The computation of some important parameters such as energy, moment of inertia, angular momentum (and to a lesser degree center of mass related measures) depends on precise anthropometrical data. This means that individual measures should be taken of each athlete. Unfortunately, this was not possible in Rome. Thus, the known data (body height and mass) was used to choose an optimal anthropometrical "model athlete" representing each actual vaulter.

3.2 EVENT SCORECARD

Start of competition: 3:30 p.m.
End of competition: 8:10 p.m.
Temperature (8:10 p.m.): +23° C
Pressure: 1014 mBar
Humidity: 75 %

RANK	NR.	NAME		CROSSBAR HEIGHTS								
				530	540	550	560	570	575	580	585	605
1	948	BUBKA	URS	-	-	-	-	O	-	-	O	XX
2	349	VIGNERON	FRA	-	-	O	-	O	-	XO	XXX	
3	953	GATAULIN	URS	-	-	-	O	XO	-	XO	XXX	
4	754	KOLASA	POL	-	-	O	XO	XXO	-	XXO	XXX	
5	120	NIKOLOV	BUL	-	O	-	O	O	XX	X		
5	1015	BELL	USA	-	O	-	O	O	XXX			
7	115	LESOV	BUL	-	O	-	O	XXX				
8	123	TAREV	BUL	-	O	-	XO	X	XX			
9	986	OBIZHAYEV	URS	-	-	O	-	XXX				
10	344	SALBERT	FRA	-	-	XO	-	-	XXX			
11	610	STECCHI	ITA	O	XO	XX	X					
12	874	ZALAR	SWE	XO	-	XXX						
	894	Lubensky	TCH	XXX								
	43	Fehringer	AUT	-	XXX							

LEGEND:
"-" pass, "O" fair jump, "X" foul jump.

3.2.1 STANDARD SETTINGS

NAME	CROSSBAR HEIGHTS							
	540	550	560	570	575	580	585	605
BUBKA	–	–	–	70 o	–	–	72 o	74 x
VIGNERON	–	?	–	60 o	–	60 o	71 x	
GATAULIN	–	–	60 o	?	–	60 o	?	
KOLASA	–	68 o	66 o	60 xx 67 o	–	?	40 x	
NIKOLOV	55 o	–	40 o	65 o	50 x	?		
BELL	55 o	–	56 o	?	?			
LESOV	46 o	–	36 o	45 xx 33 x				
TAREV	50 o	–	52 o	52 x	52 xx			

LEGEND:
The numbers represent the horizontal setting of the standard towards the landing pit (cm). The subscripts "o" and "x" denote fair and foul jumps respectively. The "?" stands for missing data.

EXAMPLE: Kolasa set the standard 66 cm back in his succesful attempt at 560 cm. In his first two unsuccessful jumps at 570 cm the standards were placed 60 cm back. In his third and fair jump over this height the standards were adjusted to be 67 cm back from the end of the box.

3.3 PERSONAL DATA

This information was compiled from the official lists (items 1-3) and from observation during the competition (items 4-8).

	1	2	3	4	5	6	7	8
BUBKA	12/63	77	184	585	P	526	517	100/11.4
VIGNERON	3/60	73	181	580	P	510	500	88/15.0
GATAULIN	11/65	77	190	580	P	518	510	95/12.8
KOLASA	8/59	90	196	580	N	510	507	102/11.8
NIKOLOV	10/64	78	182	570	P	500	485	91/14.6
BELL	8/55	82	193	570	M	520	495	97/12.5
LESOV	1/67	69	182	560	P	500	485	88/14.8
TAREV	1/58	75	180	560	P	510	495	91/14.0
Obizhayev	9/59	?	?	550	P	?	?	? / ?
Salbert	8/60	85	189	550	P	518	?	95/ ?
Stecchi	3/58	80	178	540	P	500	480	86/ ?
Zalar	3/57	71	178	530	P	510	485	88/15.5
Lubensky	12/62	75	185	-	?	510	480	84/17.0
Fehringer	12/62	82	181	-	P	500	480	91/14.6

LEGEND:

1. Month and year of birth. 2. Body mass (Kg). 3. Height (cm)
4. Crossbar height in the best fair jump (cm)
5. Pole used (P=Pacer, N=Nordic, M=Maxima)
6. Length of the pole (cm)
7. Grip height (cm) measured to the top of the upper hand
8. Rating in Kg / Flex number of the pole used.

3.4 THE APPROACH

3.4.1 APPROACH VELOCITIES
(MEASURED WITH PHOTOCELLS)

Mean approach velocities (m/s) were measured with photocells during the competition. V1 is the velocity measured over a 5 m section from 15 m to 10 m before the end of the box. V2 is the corresponding velocity in the section 10 m to 5 m from the back of the box. Both velocities were obtained by dividing the known distance between each pair of doubled IR photocells by the measured time interval. This data was available immediately after the end of the competition.

EXAMPLE: For each vaulter the heights cleared (o) or attempted (x) are given. Below the crossbar height you find the velocities V1 and V2. Thus Bubka cleared 570 in his first attempt. The mean approach velocity 15 - 10 m from the back of the box was 9.42 m/s. Bubka managed to increase this velocity to 9.65 m/s in the section 10 - 5 m from the box.

1. BUBKA (585)

	570	585	605		HEIGHT
1	o 9.42 9.65	o 9.47 9.77	x 9.42 9.67	ATTEMPT	V1 V2
2			x 9.42 9.65		

2. VIGNERON (580)

	550	570	580	585
1	o 9.16 9.14	o 9.56 9.43	x 9.42 9.40	x 9.47 9.36
2			o 9.42 9.43	x 9.45 9.42
3				x 9.42 9.33

3. GATAULIN (580)

	560	570	580	585
1	o 9.42 9.52	x 9.31 9.09	x 9.35 9.60	x 9.40 9.67
2		o 9.42 9.54	o 9.40 9.60	x 9.36 9.54
3				x 9.26 9.33

4. KOLASA (580)

	550	560	570	580	585
1	o 8.94 9.03	x 8.91 9.06	x 9.01 9.12	x 9.21 9.26	x 9.16 9.26
2		o 8.90 9.07	x 8.96 9.07	x 9.23 9.28	x 8.86 9.28
3			o 9.07 9.17	o 9.16 9.26	x 9.12 9.31

5. NIKOLOV (570)

	540	560	570	575	580
1	o 9.16 9.14	o 9.33 9.17	0 9.26 9.31	x 9.11 8.94	x 9.19 9.16
2				x 9.12 9.16	

6. BELL (570)

	540	560	570	575
1	o 9.04 9.43	o 9.12 9.49	o 9.12 9.51	x 9.07 9.42
2				x 9.07 9.42
3				x 9.14 9.38

7. LESOV (560)

	540	560	570
1	o 9.07 9.11	o 9.12 9.16	x 9.17 9.17
2			x 9.07 9.03
3			x 9.16 9.17

8. TAREV (560)

	540	560	570	575
1	o 9.36 9.23	x 9.42 9.29	x 9.29 9.29	x 9.36 9.33
2		o 9.29 9.29		x 9.28 9.33

9. OBIZHAYEV (550)

	550	570
1	o 9.09 9.29	x 9.07 9.26
2		x 9.12 9.33
3		x 9.12 9.19

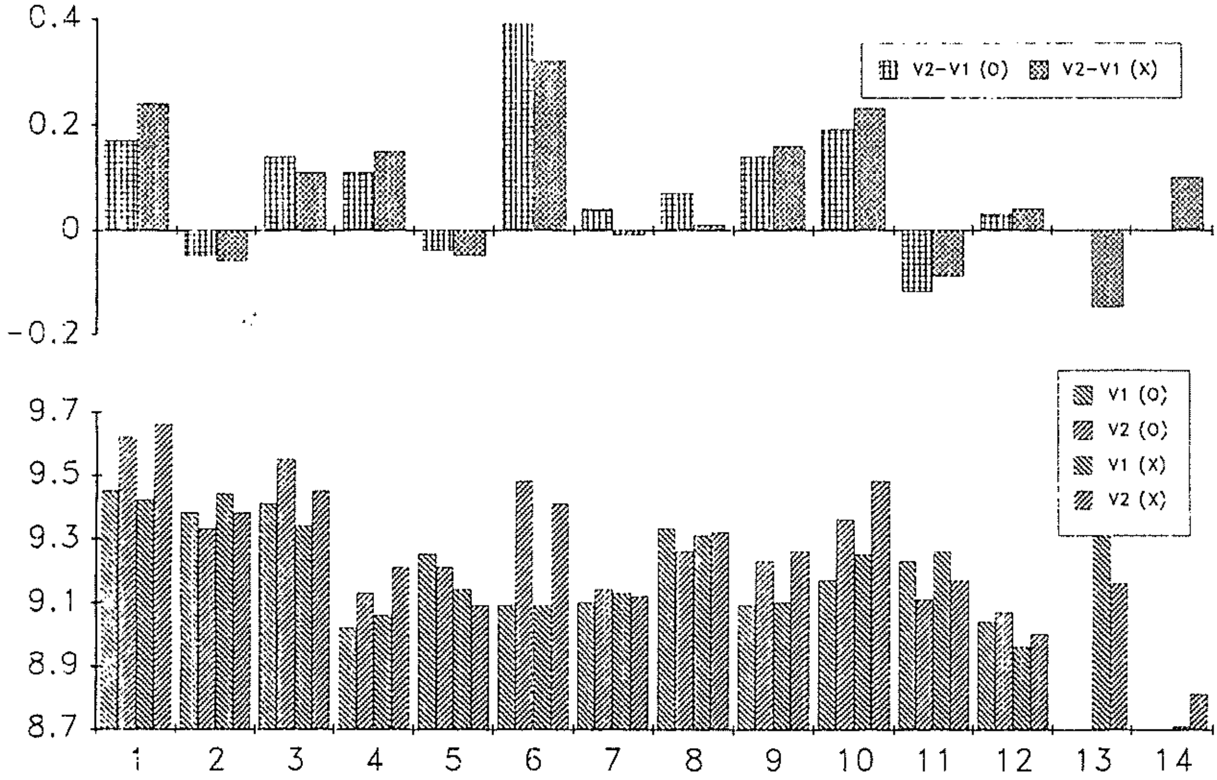
10. SALBERT (550)

	550	575
1	x 9.26 9.52	x 9.23 9.40
2	o 9.17 9.36	x 9.16 9.40
3		x 9.33 9.60

11. STECCHI (540)

	530	540	550	560
1	o 9.19 9.03	x 9.19 9.12	x 9.35 9.17	x 9.23 9.16
2		o 9.26 9.19	x 9.26 9.23	

12. ZALAR (530)		(13)LUBENSKY	(14)FEHRINGER
530	550	530	540
1 x 8.96 8.96	x 8.98 9.03	x 9.28 9.06	x 8.65 8.87
2 o 9.04 9.07	x 8.98 8.99	x 9.17 9.12	x 8.74 8.88
3	x 8.93 9.01	x 9.47 9.31	x 8.73 8.68



The graphs summarize information about the approach velocities as measured with photoelectric cells for the 14 finalists. In the bottom graph the mean velocities (m/s) for the successful [V1 (o), V2 (o)] and unsuccessful [V1 (x), V2 (x)] vaults are shown for each vaulter. In the top graph the velocity differences (m/s) are depicted.

The data suggest, that the vaulters have individual patterns in their approach run. These patterns are similar for successful and unsuccessful vaults. Some athletes (for example, (1)Bubka and (6)Bell) show a marked increase in velocity while others almost maintain their velocity or even decelerate (for example, (2)Vigneron). A high approach velocity is a necessary but non sufficient prerequisite for successful vaults. From a biomechanical point of view, high approach velocities with an acceleration into the take-off as shown by Bubka are desirable.

3.4.2 APPROACH PARAMETERS

The following section summarizes selected parameters associated with the approach phase. Due to a technical problem the approach of Bubka's winning vault could not be analyzed. Where indicated, data for the second best vault of Bubka(570) is reported.

3.4.2.1 TEMPORAL APPROACH PARAMETERS

The table summarizes time intervals. The flight time (FT) is defined as the time interval from take-off to touchdown, and the support time (ST) is defined as the sum of the braking and driving phases. The times are given in milliseconds.

	4th LAST		3rd LAST		2nd LAST		LAST		TO
	FT	ST	FT	ST	FT	ST	FT	ST	
BUBKA(570)	138	105	111	85	131	92	79	85	
VIGNERON	--	--	132	92	125	105	93	92	
GATAULIN	112	92	132	85	105	82	92	99	
KOLASA	118	99	125	112	113	105	105	112	
NIKOLOV	118	98	99	99	132	92	72	99	
BELL	112	105	118	99	118	98	98	92	
LESOV	131	105	112	85	144	92	85	92	
TAREV	131	86	125	92	131	98	105	92	

3.4.2.2 STRIDELENGTH AND FREQUENCIES

The table summarizes stride lengths [SL (m)] and stride frequencies [SF (strides/sec.)]. Each stride is defined to start and end at the time when the CM passes the respective support foot. Stride length ratio (SLR) is obtained by dividing the last stride length by the second to last stride length.

	4th LAST		3rd LAST		2nd LAST		LAST		
	SF	SL	SF	SL	SF	SL	SF	SL	SLR
BUBKA(570)	4.5	2.25	4.8	2.09	4.9	2.16	5.1	1.94	0.90
VIGNERON	---	----	4.6	2.12	4.3	2.19	4.9	2.00	0.91
GATAULIN	4.6	2.04	4.9	2.16	5.1	1.87	4.9	2.03	1.09
KOLASA	4.5	2.04	4.5	2.21	4.2	2.15	4.6	1.99	0.93
NIKOLOV	4.6	2.04	4.9	1.93	4.5	2.08	5.6	1.78	0.86
BELL	4.3	2.10	4.3	2.06	4.5	2.13	5.3	2.03	0.95
LESOV	4.4	2.06	4.6	2.00	4.6	2.15	5.3	1.76	0.82
TAREV	4.6	2.09	4.6	2.14	4.2	2.17	4.9	2.15	0.99

The last stride is shortest and stride frequency is highest for most vaulters (except for Gataulin). The SLR for Nikolov and Lesov may indicate an exaggerated stride length reduction. The literature consideres SLR in the range of 0.93 to 0.95 as being desirable.

3.4.2.3 HORIZONTAL DISTANCE OF THE CM TO THE SUPPORT FOOT

The data summarized in this table represent the horizontal distance (cm) between the CM and the support foot (M5). The distances are positive at take-off (TO) since the CM is ahead of the support foot and negative at touchdown (TD).

The last column (Dx2) is the horizontal distance between the top hand and the support foot at TD for take-off.

	4th LAST		3rd LAST		2nd LAST		LAST		
	TO	TD	TO	TD	TO	TD	TO	TD	Dx2
BUBKA(570)	40	-30	59	-33	48	-32	54	-56	-63
VIGNERON	--	--	46	-33	52	-37	58	-43	-47
GATAULIN	52	-35	49	-31	47	-29	57	-49	-54
KOLASA	50	-37	52	-45	51	-45	47	-47	-62
NIKOLOV	57	-29	58	-36	49	-27	56	-49	-56
BELL	67	-31	59	-30	58	-34	50	-51	-60
LESOV	35	-40	51	-38	37	-33	47	-40	-55
TAREV	49	-29	49	-38	47	-37	53	-58	-59

3.4.2.4 HORIZONTAL CENTER OF MASS VELOCITIES

This table summarizes horizontal CM velocities (m/s) at takeoff (TO) of each stride.

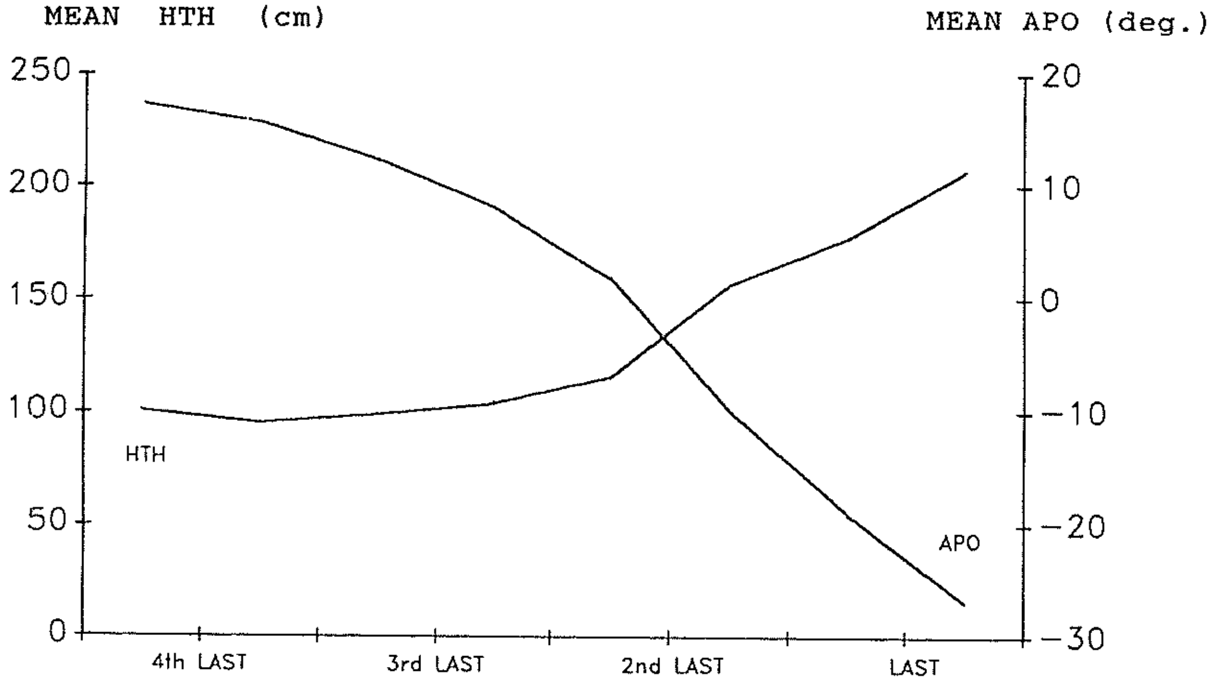
Note - these values are approximately 0.2 to 0.3 m/s faster than the mean approach velocities (V2) measured with photo-electric cells. This is due to the fact that the highest instantaneous velocity in each stride rather than mean velocity over a defined approach section (10 - 5 m from the end of the box) is reported.

	4th LAST	3rd LAST	2nd LAST	LAST	
	TO	TO	TO	TO	V2
BUBKA(570)	--	10.0	10.0	10.1	9.65
VIGNERON	--	9.6	9.9	10.0	9.43
GATAULIN	9.7	9.9	9.9	9.9	9.60
KOLASA	9.4	9.6	9.8	9.3	9.26
NIKOLOV	9.5	9.8	9.5	9.7	9.31
BELL	9.6	9.5	9.7	10.1	9.51
LESOV	9.6	9.3	9.5	9.5	9.16
TAREV	9.6	9.6	9.8	9.2	9.29

3.4.2.5 POLE KINEMATICS DURING PLANT PREPARATION AND PLANT

This table summarizes data on the height of the top hand (HTH) above the runway (cm), and gives the angle of the pole to the horizontal axis [(APO) (degrees)]. This shows the timing of the plant with respect to the stride phases touchdown (TD) and takeoff (TO).

	4th LAST		3rd LAST		2nd LAST		LAST		
	TO	TD	TO	TD	TO	TD	TO	TD	
BUBKA(570)	103	98	99	104	109	159	171	206	HTH
	18	15	11	7	2	-12	-16	-26	APO
VIGNERON	--	--	95	102	109	149	177	194	HTH
	--	--	13	8	3	-11	-26	-26	APO
GATAULIN	106	91	98	105	131	172	188	212	HTH
	19	18	14	8	1	-10	-18	-26	APO
KOLASA	113	105	114	111	122	154	181	215	HTH
	19	18	13	10	2	-8	-16	-27	APO
NIKOLOV	95	92	96	99	100	145	169	202	HTH
	19	18	16	12	7	-6	-20	-26	APO
BELL	87	86	90	95	112	158	183	218	HTH
	19	18	13	9	1	-11	-22	-30	APO
LESOV	105	101	104	113	128	157	175	207	HTH
	12	9	6	3	-5	-13	-18	-26	APO
TAREV	96	94	97	103	112	156	173	198	HTH
	15	14	12	8	3	-8	-16	-28	APO
MEAN HTH	101	95	99	104	115	156	177	207	
MEAN APO	17	16	12	8	2	-10	-19	-27	



Timing of the plant preparation and plant with respect to the last approach strides.

Since all vaulters show a very similar behaviour in the timing of the plant preparation and plant, the mean values for the height of the top hand (HTH) and the angle of the pole to the horizontal (APO) are plotted for the last four strides.

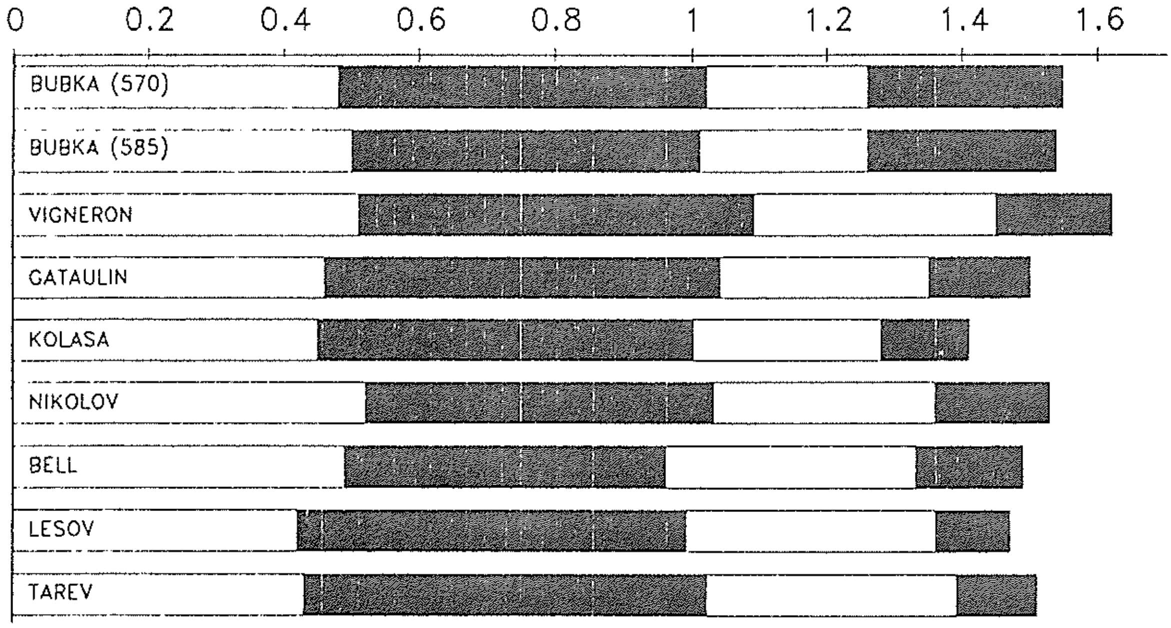
3.5 THE VAULT

PHASE STRUCTURE OF THE VAULT

The following table summarizes times and time intervals (dt) measured for the following instants and phases:

TD (Touchdown) The take-off foot contacts the ground.
PP (Pole plant) The pole makes contact with the end of the box.
TO (Takeoff) The take-off foot leaves the ground.
MPB (Maximum Pole bend) The pole chord reaches the minimum length.
PS (Pole straight) The pole is fully recoiled.
PR (Pole release) The vaulter releases the pole.
HP (High point) The vaulter's CM reaches its maximum height.

	TD	PP	TO	MPB	PS	PR	HP	
BUBKA(570)	-0.09	-0.05	0.00	0.50	1.01	1.26	1.55	
		0.04			0.51	0.25	0.29	dt
BUBKA(585)	-0.08	-0.05	0.00	0.48	1.02	1.26	1.54	
		0.03			0.54	0.24	0.28	dt
VIGNERON	-0.09	-0.02	0.00	0.51	1.09	1.45	1.61	
		0.07			0.58	0.36	0.16	dt
GATAULIN	-0.10	-0.04	0.00	0.46	1.04	1.35	1.50	
		0.06			0.58	0.31	0.15	dt
KOLASA	-0.11	-0.05	0.00	0.45	1.00	1.28	1.41	
		0.06			0.55	0.28	0.13	dt
NIKOLOV	-0.10	-0.05	0.00	0.52	1.03	1.36	1.53	
		0.05			0.51	0.33	0.17	dt
BELL	-0.09	-0.03	0.00	0.49	0.96	1.33	1.49	
		0.06			0.47	0.37	0.16	dt
LESOV	-0.09	-0.07	0.00	0.42	0.99	1.36	1.47	
		0.02			0.57	0.37	0.11	dt
TAREV	-0.09	-0.06	0.00	0.43	1.02	1.39	1.51	
		0.03			0.59	0.37	0.12	dt



Graphical comparison of the phase structure of the vaults. Time is given in seconds.

The fact that Bubka releases the pole very early (and consequently has a long free flight phase) should not be overinterpreted since Bubka has a very high vertical CM velocity at this instant. The other vaulters seem to "guide" the pole without necessarily applying downward force.

The tables on the following pages summarize data obtained from the detailed analysis of the top vaults. The data is presented in tabular rather than graphical form since it would take about 30 pages to include the individual graphs which all show similar trends, and are hard to compare through visual inspection. The reader is therefore, referred to chapter two, where the graphs of Bubka's winning vault are included in the discussion of the performance relevant parameters in the pole vault. Reading chapter two carefully will also greatly facilitate understanding the data presented in the following tables.

3.5.1 TAKE-OFF PARAMETERS

In the following tables, data obtained for parameters associated with the take-off phase is summarized. The take-off phase is defined to last from the initial contact of the take-off foot with the runway to the instant when the foot leaves the ground (TO).

	ZTH(TO)	AP		dV	Vx(TO)	Vz(TO)	V(TO)	ATO
		TD	TO					
BUBKA (570)	2.45	24	29	1.6	8.5	2.3	8.8	15
BUBKA (585)	2.43	25	29	---	8.3	2.2	8.6	15
VIGNERON	2.33	25	30	2.0	8.0	2.1	8.3	15
GATAULIN	2.51	26	30	2.0	7.9	2.5	8.3	18
KOLASA	2.59	27	33	1.6	7.7	2.0	8.0	15
NIKOLOV	2.41	24	29	1.8	7.9	2.3	8.2	16
BELL	2.44	27	31	2.0	8.1	1.7	8.3	12
LESOV	2.44	25	31	1.2	8.3	2.2	8.6	15
TAREV	2.28	24	29	1.0	8.2	2.1	8.4	15

LEGEND:

ZTH(TO) The height of the upper hand above the runway (m) at the instant of takeoff.

AP The angle of the pole (chord) to the horizontal axis (degrees) at touchdown (TD) and takeoff (TO) respectively.

dV The difference in horizontal velocity (m/s) of the flight phase of the last stride, and the horizontal takeoff velocity of the CM.

Vz(TO) The vertical CM velocity (m/s) at TO.

Vx(TO) The horizontal CM velocity (m/s) at TO.

V(TO) The resulting CM velocity (m/s) at TO.

ATO The angle of takeoff (degrees)

The CM velocity at take-off was identified as an important parameter. Interestingly enough, Bubka reaches higher values in his vault clearing 5.7 m. Consequently, he also has a larger amount of kinetic energy [Ekin(TO)] at take-off (see the following table).

If you look at the potential energy [Epot(HP)] at the peak of the flight parabola (see 3.5.3) you will notice a higher value for his winning vault. Thus, Bubka did more work on the pole (see 3.5.2). It may be hypothesized that there is an optimum V(TO) for each vaulter (on his present technical level and depending on his physical abilities). If the velocity is too low, the performance will be poor. If the velocity is too high, poor energy transformation and thus a reduced maximum CM height may be the undesirable result.

	HCM(TO)	Epot(TO)	Ekin(TO)		Etot(TO)		ICM(TO)
			(J)	(J/Kg)	(J)	(J/Kg)	
BUBKA (570)	1.18	889	3228	(41.9)	4117	(53.5)	14.5
BUBKA (585)	1.16	875	2995	(38.9)	3870	(50.3)	14.7
VIGNERON	1.15	823	2729	(37.4)	3552	(48.7)	13.3
GATAULIN	1.25	946	2833	(36.8)	3779	(49.1)	15.2
KOLASA	1.29	1141	3021	(33.6)	4162	(46.2)	20.3
NIKOLOV	1.16	885	2830	(36.3)	3715	(47.6)	15.2
BELL	1.15	929	2980	(36.3)	3909	(47.7)	18.2
LESOV	1.14	774	2678	(38.8)	3452	(50.0)	14.3
TAREV	1.08	792	2877	(38.4)	3669	(48.9)	13.7

LEGEND:

HCM(TO) Height of the CM at takeoff (m).

Epot(TO) Potential Energy at takeoff.

Ekin(TO) Kinetic Energy at takeoff. This parameter is given in absolute values (Joule) as well as in relative terms (J/Kg) to allow interindividual comparison.

Etot(TO) The total (sum) energy at takeoff, also expressed in absolute and relative terms.

ICM(TO) The moment of inertia of the vaulter about the CM at TO.

When looking at the energy related data please keep in mind the limitation stated in 3.1.
The kinetic energy depends on body mass and velocity (see chapter 2). To facilitate interindividual comparison, the values in parenthesis are corrected for body mass (E/mg).

3.5.2 POLE SUPPORT PARAMETERS

The following tables summarize data measured during the pole support phase which is defined to last from takeoff (TO) until the vaulter leaves the pole (PR).

	CL(MIN)		MPB	AP(MPB)(PS)		T45	Vz(MAX)		Vz(PR)
	(m)	(%)	(s)	(degrees)		(s)	(m/s)	(s)	(m/s)
BUBKA (570)	3.80	26	0.50	63	89	0.44	6.2	0.96	2.6
BUBKA (585)	3.83	25	0.48	60	87	0.45	6.2	0.94	2.7
VIGNERON	3.56	28	0.51	63	87	0.44	5.2	0.97	1.5
GATAULIN	3.96	22	0.46	63	86	0.43	5.1	0.92	1.5
KOLASA	3.84	23	0.45	62	86	0.40	5.0	0.85	1.6
NIKOLOV	3.65	24	0.52	58	86	----	---	----	---
BELL	3.65	26	0.49	61	86	0.36	5.3	0.86	1.6
LESOV	3.70	23	0.42	61	86	0.38	5.1	0.89	0.8
TAREV	3.82	22	0.43	58	86	0.35	5.2	0.86	0.9

LEGEND:

CL(MIN)	Minimum length of the pole chord (m) and percent reduction of chord length.
MPB	The time at which maximum pole bend occurs (TO = 0.0).
AP(MPB)	The angle of the pole chord to the horizontal at MPB.
AP(PS)	The angle of the pole chord to the horizontal axis at the instant when the pole has straightened (PS).
T45	The time at which Vz(CM) is greater than Vx(CM). This means, that the CM moves upwards at an angle greater than 45 degrees.
Vz(MAX)	The maximum vertical CM velocity during the pole extension phase (m/s) and the time at which this maximum is observed. (TO = 0.0).
Vz(PR)	The vertical CM velocity at pole release (PR).

Bubka reaches by far the highest vertical CM velocity [Vz(PR)]. The difference of about 1 m/s would account for roughly 21 cm in height. The difference in Vz(PR) between Bubka and all other vaulters is very remarkable as well.

	I(MIN)	TI(MIN)	L(MAX)	TL(MAX)	TL-	NET (J)	WORK (J/Kg)
BUBKA (570)	7.0	0.64	62	0.34	0.84	919	(11.9)
BUBKA (585)	7.0	0.61	60	0.35	0.86	1280	(16.6)
VIGNERON	3.9	0.66	60	0.29	0.85	1078	(14.8)
GATAULIN	4.2	0.47	66	0.29	0.73	1149	(14.9)
KOLASA	10.8	0.59	120	0.32	0.72	1285	(14.3)
NIKOLOV	----	0.57	---	----	----	----	----
BELL	6.1	0.66	102	0.31	0.76	1104	(13.5)
LESOV	5.8	0.56	76	0.30	0.65	837	(13.5)
TAREV	6.1	0.56	57	0.29	0.78	1036	(13.8)

LEGEND:

I(MIN) Smallest moment of inertia about the vaulter's CM ($Kg*m^2$).

TI(MIN) Time at which I(MIN) occurs (TO = 0.0).

L(MAX) Largest value for the angular momentum about the vaulter's CM (Kgm^2/s).

TL(MAX) The time at which the maximum value for the angular momentum is measured.

TL- The time at which the angular momentum changes sign. (The direction of rotation changes).

NET WORK The net work is computed from the difference of the total energy at the highest point of the flight parabola, and the total energy at takeoff.

The time at which the rotation of the vaulter changes direction (TL-) indicates that the better vaulters rotate "backwards" longer. This may be an interesting point for Lesov.

3.5.3 FREE FLIGHT PARAMETERS

The following table summarizes data associated with the free flight phase which begins as the vaulter releases the pole.

	dH (cm)	Vx(HP) (m/s)	Ekin(HP) (J)	(J/Kg)	Epot(HP) (J)	H(MAX) (m)
BUBKA (570)	34	2.2	295	(3.8)	4781	6.28
BUBKA (585)	37	2.0	253	(3.3)	4805	6.49
VIGNERON	12	1.3	130	(1.8)	4500	6.28
GATAULIN	12	1.6	175	(2.3)	4753	6.29
KOLASA	13	1.4	177	(2.0)	5250	5.95
NIKOLOV	--	1.9	---	---	----	----
BELL	13	1.5	160	(2.0)	4853	6.03
LESOV	3	1.5	190	(2.8)	4099	6.06
TAREV	4	2.0	306	(4.1)	4399	5.98

LEGEND:

dH Vertical rise of the CM after pole release (cm).

Vx(HP) Horizontal velocity of the CM at the highest point of the flight parabola (HP).

Ekin(HP) Remaining kinetic energy, expressed in absolute (J) and relative (J/Kg) terms.

Epot(HP) Potential energy at HP.

H(MAX) Maximum CM height calculated from Epot(HP).

H(MAX) is not identical with the actual maximum CM height. The problem calculating energy of the human body with insufficient anthropometrical data is briefly discussed in 3.1. The value obtained by dividing Epot(HP) by mg gives an indication of how well the anthropometrical model represents the actual vaulter.

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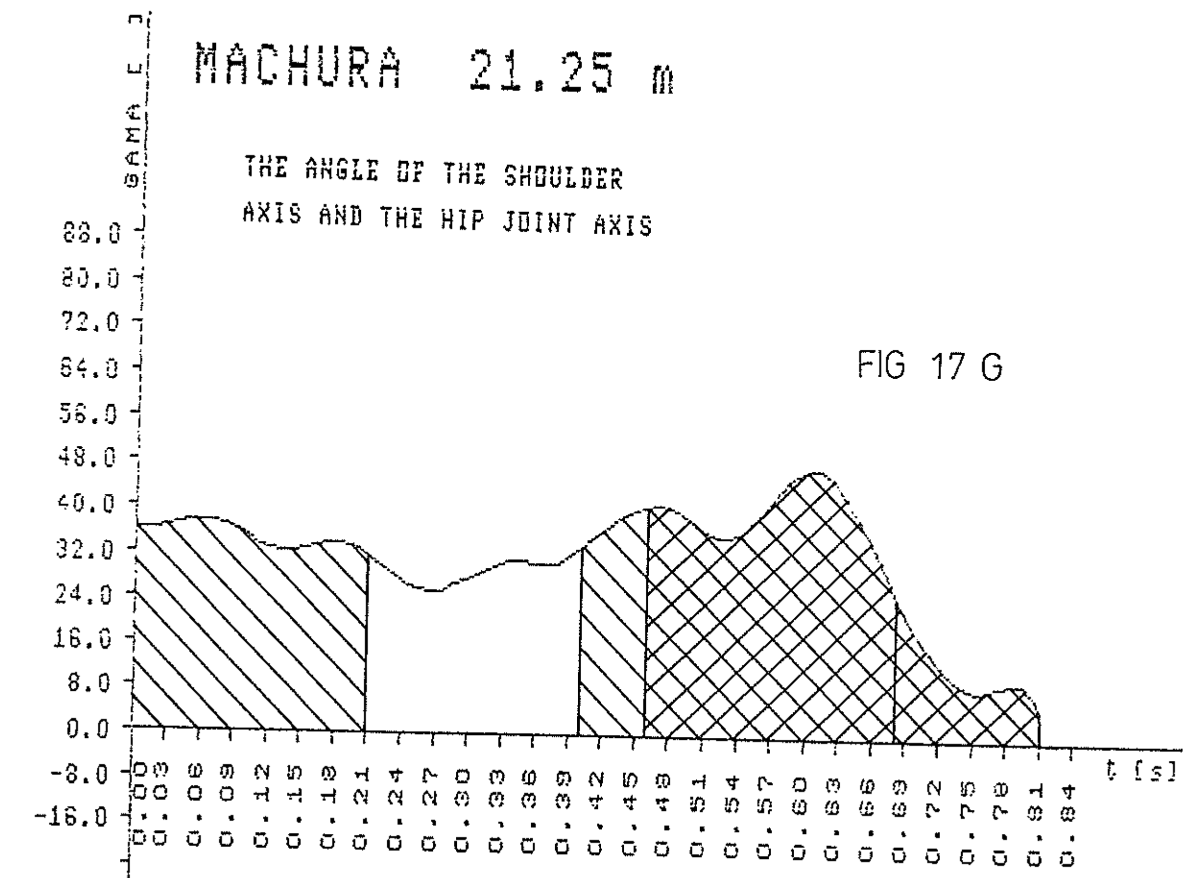
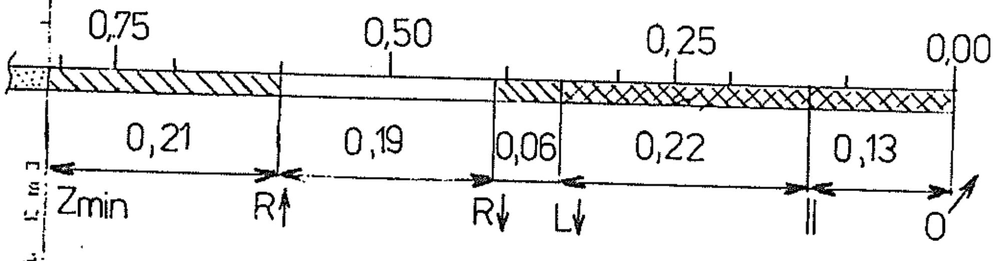


FIG 17 G



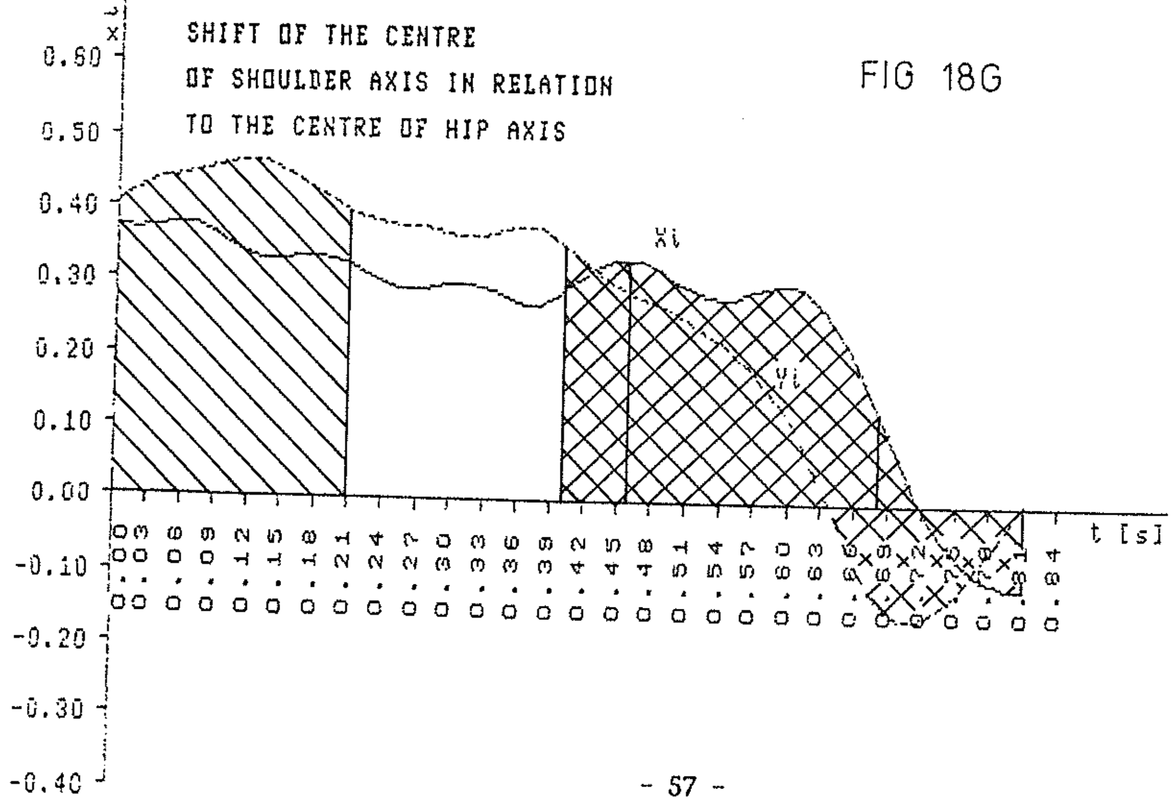
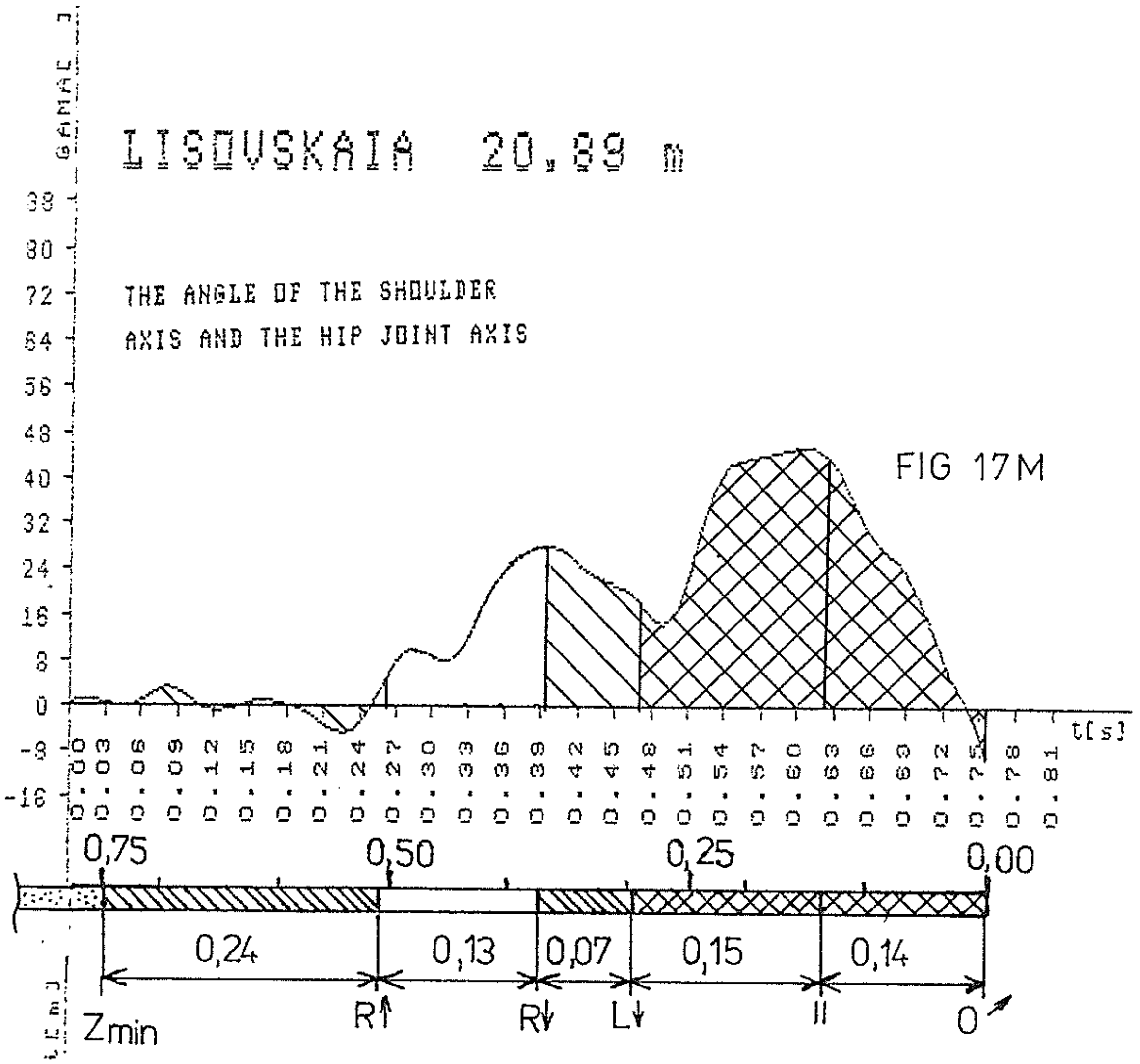
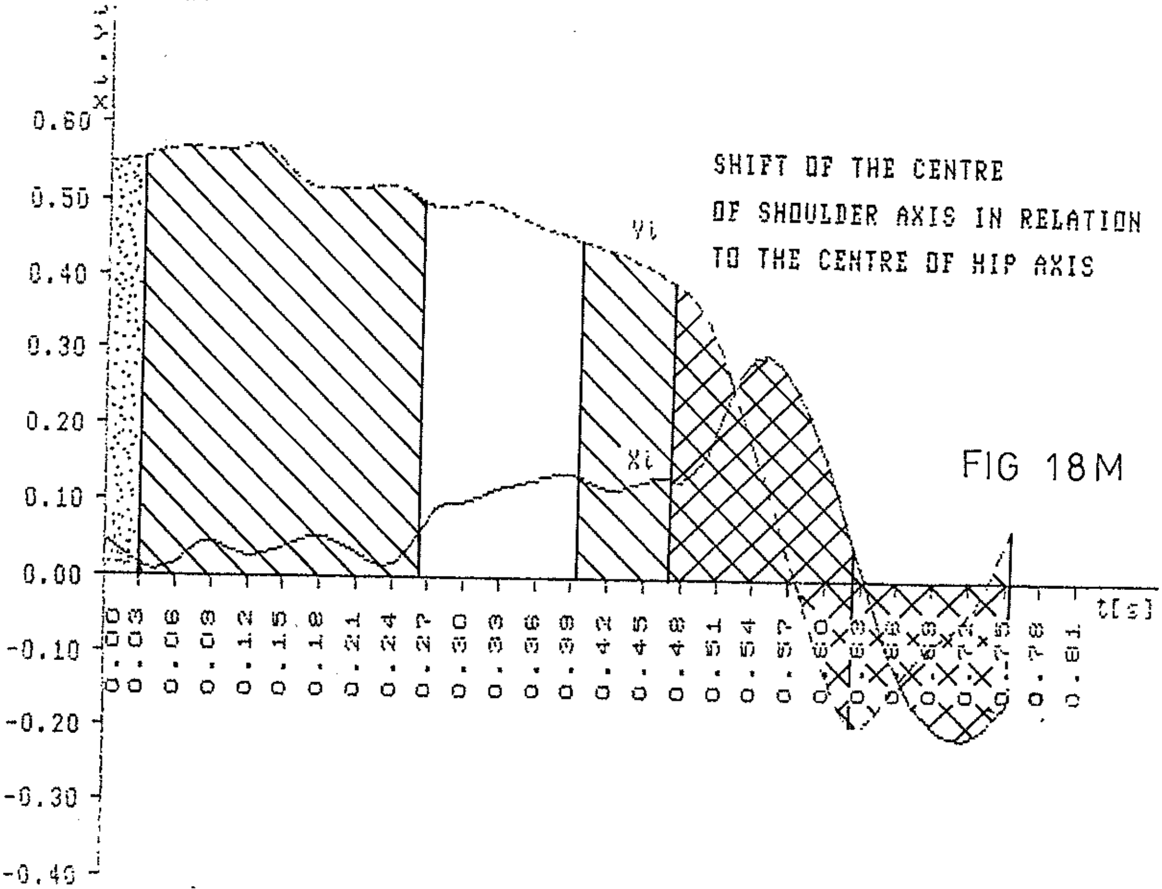


FIG 18G


LISOVSKAIA 20,89 m
GAMMA [ ]
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
FIG 17M
t[s]
0,75
0,50
0,25
0,00
0,24
0,13
0,07
0,15
0,14
Zmin
R↑
R↓
L↓
II
O


Xi, Yi [m]
SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
yi
xi
FIG 18M
t[s]

LISOVSKAIA 20.89 m

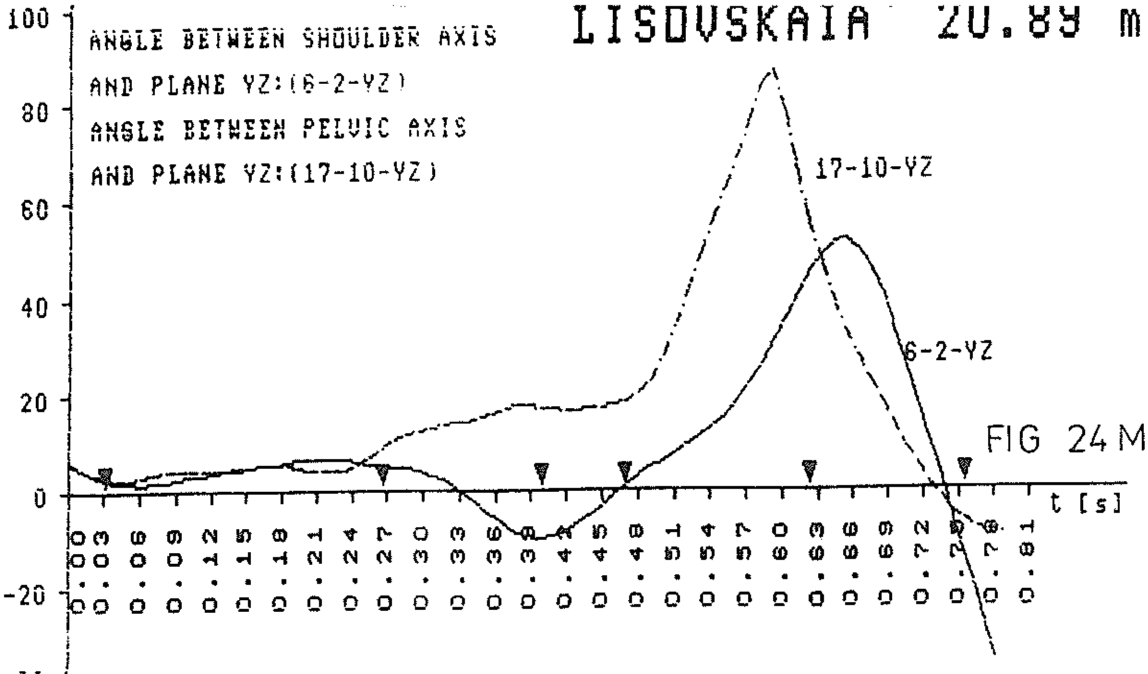


FIG 24M

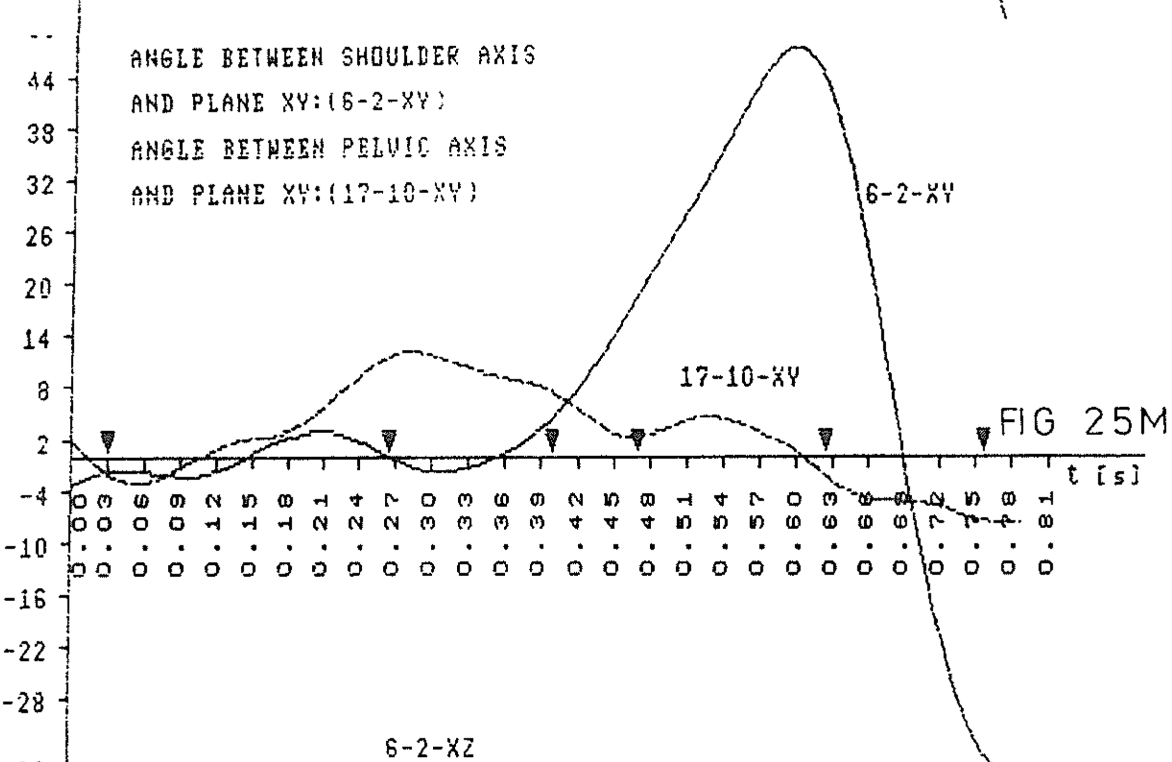


FIG 25M

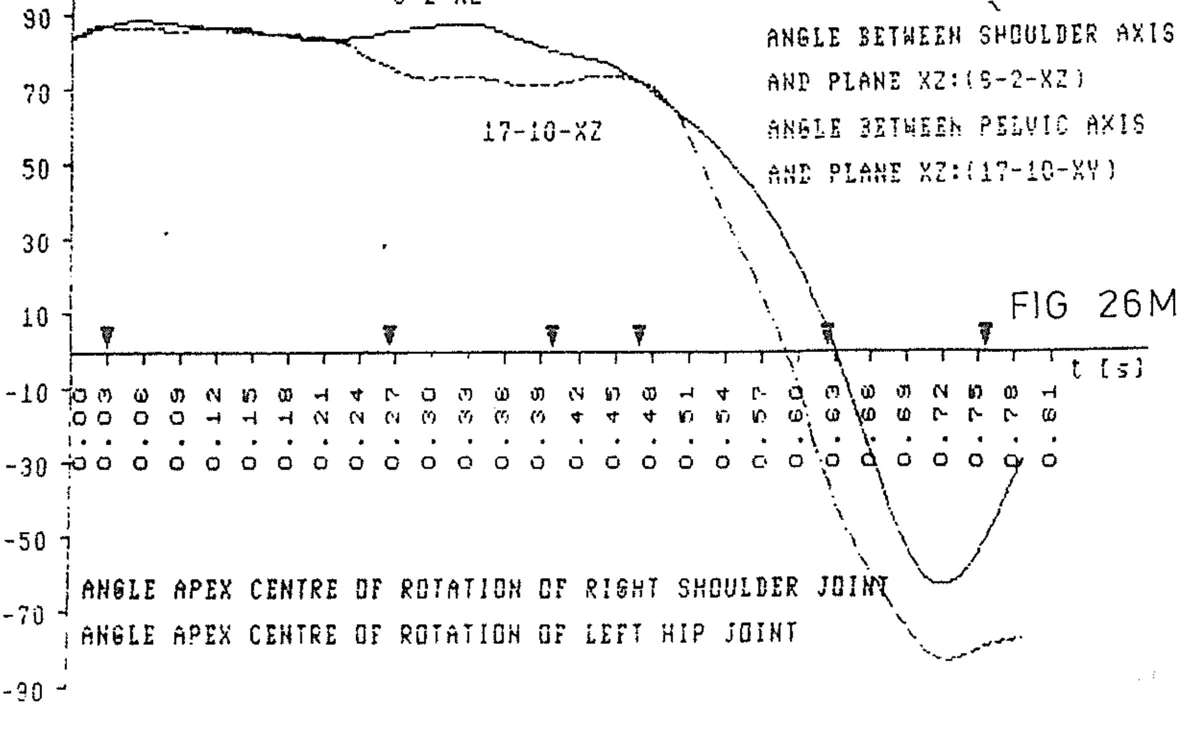
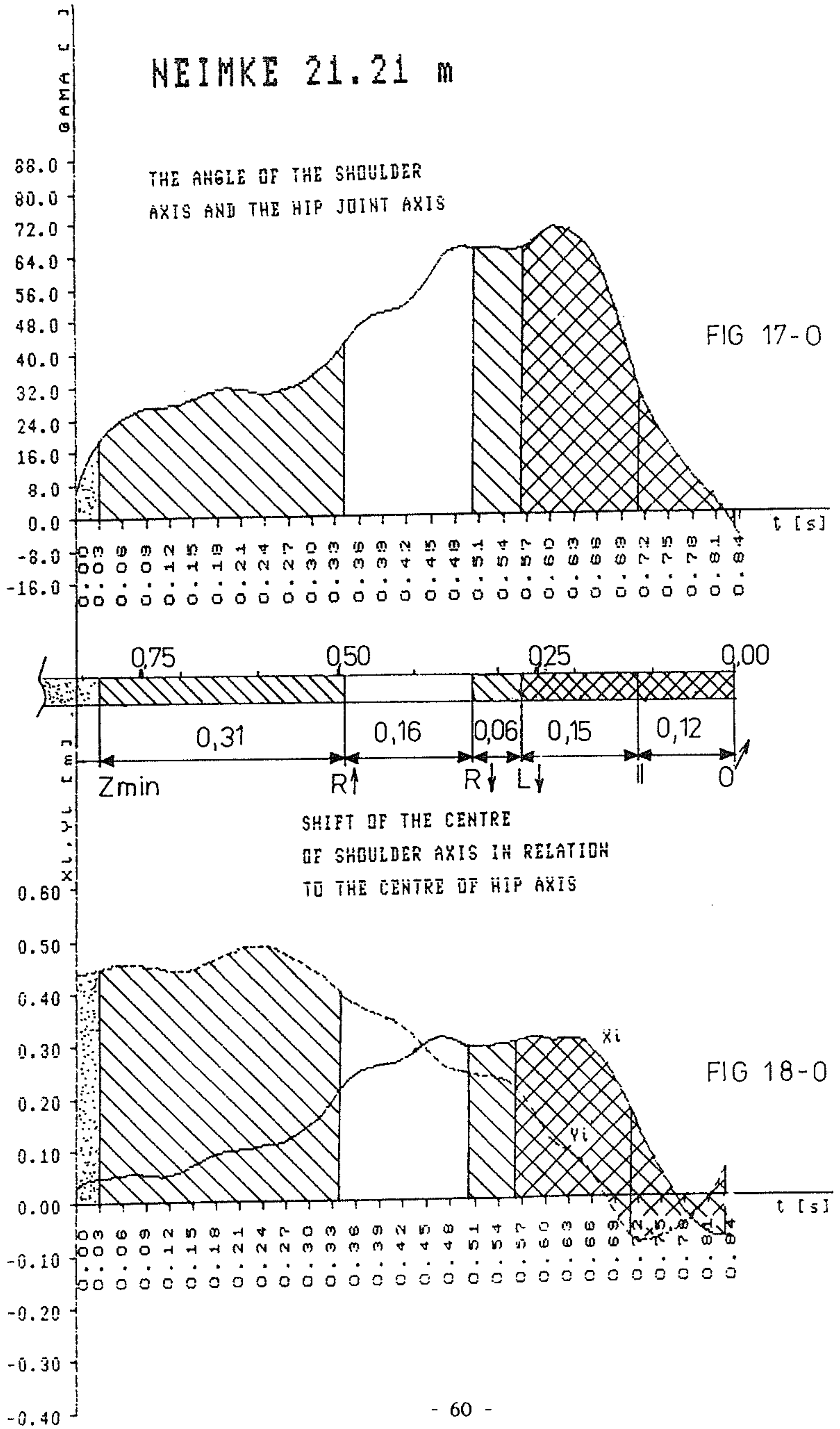
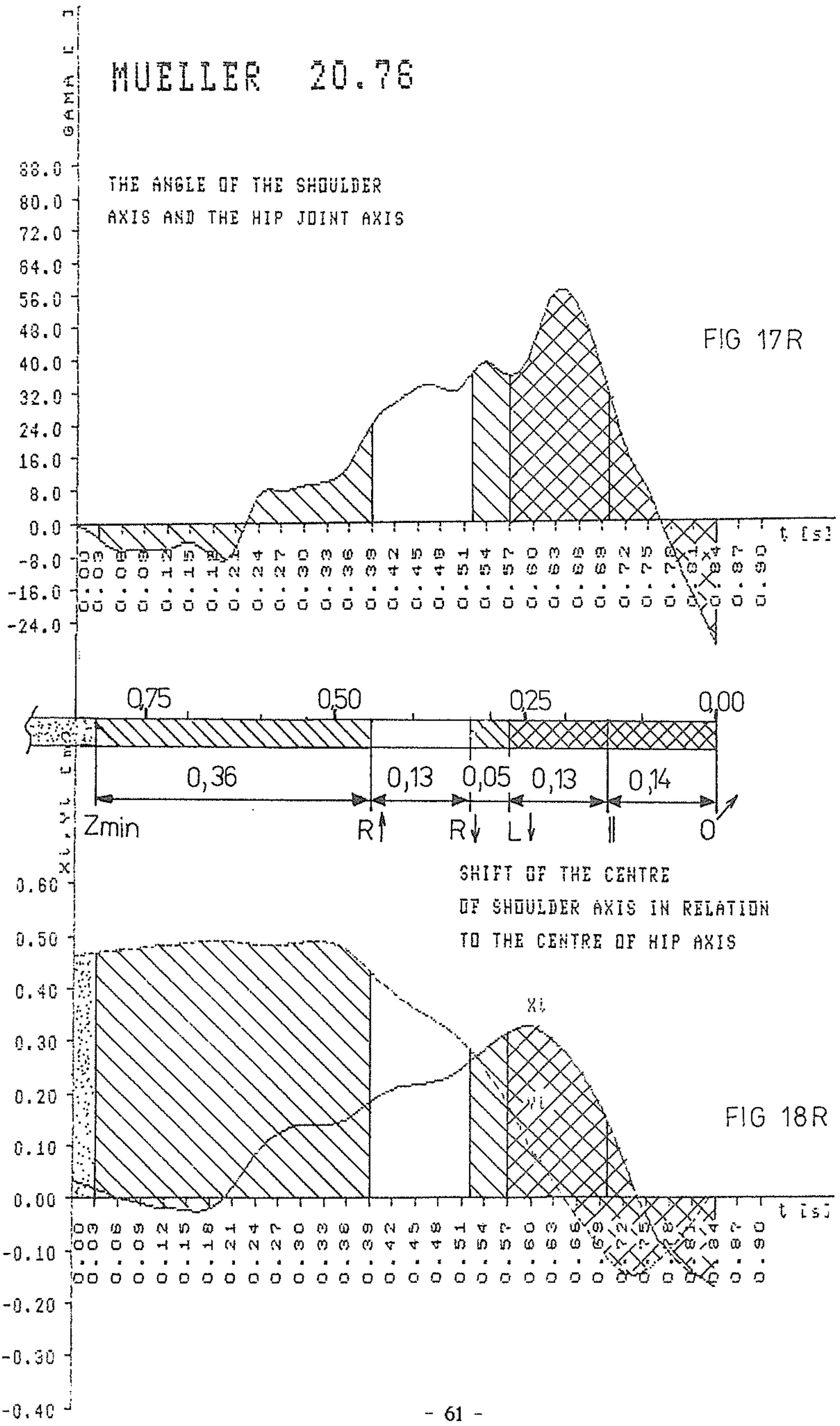
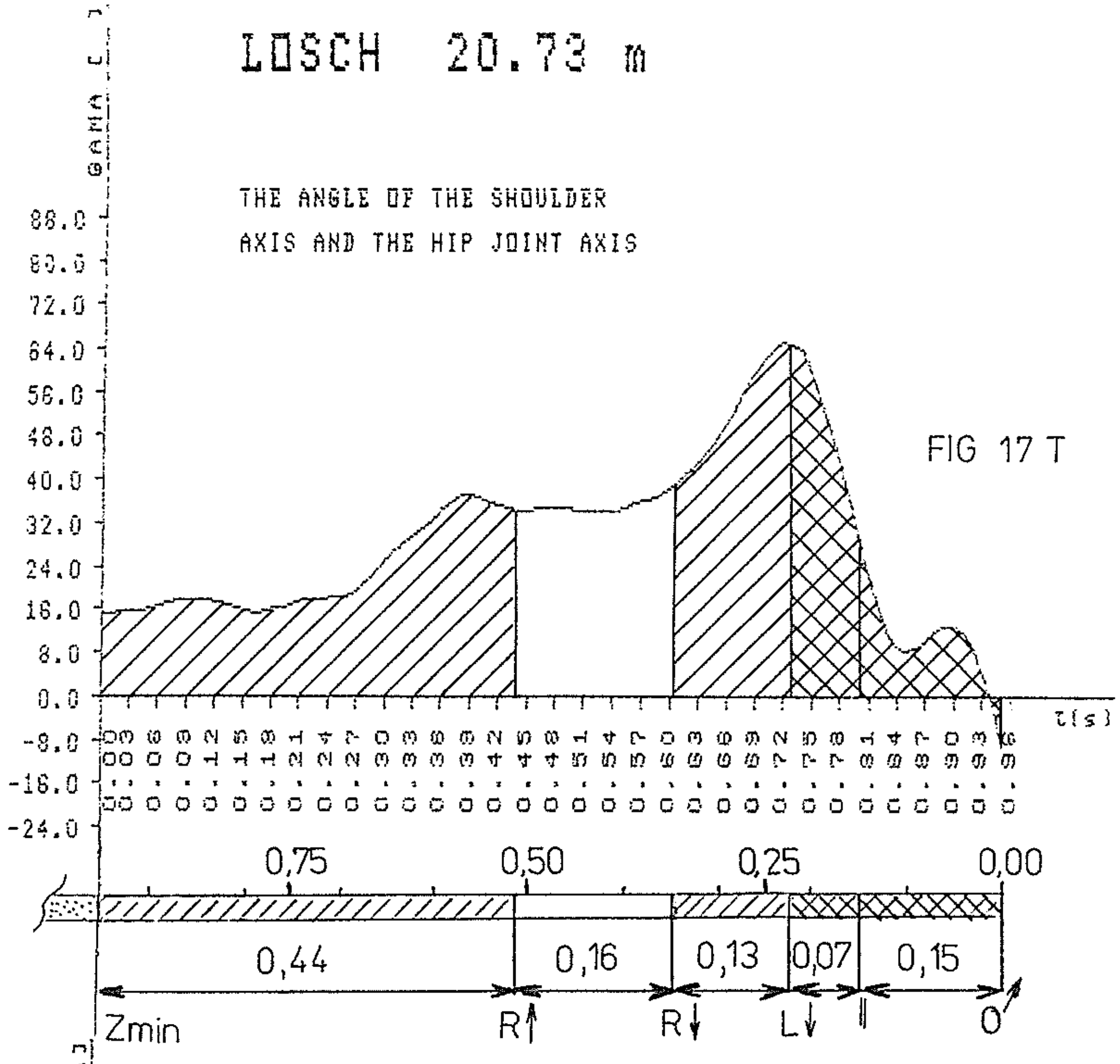


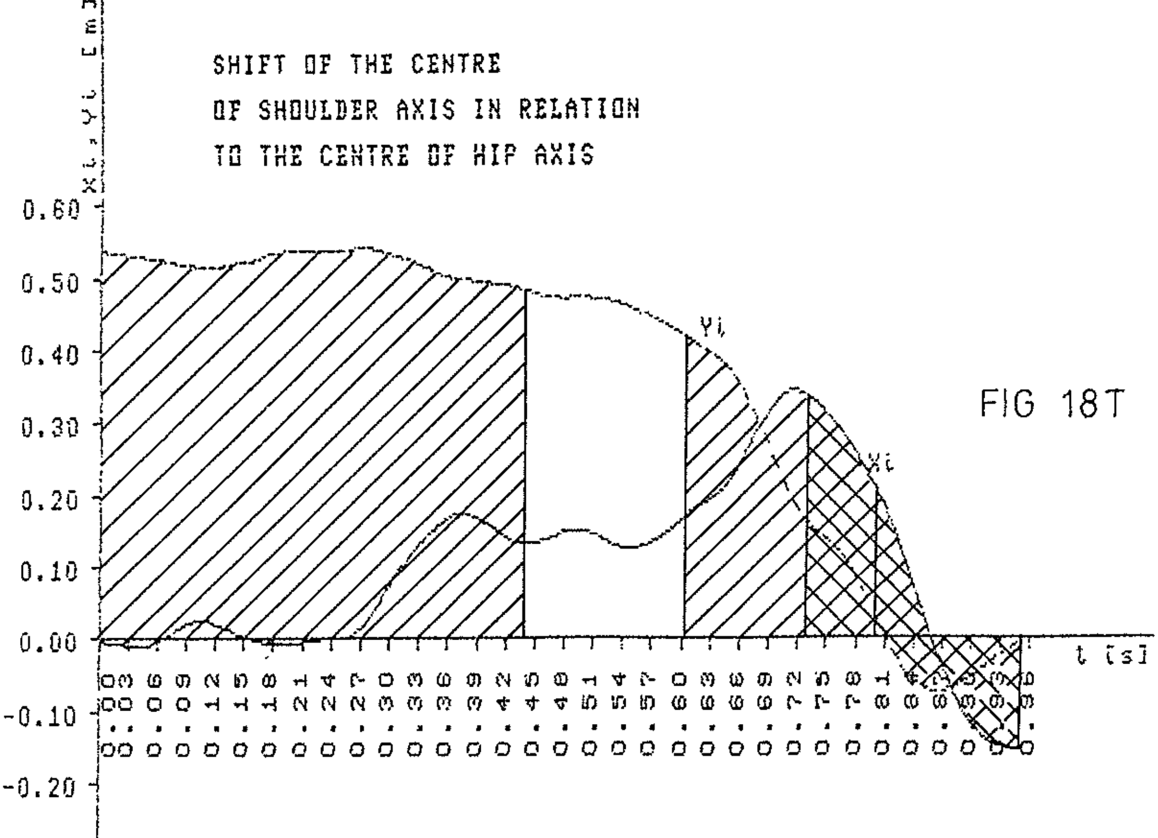
FIG 26M

DEFINITION OF PLANES AND ORIENTATION OF ANGLES SEE FIG.21


NEIMKE 21.21 m
GAMA [ ]
THE ANGLE OF THE SHOULDER AXIS AND THE HIP JOINT AXIS
FIG 17-0
88.0
80.0
72.0
64.0
56.0
48.0
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
t [s]
0.75
0.50
0.25
0.00
0,31
0,16
0,06
0,15
0,12
Zmin
R↑
R↓
L↓
||
O
XL, YL [m]
SHIFT OF THE CENTRE OF SHOULDER AXIS IN RELATION TO THE CENTRE OF HIP AXIS
FIG 18-0
Xi
Yi
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
t [s]


MUELLER 20.76
GAMA [ ]
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
FIG 17R
88.0
80.0
72.0
64.0
56.0
48.0
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
t [s]
0,75
0,50
0,25
0,00
0,36
0,13
0,05
0,13
0,14
Zmin
R↑
R↓
L↓
‖
O
Xt, Yt [m]
SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18R
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Xt
Yt
t [s]


LOSCH 20.73 m
GAMA [ ]
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
88.0
80.0
72.0
64.0
56.0
48.0
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
t [s]
FIG 17 T
0,75
0,50
0,25
0,00
0,44
0,16
0,13
0,07
0,15
Zmin
R↑
R↓
L↓
‖
O


Xi, Yi [m]
SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Yi
Xi
FIG 18T
t [s]

4.3. Functional course of the paths and velocities of body CM and the implement

The mutual position of the shot and the putter's body is determined in the competition rules (Rule 181.5): "The shot shall be put from the shoulder with one hand only. At the time the competitor takes a stance in the ring to commence a put, the shot shall touch or be in close proximity to the chin and the hand shall not be dropped below this position during the action of putting. The shot must not be taken behind the line of the shoulders."

The whole action of the Shot Put can be divided into 2 main phases. In the first phase (from initial moment to the moment when the putting action begins by extending the arm) the putter must accelerate the movement of the whole body, including the shot, as a relatively rigid system. Conversely, in the second phase the putter must stop, gradually, the forward movement of the body and accelerate the shot movement as much as possible through the arm extension in coordination with lifting and rotating the trunk.

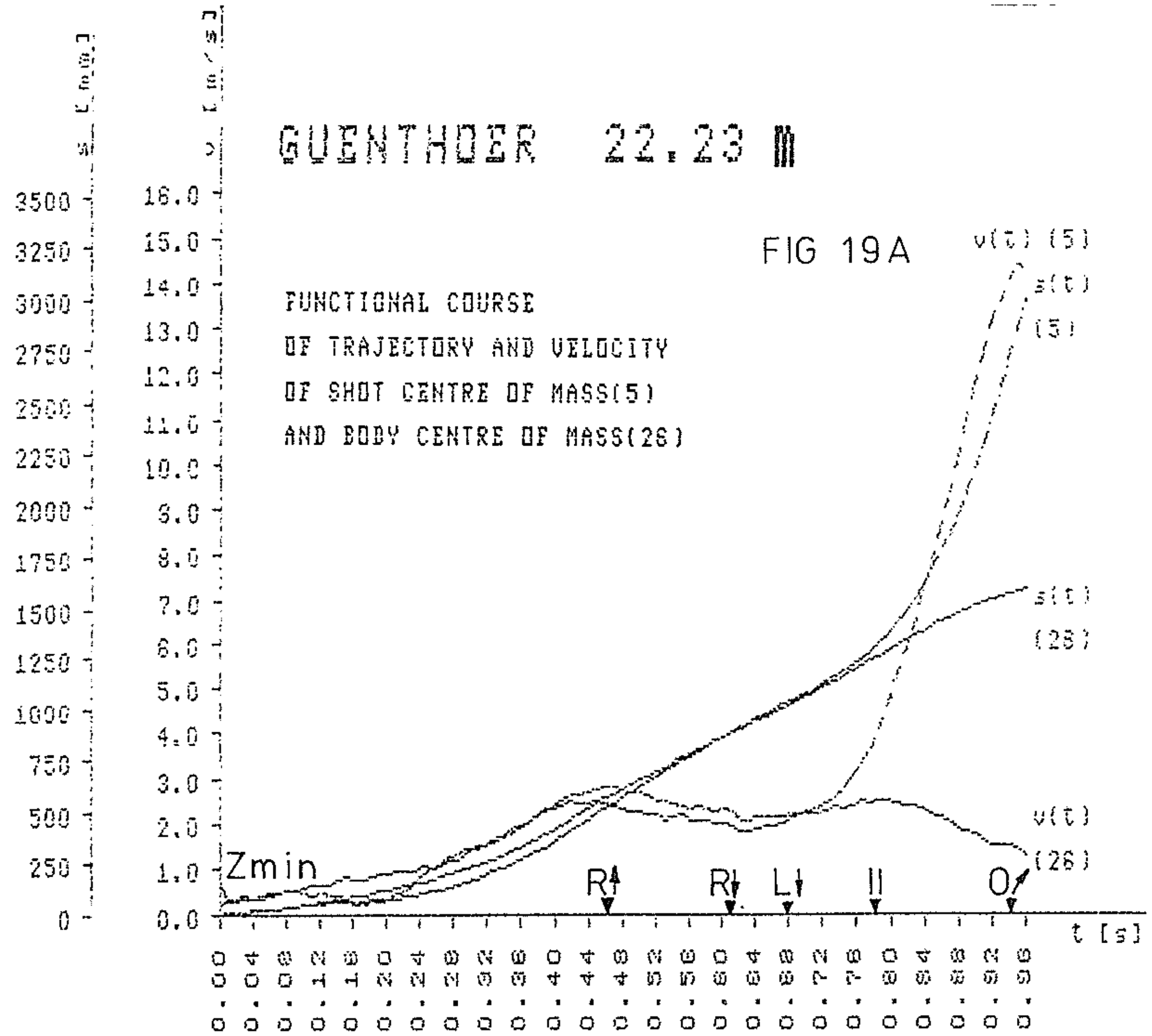
The character of the functional course of the implement velocity - v (t) (5) and that of the body CM - v (t) (26) corresponds fully to these assumptions (Figs 19 A to Z). In the first part of the put (Z_{min} - R↑) putters accelerate the movement of the whole body, including the implement. At the moment of glide beginning (R↑) they reach a velocity of up to 3 m/s. In the glide phase (R↑ - R↓) the velocity drops moderately. A different putting action is displayed in the character of the functional course of the velocity of the shot movement during the transitory phase (R↓ - L↓) and that of the shoulder rotation (R↓ - ∥). The extension of the arm with the shot starts from the moment when the shoulder rotation reaches a position parallel with the putting direction (∥). The shot velocity increases dramatically. Conversely, the velocity of the body CM begins to drop.

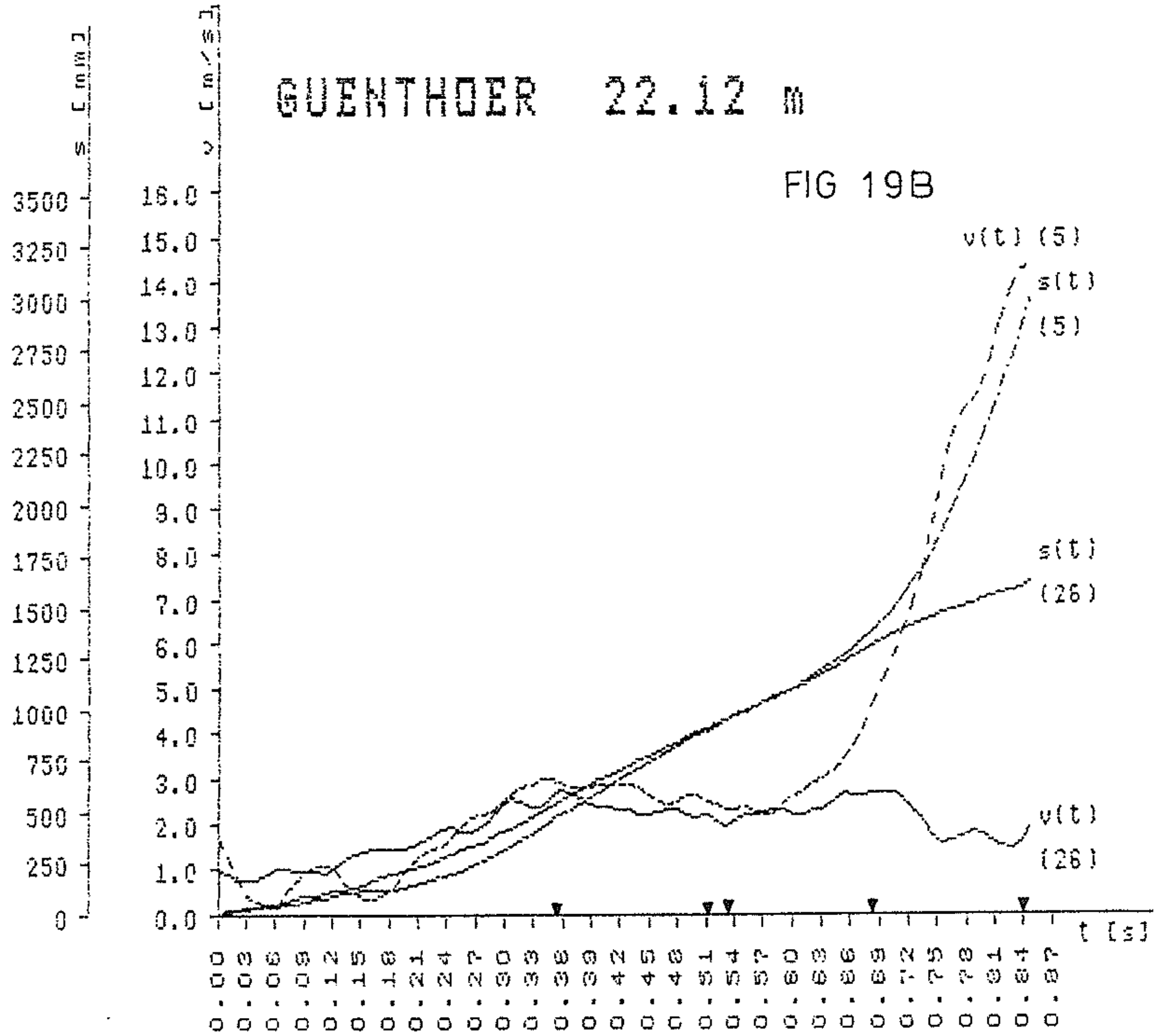
Beyer tries to accelerate the shot movement continuously even before the left foot landing (L↓), but at the right foot landing, shot velocity is low - less than 2 m/s; Bodenmueller and Gavriushin attempt this as well (but for the latter, before the left foot landing (L↓), a new drop in velocity occurs). This is the same for Losch and Li; but both of them accelerate the shot movement along a shorter path.

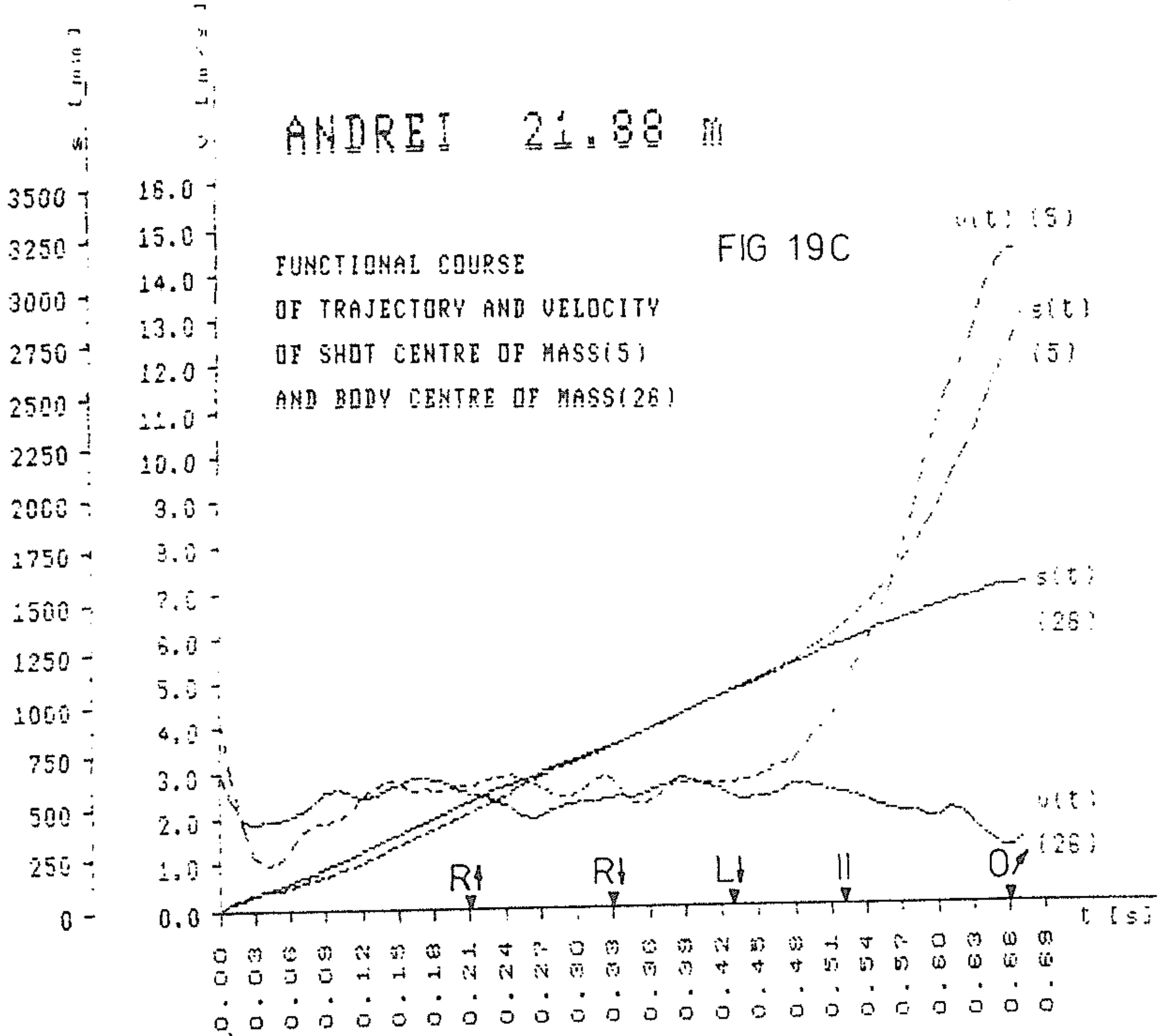
The best execution of this phase is shown by Timmermann. At the moment of take-off into the glide (R↑) he reaches a relatively high velocity of shot movement (over 3 m/s); in the transitory phase the shot velocity drops only slightly under the limit of 3 m/s and subsequently increases gradually along a long delivery path.

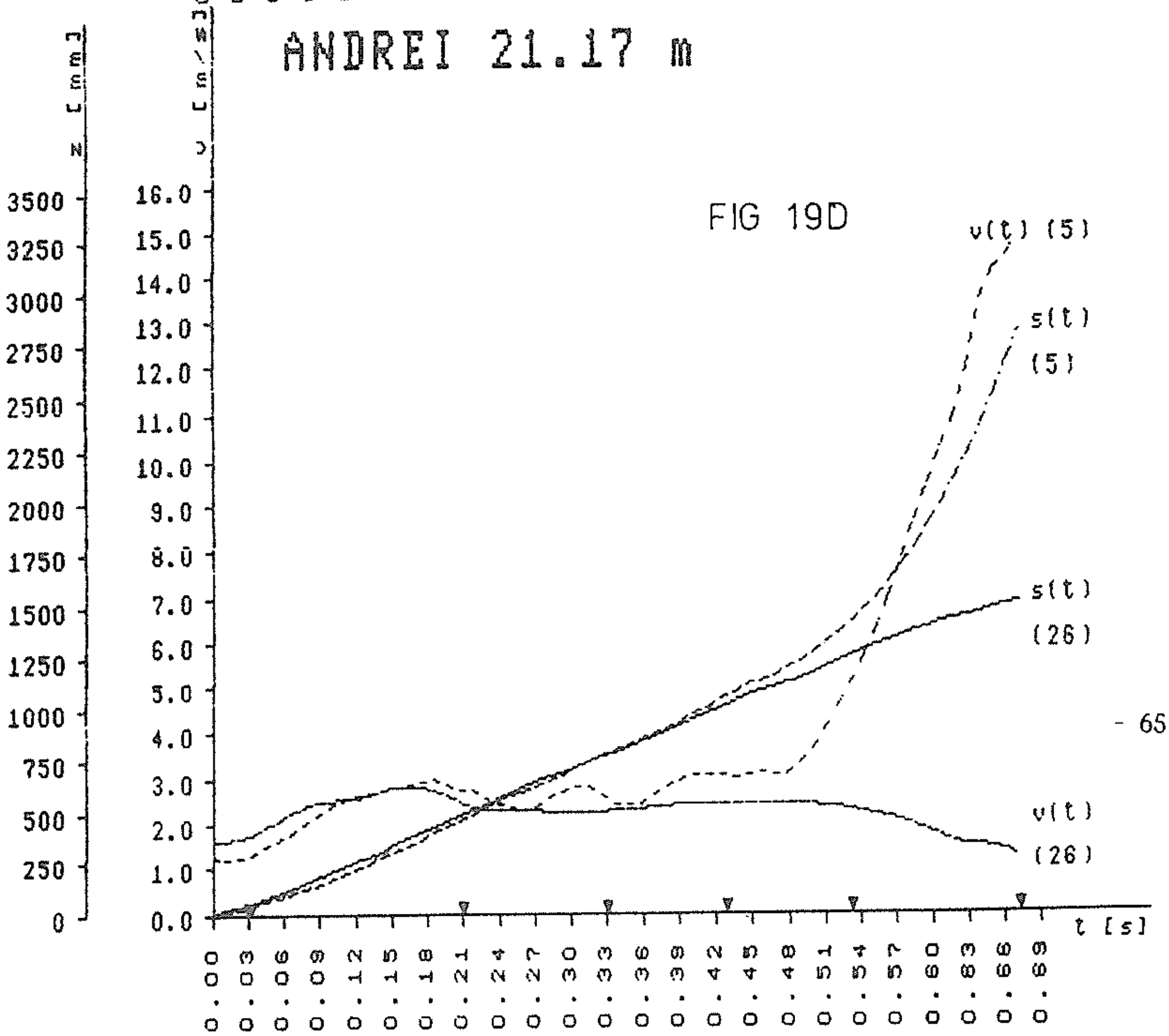
Conversely, Machura, Lisovskaya and Niemka achieve a relatively high velocity at the moment of the glide beginning (over 3 m/s). Nevertheless not only during the glide, but once again after the landing of the left foot (L↓), shot velocity drops. Thus the effective length of a relatively long path that could be utilized for accelerating the shot movement is shortened.

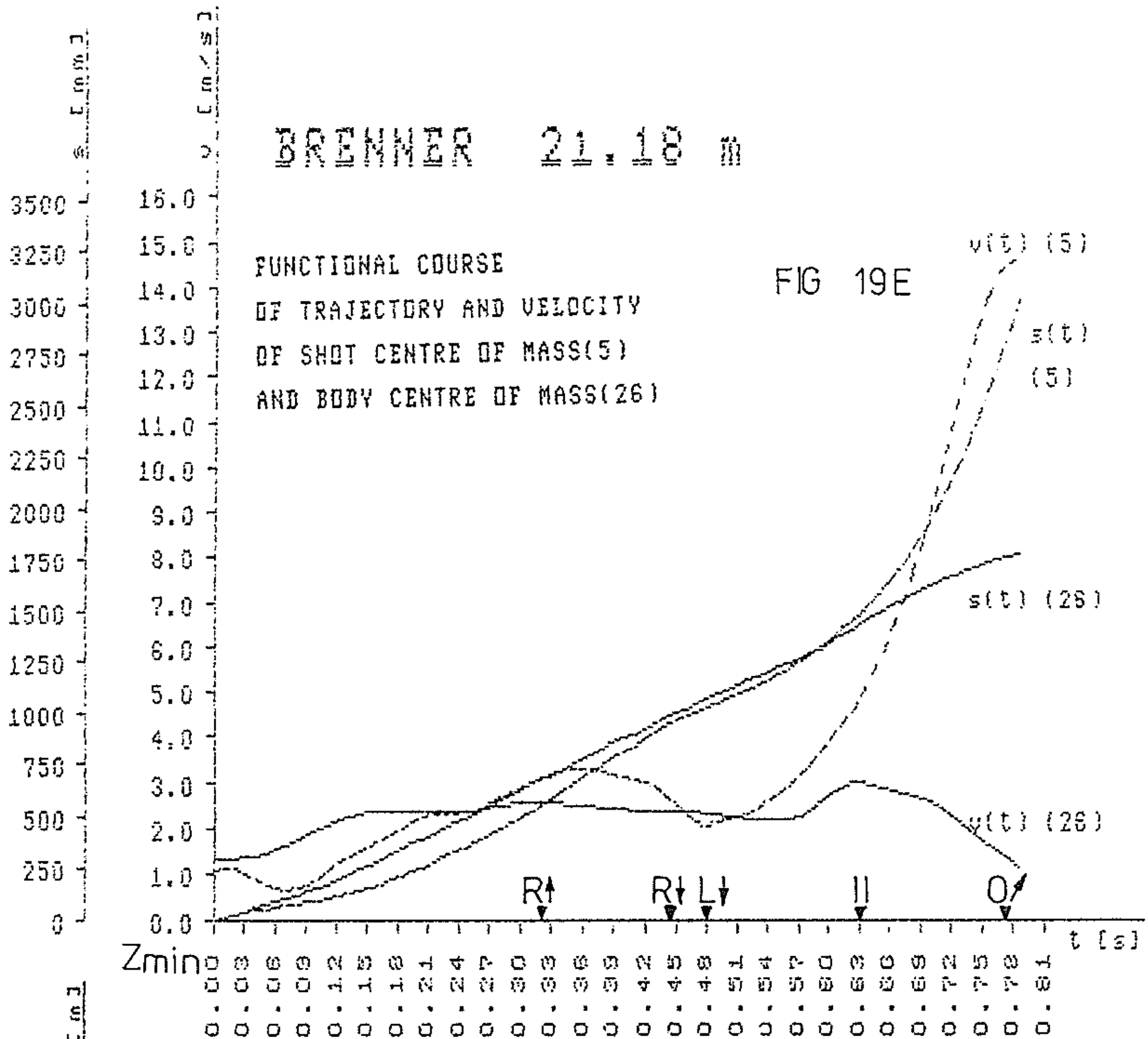
By "effective - length of the shot path" (S_E) we mean the path section covered by the shot from the moment the shot starts to increase its velocity markedly until the moment the implement leaves the putter's fingers.

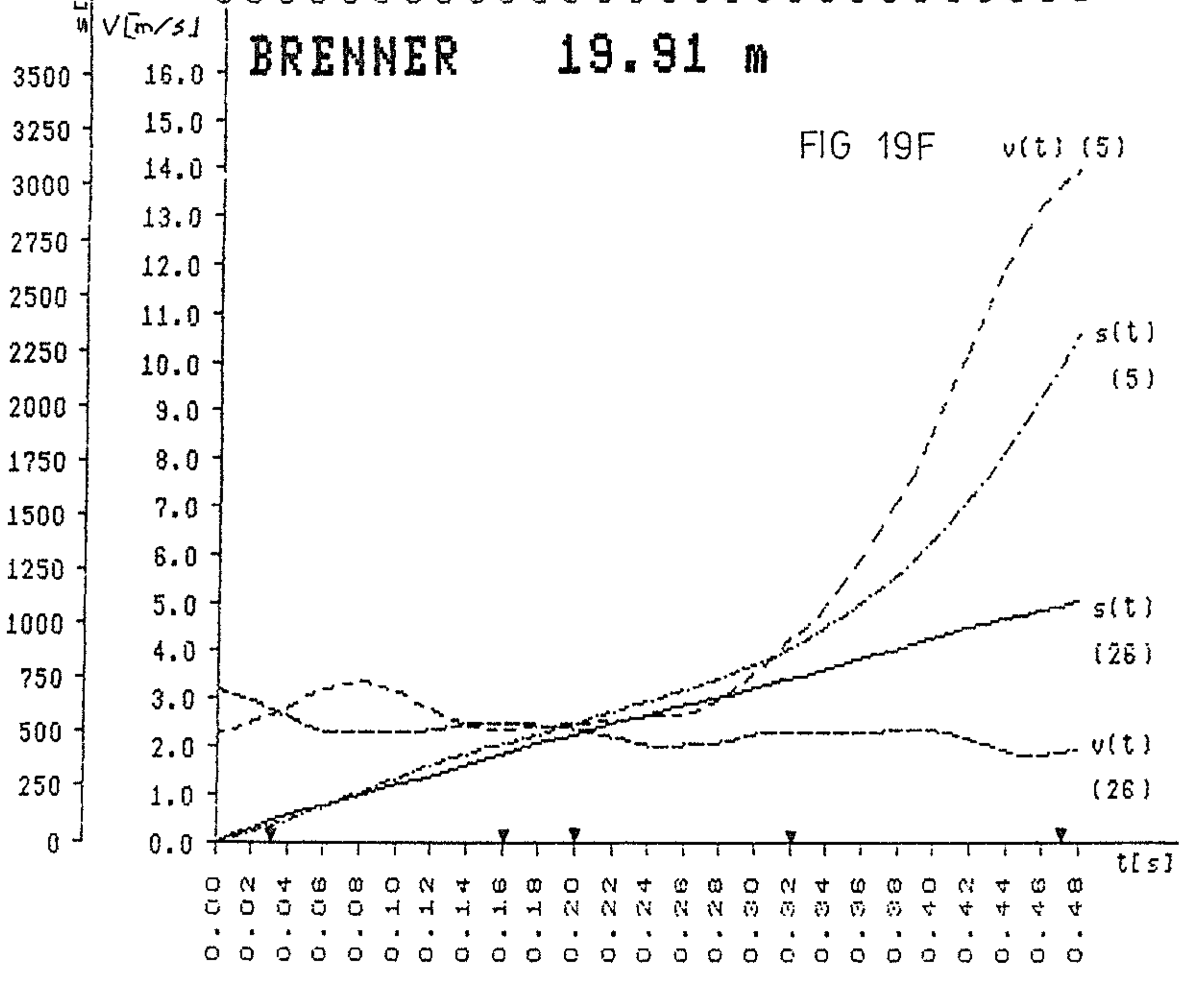

GUENTHOER 22.23 m
FIG 19A
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
s [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
Zmin
R
R
L
II
O
t [s]

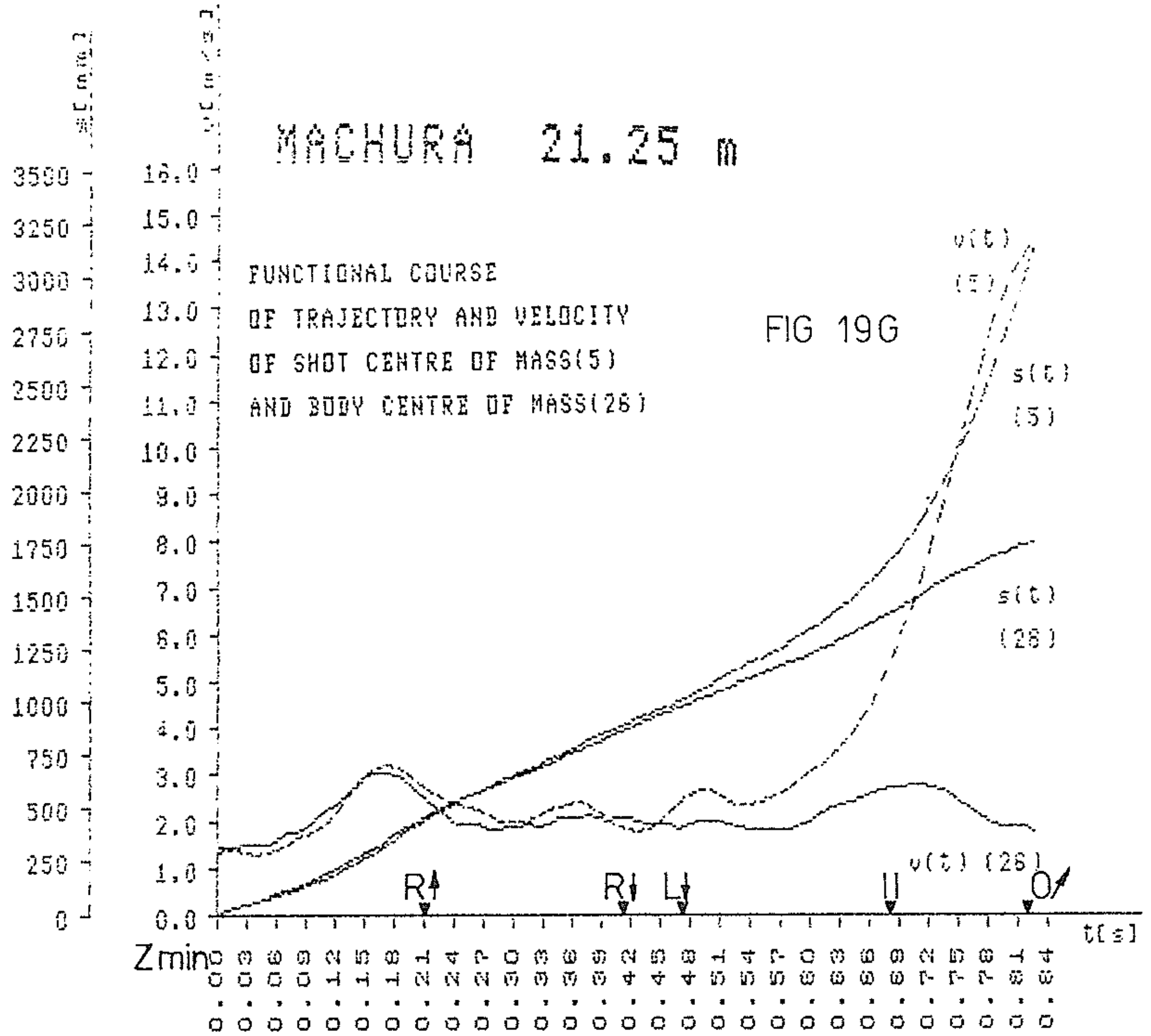

GUENTHOER 22.12 m
FIG 19B
s [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
t [s]

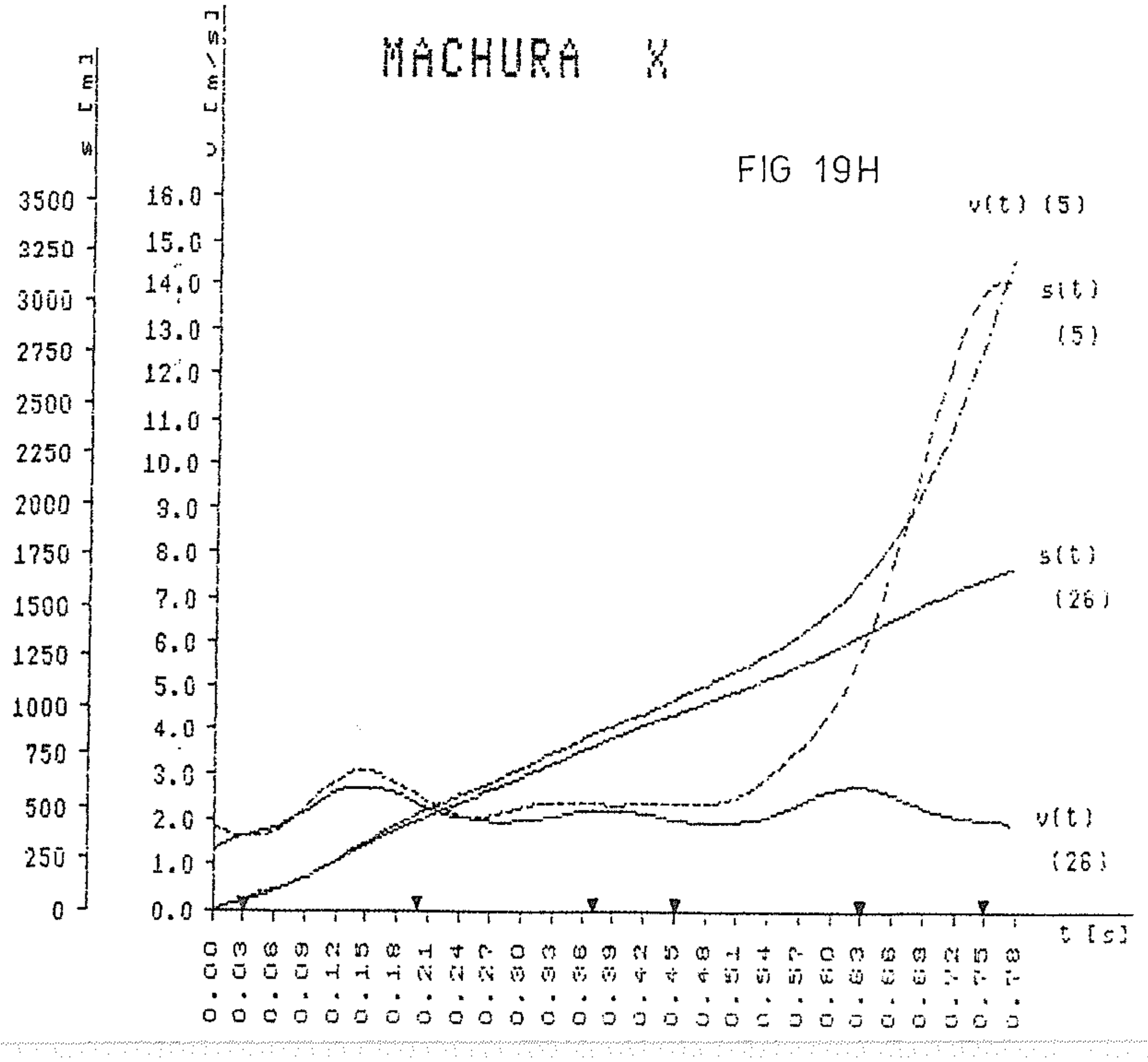

ANDREI 21.88 m
FIG 19C
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
s [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
R
R
L
II
O
t [s]


ANDREI 21.17 m
FIG 19D
z [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
t [s]

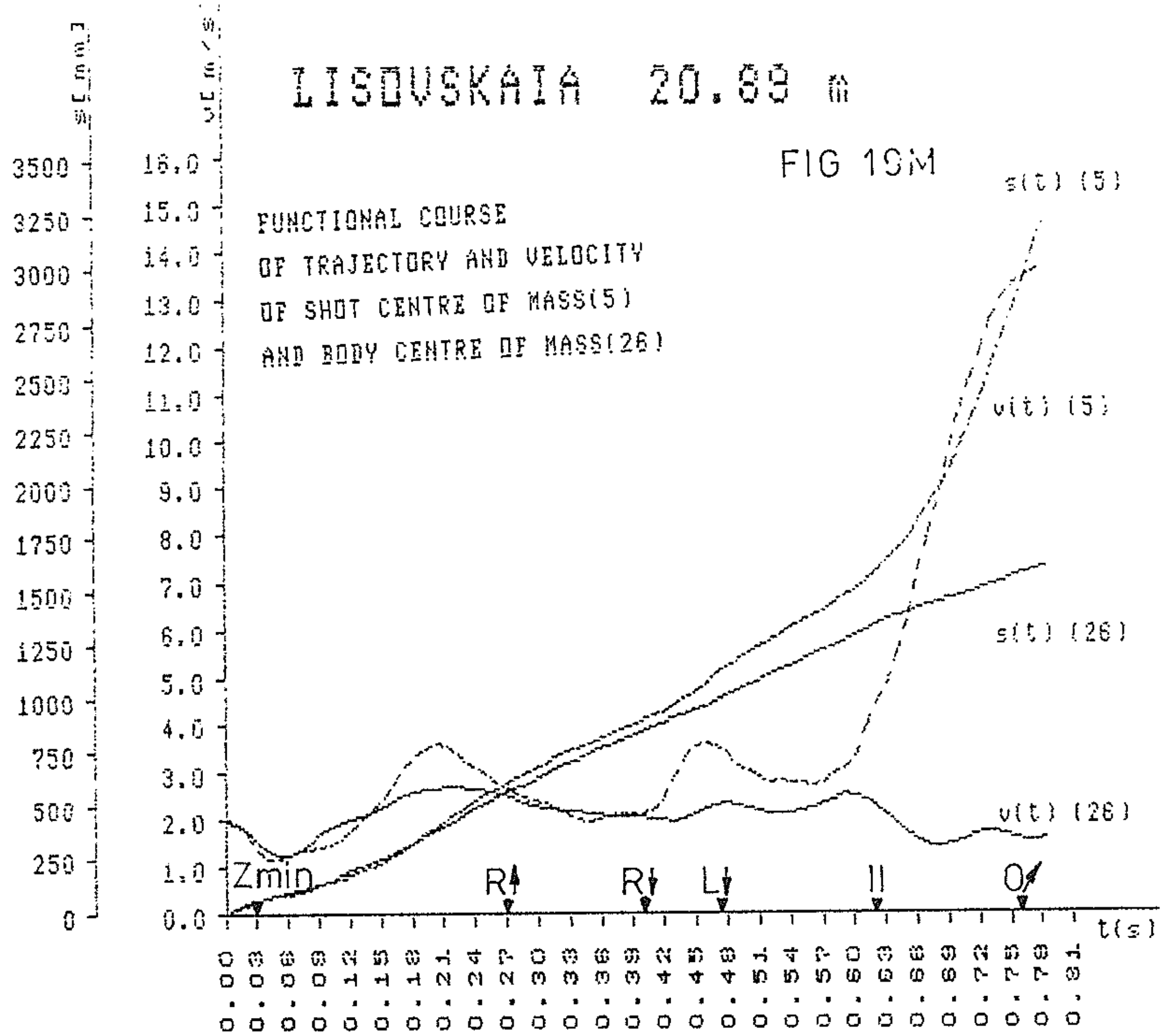

BRENNER 21.18 m
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
FIG 19E
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
s [mm]
v [m/s]
t [s]
Zmin
R↑
R↓ L↓
II
O


BRENNER 19.91 m
FIG 19F
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
s[m]
V[m/s]
t[s]

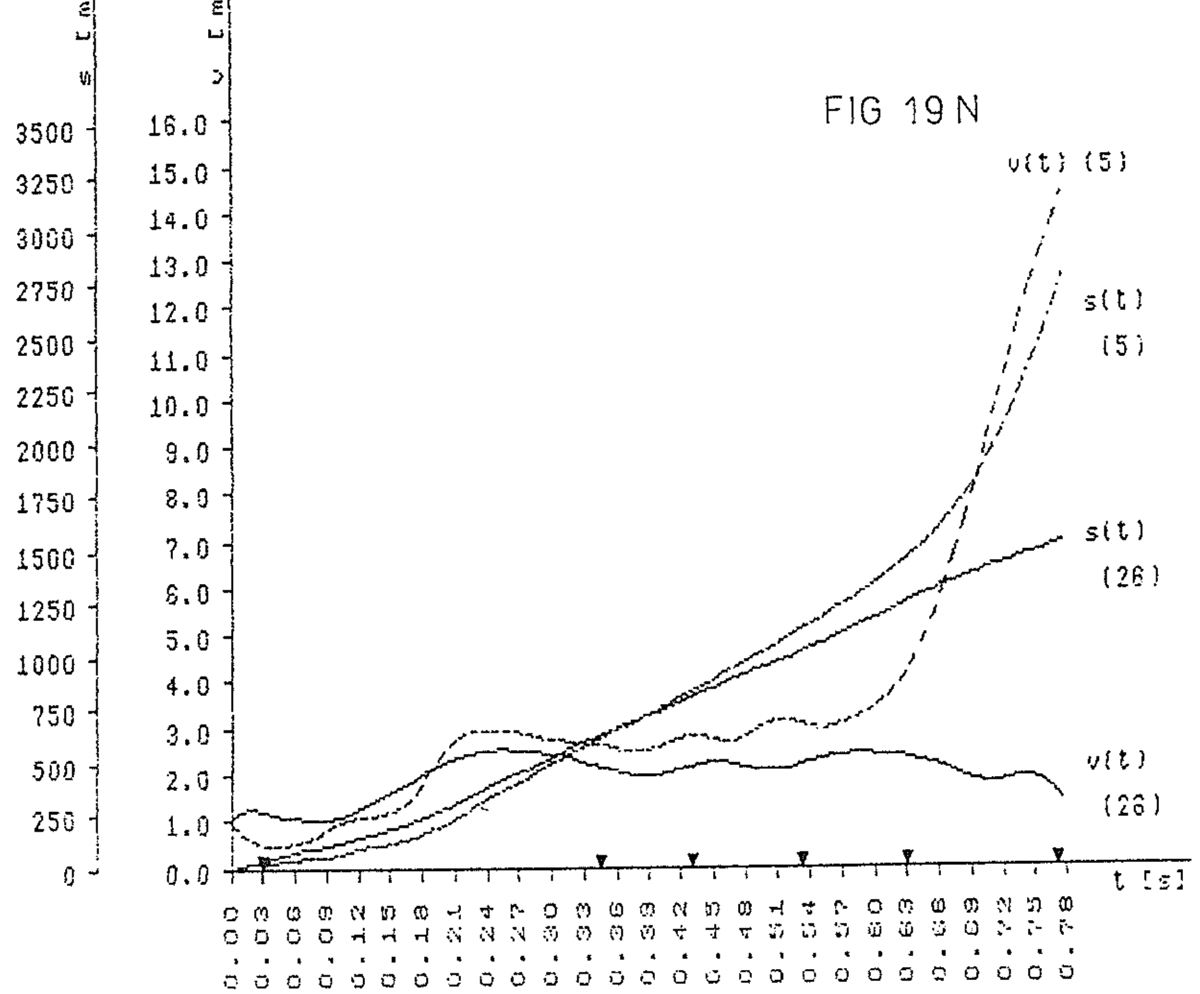

MACHURA 21.25 m
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
FIG 19G
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
s[mm]
v[m/s]
t[s]
Zmin
R
R
L
II
O

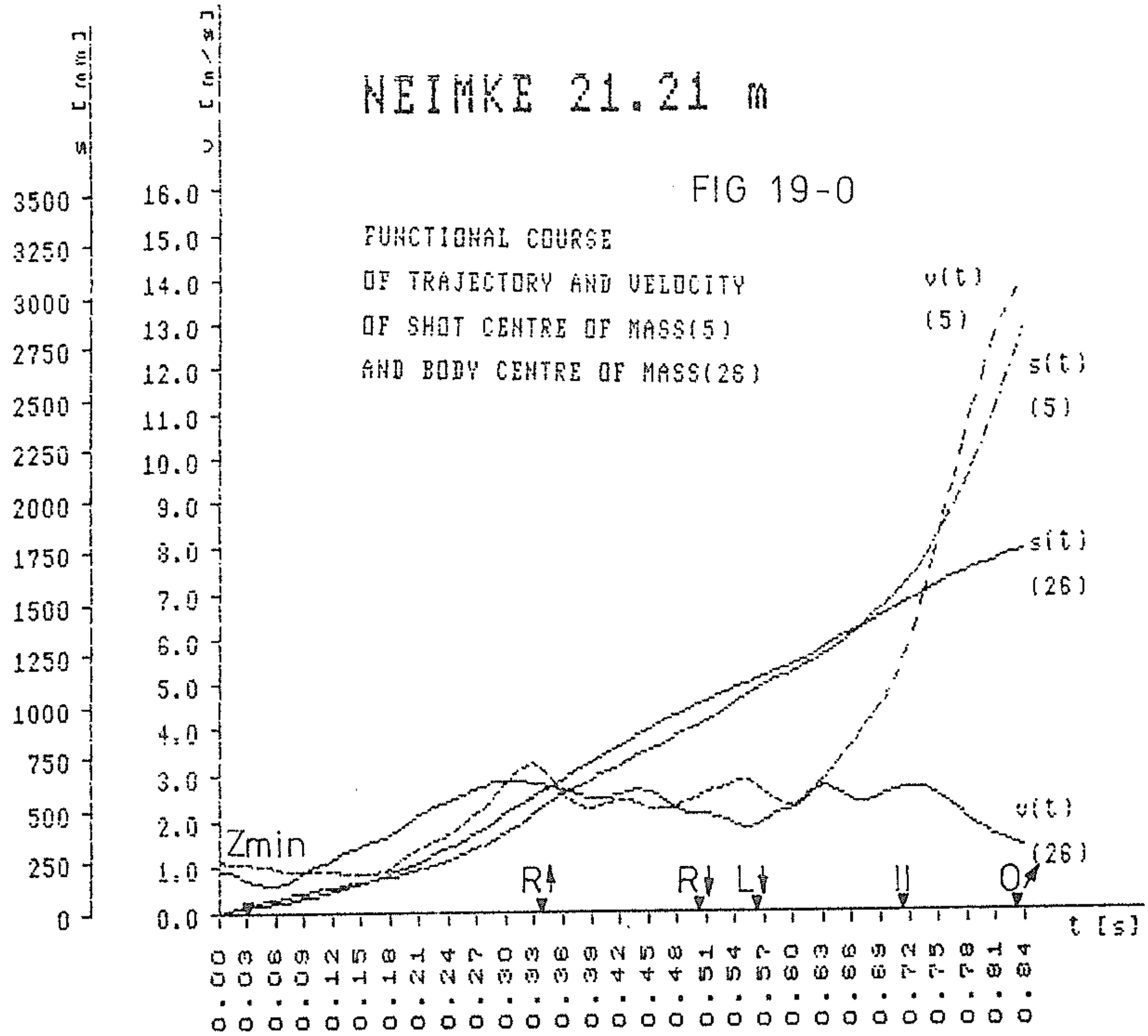

MACHURA X
FIG 19H
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
s [m]
v [m/s]
t [s]

LISOVSKAIA 20.89 m

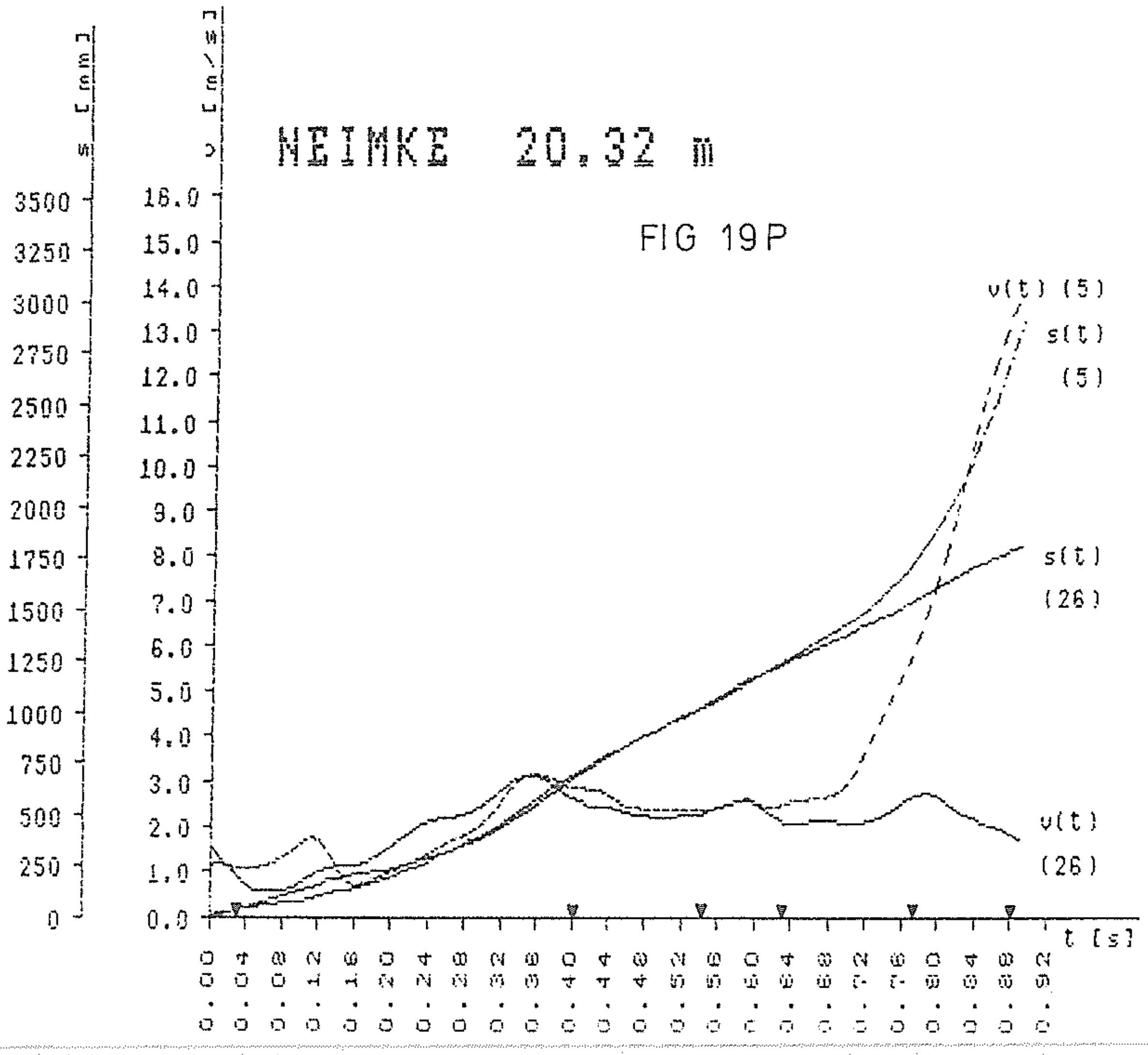


LISOVSKAIA 20.22 m





NEIMKE 21.21 m
FIG 19-0
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
s [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
Zmin
R
R
L
II
O
t [s]



NEIMKE 20.32 m
FIG 19P
s [mm]
v [m/s]
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
t [s]

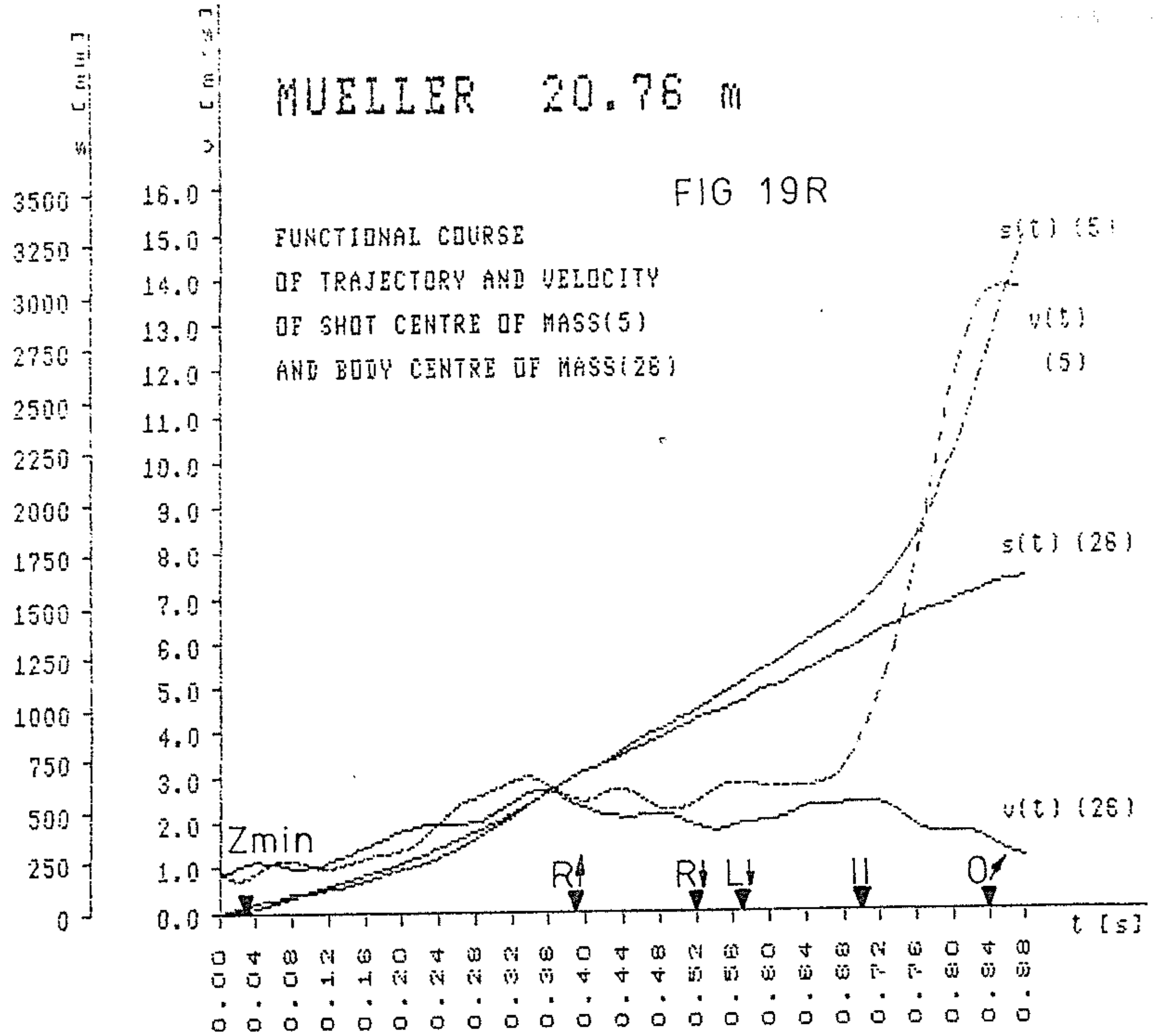


FIG 19R

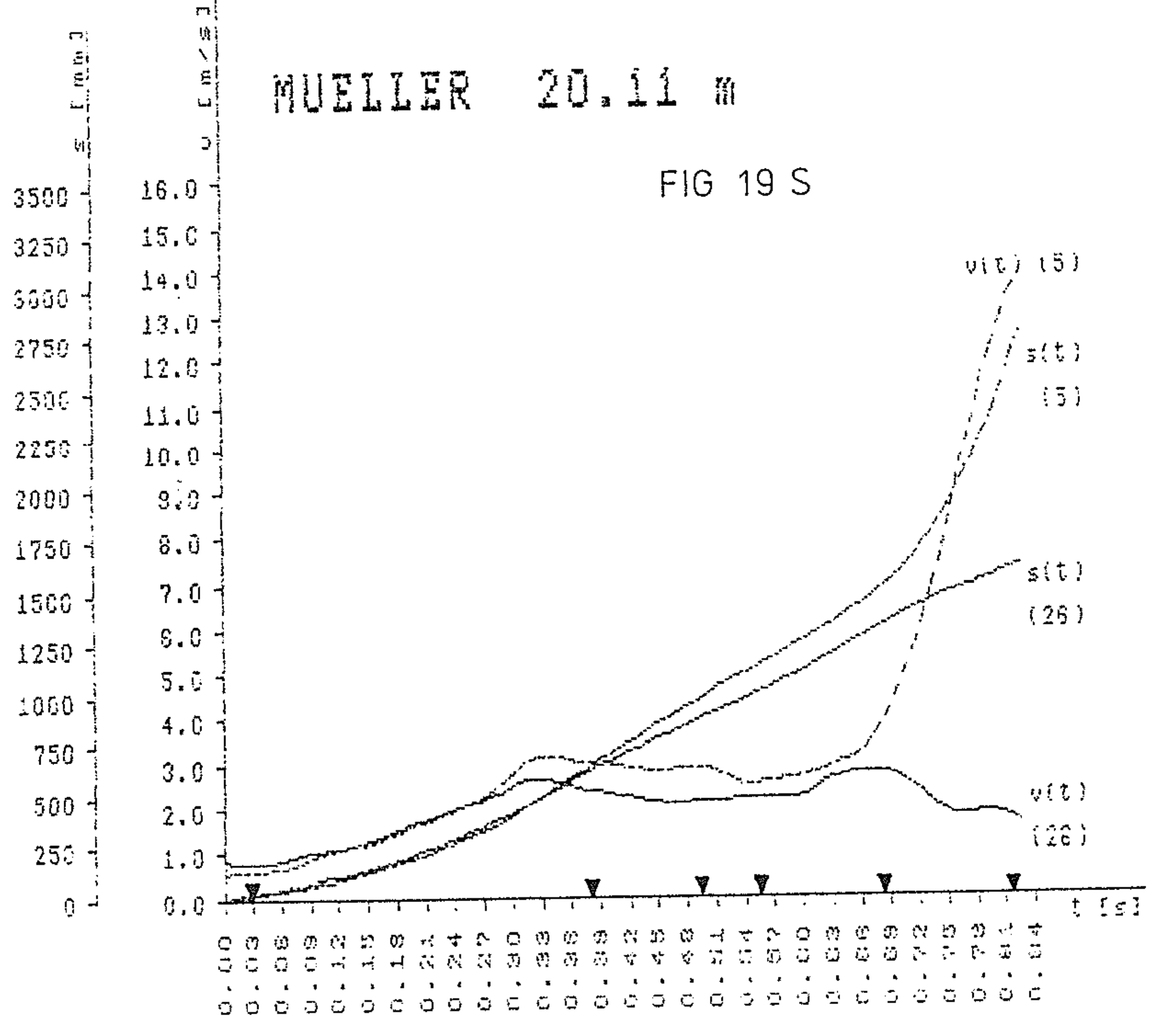
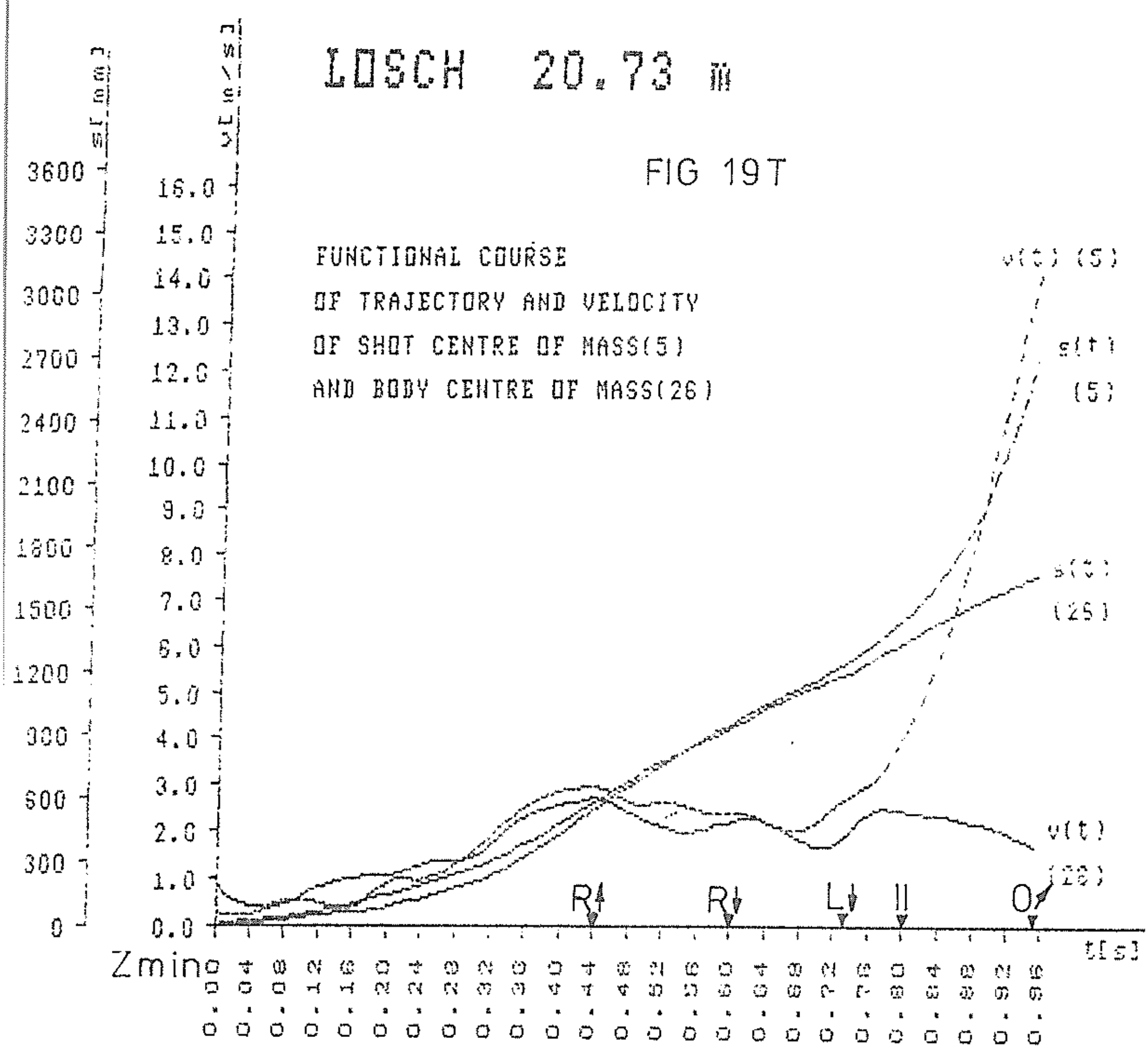


FIG 19 S


LOSCH 20.73 m
FIG 19T
FUNCTIONAL COURSE
OF TRAJECTORY AND VELOCITY
OF SHOT CENTRE OF MASS(5)
AND BODY CENTRE OF MASS(26)
s[mm]
v[m/s]
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
v(t) (5)
s(t) (5)
s(t) (26)
v(t) (26)
R
R
L
II
O
t[s]
Zmin
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
0.40
0.44
0.48
0.52
0.56
0.60
0.64
0.68
0.72
0.76
0.80
0.84
0.88
0.92
0.96

5. Discussion

Evaluating the technique of the best athletes at the II WC by means of biomechanical methods we have to conclude that the development of shot put technique has been stagnating. In addition, far too many shot putters who participated in the top contest of the year made obvious technical errors.

The choice of the technique of execution in the Shot Put depends on athropometric factors, the level of speed and the strength potential of each putter. Individual differences in technique are further conditioned by the range of joint mobility and level of coordination abilities of the athlete. The final choice of technical execution should be made on the basis of a kinesiological study which will influence not only the choice of the technical variants, but of relevant training methods as well. The biological parameters of every individual are reflected distinctly in the timing and geometry of the action. Although the knowledge of the putting technique can be generalized, we still must take into consideration the individual pecularities of each athlete and apply an empirical approach to evaluating a chosen variant of the putting action.

On the basis of complex reasoning on the technical execution of the Shot Put, it should not happen that female putters have a glide that is shorter by an average 0.15 m than that of the men, and thus a wider delivery stance when, more than probably, in most cases they do not possess a corresponding strength potential.

A rule of thumb could be proposed that blindly copying the technique of a successful athlete is counterproductive. The technical execution used by Slupianek could never be put into effect by Fibingerova, although both of them were, practically at the same time, world record holders, having both achieved performances on the level of 22.50 m.

Basic parameters of the Shot Put

Previous studies and analyses of the best athletes' technique showed that release height h_o and over-reaching + Δl are of no importance for the effective increase of performances.

The release angle α_o is important, though. The average values of 38^o in women and 37^o in men are markedly lower than the optimum 42^o. This obviously affects the performance. Even so it cannot be said that improving technical execution should be directed solely to delivery at the "optimum" angle of 42^o. Only individual biomechanical study and its verification in the training process can determine the optimum release angle of each athlete.

Release velocity v_o , a factor that is clearly crucial for the resulting performance is a summary parameter containing the athlete's speed and strength as well as the geometric and kinematic parameters of the separate phases of the put. They are - in the order of importance for reaching maximum release velocities: starting phase (z_{min} - R↑); glide (R↑ - R↓); transitory phase (R↓ - L↓); trunk rotation (L - ‖); delivery (‖ - O↗). Consistent attention should thus be paid to all details that can promote the final release velocity, and, simultaneously, to all details that can affect the optimum delivery stance and the chance of reaching maximum release velocity.

Selected time and geometric parameters affecting shot put performance

Unless there are relevant reasons for execution of the put along an axis diverted to the right of the circle axis laid out through the centre of the putting sector, it may be advantageous to execute the put to the left of the axis. One of the parameters is the side deflection from the movement direction (putting axis). It should not exceed 0.25 m. (In less successful trials of the selected putters, side deflections exceeding 0.35 m in men and 0.30 m in women were observed).

The position of the left foot during the glide (R↑ - R↓) and especially at the glide ending moment (R↓) affects the speed of assuming the double-support delivery stance. At the R↓ moment the left foot should be as close to the ground as possible. In addition, its position should be deflected ca 0.2 m to the left from the circle axis, or - as a limit - be on the circle axis. Landing of the left foot to the right of the circle axis limits the rotation in the pelvic area.

The present-day variants of technique and the effort to prevent a premature lift of the trunk define the time in which the rise of the body CM should not occur. The effort for the lowest position of CM should be maintained until 0.35 s before the release. Prolonging the lowered position still further is a question of individual style.

One of the criteria making it possible to judge if the body's kinetic energy has been transmitted to the implement, can be the zero value of the angle between the shoulder axis and pelvic axis (ending of trunk rotation) and the position of the centre of the line connecting the shoulder joints over the centre of the line connecting the hip joints. (Where the centre of the line connecting the shoulder joints diverts farther from this position ($y_i > 0$) an undesirable forward lean of trunk is indicated). In moments close to the release (O↗), a further movement in the direction of the pelvic axis must be eliminated (this movement is caused by an undesirable deviation of the trunk from the putting direction).

One of the factors affecting both performance and its stability is the technical level of the action discussed in this study. Sufficient room should therefore be given in training to improving the putting technique, i.e. frequent puts over a distance of 90 % or more of the maximum performance, with the regulation implement and with implements 10 - 15 % heavier and lighter, all according to the specific periods of the annual training cycle.

8. Conclusions

The method of 3-dimensional action analysis (using 2 synchronized high-speed cameras and a complex software system for analyzing the geometry and kinematics of the action) is suitable for evaluating the technical level of the athlete and his/her individual trials, even though the exactness of determining momentary velocities, and especially accelerations at particular moments of the action is limited by present-day methodology. The method used makes it possible to analyse details of the technical execution that are not noticeable in visual observation or in routine videorecording.

On the basis of detailed 3-D analyses by videoanalyzers, it is possible to ascertain improved techniques in terms of the desirable points more effectively while paying attention to individual style features.

The present study focused on the following selected parameters with a view to expressing at least some of their mutual relations: - length of glide, - width of the delivery stance - shot position at the moment of glide ending (R↓) and lef foot landing (L↓), - position of the pelvic and shoulder axes in separate phases (transitory, rotation of shoulders, delivery, i.e. R↓ - L↓ - ∥ - O↗).

Using a high-speed videorecorder in the training process, the possibility of a more effective improvement of technique is greatly enhanced, at least in terms of the time parameters involved in the above geometric view on the shot put technique.

Other facts mentioned in this study and their relationships cannot be investigated without proper 3-D analysis.

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1. List of analysed trials

Men

A	Guenthoer	22.23 m	Report
B	Guenthoer	22.12 m	Appendix
C	Andrei	21.88 m	Report
D	Andrei	21.17 m	Appendix
E	Brenner	21.18 m	Report
F	Brenner	19.91 m	Appendix
G	Machura	21.25 m	Report
H	Machura	X	Appendix
I	Timmermann	21.35 m	Appendix
J	Beyer	21.02 m	Appendix
K	Bodenmueller	19.52 m	Appendix
L	Gavriushin	19.83 m	Appendix

Women

M	Lisovskaia	20.89 m	Report
N	Lisovskaia	20.22 m	Appendix
O	Neimke	21.21 m	Report
P	Neimke	20.32 m	Appendix
R	Mueller	20.76 m	Report
S	Mueller	20.11 m	Appendix
T	Losch	20.73 m	Report
U	Achrimenko	20.20 m	Appendix
V	Li	20.00 m	Appendix
Z	Vasickova	18.71 m	Appendix

I

BIOMECHANICAL ANALYSIS OF THE SHOT PUT

Sušanka, P.; Štěpánek, J.

CONTENTS

1. Introduction

Just before the II World Championships in Athletics in Rome, 1987 both the men's and women's world records in the shot put were broken by Alessandro Andrei (ITA) with 22.91 m and Natalya Lisovskaya (URS) with 22.63 m. These results continue the trend of improving performances (Figs 1 and 2).

Nevertheless, the biomechanical analyses of the Shot Put in Rome indicates a stagnation in technical development and, in some individuals, both technical shortcomings and a poor level of technical skill's on certain trials of the finals. It is difficult to assess it,and to what degree, this problem was influenced by the methods of strength training used by the athletes and the different approach in the biochemical preparation of the athletes in connection with more consistent doping control.

In any case, the level of doping control did affect the whole complex of the final preparation for the main competition of the year. Even if we admit the possibility of other factors (e.g. psychological ones) which could affect the performances, differences between the best performances of the year and the performances in Rome were too big to be explained otherwise (Tables 1 and 2).

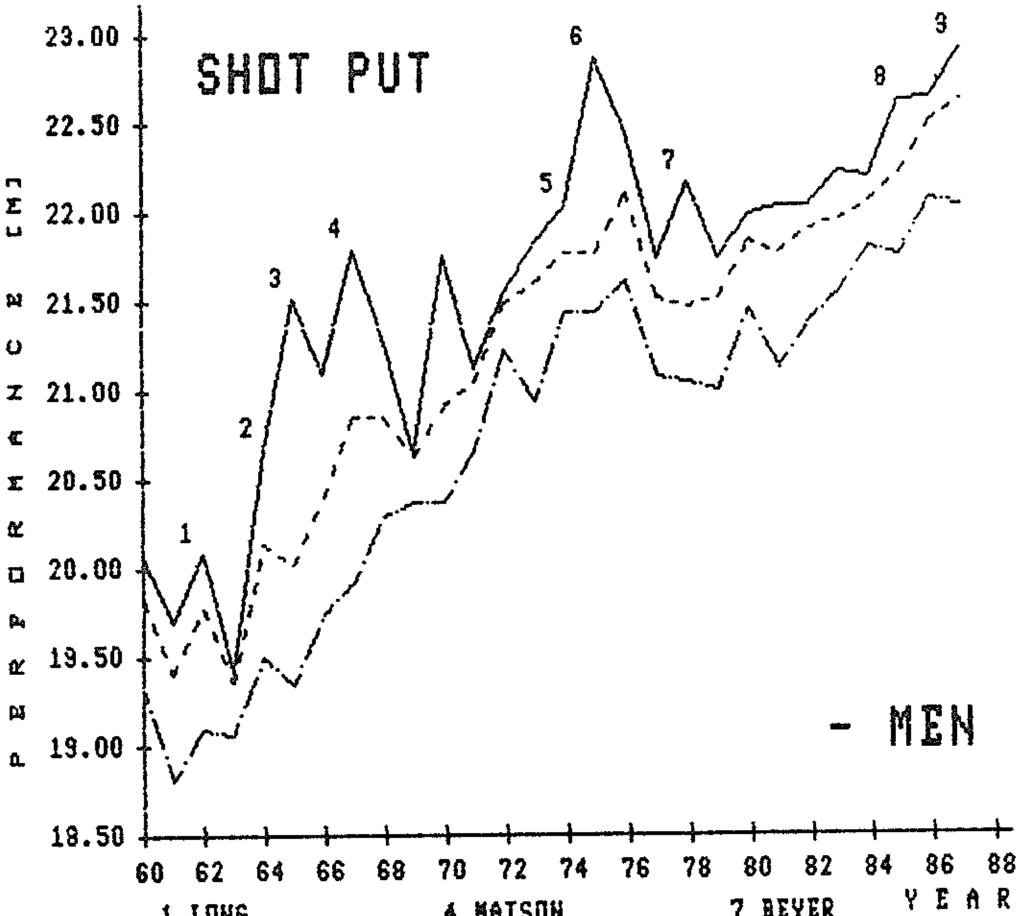
Differences in performance between the best shot-putters and those ranked between 30 and 40 on the world lists are very big (for both men and women up to 2.5 m). Therefore, in the Shot Put, no athlete who was not ranked among the first 30 on the 1987 world lists or approximately among the first 20 on the "reduced" (maximum 3 per country) on the 1987 world lists prior to the WC could expect to advance as far as the competition in Rome (Tables 3 and 4).

Improved performance, or a drop of not more than 0.5 - 0.7 m compared to the athlete's best for the year can be expected to result in an improved placement in the top world competitions in relation to the list rankings. On the other hand a drop in performance exceeding 6% means, almost without exception, a deteriorated placement in the competitions proper in relation to the expectations expressed by the best result of the year in the world list rankings.

Surprisingly, not one elite shot putter used the rotational technique at the II WC. Undoubtedly, the execution of the rotational technique is more demanding. It requires a significantly longer time of learning, and, if not mastered properly, will cause more failures in competitive trials. But, from the biomechanical point of view, the rotational technique has many advantages which have not been fully tapped yet. One of the possible reasons this technique was not used could be that a proper metho dology of teaching this technique is still lacking. However, we can assume that, after a period of exaggerated accentuation on the development of strength capacity, athletes will pay greater attention to a more balanced development of all again.

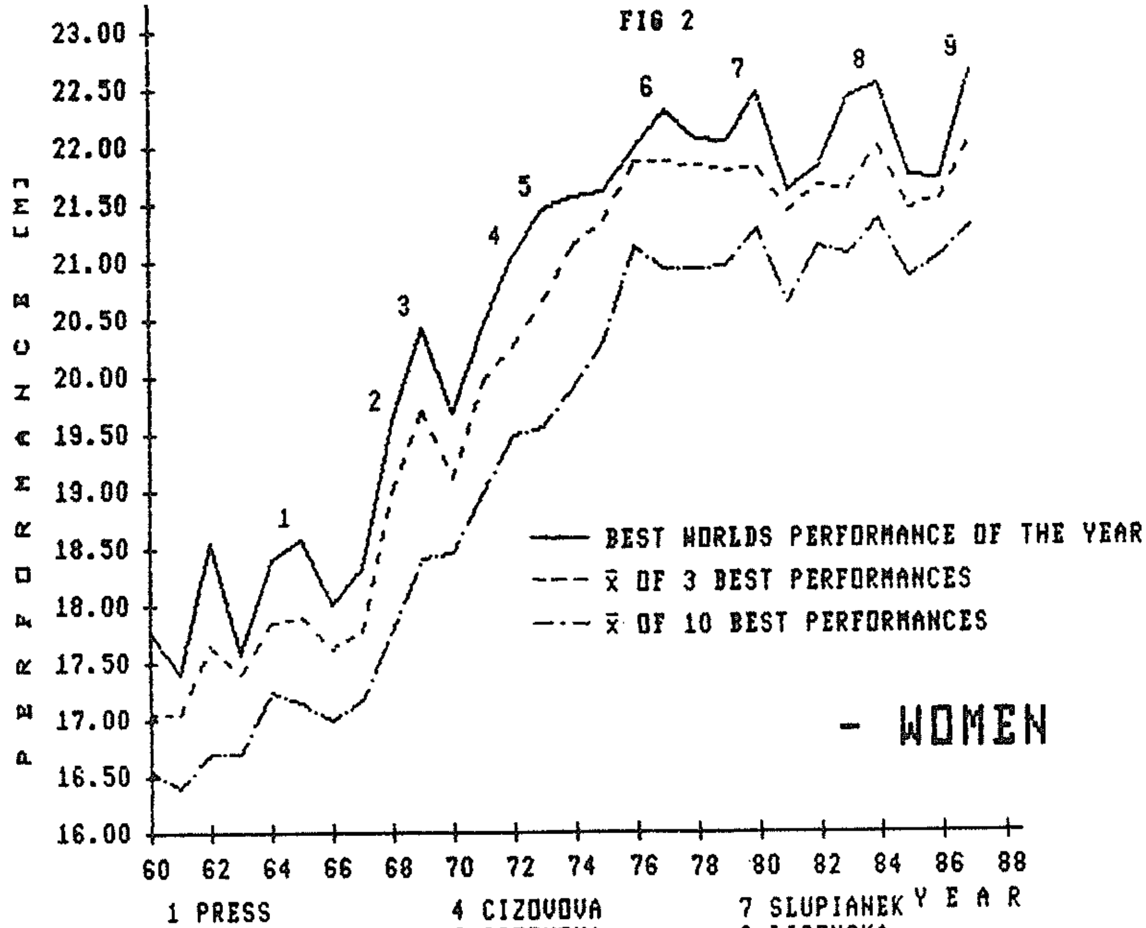
In this biomechanical study of the shot put at the II WC, the glide technique, as demonstrated in the finals, is analyzed. Attention is directed to differences in execution and to some technical shortcomings in the trials under analysis.

FIG 1



1 LONG
2 LONG
3 MATSON
4 MATSON
5 WOODS
6 OLDFIELD
7 BEYER
8 TIMMERMANN
9 ANDREI

FIG 2



1 PRESS
2 GUMMEL
3 CIZOVOVA
4 CIZOVOVA
5 CIZOVOVA
6 FIBINGEROVA
7 SLUPIANEK
8 LISOVSKA
9 LISOVSKA

WORLD LIST 1987 (at 15th October 1987) SHOT PUT MEN

22.91	Alessandro	Andrei	59	ITA	1	Viareggio	1208	2.	-1.03
22.52	John	Brenner	61	USA	1	Walnut MSR	2604	3.	-0.77
22.47	Werner	Günthör	61	SUI	1	Helsinki WG	0207	1.	-0.24
22.31	Udo	Beyer	55	GDR	1	Potsdam NC	2008	6.	-1.18
22.01	Ulf	Timmermann	62	GDR	1	Praha EP/A	2706	5.	-0.66
21.93	Remigius	Machura	60	TCH	1	Praha	2308	4.	-0.54
21.85	Sergej	Gavrjušin	59	URS	1	Torino vIta	2805	8.	-1.70
21.74	Sergej	Smirnov	60	URS	1	Tbilisi	1705	R	
21.32	Gregg	Tafralis	58	USA	2	Walnut MSR	2604	N	-1.70
21.22	Klaus	Görmer	63	GDR	3	Potsdam NC	2008	-	
21.14	Maris	Petraško	61	URS	1	Limbaši	1107	R	
21.10	Vjačeslav	Lycho	67	URS	1	Moskva	2607	9.	-1.12
21.06	Michail	Kostin	59	URS	1	Grudziadz Mal	0406	R	
20.94	Randy	Barnes	66	USA	1	Arlington	0905	R	
20.92	Arne	Pedersen	61	NOR	1	Knoxville Gator	2305	dns	
20.91	Saulis	Klejza	64	URS	2	Leselidze	1305	R	
20.85	Lars Arvid	Nilsen	65	NOR	1	Des Moines Drake	2504	-	
20.82	Helmut	Krieger	58	POL	4	Praha EP/A	2706	12.	-1.67
20.79	Klaus	Bodenmüller	62	AUT	1	Linz	1306	7.	-0.38
20.74	Udo	Gelhausen	56	FRG	1	Bonn	2208	N	-1.64
20.70	Karsten	Stolz	64	FRG	1	Bruchkobel	0905	11.	-1.48
20.69	Georgi	Todorov	60	BUL	1	Şofia NC	1608	N	-1.26
20.68	Vladimir	Jaryškin	63	URS	1	Žitomir	0809	R	
20.66	Garry	Frank	64	USA	2	Knoxville Gator	2305	R	
20.63	Donatas	Stukonis	57	URS	1	Minsk	1406	R	
20.60	Richard	Navara	64	TCH	2	Nitra vHun,GB	3105	-	
20.53	Kevin	Akins	60	USA	3	Westwood Pepsi	1605	R	
20.51	Igor	Palčikov	61	URS	1	Irkutsk	-0908	R	
20.50	Janne	Ronkainen	63	FIN	1	Karhula	2207	N	-1.14
20.47	Janis	Bojars	56	URS	2	Limbaši	1107	R	
20.41	Gert	Weil	60	CHI	1	Bad Neuenahr	2607	10.	-0.70

TAB 1

WORLD LIST 1987 (at 15th October 1987) SHOT PUT WOMEN

22.63	Natalja	Lisovskaja	62	URS	1	Moskva Znam	0706	1.	-1.39
22.19	Claudia	Losch	60	FRG	1	Hainfeld	2308	4.	-0.46
21.34	Natalja	Achrimenko	55	URS	1	Soči	2205	5.	-0.66
21.21	Katrin	Neimke	66	GDR	2	Roma WCh	0509	2.	+0.40
21.20	Ines	Müller	59	GDR	2	K-Marx-St. vSov	2106	3.	-0.44
21.11	Heike	Hartwig	62	GDR	1	Potsdam NC	2108	6.	-0.48
20.99	Larisa	Pelešenko	64	URS	1	Leselidze	1305	R	
20.91	Svetla	Mitkova	64	BUL	1	Sofia	2405	9.	-1.54
20.83	Helena	Fibingerová	49	TCH	1	Bratislava PTS	1206	8.	-0.54
20.72	Grit	Haupt	66	GDR	3	Neubrandenburg	1006	R	
20.66	Li	Mei-su	59	PRC	1	Anshan	2706	7.	-0.23
20.55	Soňa	Vašíčková	62	TCH	1	Třinec NC	1508	13.	-1.84
20.52	Ilona	Briesenick	56	GDR	3	Berlin	2508	R	
20.28	Valentina	Fedjušina	65	URS	3	Tbilisi	1705	R	
20.27	Danguole	Bimbaite	62	URS	2	Leselidze	1305	R	
20.27	Cordula	Schulze	59	GDR	2	Halle WCT	2606	R	
20.27	Ljudmila	Vojevudskaja	59	URS	1	Nikolajev	08	R	
20.18	Iris	Plotzitzka	66	FRG	4	München HB	0909	12.	-0.99
20.11	Ilke	Wyludda	69	GDR	2	Leipzig	2907	R	
20.01	Marina	Antonjuk	62	URS	3	Moskva Znam	0706	R	
19.96	Huang	Zhihong	65	PRC	2	Anshan	0509	11.	-0.61
19.90	Stephanie	Storp	68	FRG	1	Hamburg NC-j	1608	10.	-0.54
19.72	Heidi	Krieger	65	GDR	3	Halle WCT	?2606	R	
19.61	Livia	Mehes	65	ROM	1	Bucuresti IntC	1406	-	
19.56	Mihaela	Loghin	52	ROM	1	Pitesti NC	0908	dns(-0.29)	
19.48	Ines	Wittich	69	GDR	5	Leipzig	2907	R	
19.48	Ljubov	Vasiljeva	57	URS	2	Moskva	1608	R	
19.43	Zdeňka	Šilhavá	54	TCH	2	Praha	1309	-	
19.40	Simona	Andrusca	62	ROM	2	Pitesti NC	0908	-	
19.30	Alena	Vitoulová	60	TCH	3	Ostrava ZT	1006	R	
19.29	Vera	Schmidt	61	FRG	2	Gelsenkirchen NC	1207	R	
19.22	Ramona	Pagel	61	USA	4	London PTG	1007	N	-1.10

TAB 2

ATHLETES' PLACEMENT AT THE II WC

IN RELATION TO THE REDUCED WORLD LISTS 1987

AND RANKING LISTS OF II WC PARTICIPANTS

MEN

Reduced ranking		1	2	3	4	5	6	7	8	9	10		11	12	13	14	15	16		17	18	19	20	21	22
World lists 1987	1-10											11-20							21-30						
Reduced world lists 1987	1-10											11-16							17-22						
Starting at the 2nd WC	1 - 8	x	x	x	x	x	x	x	-	x	-	9-12	x	-	x	-	x	x	13-17	x	x	x	-	x	x
Lists ranking of participants		1	2	3	4	5	6	7	-	8	-		9	-	10		11	12		13	14	15	-	16	17
Performance improved + [m]												↑							↑						
⟨0,1; 1,0⟩									-		-			-		-							-		
Performance worsened - [m]															DNS										
⟨0,10; 0,70⟩ ≐ 0,70 m				x			x		-		-			-		-		x					-		x
⟨0,71; 1,20⟩ ≐ 0,50 m		x	x		x	■			-		-		■	-		-							-	x_Q	
⟨1,21; 1,81⟩ ≐ 0,70 m								x	-	x_Q	-	↓		-		-	x		↓	x_Q	x	x_Q	-		
Displacement in ranking															DNS										
Better placement ↑				1			4		-		-	↑		-		-		7	↑		11		-		10
Equal ■						5			-		-	■	9	-		-			■				-		
Worse placement ↓		2	3		6			8	-	N	-	↓		-		-	12		↓	N		N	-	N	

Only exception ↑

TAB 3

WOMEN

Reduced ranking		1	2	3	4	5	6	7	8	9		10	11	12		13	14	15	16	17	18	19
World lists 1987	1-10										11-20				21-30							
Reduced world lists 1987	1 - 9										10-12				13-16							
Starting at the 2nd WC	1 - 8	x	x	x	x	x	x	-	x	x	9-11	x	x	x	12-14	x	x	-	x	-	-	x
Lists ranking of participants		1	2	3	4	5	6	-	7	8		9	10	11		12	13	-	14	-	-	15
Performance improved + [m]											↑				↑				DNS			
⟨0,1; 1,0⟩					x		.	-										-		-	-	
Performance worsened - [m]																						
⟨0,10; 0,70⟩ ≐ 0,70 m						x	x	-		x		x				x	x	-	x	-	-	
⟨0.71; 1,20⟩ ≐ 0,50 m								-						x				-		-	-	x_Q
⟨1,21; 1,81⟩ ≐ 0,70 m		x	x	x				-	x		↓		x		↓			-		-	-	
Displacement in ranking																			DNS			
Better placement ↑					2	3		-			↑	7			↑	11	10	-		-	-	
Equal ■		1					6	-		8	■				■			-	14	-	-	
Worse placement ↓			4	5				-	9		↓		13	12	↓			-		-	-	N

DNS ... DID NOT START

(DID NOT COMPETE IN THE FINAL)

N ... DID NOT ADVANCE FROM QUALIFIKATION

Q ... QUALIFIKATION

TAB 4

3. Biomechanics of the Shot Put

In terms of physics, the conditions for achieving a certain performance in the shot put can be characterized fairly simply. Owing to the fact that air resistance has practically no influence on performance, the task can be described as an oblique putting action.

At the moment of the implement's release the parameters affecting performance distance can be reduced to release velocity (v_o), release angle (α_o), release height (h_o) and the amount of the overreaching or incomplete reaching of the hand (implement centre of mass) at the moment of release ($\pm \Delta l$).

The choice and quantification of biomechanical parameters present more complicated problems. It involves a description of the whole motor manoeuvre of the shot put, mainly in the following terms:

- range and intensity of use of the largest muscle groups;
- optimization of spatial positions of separate biokinematic couples (neighbouring segments);
- suitable timing of separate partial movements (gradual engaging of the kinematic chains);
- use of inertia moments of separate body segments, the upper body in particular, in an effort to influence positively the velocity and acceleration in the final phase of the delivery and at the moment of release.

Here, the literature still has not provided a number of answers let alone practical advice. If the method of 3-dimensional kinematic analysis continues to be improved, it may become a suitable research method for solving the problems in question.

At the present time we can only indicate several parameters with relation to the putter's motor apparatus which are of only partial significance. Nevertheless even now we do consider some information to be significant, because it can influence the training process and technical execution of the put.

The technical conditions have been sufficiently discussed in the literature and in the previous report on the World Junior Athletics Championships in Athens, 1986. Still, it can be claimed that the participants in Rome were far from using present-day knowledge to improve technical execution. Before analyzing individual trials we will sum up the chief physical output parameters and their mutual relation from the point of view of top-level performances.

Performances in top-level competitions in both the men's and women's categories range from 18 to 23 m. Final release velocity corresponding to these performances varies between 12.9 and 14.8 m/s (in the case of an extremely small release angle $\alpha_o = 33^o$ and relatively low release height $h_o = 1.9$ m). An increase in the release angle α_o means that the same performance can be achieved with a lower release velocity v_o. A better performance is automatically achieved if the athlete has the ability to maintain the same release velocity.

MEN

QUALIFYING 29/8 - 10.30

Qualification Standard 20.40

A

1. 574 Andrei Alessandro 21.57 — —	ITA	21.57 Q	CR
2. 489 Timmermann Ulf 21.11 — —	GDR	21.11 Q	
3. 976 Lyko Viacheslav 19.28 19.29 20.99	URS	20.99 Q	
4. 829 Guenthoer Werner 20.66 — —	SUI	20.66 Q	
5. 756 Krieger Helmut 18.76 18.67 19.73	POL	19.73 q	
6. 397 Stolz Karsten 19.56 18.78 19.69	FRG	19.69 q	
7. 1086 Tafralis Greg 19.41 19.61 19.62	USA	19.62	
8. 124 Todorov Georgi 19.43 X 18.97	BUL	19.43	
9. 1011 Backes Ron 19.34 X X	USA	19.34	
10. 509 Koutsoukis Dimitris 18.73 X 19.05	GRE	19.05	
731 Sagedal Jan	NOR	DNS	

Ore/Time 11:10 — Temp.: +23 °C
Press.: 1015 mBar — Umidità/Humidity: 49%

B

1. 459 Beyer Udo 20.95 — —	GDR	20.95 Q
2. 1017 Brenner John 20.28 19.05 —	USA	20.28 q
3. 895 Machura Remigius 20.14 20.27 X	TCH	20.27 q
4. 40 Bodenmueller Klaus 19.86 19.96 19.76	AUT	19.96 q
5. 954 Gavriushin Sergej 19.76 19.96 X	URS	19.96 q
6. 172 Weil Gert 19.76 19.46 19.46	CHI	19.76 q
7. 361 Gelhausen Udo 17.00 X 19.10	FRG	19.10
8. 298 Ronkainen Janne 18.36 18.26 18.04	FIN	18.36
9. 870 Sundin Lars 16.92 17.25 17.04	SWE	17.25
730 Pedersen Arne	NOR	DNS

Ore/Time 11:15 — Temp.: +24 °C
Press.: 1015 mBar — Umidità/Humidity: 58%

FINAL 29/8 - 18.10

1.	829	Guenthoer Werner 21.63 21.19 20.88 22.12 20.67 22.23	61	SUI	22.23
2.	574	Andrei Alessandro 21.12 X 21.17 X 21.88 21.76	59	ITA	21.88
3.	1017	Brenner John X 21.75 21.14 X 19.91 21.18	61	USA	21.75
4.	895	Machura Remigius 21.15 X 21.39 X X 21.25	60	TCH	21.39
5.	489	Timmermann Ulf 20.80 21.22 21.28 21.35 X 21.05	62	GDR	21.35
6.	459	Beyer Udo 21.13 X X 21.02 X 20.39	55	GDR	21.13
7.	40	Bodenmueller Klaus 19.30 20.41 X 18.74 X 19.52	62	AUT	20.41
8.	954	Gavriushin Sergej 19.99 19.83 X X 20.15 X	59	URS	20.15
9.	976	Lykho Viacheslav 19.78 19.63 19.98 — — —	67	URS	19.98
10.	172	Weil Gert 19.23 19.71 X — — —	60	CHI	19.71
11.	397	Stolz Karsten 19.16 19.22 19.18 — — —	64	FRG	19.22
12.	756	Krieger Helmut 19.15 18.96 X — — —	58	POL	19.15

• Ore/Time 19:30 — Temp.: +24 °C
• Press.: 1016 mBar — Umidità/Humidity: 73%

WOMEN

QUALIFYING 10.30

Qualification Standard 19.00

A

1. 306 Neimke Kathrin 18.34 18.89 20.26	GDR	20.26 Q
2. 230 Losch Claudia 19.73 — —	FRG	19.73 Q
3. 118 Li Meisu 19.47 — —	PRC	19.47 Q
4. 296 Hartwig Heike 18.44 19.35 —	GDR	19.35 Q
5. 580 Lisovskaia Natalia 19.22 — —	URS	19.22 Q
6. 539 Vasickova Sona 19.09 — —	TCH	19.09 Q
7. 234 Plotzitzka Iris 19.08 — —	FRG	19.08 Q
8. 269 Oakes Judy 18.18 18.33 18.43	GBR	18.43
9. 650 Pagel Ramona 18.12 16.90 X	USA	18.12
10. 178 Hovi Asta 17.71 17.57 17.89	FIN	17.89

Ore/Time 10:55 — Temp.: +22 °C
Press.: 1015 mBar — Umidità/Humidity: 75%

B

1. 533 Fibingerova Helena X 20.40 —	TCH	20.40 Q
2. 304 Mueller Ines 19.96 — —	GDR	19.96 Q
3. 242 Storp Stephanie 19.64 — —	FRG	19.64 Q
4. 488 Loghin Michaela 18.53 18.92 19.27	ROM	19.27 Q
5. 550 Akhrimenko Natalia 19.21 — —	URS	19.21 Q
6. 115 Huang Zhihong 19.18 — —	PRC	19.18 Q
7. 66 Mitkova Svetla 19.07 — —	BUL	19.07 Q
8. 622 Dasse Bonnie 17.63 17.68 16.62	USA	17.68
9. 685 Saint Phard Deborah 15.38 16.54 16.37	HAI	16.54
10. 104 Torcolacci Melody 15.29 15.62 15.98	CAN	15.98

Ore/Time 11:00 — Temp.: +22 °C
Press.: 1015 mBar — Umidità/Humidity: 74%

FINAL 5/9 - 18.00

1.	580 Lisovskaia Natalia 20.89 20.22 21.16 20.93 21.24 20.80	62	URS	21.24 CR
2.	306 Neimke Kathrin 20.32 21.21 20.12 20.53 20.59 X	66	GDR	21.21
3.	304 Mueller Ines 20.76 20.11 20.05 X 19.96 20.20	59	GDR	20.76
4.	230 Losch Claudia 20.05 20.73 X 19.88 20.33 20.61	60	FRG	20.73
5.	550 Akhrimenko Natalia 20.20 19.68 20.53 20.09 X 20.68	55	URS	20.68
6.	296 Hartwig Heike 19.79 19.97 19.84 20.63 X 20.25	62	GDR	20.63
7.	118 Li Meisu 19.95 20.00 20.09 20.43 19.98 20.14	59	PRC	20.43
8.	533 Fibingerova Helena 19.97 X 19.51 20.05 20.15 20.29	49	TCH	20.29
9.	66 Mitkova Svetla 19.37 X 18.87 — — —	64	BUL	19.37
10.	242 Storp Stephanie 19.36 19.10 18.87 — — —	68	FRG	19.36
11.	115 Huang Zhihong 18.93 18.73 19.35 — — —	65	PRC	19.35
12.	234 Plotzitzka Iris 17.08 19.19 19.07 — — —	66	FRG	19.19
13.	539 Vasickova Sona 18.17 18.71 X — — —	62	TCH	18.71
	488 Loghin Michaela	52	ROM	DNS

Ore/Time 19:30 — Temp.: +24 °C
Press.: 1015 mBar — Umidità/Humidity: 69%

Release velocity

The release velocity (v_0) influences performance to the greatest extent. With an increase of the release velocity of only 0.1 m/s, the performance will be some 0.25 m longer. The influence of release velocity on performance will be made clearer by the following simplified examples. These examples are designed to show how a seemingly insignificant change (lengthening or shortening) of the trajectory or the time taken for the final part of the delivery can affect the performance. In these cases the release angle ($\alpha_0 = 37^{\circ}$) and release height (h_0 = 2.2 m) are constant:

A. With the time Δt constant (e.g. 0.036 s), the final section of the shot trajectory (in the delivery) is lengthened or shortened by 0.01 m (i.e. by 1 cm!!). The average release velocity 13.89 m/s changes by ± 0.28 m/s. If these release velocities are achieved (theoretically), the performance of 21.48 m will change by - 0.77 m (or + 0.78 m respectively).

Δs (m)	Δt (s)	Δv (m/s)	l (m)
0.49	0.036	13.61	20.71
0.50	0.036	13.89	21.48
0.51	0.036	14.17	22.26

B. Here the constant value is the final section of the shot trajectory Δs (e.g. 0.5 m). The time Δt is lenthened or shortened by ± 0.001 s (i.e. ± 1 ms !!). The average release velocity 14.29 m/s changes by + 0.42 m/s (or - 0.40 m/s). The performance of 22.58 m is lengthened by + 1.21 m (or shortened by - 1.11 m).

Δs (m)	Δt (s)	Δv (m/s)	l (m)
0.5	0.034	14.71	23.79
0.5	0.035	14.29	22.58
0.5	0.036	13.89	21.47

Consequently, coaches and athletes should concentrate on creating such conditions (in terms of the motor apparatus potential) that will enable them to speed up the final phase of the delivery (or to extend it, over the same time), even at the expense of other parameters, namely release height and overreaching.

Release angle

The effect of the magnitude of the release angle (α_o) on performance is shown in the nomogram in Fig. 3. But we must take into account that this is fully valid only in the case of the selected height (h_o) and gravitational acceleration (g = 9.81 m/s). When h_o and g change, the magnitudes and mutual relations change to a certain extent as well (h_o ,v_o , α_o).

An example of the changes in performance in relationship to changes in the release angle α_o and the release velocity v_o is indicated in Table 5 (for h_o = 2.2 m).

α[°] \ v[m/s]	12.9	13.4	13.6	13.8	14.0	14.2	14.4
33	18.36	19.61	20.12	20.64	21.17	21.71	22.25
35	18.63	19.91	20.44	20.94	21.52	22.07	22.62
37	18.83	20.14	20.68	21.23	21.78	22.34	22.91
39	18.97	20.30	20.85	21.40	21.96	22.50	23.11
41	19.03	20.38	20.93	21.49	22.06	22.63	23.21
42	19.04	20.39	20.94	21.50	22.07	22.65	23.23
43	19.02	20.37	20.93	21.49	22.06	22.64	23.23

Table 5.

The nomogram (Fig. 3) and Table 5 suggest:

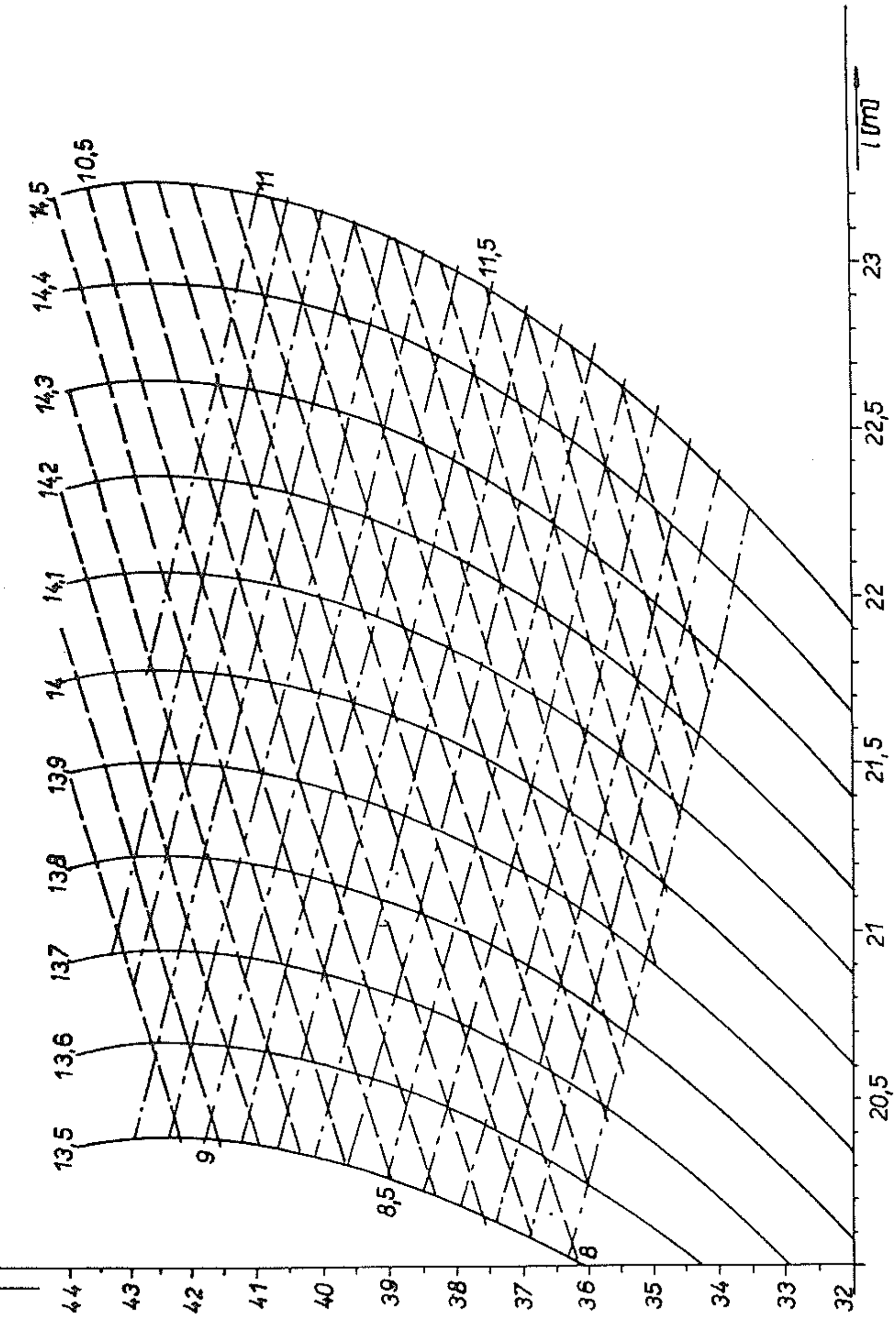
- the greater the release angle, the better the performance (up to α_o = 42 ^{o}); but the greater the release angle, the smaller the increase of the distance;
- with the same increment of the release angle and with increasing release velocity, the increment of the distance is negligible; e.g. increment of 2 ^{o} (for instance from 35 ^{o} to 37 ^{o}) at the velocity 13.4 m/s the distance will be 0.23 m longer, at the velocity 14.4 m/s 0.29 m longer etc.;
- with release angles 41 ^{o} - 43^o performances are practically identical.

A release angle α_o in the range from 33^o to 42 ^{o} affects the performance by as much as 0.7 m at lower release velocities and as much as 1.0 m at maximum release velocity.

MODEL OF NECESSARY PRICONDITIONS

FOR PERFORMANCES 20 - 23 m

(FOR RELEASE HEIGHT ho=1.9 m AND GRAVITATIONAL AKCELERATION g=9.81m/s)



RELEASE VELOCITY vo [m/s]

HORIZONTAL RELEASE VELOCITY vox [m/s]

VERTICAL RELEASE VELOCITY voy [m/s]

FIG 3

Release height and overreaching (no-reaching)

A change in the release height ($\pm h_0$), or the shot's vertical position ($\pm h_0$) at the moment of release corresponds approximately to the change in the length of flight $\pm\Delta l$. It holds then hat for as many centimetres the vertical position of the tshot is higher or lower, there will be an increase (decrease) by the same amount in the final performance.

By overreaching or no-reaching ($\pm\Delta l$) we mean the horizontal deviation of the shot position at the moment of release in relation to the measuring spot (inside the circumference of the circle). By overreaching ($+\Delta l$) the officially measured distance is extended in relation to the distance actually achieved (obviously, by the same tdistance Δl); in the case of no -reaching ($-\Delta l$) the opposite is true.

Generally, it can be stated that overreaching $+\Delta l$ is of limited importance as means of improvement as an athlete can gain maximally 0.1 - 0.2 m on the officially measured distance. A struggle to achieve increased overreaching can adversely affect the values of the putting angle and velocity.

Release height is of similarly limited importance. Through an increase of the average value h_0 , a maximal gain of 0.2 m in the total distance can be obtained. A struggle for increased h_0 by means of exaggerated and intentional jumping results in lowering the release angle, which has consequent effects on the release velocity.

Searching for the optimum and release angle (α_0), release velocity (v_0), in each case, individual concept of putting technique we must take into consideration the speed and strength potential of the athlete and his anatomical (anthropometric) potential, joint mobility etc. This statement does not deny the unambiguous fact that general throwing laws exist and must be respected when learning the technique.

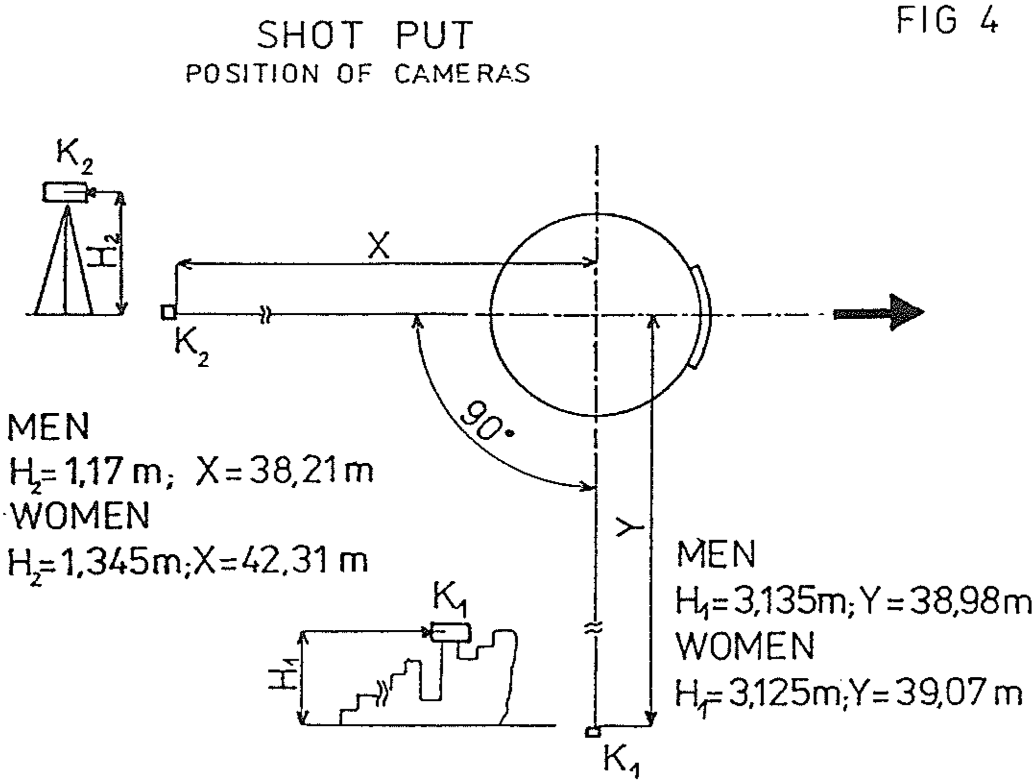
Consequently, the task for the athlete and coach is to master the complex of optimizing the necessary conditions for attaining the highest possible release velocity at an individually optimum release angle.

There are many examples corroborating the statement that an extreme development of one of the components conditioning the performance does not lead to the expected result, and, in some cases, may even seriously affect it. E.g. an extreme development of strength without parallel development of joint mobility, muscle elasticity, coordination etc. negatively affects performance. Continuously increasing the volume of training load to the detriment of its intensity or number of "technical" puts at 90 % and higher intensity level does not lead to the desirable results either.

Improving technique by use in training of implements of varying weight (±10 - 15%) should be a constant and mandatory part of the training process. Every training session and every put should also be attended by concentrated self control and external control of the technical execution from the side of the coach.This should be complemented, from time to time, by a corresponding analysis and interpretation by means of video and film shots.

3. Methods and procedures

For analyzing this technical event three dimensional high-speed kinematography was used. The action was shot by synchronized Photosonics 500 cameras at a frequency of 200 frames per second. The technical conditions in the Olympic Stadium in Rome called for a location of cameras as shown in Fig. 4.



For computing the three dimensional coordinates, generally known procedures of analytic geometry were used. For better orientation in the text, pictures and analyses we stick to the traditional division of the whole motor manoeuvre into separate phases by means of so called key points:

Symbol	Key Points	Phase
z_{max}	highest point of the shot	Descending
z_{min}	lowest point of the shot path	Starting
R↑	moment of glide beginning	Glide
R↓	moment of glide end	Transition
L↓	moment of foot landing in the double-support position	Shoulders Rotation
‖	moment when shoulders axis reaches position parallel to the put direction	Delivery
O⁄	moment when the shot leaves the fingers	

The coordinate system O, x, y, z is directed to the centre of the circle and located in relation to the putting direction as shown on the layout in Fig. 5.

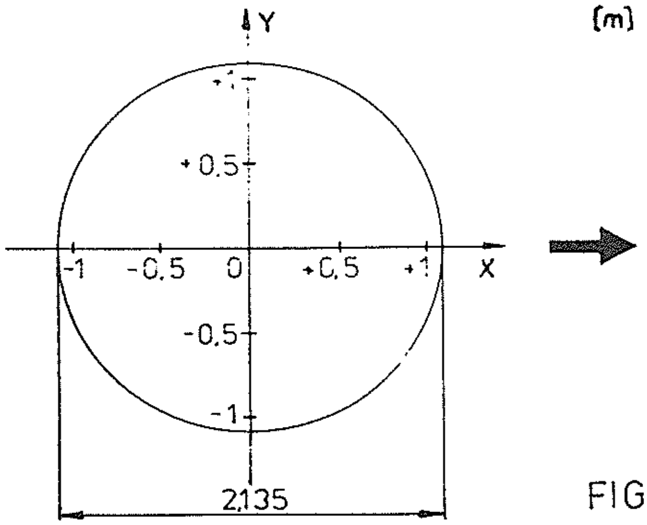


FIG 5

In all throwing events, especially the shot put, we consider the action of the upper body during the putting action to be of extreme importance.

To make the point more clearly, we have introduced an auxiliary coordinate system O, x', y' into the centre of the line connecting both hip joints, where the x' axis is identical with the pelvic axis running through the centres of rotation of the hip joints (Fig. 6).

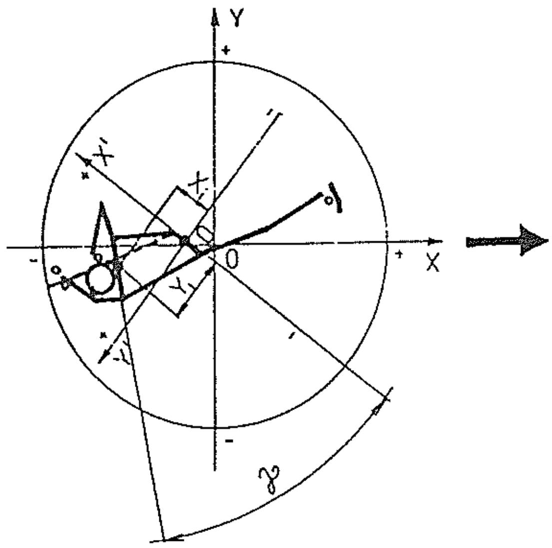


FIG 6

Defined in this way, this coordinate system enables us to express, in ground projection, the position of the centre of the line connecting the shoulder joints in relation to the centre of the line connecting the hip joints, and also the mutual deviations of the shoulders axis in relation to the pelvic axis (γ).

4. Analysis of the Shot Put competition at II World Championships in Athletics

On the basis of a biomechanical analysis by means of 3-D film we chose some geometric and kinematographic parameters that have direct or indirect influence on the performance.

In evaluating our finding we have proceeded from data that has a very marked influence to that which has no direct influence on the final performance.
Within these parameters we try to find significant mutual relationship and we assume that on this basis we can judge the individual features of the technique.

From all film shots made during the II WC , 12 trials in the men's category (with performances 19.55 m - 22.23 m) and 10 trials in the women's category (18.71 m - 21.21 m) were chosen for biomechanical analysis.

The variance range of the release velocity of the implement (v_0) is in direct proportion to the above performances, both in men (13.07 - 14.19 m/s) and in women (12.82 - 13.85 m/s).

4.1. Geometric parameters

The release height (h_0) is influenced by the techique of the final phase of the put (height of the "reverse" jump); but it depends primarily on the athlete's height. That is why the average release height in men (2.22 m) is 0.15 higher than in women (2.07 m), corresponding to the average difference in body height between men and women (about 0.13 m). The direct influence of this parameter is negligible and any effort to develop it through training would be futile.

It is a similar situation with overreaching ($\pm \Delta l$). This parameter will be discussed later in connection with the body position at the moment of release.

The release angle (α_0) can be easily influenced by the athlete. Although the optimal release angle for the velocities under consideration is about 42^o , we found that the average value of this angle was as low as 38 ^{o} in women and 37^o in men. It is probably easier to accelerate the shot at a lower elevation angle. The difference in the implement weight (almost 50 %), and wrong timing of the driving action of the lower extremities (premature "reverse" jump) are the main contributing factors to this fact. A performance is most notably influenced by the basic geometric parameters of the shot at the moment it leaves the putter's fingers and, especially, by the final release velocity.

4.1.1. Characteristic body positions during the put

In terms of action timing, the duration of the starting phase differs considerably (characteristic positions - "key" moments and phases - see Section 3 and Fig. 9). The reason is the individual concept of the start of the action (slower start: Guenthoer and Mueller; faster start: Andrei and Akhrimenko). Extremely slow execution of the start or even prolonged interruption of the action cannot benefit the further course of the action.

The duration of the glide undoubtedly corresponds to the velocity of execution, but also to the glide length (to be discussed later).

A well-timed landing of the left foot (L↓) into the double support position is the initial condition for a long delivery path (see Tables 11 and 12). E.g. Guenthor (R↓ - L↓) 0.02 s (Δ s) 1.96 m; Neimke 0.06 s - 1.75 m; and, conversely Gavriushin 0.15 s - 1.59 m ; Li 0.12 s - 1.58 m.

The moment of rotation of the shoulder axis in parallel with the put axis (‖) and the release moment (O↗) define, very approximately, the time section in which the strength involvement of the lower extremities prevails. The moment of rotation of the shoulder axis also correlates with the length of the delivery path, and probably also influences the release angle of the shot. E.g. Brenner 0.15 s - 39.8^{o}; Lisovskaya 0.15 s - 42.6^{o}; conversely Andrei 0.10 s - 34.2^{o}; Li 0.10 s - 35.3^{o} .

Here, characteristic differences occur which are caused by individual differences in technical execution.

Individual features show up mainly in the following:

- glide length,
- width of delivery stance,
- shot position at the moment of left foot landing (L↓),
- duration of the phase of the shoulder axis rotation Δt (R↓ - ‖),
- length of the delivery path $\Delta s_{V.-VI.}$.
- release angle α_o (see Figs 7 and 8 and Tables 6 - 12).

The duration of the delivery phase (‖ - O↗) does not reveal significant individual difference. On average, this phase is slightly shorter in women. The explanation is in the lower implement weight and a shorter delivery path.

Conversely the total duration of the Vth - VIth phase ($\Delta t_{V.-VI.}$). in conjunction with the total length of the shot path in these phases ($\Delta s_{V.-VI.}$) and, above all, with the "effective" length of the shot path (s_E) are directly related to the performance.

The effective length of the shot delivery path in male athletes with better performances is longer by an average 0.10 m than that of athletes with inferior performances (the average length is about 1.70 m). For women athletes, due to the difference in body size, the effective length is shorter. Significant variations of the length of the path occur in both categories. Further analysis of larger samples and investigations of correlations with other data will be needed to explain this variability.

The average velocity of the shot movement on the effective path (v_E) is lower in longer puts. E.g. Andrei 21.88 m - 7.13 m/s; 21.17 m - 8.10 m/s; the same in the trials of Guenthoer, Brenner, Machura (see Table 11); among women Mueller 20.76 m - 7.00 m/s; 20.11 m - 7.47 m/s; and the same for Lisovskaya. Neimke is an exception (see Table 12). This fact is even more notable in the average velocity in the Vth and VIth phases (Table 12). In less successful trials the involvement of the final effort required for proper delivery probably occurred too early.

SHOT PUT MEN (m)			GUNTHOER 22.23 m	GUNTHOER 22.12 m	ANDREI 21.88 m	ANDREI 21.77 m
1	Length of glide (toe-toe of right foot)		0,87	0,87	0,94	0,98
2	Width of delivery position (toe-toe of right foot)		1,15	1,17	1,17	1,17
3	Position of left foot at glide beginning (toe)	x y z	0,78 0,18 0,21	0,81 0,16 0,15	0,64 0,05 0,22	0,64 0,14 0,22
4	Position of right foot at glide ending (toe)	x y	-0,20 0,06	-0,20 0,03	-0,20 -0,24	-0,17 -0,22
5	Position of left foot at glide ending (toe)	x y z	0,93 0,30 0,09	0,94 0,30 0,02	0,73 -0,04 0,05	0,75 0,02 0,06
6	Position of left foot in the moment of landing of left foot (toe)	x y	0,93 0,32	0,94 0,30	0,98 0,04	1,00 0,06
7	Position of right hip (in the moment of delivery)	x y z	0,53 0,05 1,11	0,59 0,02 1,15	0,52 -0,26 0,97	0,59 -0,21 0,99
8	Position of centre of mass (in the moment of delivery)	x y z	0,52 0,32 1,14	0,61 0,27 1,15	0,57 -0,02 1,06	0,60 0,01 1,10
9	Position of right shoulder (in the moment of delivery)	x y z	0,55 0,24 1,80	0,65 0,19 1,74	0,59 -0,16 1,70	0,58 -0,12 1,71
10	Height of right foot - toe (in the moment of delivery)	z	0,04	0,10	0,00	0,00
11	Height of left foot - toe (in the moment of delivery)	z	0,01	0,01	0,04	0,04

TAB 6

SHOT PUT MEN (m)

			BRENNER 21.18 m	BRENNER 19.91 m	MACHURA 21.25 m	MACHURA $\bar{x}$
1	Length of glide (toe-toe of right foot)		1,17	1,06	1,20	1,15
2	Width of delivery position (toe-toe of right foot)		1,07	1,12	0,87	0,93
3	Position of left foot at glide beginning (toe)	x y z	0,87 0,18 0,10	0,88 0,23 0,12	0,86 -0,26 0,74	0,90 -0,21 0,70
4	Position of right foot at glide ending (toe)	x y	-0,02 -0,30	-0,03 0,26	0,07 -0,36	0,05 -0,31
5	Position of left foot at glide ending (toe)	x y z	0,96 0,15 0,07	0,96 0,18 0,05	0,95 -0,28 0,01	0,93 -0,33 0,05
6	Position of left foot in the moment of landing of left foot (toe)	x y	1,01 0,14	1,03 0,16	0,96 -0,18	0,98 -0,17
7	Position of right hip (in the moment of delivery)	x y z	0,69 -0,10 1,14	0,61 -0,05 1,09	0,65 -0,32 1,15	0,59 -0,26 1,11
8	Position of centre of mass (in the moment of delivery)	x y z	0,58 0,10 1,13	0,55 0,17 1,16	0,71 -0,11 1,18	0,70 -0,07 1,16
9	Position of right shoulder (in the moment of delivery)	x y z	0,63 -0,38 1,79	0,56 0,07 1,76	0,65 -0,23 1,79	0,65 -0,18 1,73
10	Height of right foot - toe (in the moment of delivery)	z	0,05	0,03	0,07	0,06
11	Height of left foot - toe (in the moment of delivery)	z	0,06	0,08	0,06	0,05

TAB 7

SHOT PUT MEN (m)			TIMMERMANN 21.35 m	BEYER 21.02 m	BODENMUELLER 19.52 m	GAVRIUSHIN 19.83 m
1	Length of glide (toe-toe of right foot)		0,81	0,81	1,03	1,03
2	Width of delivery position (toe-toe of right foot)		1,24	1,20	1,14	1,04
3	Position of left foot at glide beginning (toe)	x y z	0,68 -0,12 0,17	0,82 0,79 0,91	0,77 0,28 0,21	0,79 -0,05 0,42
4	Position of right foot at glide ending (toe)	x y	-0,34 -0,14	-0,25 0,05	-0,08 -0,21	-0,05 -0,11
5	Position of left foot at glide ending (toe)	x y z	0,83 -0,07 0,05	0,95 0,64 0,34	0,96 0,19 0,10	0,87 0,09 0,15
6	Position of left foot in the moment of landing of left foot (toe)	x y	0,95 0,08	0,91 0,41	1,01 0,19	1,01 -0,03
7	Position of right hip (in the moment of delivery)	x y z	0,62 -0,21 1,05	0,55 0,02 1,09	0,61 -0,09 1,08	0,53 -0,15 1,08
8	Position of centre of mass (in the moment of delivery)	x y z	0,64 0,03 1,14	0,63 0,26 1,17	0,59 0,14 1,16	0,60 0,04 1,17
9	Position of right shoulder (in the moment of delivery)	x y z	0,64 -0,11 1,78	0,69 0,05 1,80	0,63 -0,01 1,80	0,51 -0,14 1,78
10	Height of right foot - toe (in the moment of delivery)	z	0,01	0,03	0,05	0,04
11	Height of left foot - toe (in the moment of delivery)	z	0,03	0,03	0,04	0,09

TAB 8

SHOT PUT WOMEN (m)			LISOVSKAIA 20.83 m	LISOVSKAIA 20.22 m	NEIMKE 21.21 m	MUELLER 20.76 m
1	Length of glide (toe-toe of right foot)		0,79	0,63	1,00	0,80
2	Width of delivery position (toe-toe of right foot)		1,22	1,45	1,09	1,24
3	Position of left foot at glide beginning (toe)	x y z	0,77 -0,17 0,34	0,88 -0,11 0,37	0,66 0,18 0,30	0,81 0,05 0,36
4	Position of right foot at glide ending (toe)	x y	-0,32 -0,16	-0,46 -0,16	-0,07 -0,10	-0,28 -0,20
5	Position of left foot at glide ending (toe)	x y z	0,89 -0,03 0,12	0,95 0,01 0,17	0,91 0,27 0,08	0,96 -0,04 0,11
6	Position of left foot in the moment of landing of left foot (toe)	x y	0,90 -0,07	0,98 0,16	0,98 0,25	0,96 -0,01
7	Position of right hip (in the moment of delivery)	x y z	0,52 -0,11 1,04	0,47 -0,16 1,08	0,56 -0,01 0,96	0,41 0,09 0,96
8	Position of centre of mass (in the moment of delivery)	x y z	0,57 0,11 1,08	0,54 0,06 1,12	0,63 0,15 1,06	0,52 0,07 1,01
9	Position of right shoulder (in the moment of delivery)	x y z	0,62 0,04 0,16	0,57 -0,04 1,69	0,64 0,00 1,56	0,56 -0,02 1,52
10	Height of right foot - toe (in the moment of delivery)	z	1,64	0,08	0,04	0,02
11	Height of left foot - toe (in the moment of delivery)	z	0,01	0,07	0,05	0,03

TAB 9

SHOT PUT WOMEN (m)			MUELLER 20.11 m	AKHRIMENKO 20.20 m	LI 20.00 m	VASICKOVA 18.71 m
1	Length of glide (toe-toe of right foot)		0,72	0,92	0,95	
2	Width of delivery position (toe-toe of right foot)		1,33	0,95	1,24	
3	Position of left foot at glide beginning (toe)	x y z	0,81 0,09 0,34	0,53 0,07 0,26	0,87 -0,08 0,41	
4	Position of right foot at glide ending (toe)	x y	-0,43 -0,29	-0,23 -0,41	-0,22 -0,39	
5	Position of left foot at glide ending (toe)	x y z	0,94 0,03 0,15	0,70 -0,19 0,08	0,86 -0,23 -0,14	
6	Position of left foot in the moment of landing of left foot (toe)	x y	0,97 0,12	0,77 -0,21 -0,02	1,05 -0,21	
7	Position of right hip (in the moment of delivery)	x y z	0,48 -0,05 1,03	0,46 -0,28 1,00	0,58 -0,47 0,90	0,49 -0,09 1,04
8	Position of centre of mass (in the moment of delivery)	x y z	0,55 0,10 1,06	0,53 -0,15 1,07	0,61 -0,29 0,99	0,54 0,13 1,05
9	Position of right shoulder (in the moment of delivery)	x y z	0,59 0,00 1,55	0,54 -0,36 1,55	0,63 -0,43 1,50	0,59 0,08 1,57
10	Height of right foot - toe (in the moment of delivery)	z	0,07	0,00	0,01	
11	Height of left foot - toe (in the moment of delivery)	z	0,00	0,16	0,02	

TAB 10

SHOT PUT MEN TAB 11		GUENTHOER 22.23 m	GUENTHOER 22.12 m	ANDREI 21.88 m	ANDREI 21.17 m	BRENNER 21.18 m	BRENNER 19.91 m	MACHURA 21.25 m	TIMMERMANN 21.35 m	BEYER 21.02 m	BODENMUELLER 19.52 m	GAVRIUSHIN 19.83 m	MACHURA 20.80 m
1	$\pm \Delta l$	0,08	0,20	0,09	0,13	0,08	0,05	0,17	0,10	0,13	0,08	-0,04	0,19
2	h_o	2,24	2,29	2,13	2,27	2,22	2,25	2,24	2,22	2,19	2,22	2,22	2,18
3	α_o	35,5	37,0	35,5	34,2	39,8	38,5	38,0	35,8	34,1	39,3	41,0	37,7
4	v_o	14,19	14,02	14,10	13,84	13,67	13,23	13,75	13,86	13,82	13,07	13,21	13,56
5	l	22,15	21,92	21,79	21,04	21,10	19,86	21,23	21,26	20,89	19,44	19,87	20,61
6	ΔS V.-VI.	1,81	1,96	1,65	1,73	1,76	1,76	1,99	1,83	1,70	1,75	1,59	1,83
7	Δt V.-VI.	0,26	0,30	0,24	0,24	0,29	0,27	0,35	0,26	0,24	0,25	0,24	0,30
8	$\bar{v}$ V.-VI.	6,96	6,53	6,88	7,21	6,07	6,52	5,69	7,04	7,08	7,00	6,63	6,10
9	S_E	1,66	1,70	1,64	1,62	1,56	1,55	1,83	1,79	1,60	1,66	1,50	1,66
10	Δt_E	0,20	0,20	0,23	0,20	0,20	0,19	0,28	0,25	0,21	0,23	0,21	0,23
11	$\bar{v}_E$	8,30	8,50	7,13	8,10	7,80	8,16	6,54	7,16	7,62	7,22	7,14	7,22

1	$\pm \Delta l$	Overreaching	[m]
2	h_o	Release height	[m]
3	α_o	Release angle	[°]
4	v_o	Release velocity	[m/s]
5	l	Real length of throw	[m]
6	ΔS V.-VI.	Length of trajectory (phase V.+VI.)	[m]
7	Δt V.-VI.	Time section (phase V.+VI.)	[s]
8	$\bar{v}$ V.-VI.	Average velocity of shot (phase V.+VI.)	[m/s]
9	S_E	Effective accelerative trajectory	[m]
10	Δt_E	Time section of S_E	[s]
11	$\bar{v}_E$	Average velocity of S_E	[m/s]

Table 11.

	SHOT PUT WOMEN TAB 12	LISOVSKAYA 20,89 m	LISOVSKAYA 20,22 m	NEIMKE 21,21 m	NEIMKE 20,32 m	MUELLER 20,76 m	MUELLER 20,11 m	LOSCH 20,73 m	AKHRIMENKO 20,20 m	LI 20,00 m	VASICKOVA 18,71 m
1	$\pm \Delta l$	-0,04	-0,12	0,11	0,05	-0,03	-0,02	-0,09	0,11	0,03	-0,05
2	h_o	2,17	2,24	2,03	2,04	1,99	1,98	2,11	2,03	1,94	2,15
3	α_o	42,6	41,8	36,7	37,1	34,4	34,1	42,0	37,9	35,3	40,0
4	v_o	13,61	13,37	13,83	13,50	13,85	13,63	13,59	13,41	13,44	12,82
5	l	20,93	20,34	21,10	20,27	20,79	20,13	20,82	20,09	19,77	18,76
6	ΔS V.-VI.	1,74	1,65	1,75	1,65	1,63	1,62	1,48	1,78	1,58	1,67
7	Δt V.-VI.	0,29	0,24	0,27	0,25	0,27	0,28	0,22	0,34	0,22	0,25
8	$\bar{v}$ V.-VI.	6,00	6,88	6,48	6,60	6,04	5,79	6,73	5,24	7,18	6,68
9	S_E	1,48	1,56	1,65	1,65	1,47	1,42	1,56	1,52	1,49	1,53
10	Δt_E	0,20	0,21	0,23	0,25	0,21	0,19	0,25	0,22	0,20	0,20
11	$\bar{v}_E$	7,40	7,43	7,17	6,60	7,00	7,47	6,24	6,91	7,45	7,65

1	$\pm \Delta l$	Overreaching	[m]	2	h_o	Release height	[m]
3	α_o	Release angle	[°]	4	v_o	Release velocity	[m/s]
5	l	Real length of throw	[m]	6	ΔS V.-VI.	Length of trajectory (phase V.+VI.)	[m]
7	Δt V.-VI.	Time section (phase V.+VI.)	[s]				
8	$\bar{v}$ V.-VI.	Average velocity of shot (phase V.+VI.)	[m/s]				
9	S_E	Effective accelerative trajectory	[m]				
10	Δt_E	Time section of S_E	[s]	11	$\bar{v}_E$	Average velocity of S_E	[m/s]

Table 12.

The mutual position of the feet (□) at the moment of the glide beginning (R↑), glide ending (R↓), left foot landing (L↓) the shot position (X) at the moment of glide-ending (R↓), left foot landing (L↓) and at shot-release (O↗) are shown in Figs 7 and 8. This is another example of characteristic differences in technique. Andrei, Timmermann and Beyer aim at lengthening the effective path of the shot movement in the double-support position by means of shortening the glide length (Tables 6 - 8). They take a very wide delivery stance; e.g. Timmermann 1.24 m. But the shortening of the effective path occurs in the transitory phase (R↓ - L↓) as seen the position of the shot (X) at the moment of the left-foot landing (L↓).

Conversely Brenner, Machura and, to some extent, Bodenmueller use a longer glide and, by leaning and simultaneously rotating the trunk axis, achieve a greater difference between the position of the right foot landing and the position of the shot in the horizontal direction - see Fig. 7 (E,F,G,H,K) . In this way, they extend the effective path during delivery. The precondition of this variant is an intensive involvement of the main muscle groups of the lower extremities and of the trunk rotators in the delivery proper.

Guenthoer, in keeping with his anthropometric parameters and strength dispositions, tried very successfully to combine the advantages of both techniques of delivery.

The right foot position, at the moment of glide ending (R↓), off the axis of the put probably helps Brenner and Machura to increase the trunk muscle pre-tension before rotation. But Machura's left foot landing is to the right of the put axis, due to the restricted movement of the pelvic area. The potential for hip and trunk rotation in the final phase of delivery is thus limited. This also causes a greater side deviation of the shot path from the put axis.

For women the glide is shorter by an average 0.15 m than for the men. Women have an extremely wide delivery stance (Tables 9 and 10 and Fig. 8). The reason may be a certain imbalance in the strength development of the upper and lower extremities, or, possibly, the uncritical copying of the technique used by Slupianek, who had extraordinary strength in her lower extremities and was able gradually to accelerate the relatively light implement (4 kg) before the foot landing.

The position of the left toe-tip at the glide beginning and ending (R↑ ;R↓) indicates the level of readiness for a well-timed landing in the double support position. In male putters, the average left toe-tip distance from the front edge of the circle is less than 0.3 m at a height of ca 0.18 m. Machura, Beyer and Gavriushin who use a pronounced swing of the left leg when starting into the glide have the left toe-tip fairly high at this moment (R↑). At the moment of glide ending (R↓), in male putters, the left toe-tip is as close to the ground as 0.06 m. Only Beyer (0.34 m) and Gavriushin (0.15 m) get into the double support stance later.

For female putters, the left toe-tip is as much as twice as high as that for men in both positions (R↑ 0.34 m, R↓ 0.12 m). Like Beyer and Gavriushin, they land in the double support position later.

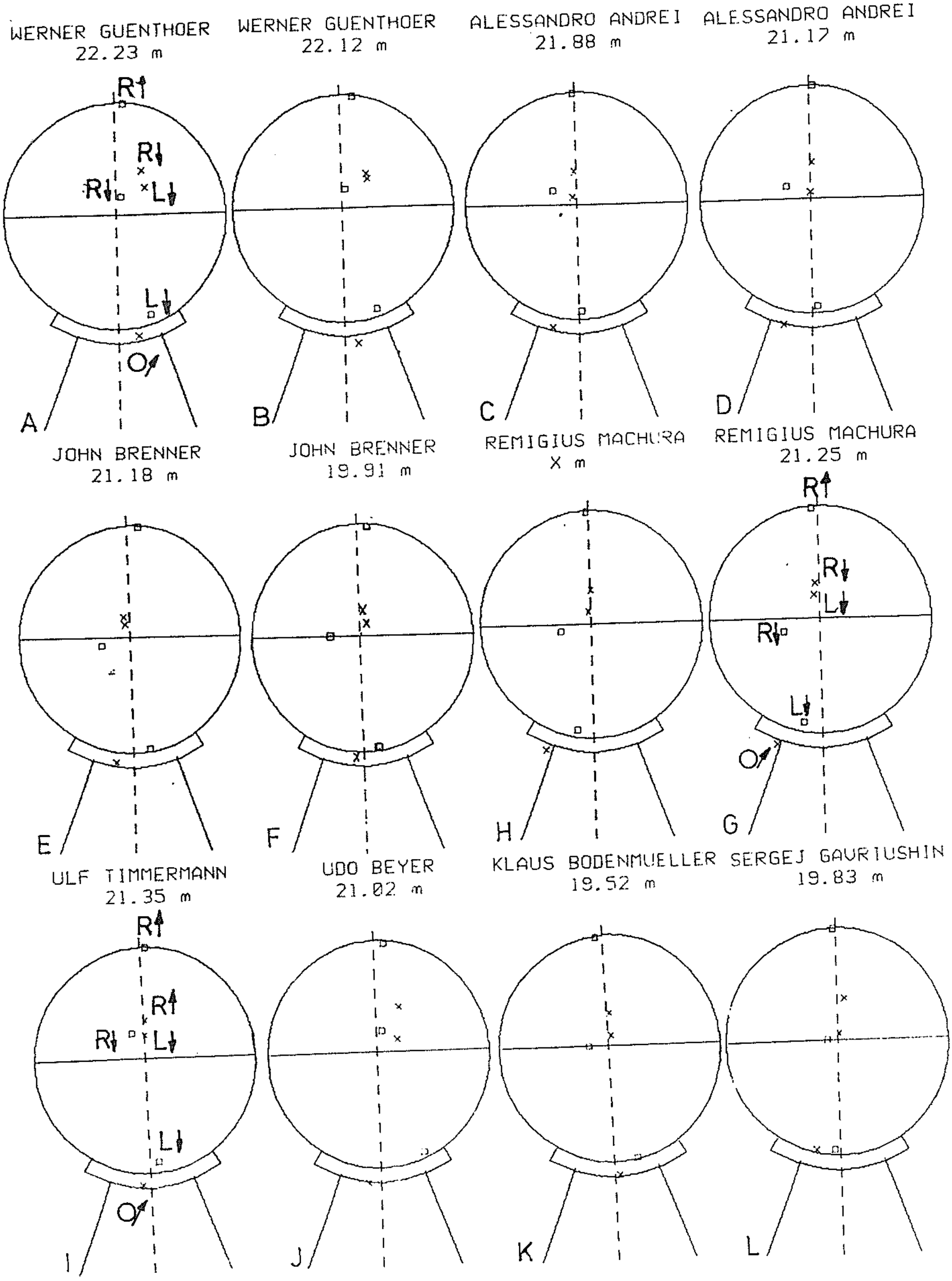

WERNER GUENTHOER
22.23 m
WERNER GUENTHOER
22.12 m
ALESSANDRO ANDREI
21.88 m
ALESSANDRO ANDREI
21.17 m
R
R
R
L
L
O
A
B
C
D
JOHN BRENNER
21.18 m
JOHN BRENNER
19.91 m
REMIGIUS MACHURA
X m
REMIGIUS MACHURA
21.25 m
R
R
L
R
L
O
E
F
H
G
ULF TIMMERMANN
21.35 m
UDO BEYER
21.02 m
KLAUS BODENMUELLER
19.52 m
SERGEJ GAVRIUSHIN
19.83 m
R
R
R
L
L
O
I
J
K
L

FIG 7

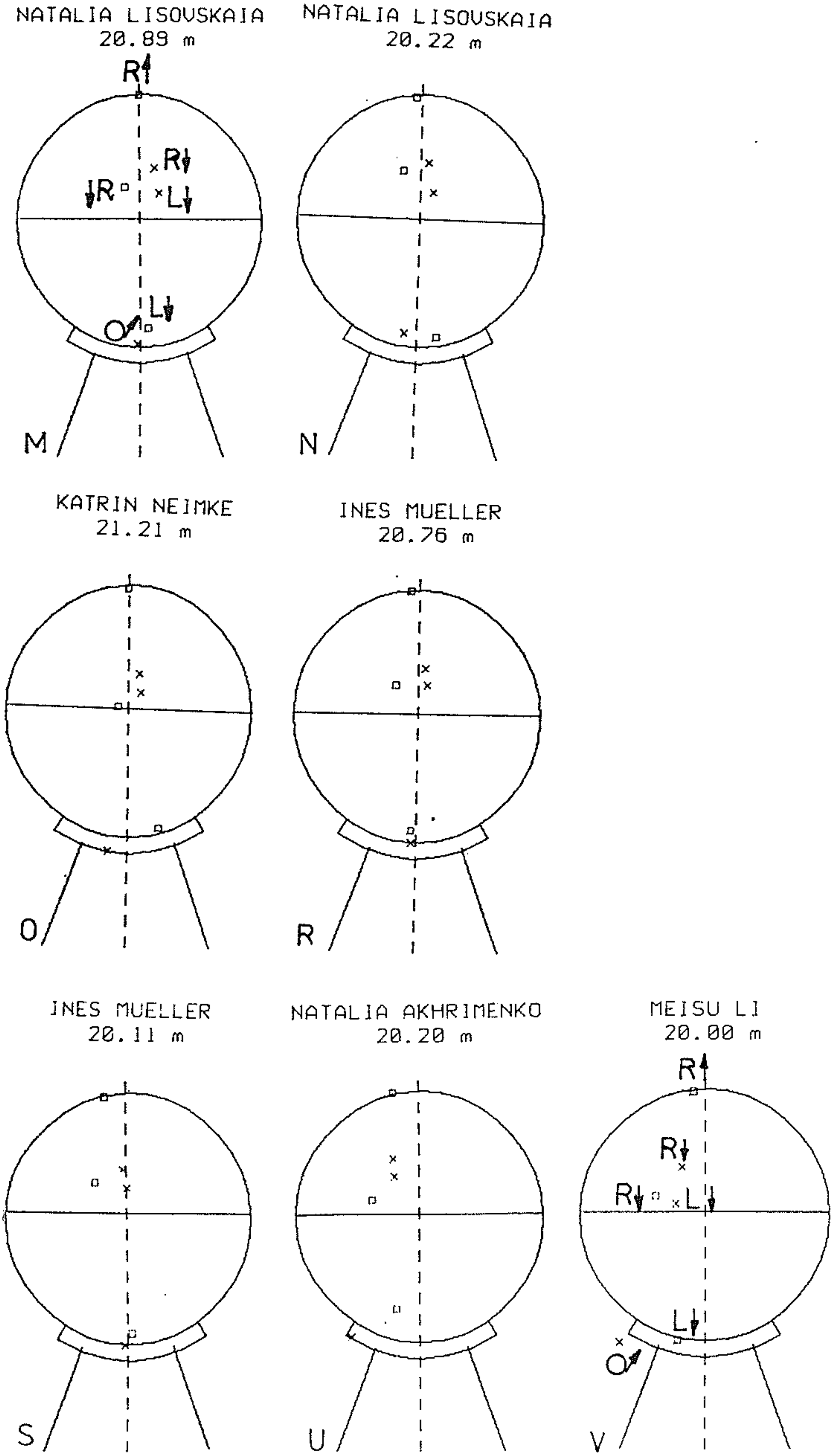

NATALIA LISOVSKAIA
20.89 m
NATALIA LISOVSKAIA
20.22 m
M
N
KATRIN NEIMKE
21.21 m
INES MUELLER
20.76 m
O
R
INES MUELLER
20.11 m
NATALIA AKHRIMENKO
20.20 m
MEISU LI
20.00 m
S
U
V

FIG 8

4.1.3. Trajectory of body and implement centre of mass

A graphic representation of the path of the shot centre (5) and of the body centre of mass (26) in 3-dimensional reconstruction is shown in Figs 10, 11 and 12. For the ground projection of the movement of those points see Figs 13, 14 and 15.

The coordinates of the position of the shot centre of mass (5) and the body and implement centre of mass (26) in separate key moments of the put are shown to the right of Fig. 10 (in the best trials of the winners to the right of Fig. 12). Key moments and discrete phases are described in Section 3 and Fig. 9 (z_{min} , R↑ , R↓ , L↓ , O↗). Where only 5 key moments are indicated in the tables, the moment z_{min} is omitted.

The theoretical demand that the path of the shot should approximate a straight line is met only by Guenthoer, Timmermann, Beyer and, to some extent, Bodenmueller. The other putters of shorter stature or those striving for a more pronounced strength involvement of the lower extremities in the final phase of delivery carry the implement in the middle phase of the action along a path of different length, parallel with the ground, in an effort to reach a lower shot position at the moment of the left foot landing (L↓). But for Machura, in the middle phase of the put and even after the left foot landing the shot descends. Neimke commits a similar error, especially on her less successful trials. The body centre of mass has an analogous trajectory (26). Here only Guenthoer and Timmermann succeed in keeping its ascending tendency, as does Andrei on his better trials. For other putters, in the middle part of the put, the body centre of mass moves parallel with the ground or even descends moderately; for Machura by as much as 0.06 m.

The line connecting the shot centre (5) and the body centre of mass (26) expresses the trunk lean of the putter, especially in the middle part of the put (Fig. 12). Athletes with a greater trunk lean (Machura, Brenner; Neimke and Li) carry the shot lower in the first and middle sections of the put in an effort to prolong the total shot trajectory which can be utilized for the shot acceleration.

The ground projection (Figs 13, 14 and 15) of the shot movement (5) and the body centre of mass (26) shows, above all, the character of the side deviation of the shot path from the put axis. Here the theoretical assumption of the linear character of the shot trajectory is problematic. In the middle part of the put when the rotation of the shoulder axis occurs, deviations from the linear path of the shot path, and thus from the axis, are quite regular. The mean side deviation of the shot trajectory from the body centre of mass (Fig. 13) is ca 0.32 m in men and ca 0.27 m in women. In better performances side deviation does not exceed 0.25 m; in inferior performances it exceeds 0.35 m in men and 0.30 m in women.

The character of the trajectory of the body centre of mass (26) projected into the ground plane indicates the expected direction of the left leg movement and provides a pointer to the spot where the left foot will land (L↓). Most putters locate their left foot more than 0.2 m to the left of the put axis; only some of them in the axis direction. Conversely, Machura puts his left foot to the right of the axis. The side deviation of the shot trajectory is then more than 0.45 m.

The dissipation of the forces caused by this technique of the final phase of the putting manoeuvre lowers the shot velocity at release, affecting the performance.

The positions of the hips, body centre of mass and shoulders at the moment of release (Tables 6 - 8) influence the other parameters: release height (h_o), release angle (α_o) and the so called over-reaching ($\pm \Delta l$). On average, for men the hips, body centre of mass and shoulders are the same distance from a vertical line drawn from the inner edge of the stop board.

For women, due to the shorter glide and extremely wide delivery stance, the average distance of the hips from this vertical is ca 0.57 m, the body centre of mass ca 0.51 m, and of the right shoulder ca 0.48 m.They thus end the delivery in a moderate forward lean. In spite of this they do not even reach as far as the inner edge of the stop board ($\pm \Delta l$ = - 1 cm). Conversely, mean are closer to the stop board and, in the final phase of delivery they reach at least 0.1 m beyond the inner edge of it (on average).

GUENTHOER 22.23 m

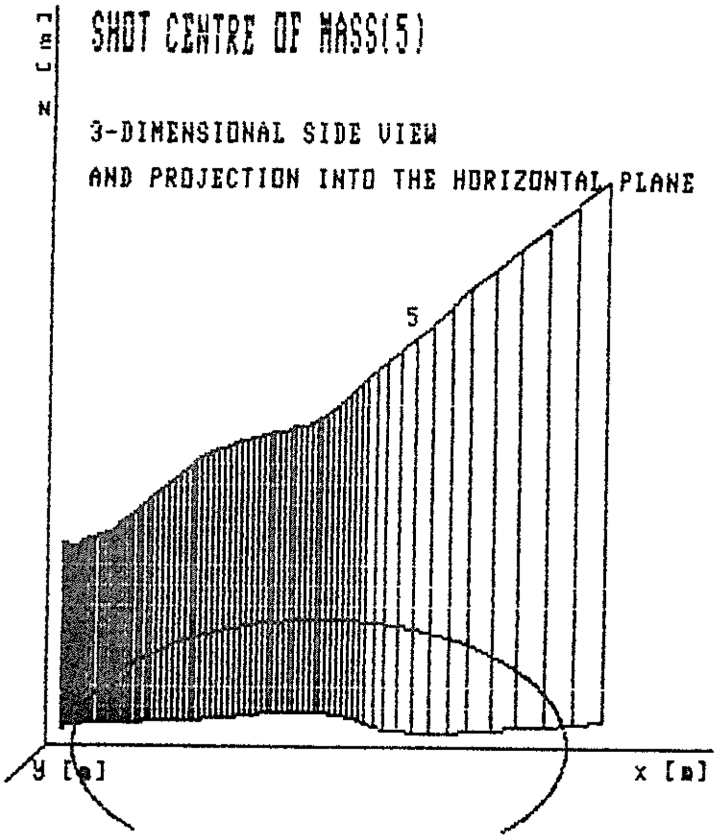


FIG 10A

THE KEY MOVEMENT OF THE SHOT PUT		PHASE
0.	Zmax	
		DESCENDING
I.	Zmin	
		STARTING
II.	R ↑	
		GLIDE
III.	R ↓	
		TRANSITION
IV.	L ↓	
		SHOULDERS ROTATION
V.	II	
		DELIVARY
VI.	o↗	

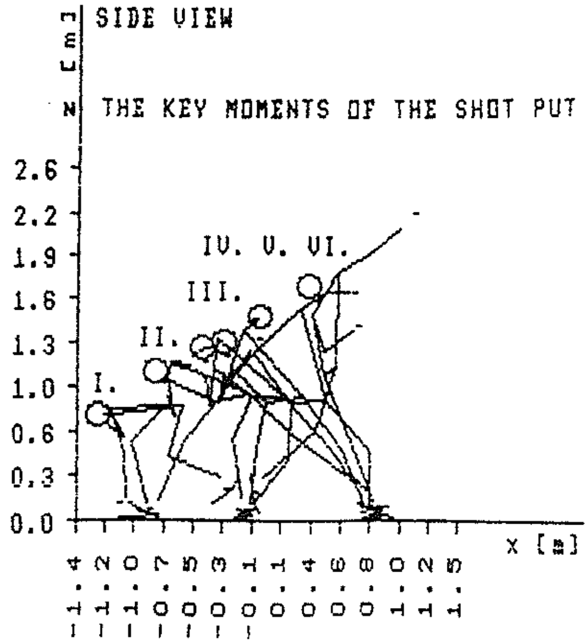


FIG 9

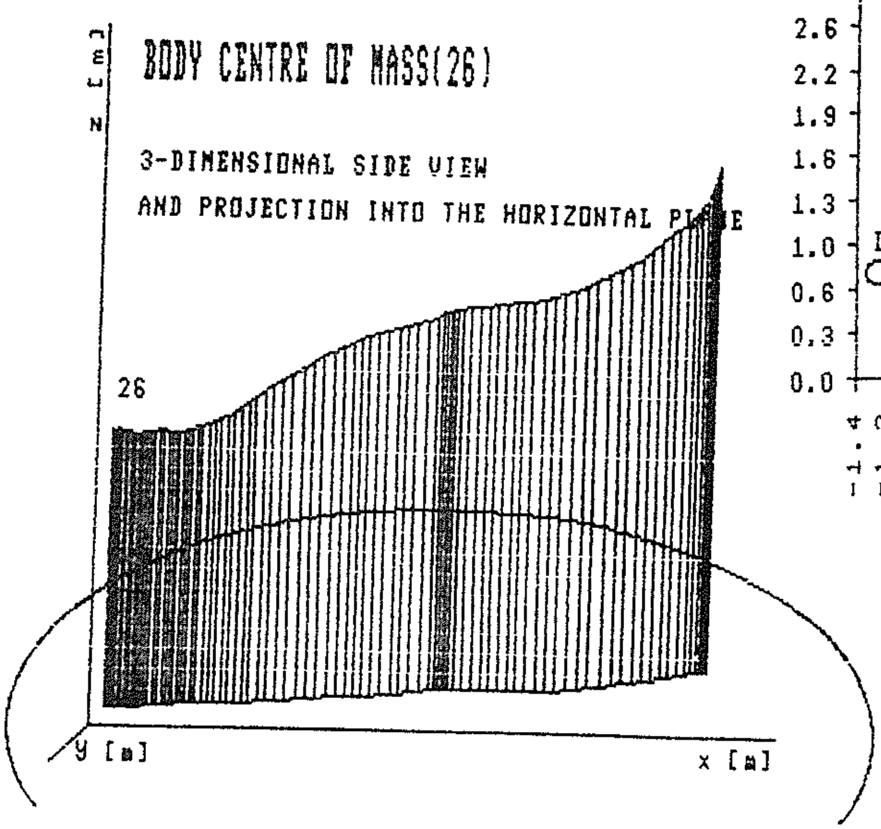


FIG 11A

GUENTHOER 22.23 m

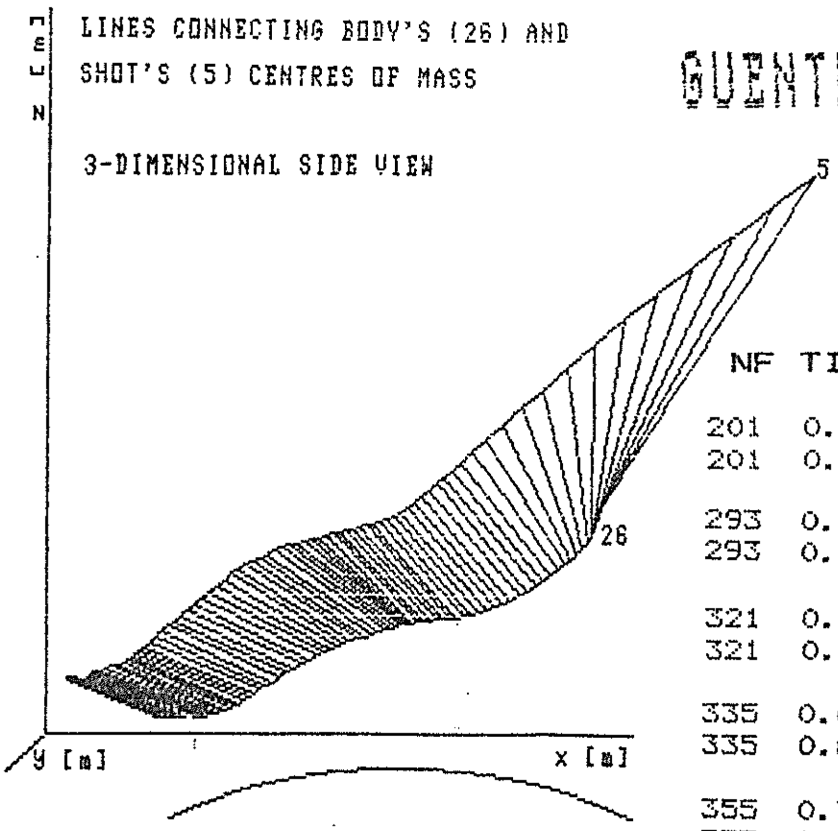


FIG 12A

3-DIMENSIONAL COORDINATES

NF	TIM	IP	X:	Y:	Z:
201	0.00	5	-1185	141	753
201	0.00	26	-896	89	690
293	0.46	5	-740	199	994
293	0.46	26	-403	152	863
321	0.61	5	-430	249	1138
321	0.61	26	-108	193	913
335	0.68	5	-279	275	1166
335	0.68	26	35	199	917
355	0.78	5	-37	248	1303
355	0.78	26	271	233	973
387	0.94	5	1126	199	2239
387	0.94	26	497	313	1201

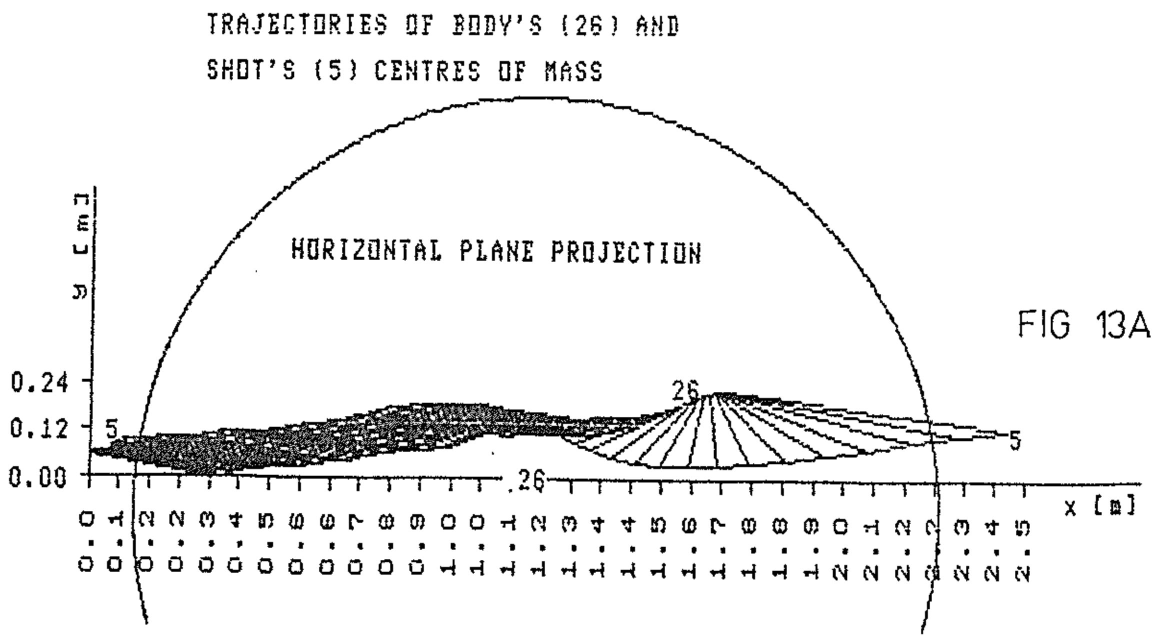


FIG 13A

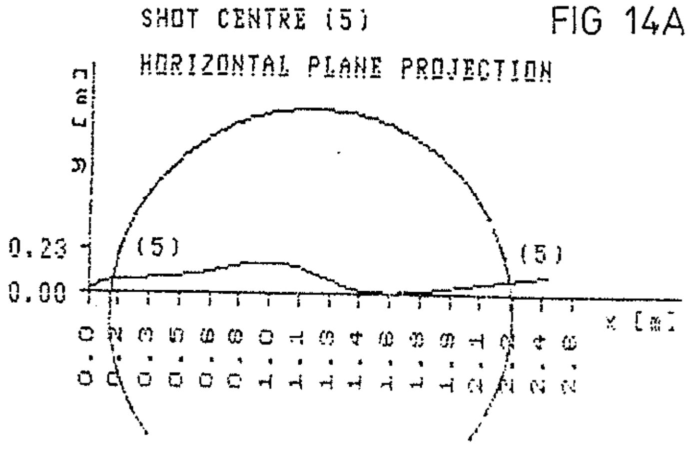


FIG 14A

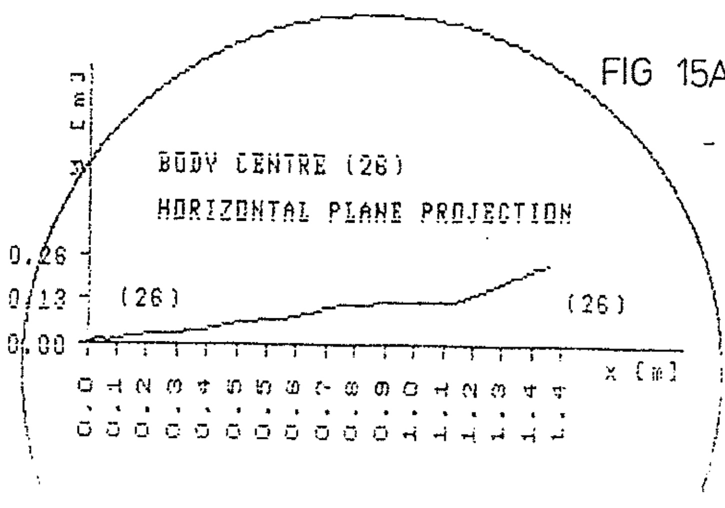


FIG 15A

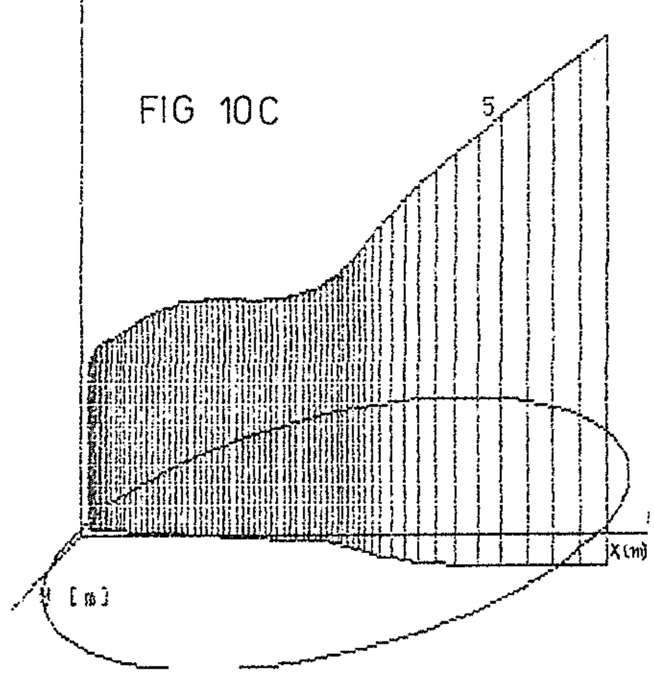
ANDREI 21.88 m

SHOT CENTRE OF MASS(5)

3-DIMENSIONAL SIDE VIEW

AND PROJECTION INTO THE HORIZONTAL PLANE

FIG 10C



3-DIMENSIONAL COORDINATES

[mm]

NF	TIM	IP	X:	Y:	Z:
15	0.00	5	-1035	55	650
15	0.00	26	-767	-24	478
58	0.21	5	-642	13	900
58	0.21	26	-280	-36	668
81	0.33	5	-337	-27	933
81	0.33	26	-25	-63	665
100	0.43	5	-94	-44	972
100	0.43	26	220	-65	691
118	0.52	5	143	-114	1155
118	0.52	26	434	-49	754
145	0.66	5	1122	-256	2019
145	0.66	26	572	-20	955

BODY CENTRE OF MASS(26)

3-DIMENSIONAL SIDE VIEW

AND PROJECTION INTO THE HORIZONTAL PLANE

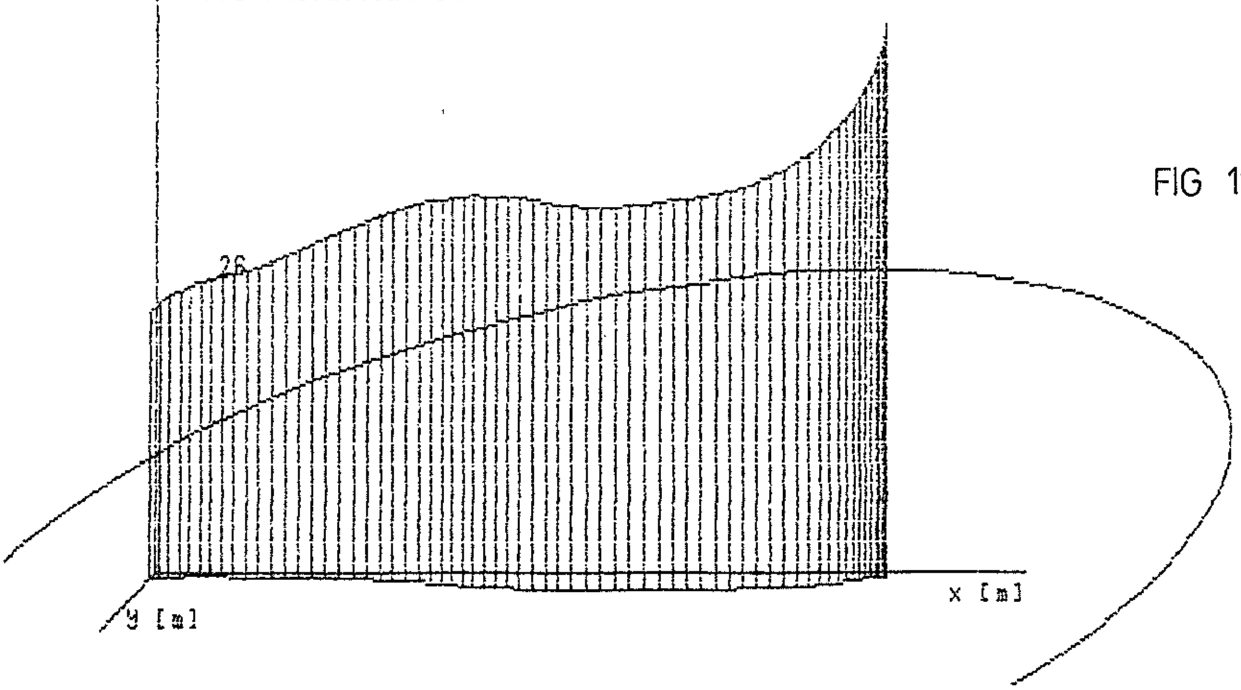


FIG 11C

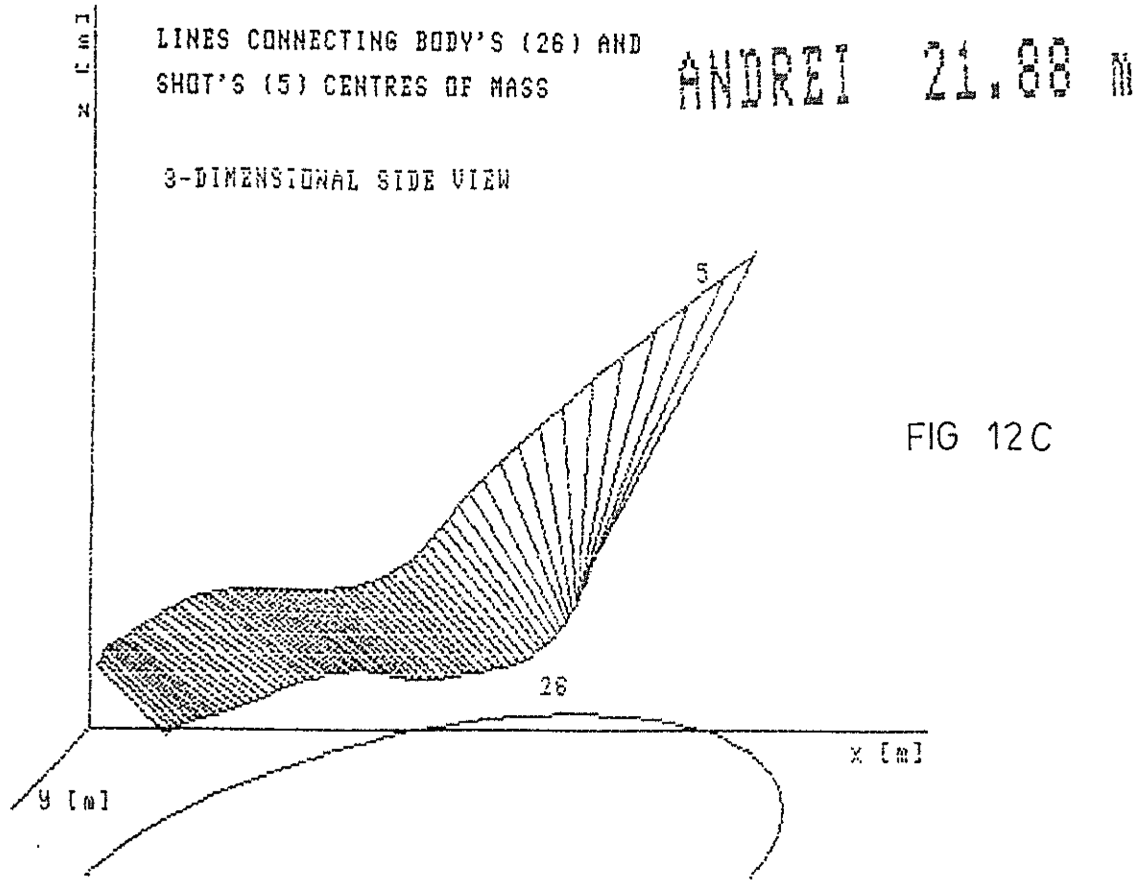


FIG 12C

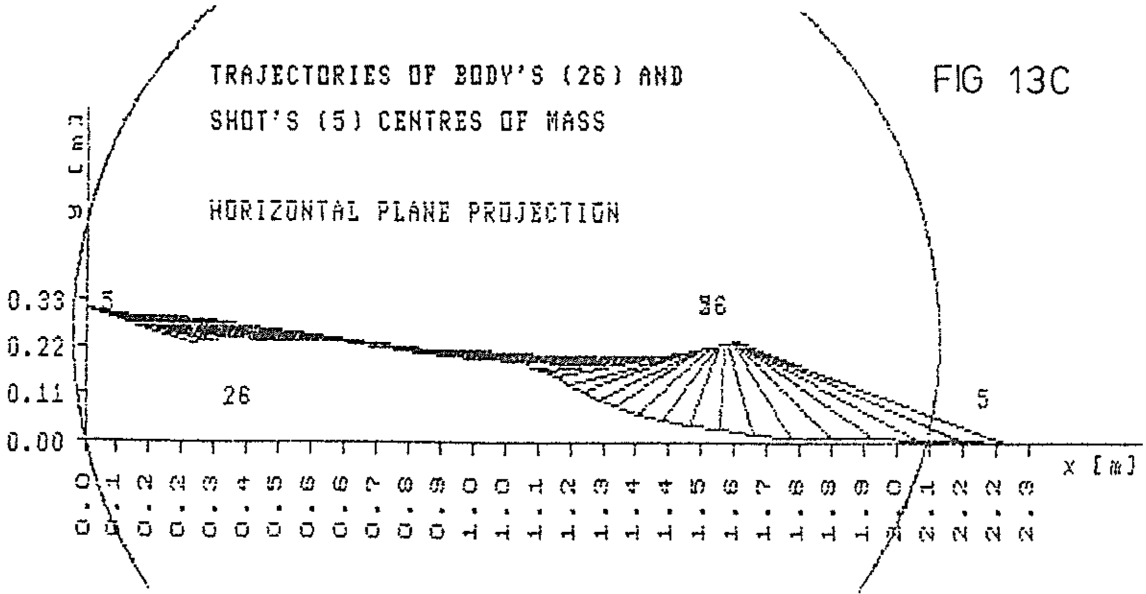


FIG 13C

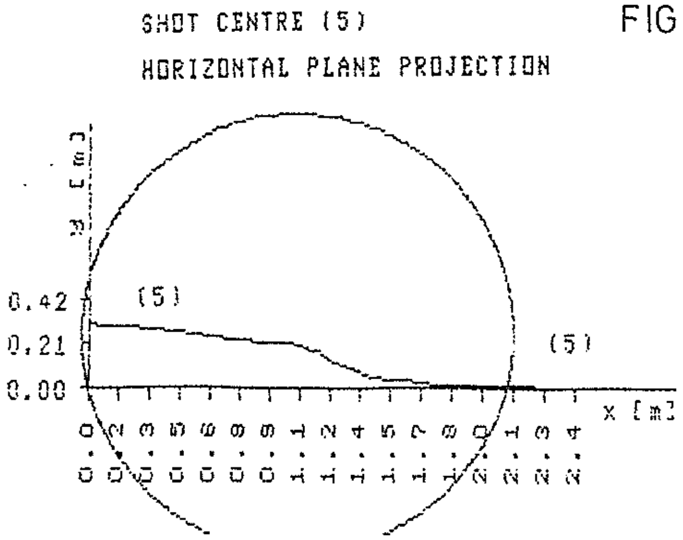


FIG 14C

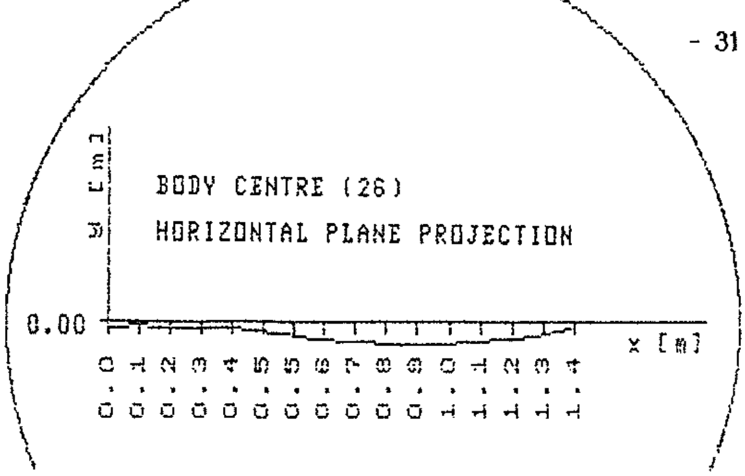


FIG 15C

BRENNER 21.18 m

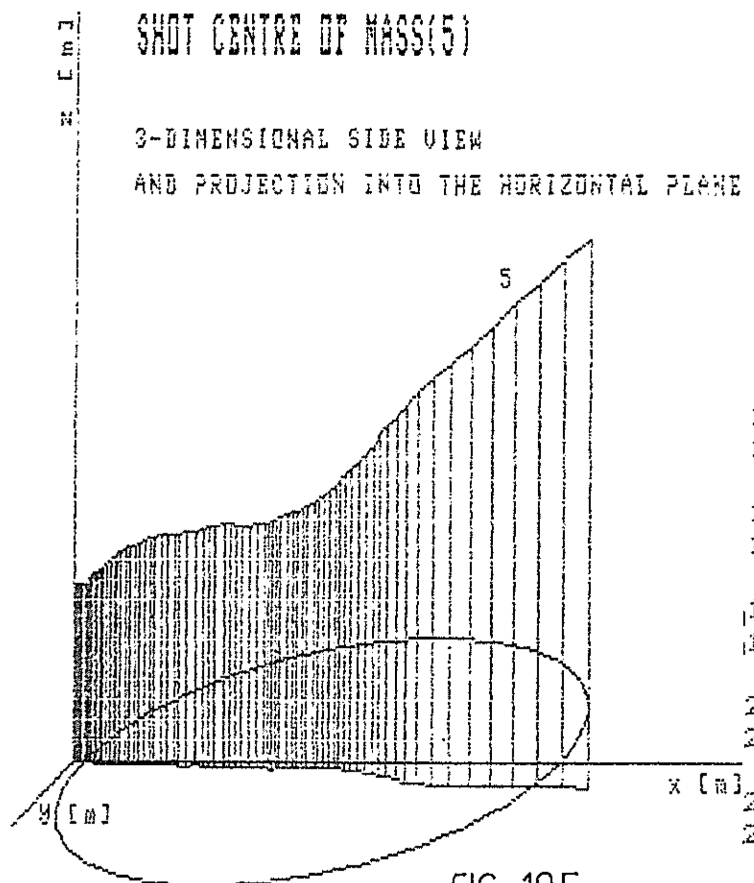


FIG 10E

3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
80	0.00	5	-1113	10	759
80	0.00	26	-841	-92	611
143	0.32	5	-632	-37	1000
143	0.32	26	-200	-12	775
168	0.44	5	-243	-61	1059
168	0.44	26	105	-16	802
176	0.48	5	-157	-55	1078
176	0.48	26	201	-10	796
205	0.63	5	211	-86	1353
205	0.63	26	470	24	982
231	0.77	5	1129	-209	2220
231	0.77	26	583	99	1252

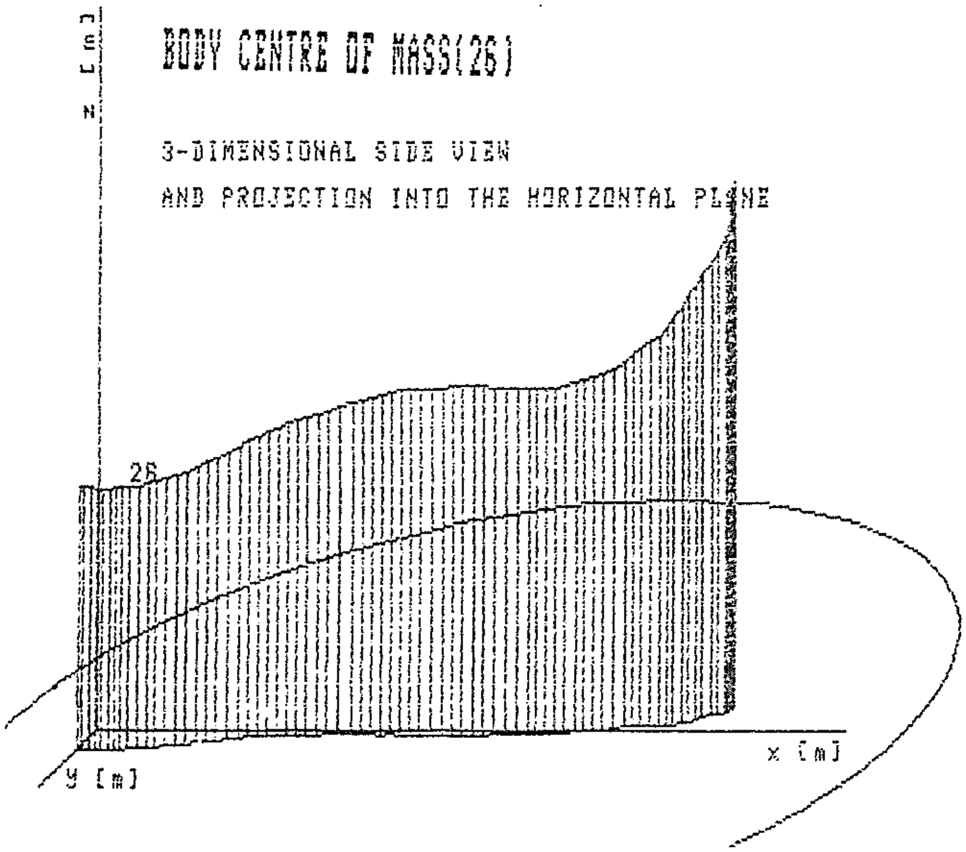


FIG 11E

BRENNER 21.18 m

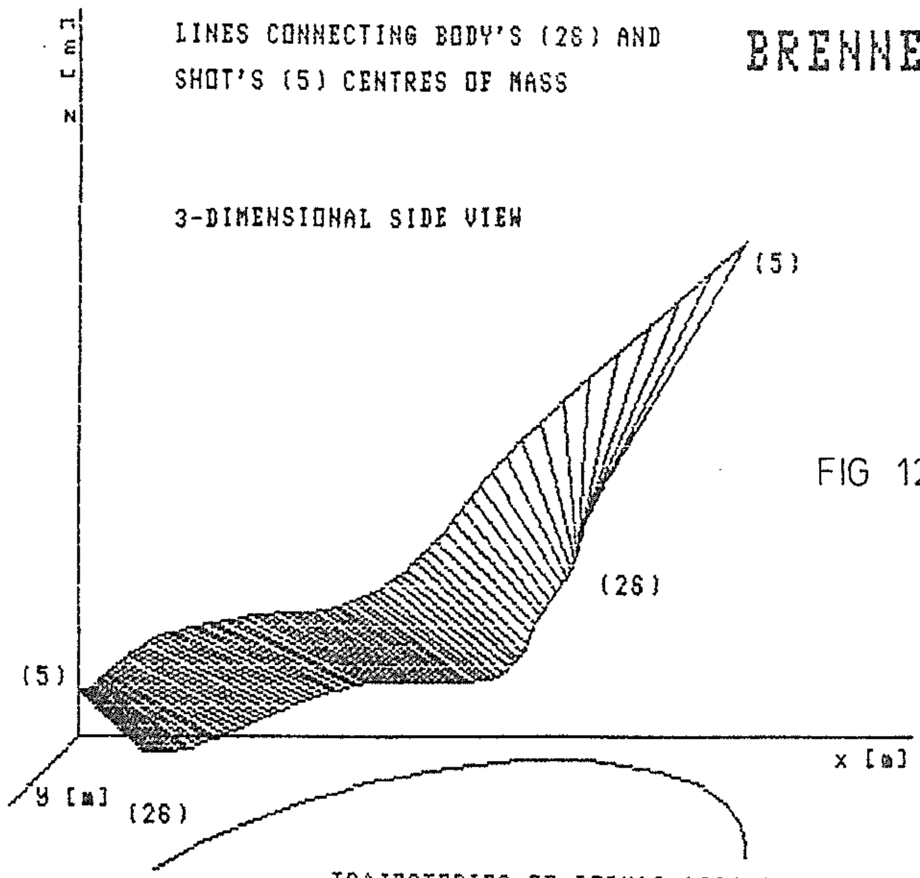


FIG 12E

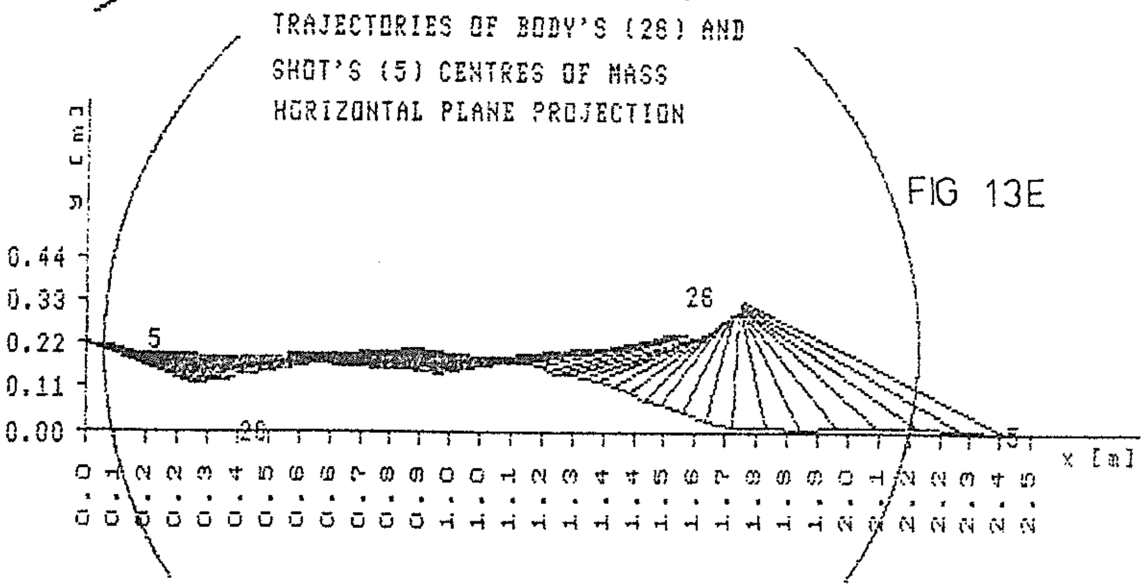


FIG 13E

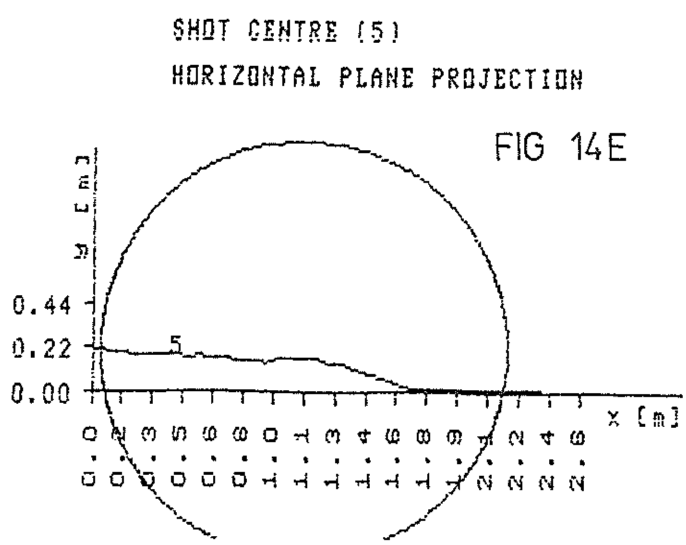


FIG 14E

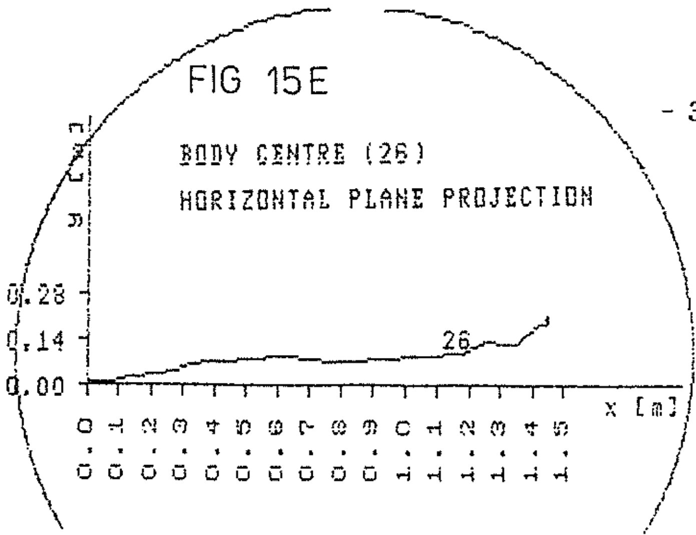


FIG 15E

MACHURA 21.25 m

6. ATTEMPT

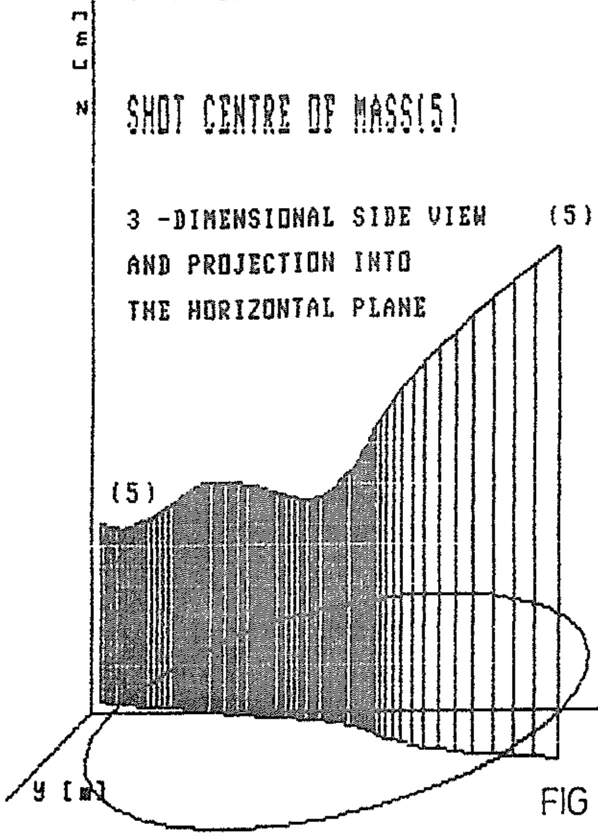


FIG 10G

3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
1	0.00	5	-1164	90	814
1	0.00	26	-754	-68	666
43	0.21	5	-763	38	962
43	0.21	26	-336	-125	839
81	0.41	5	-359	-44	1042
81	0.41	26	38	-180	819
93	0.47	5	-246	-58	1017
93	0.47	26	151	-189	778
135	0.68	5	252	-188	1338
135	0.68	26	542	-171	926
161	0.82	5	1156	-428	2241
161	0.82	26	708	-108	1183

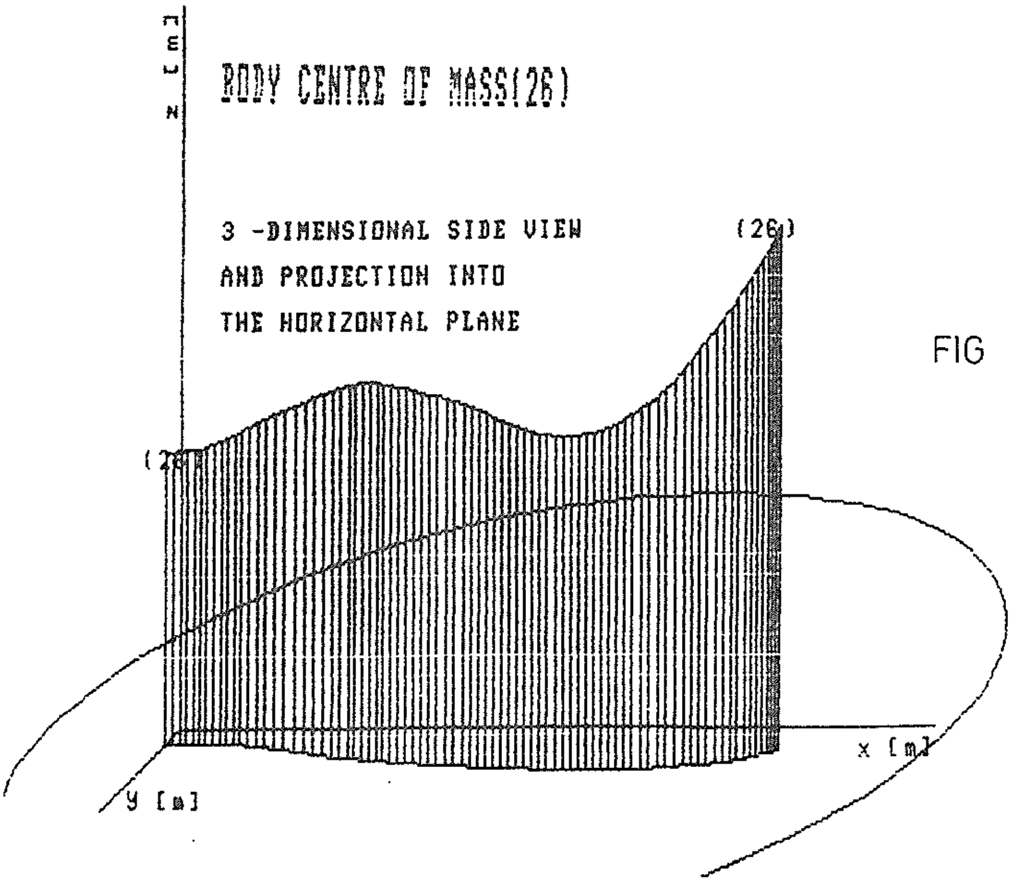


FIG 11G

MACHURA 21.25 m

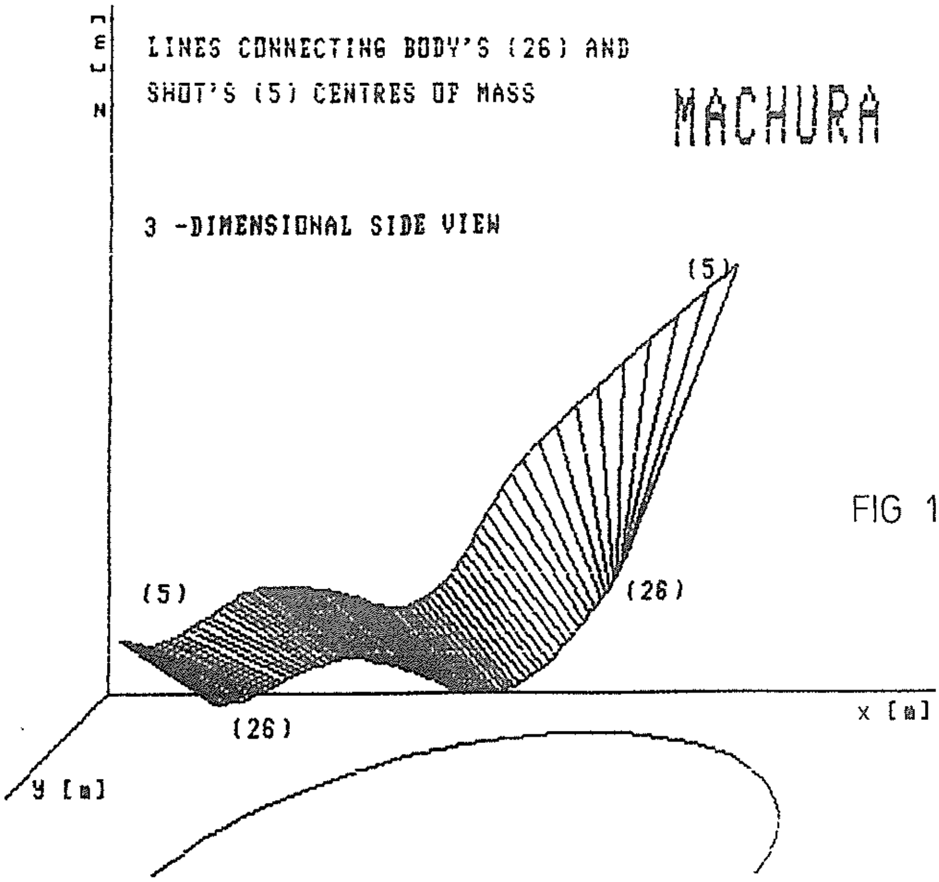


FIG 12G

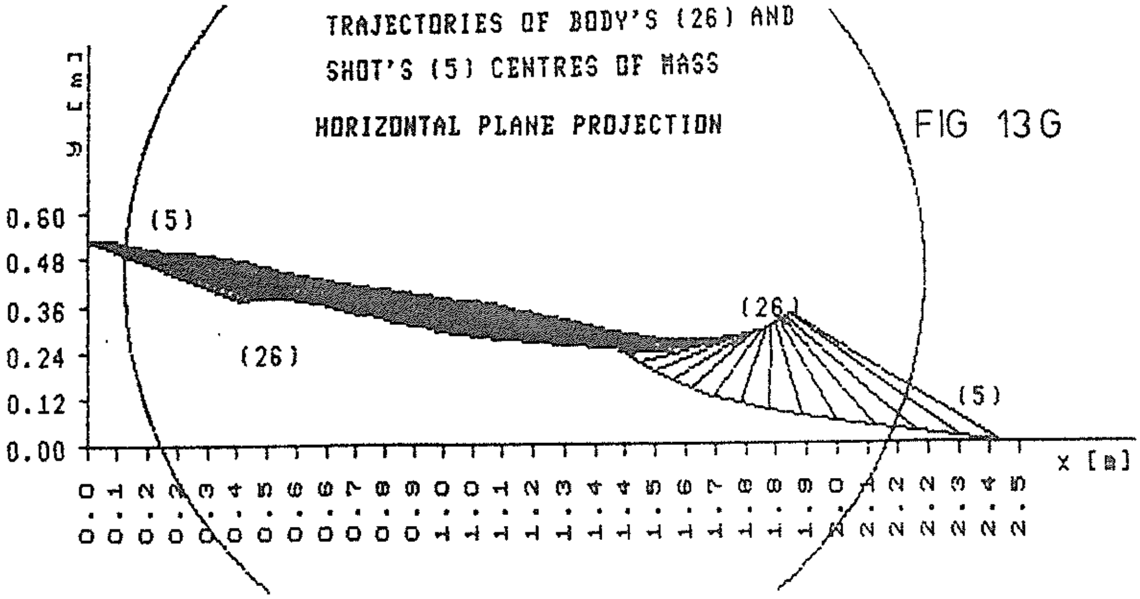


FIG 13G

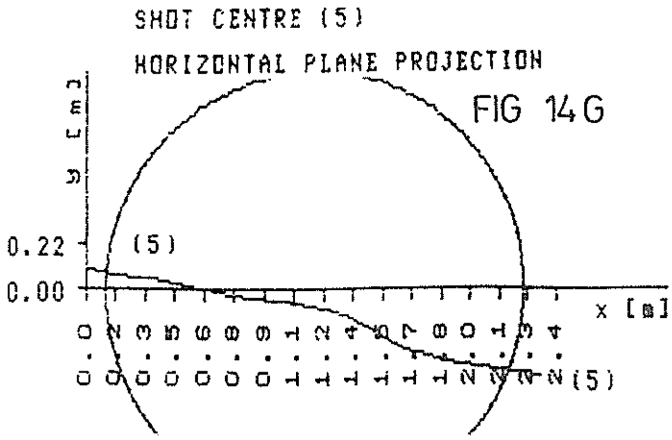


FIG 14G

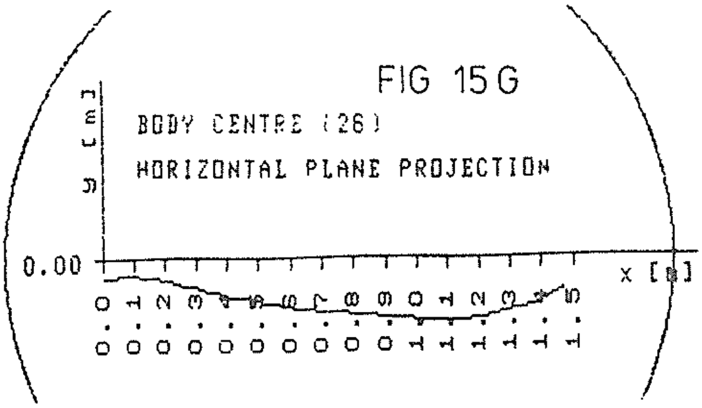


FIG 15G

LISOVSKAIA 20,89 m

SHOT CENTRE OF MASS(5)

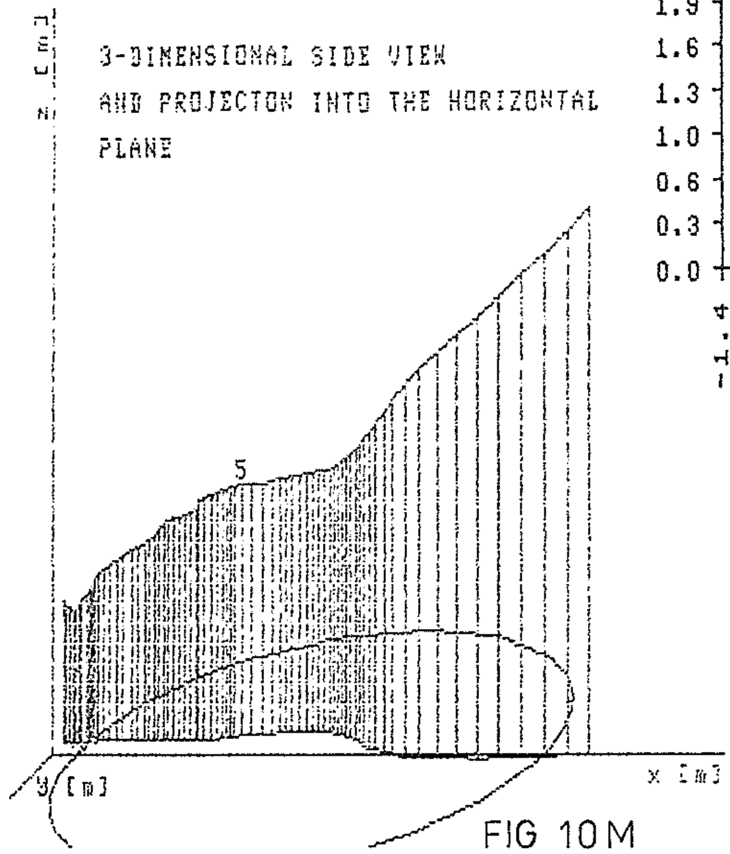


FIG 10M

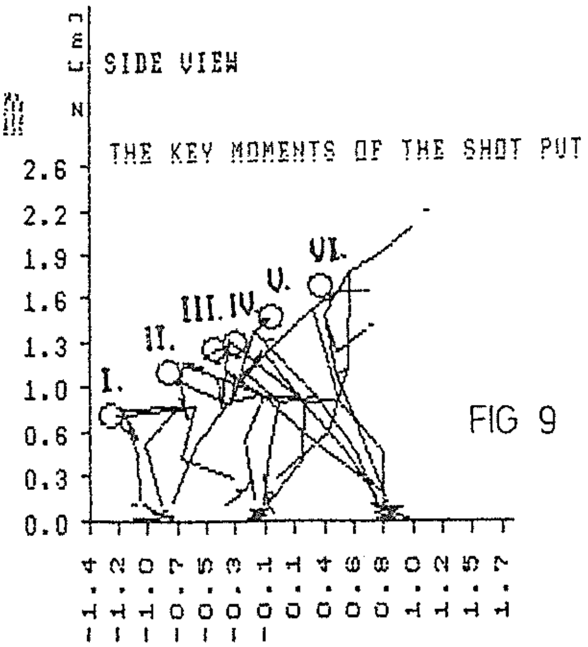


FIG 9

THE KEY
MOMENTS
OF THE SHOT PUT PHASE

0. Zmax
DESCENDING
I. Zmin
STARTING
II. R↑
GLIDE
III. R̄↓
TRANSITION
IV. L↓
SHOULDERS
RATATION
V. II
DELIVARY
VI. o↗

BODY CENTRE OF MASS(26)

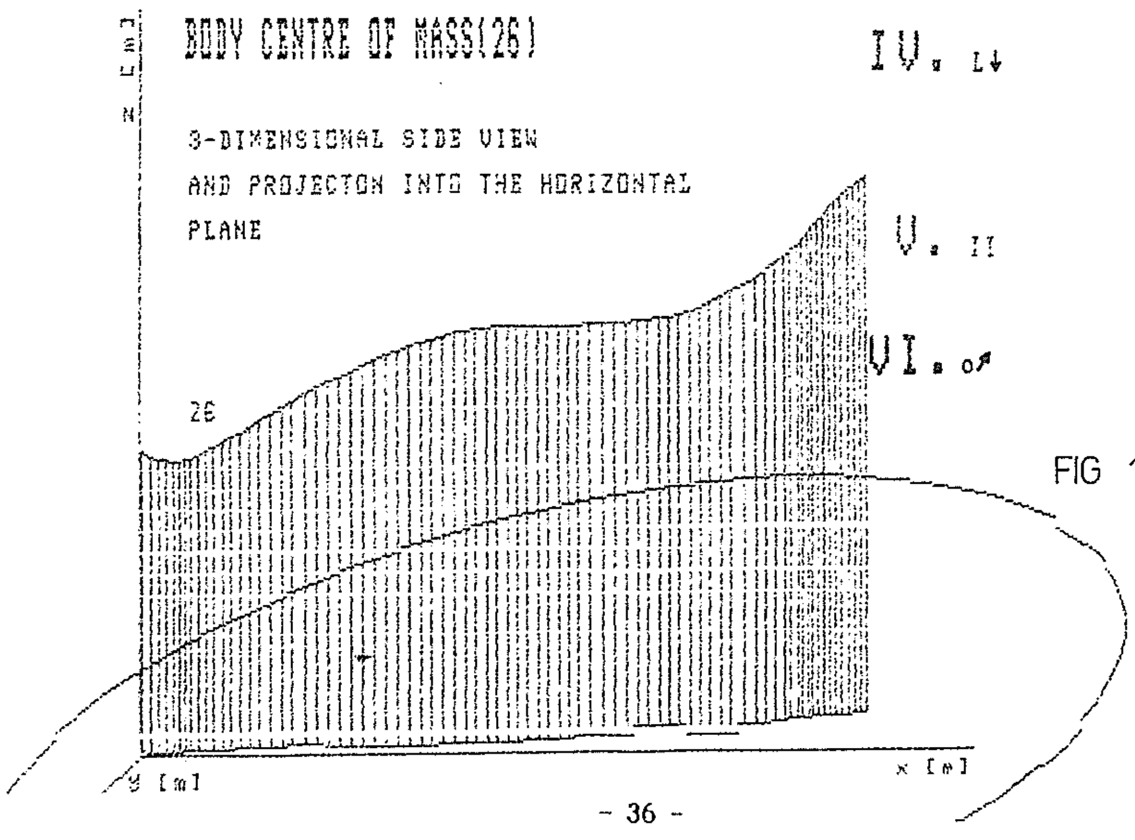


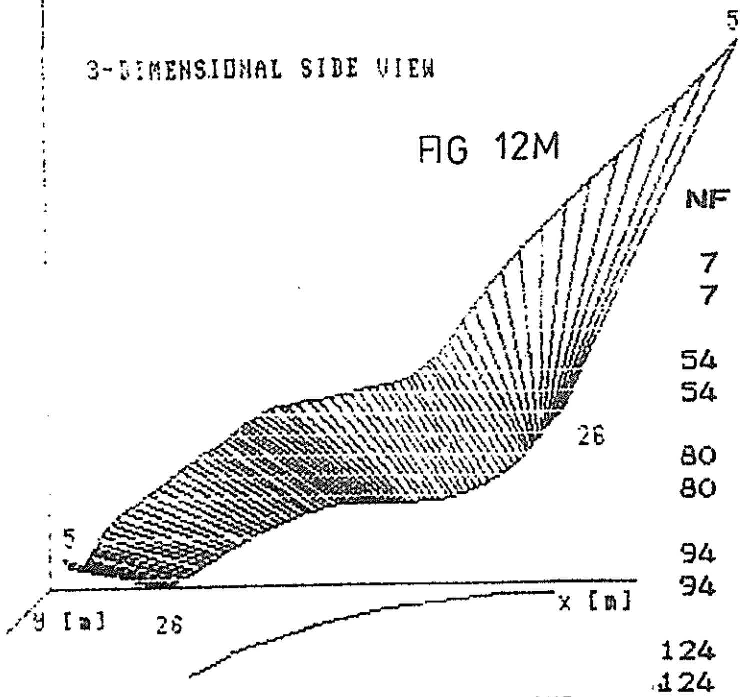
FIG 11M

LINES CONNECTING BODY'S (26) AND SHOT'S (5) CENTRES OF MASS

LISOVSKAIA 20.89 m

3-DIMENSIONAL SIDE VIEW

FIG 12M



TRAJECTORIES OF BODY'S (26) AND SHOT'S (5) CENTRES OF MASS

3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
7	0.03	5	-1129	82	596
7	0.03	26	-799	11	573
54	0.27	5	-711	115	945
54	0.27	26	-340	29	778
80	0.40	5	-462	132	1089
80	0.40	26	-57	48	825
94	0.47	5	-250	175	1113
94	0.47	26	90	66	818
124	0.62	5	156	102	1295
124	0.62	26	416	82	924
150	0.76	5	1028	-32	2167
150	0.76	26	566	115	1072

HORIZONTAL PLANE PROJECTION

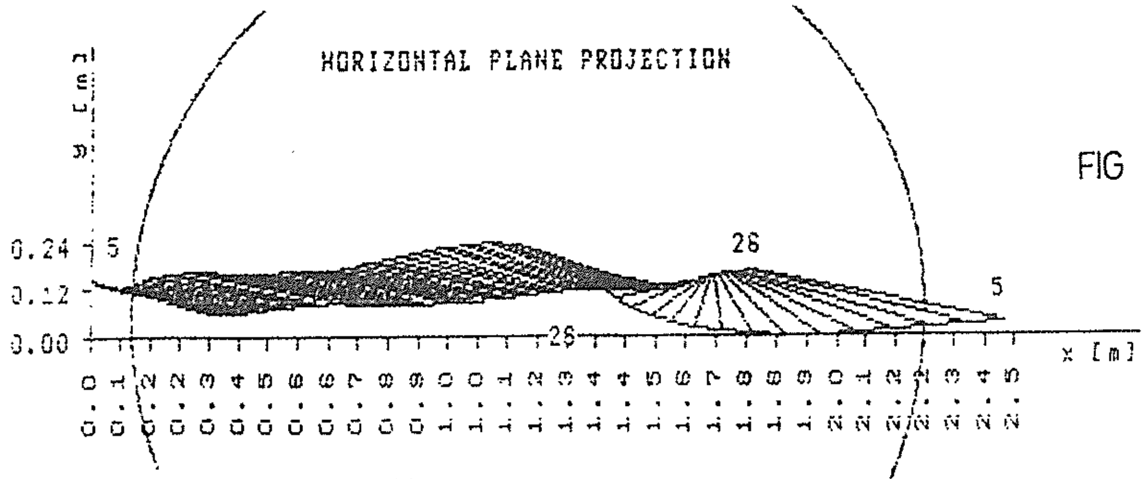


FIG 13M

SHOT CENTRE (5)
HORIZONTAL PLANE PROJECTION

FIG 14M

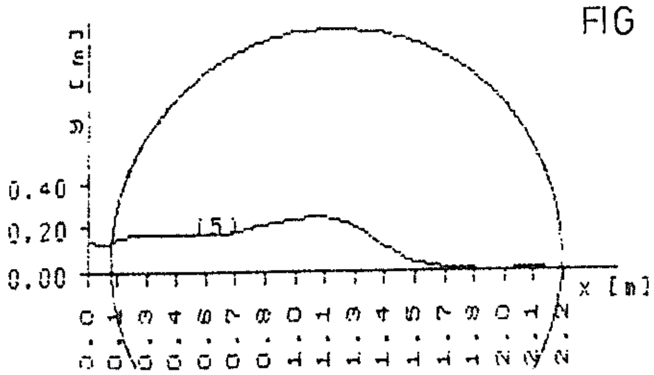
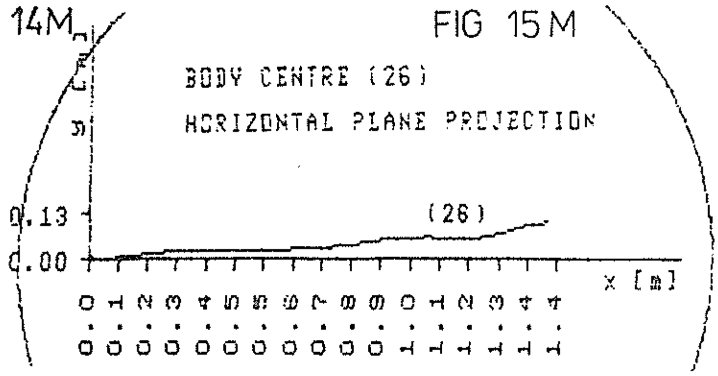


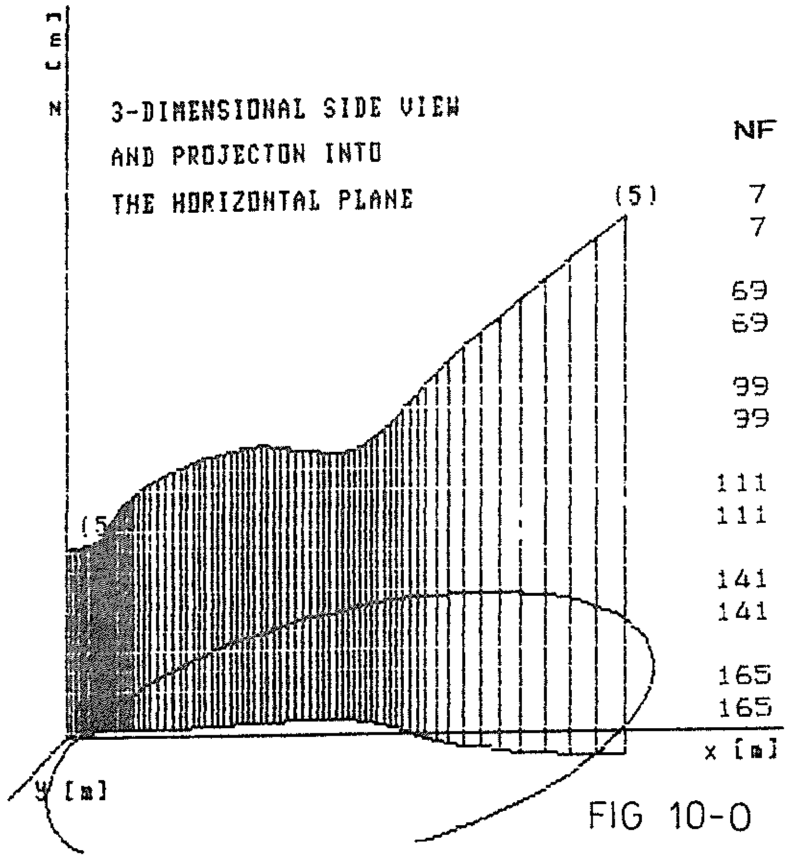
FIG 15M

BODY CENTRE (26)
HORIZONTAL PLANE PROJECTION



NEIMKE 21.21 m

SHOT CENTRE OF MASS(5)



3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
7	0.03	5	-1078	35	701
7	0.03	26	-884	-30	577
69	0.34	5	-696	49	987
69	0.34	26	-344	18	752
99	0.50	5	-344	93	1044
99	0.50	26	27	58	762
111	0.56	5	-179	105	1018
111	0.56	26	147	61	750
141	0.71	5	231	4	1248
141	0.71	26	488	105	852
165	0.83	5	1163	-170	2029
165	0.83	26	631	148	1059

FIG 10-0

BODY CENTRE OF MASS(26)

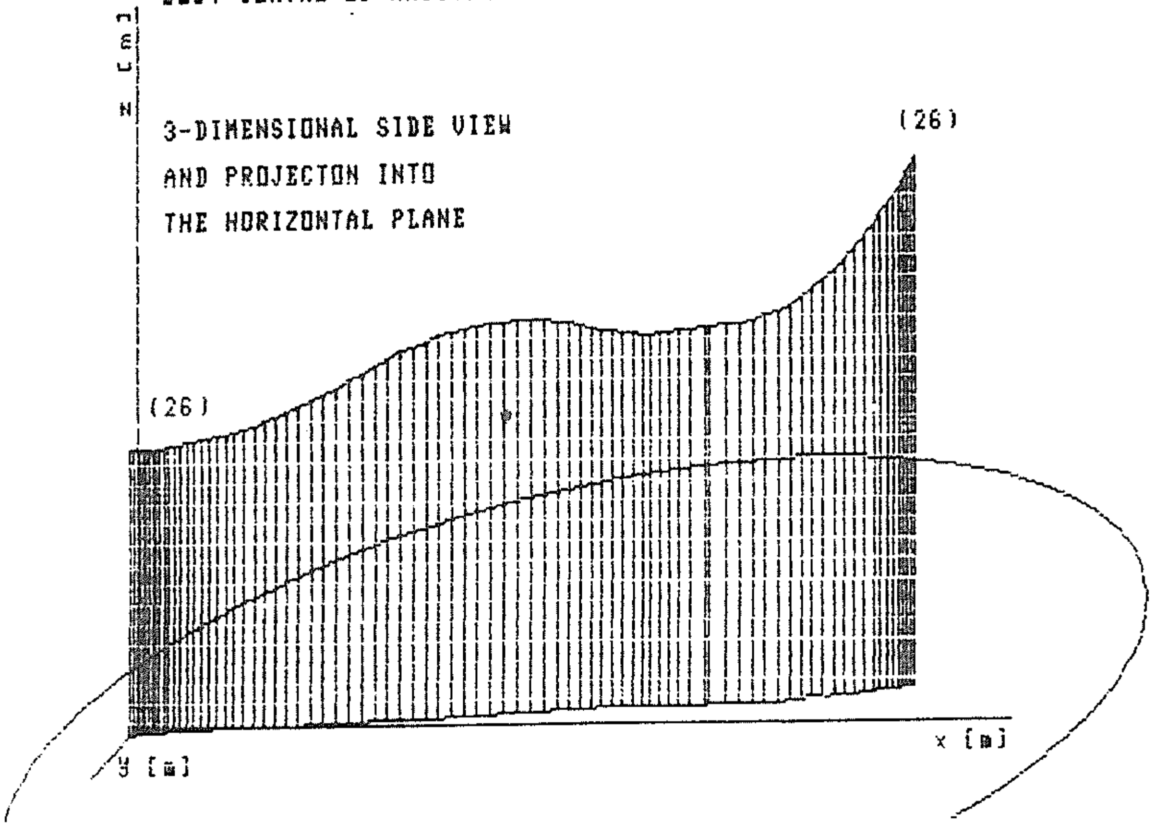


FIG 11-0

NEIMKE 21.21 m

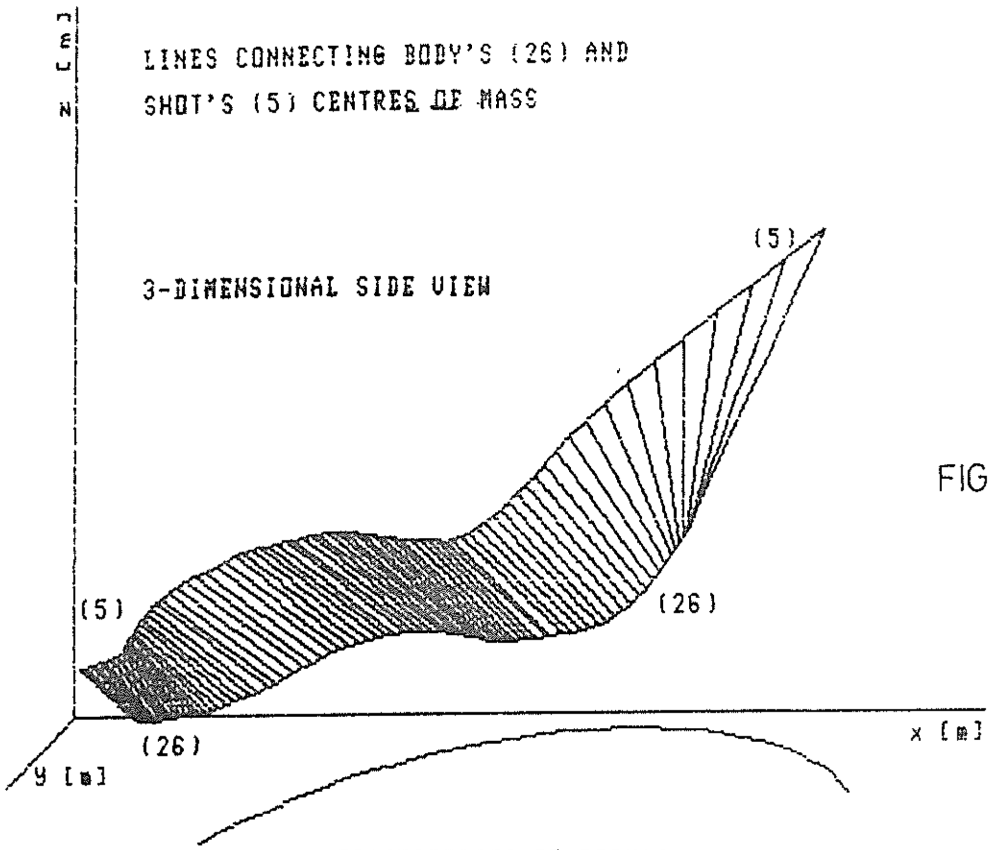


FIG 12-0

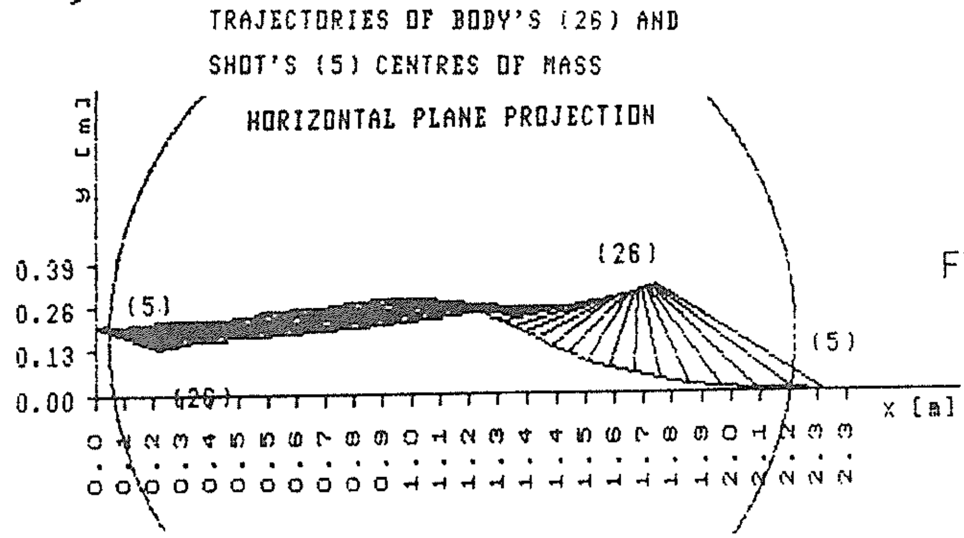


FIG 13-0

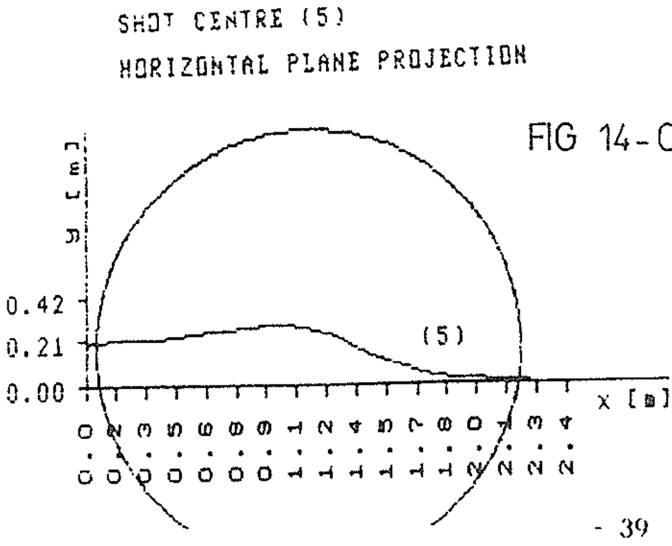


FIG 14-0

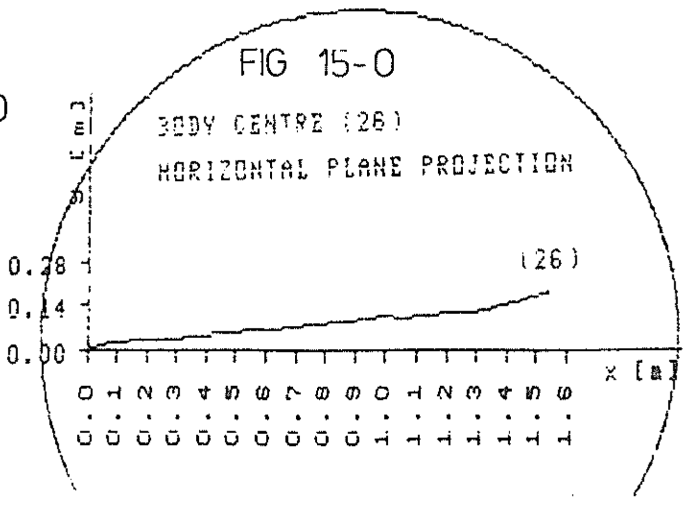


FIG 15-0

MUELLER 20.76 m

SHOT CENTRE OF MASS(5)

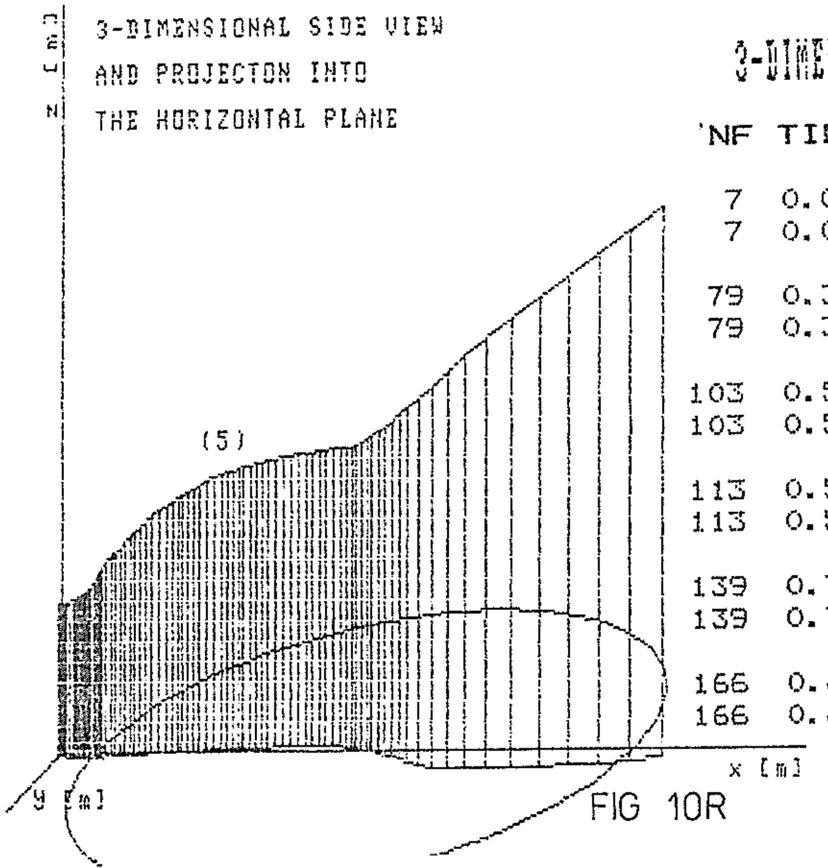


FIG 10R

3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
7	0.03	5	-1200	-9	589
7	0.03	26	-849	-62	515
79	0.39	5	-706	40	996
79	0.39	26	-275	-34	782
103	0.52	5	-424	71	1090
103	0.52	26	-24	-20	791
113	0.57	5	-288	87	1109
113	0.57	26	69	-15	778
139	0.70	5	63	24	1229
139	0.70	26	349	15	828
166	0.84	5	1038	-12	1990
166	0.84	26	522	66	1008

BODY CENTRE OF MASS(26)

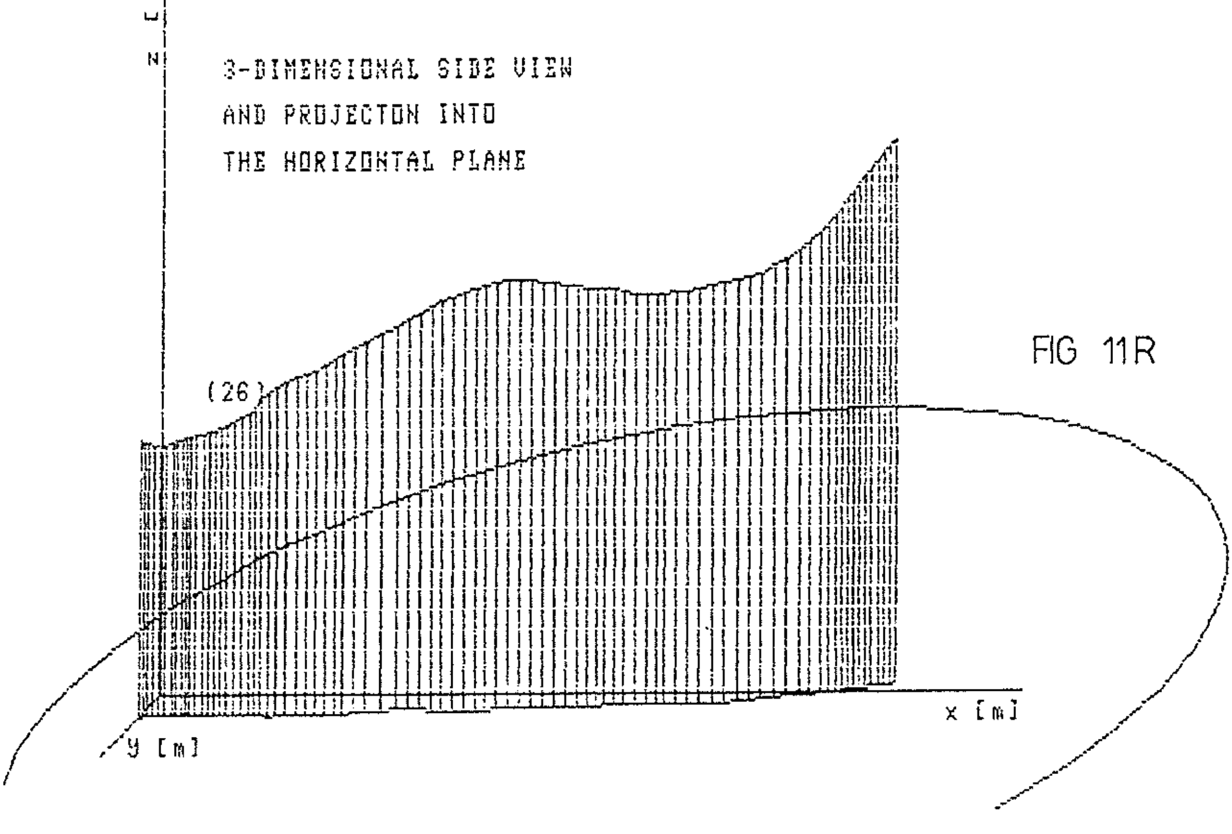


FIG 11R

MUELLER 20.78 m

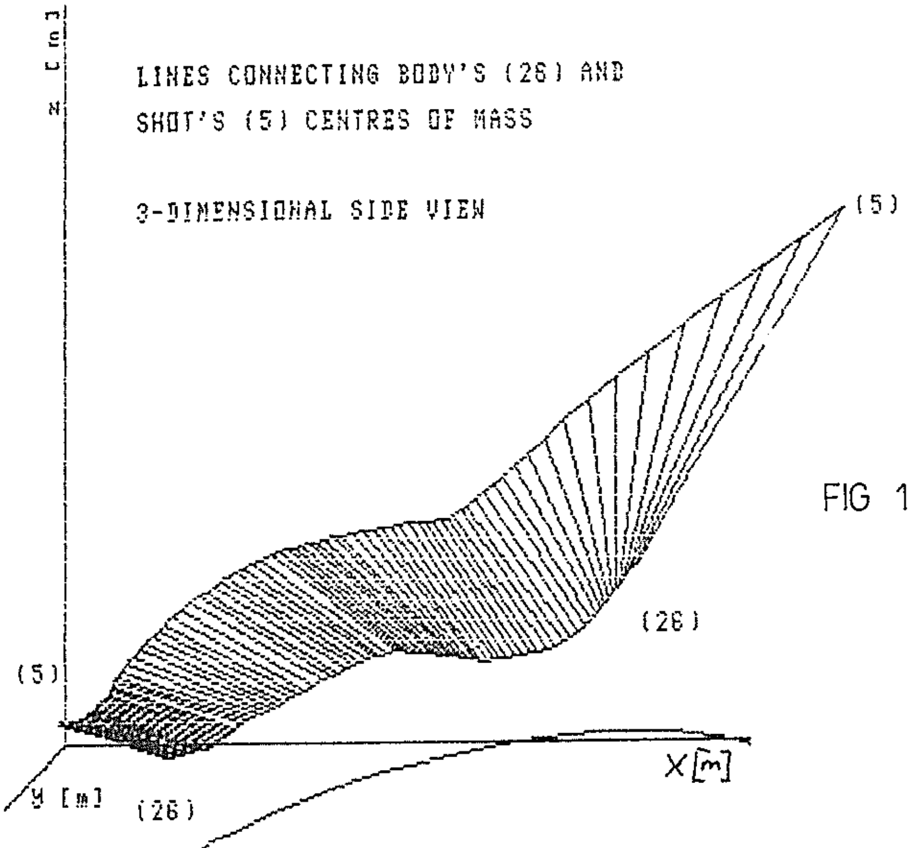


FIG 12R

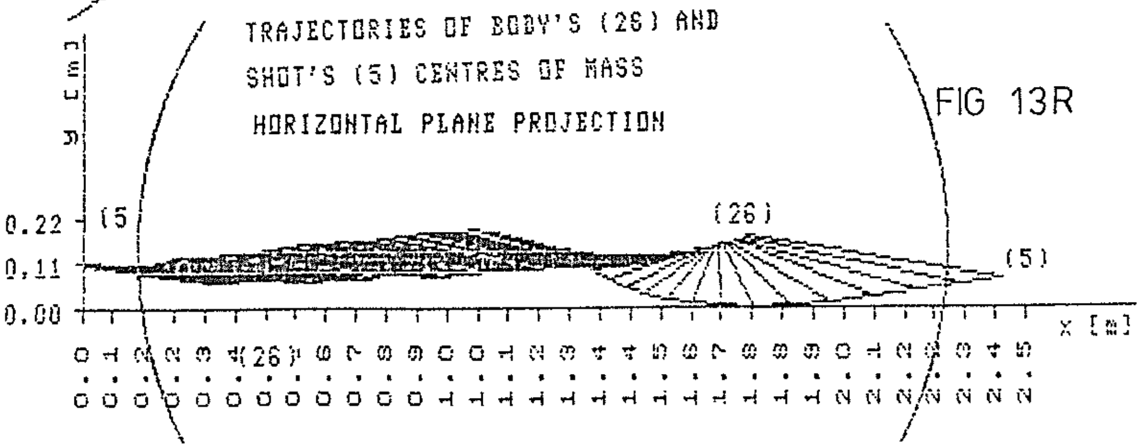


FIG 13R

SHOT CENTRE (5)
HORIZONTAL PLANE PROJECTION

FIG 14R

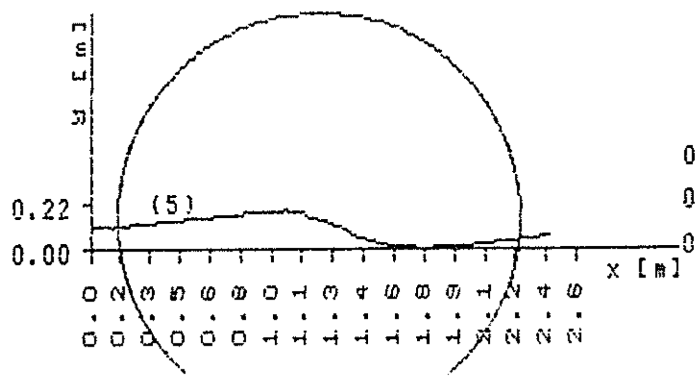
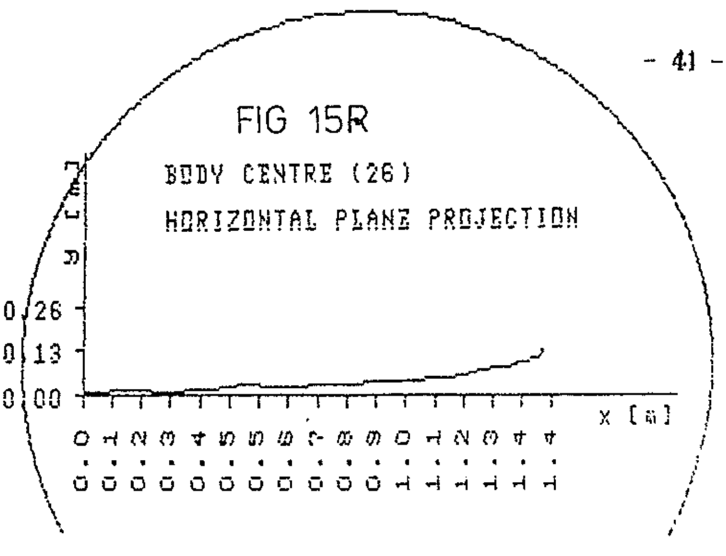


FIG 15R



LOSCH 20.73 m

SHOT CENTRE OF MASS(5)

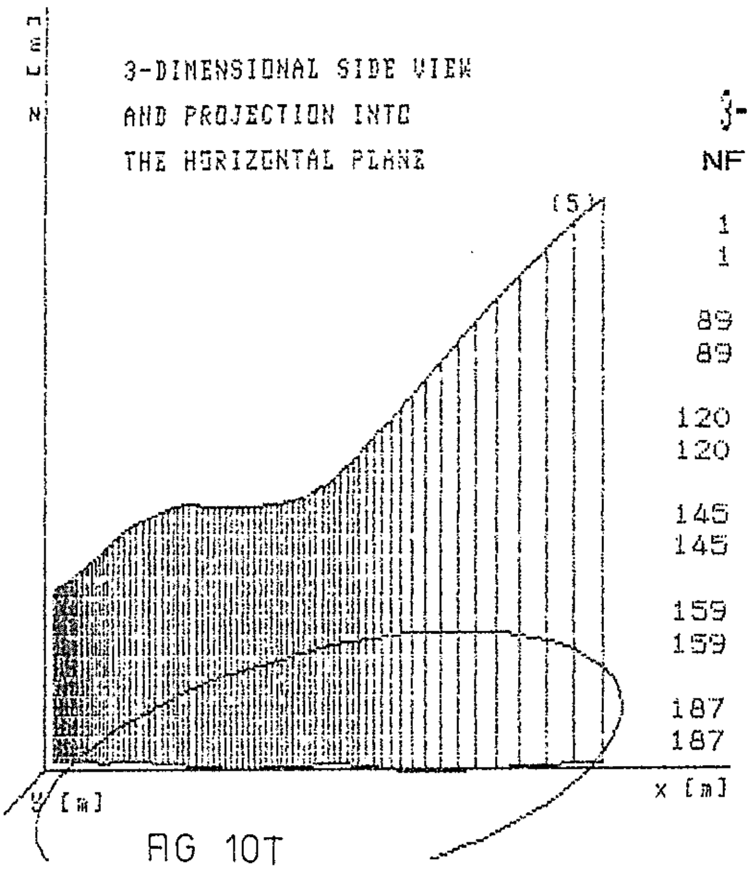


FIG 10T

3-DIMENSIONAL COORDINATES [mm]

NF	TIM	IP	X:	Y:	Z:
1	0.00	5	-1150	65	638
1	0.00	26	-907	-13	619
89	0.44	5	-728	48	971
89	0.44	26	-368	35	836
120	0.60	5	-339	-1	1029
120	0.60	26	-31	54	860
145	0.73	5	-65	28	1074
145	0.73	26	203	105	856
159	0.80	5	119	20	1219
159	0.80	26	351	150	916
187	0.95	5	979	32	2112
187	0.95	26	552	224	1125

BODY CENTRE OF MASS(26)

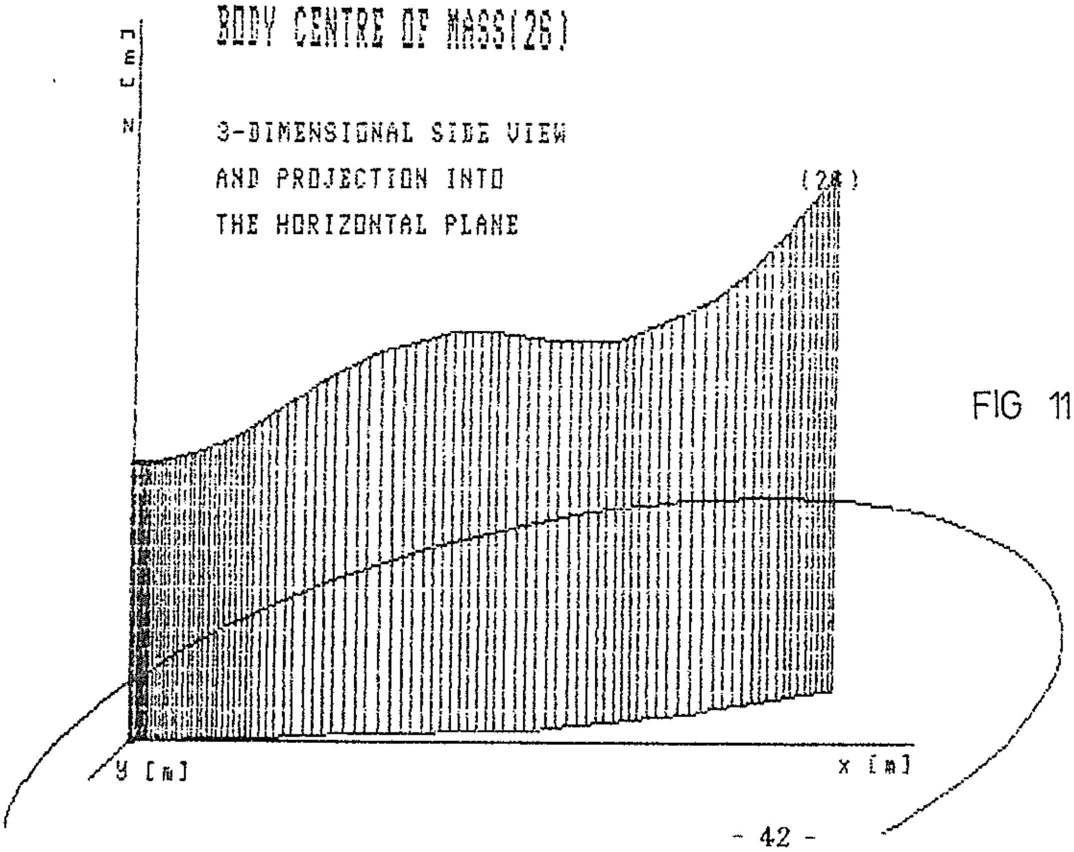


FIG 11T

LOSCH 20.73 m

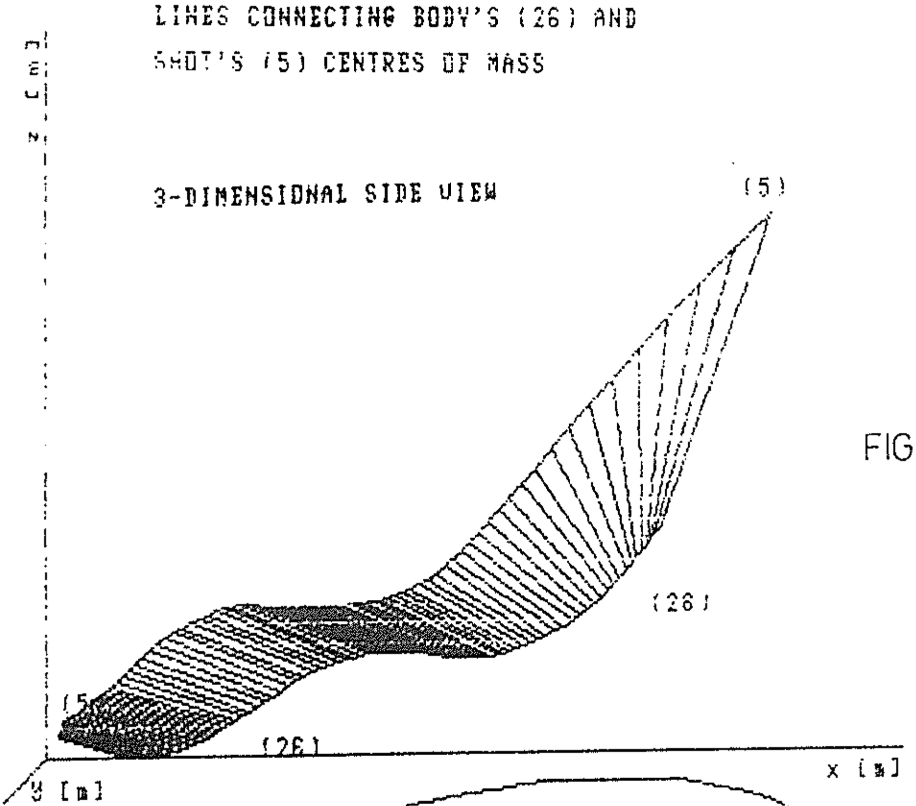


FIG 12 T

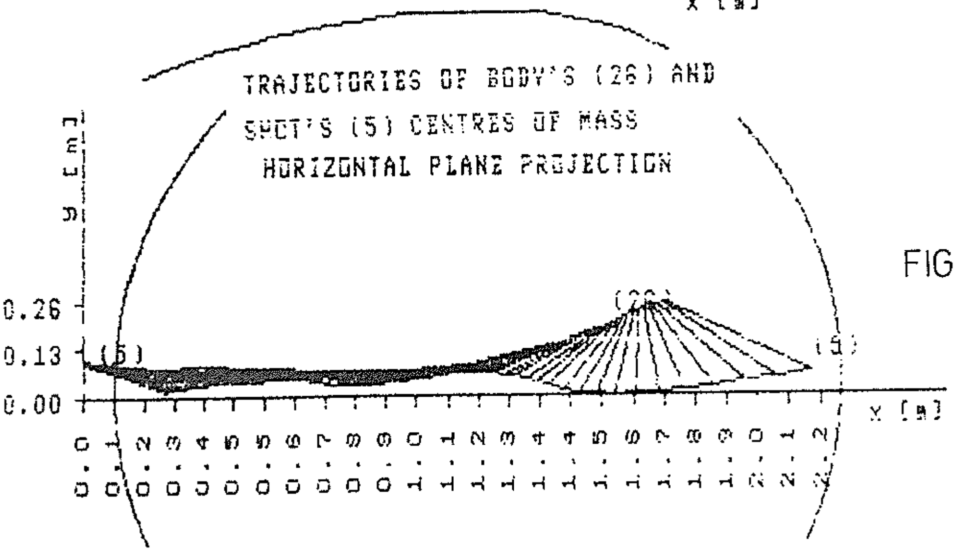


FIG 13T

FIG 14T

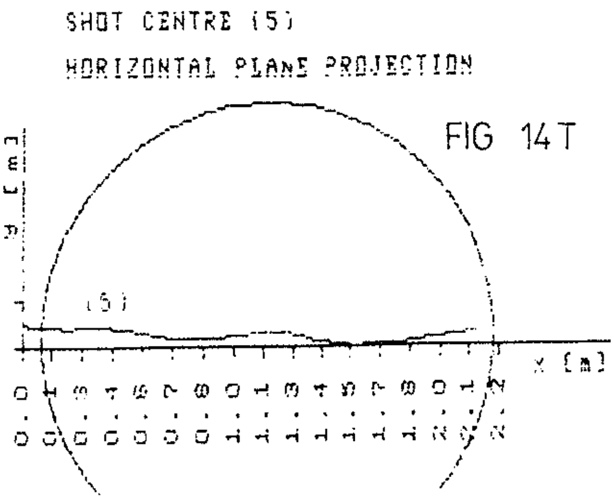
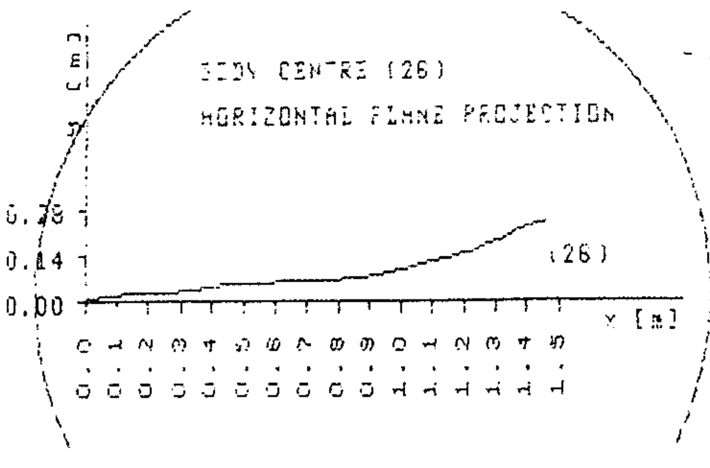


FIG 15T



4.1.3. Vertical positions (height z) of the centre of the shoulder axis, pelvis and body CM

The course of the height of the centre of the shoulder axis, pelvis and body centre of mass over the ground (shot circle) in time (z_{24} (t); z_{25} (t); z_{26} (t)) is another parameter, that facilitates the evaluation of the action in the shot put. This parameter easily visible in a videorecording, can- even without further biomechanical analysis at point 24 (centre of line connecting the shoulder joints) and 25 (centre of line connecting the hips joints) - draw our attention to differences in technical execution, and to the advantages or technical shortcomings of each trial.

Among the men, the variant of a marked trunk lean, when the centre of the shoulders axis, after having reached the z_{min} position, gets under the level of body CM, was used only by Timmermann. Among the women, again obviously due to their anthropometric conditions, this variant appears more often: Lisovskaya, Mueller, Losch, Vasickova. Close to this variant are Guenthoer, Machura, Bodenmueller, Gavriushin and among the women, Neimke.

A piked body position (i.e. with the trunk CM lower than the centre of the line connecting the hip joints) is used in the starting phase by Andrei, Brenner, Machura, Beyer, Bodenmueller and Gavriushin, and by all the women.

The effort to keep the body CM as low as possible shows up in the fact that the height of the body CM is lower than the height of the pelvis centre ($z_{26} < z_{25}$) as late as 0.35 s before release. E.g . for Guenthoer 0.33 s, i.e. at the moment of the right foot landing (R↓). Timmermann holds this position even before the landing of the left foot (L↓) and Machura until the delivery phase proper (0.25 s before release). From Fig. 16 C,D it can be seen that from this point of view Andrei probably commits an error and lifts the total body CM too soon (0.4 s before release). In current coaching terminology - he opens the trunk position prematurely. Similarly, (as in other sections of this report) other relationships could be derived from the functional courses, but the limited extent of this study does not allow it. Further proceeding is suggested in Section 5.

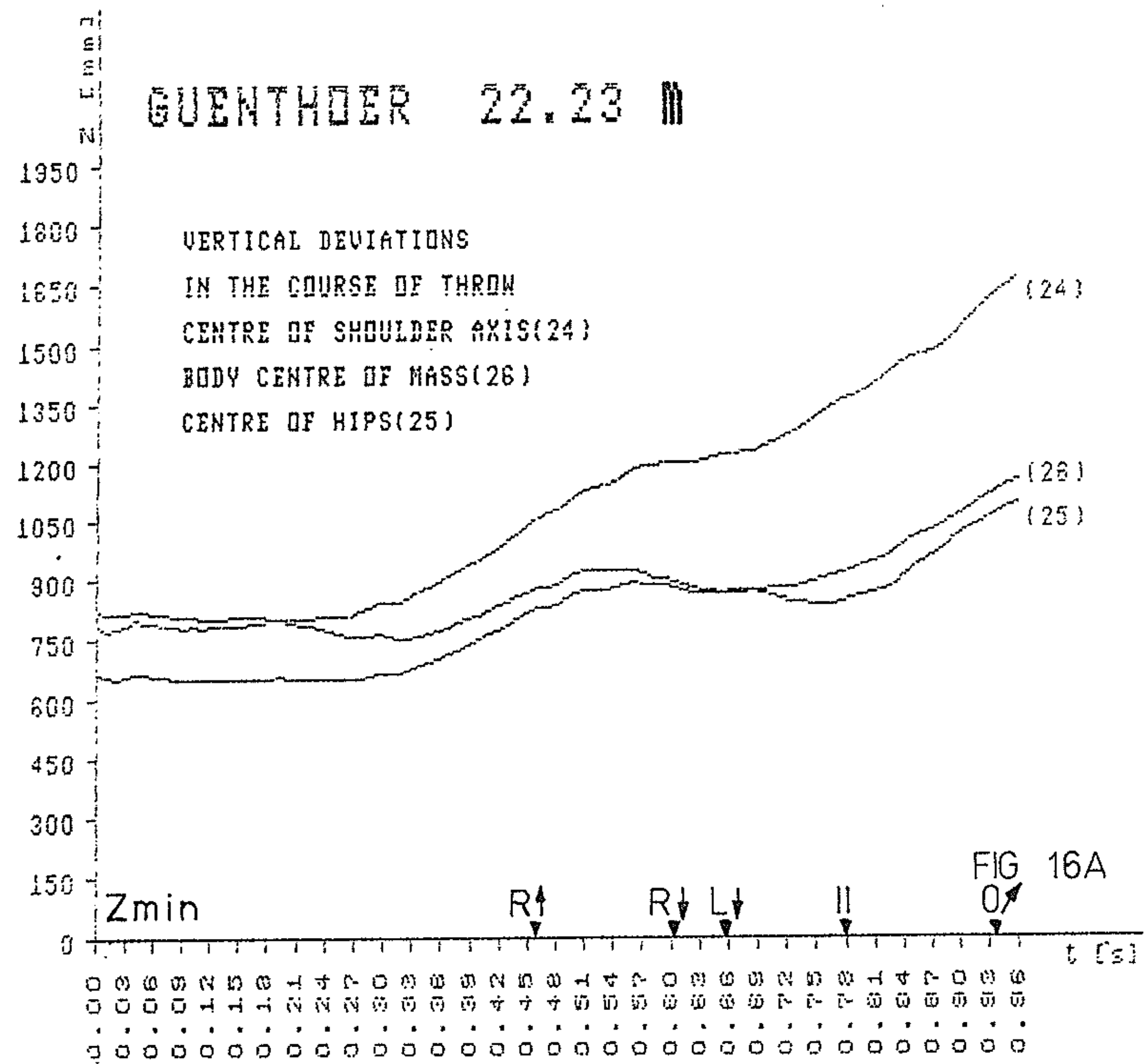


FIG 16A

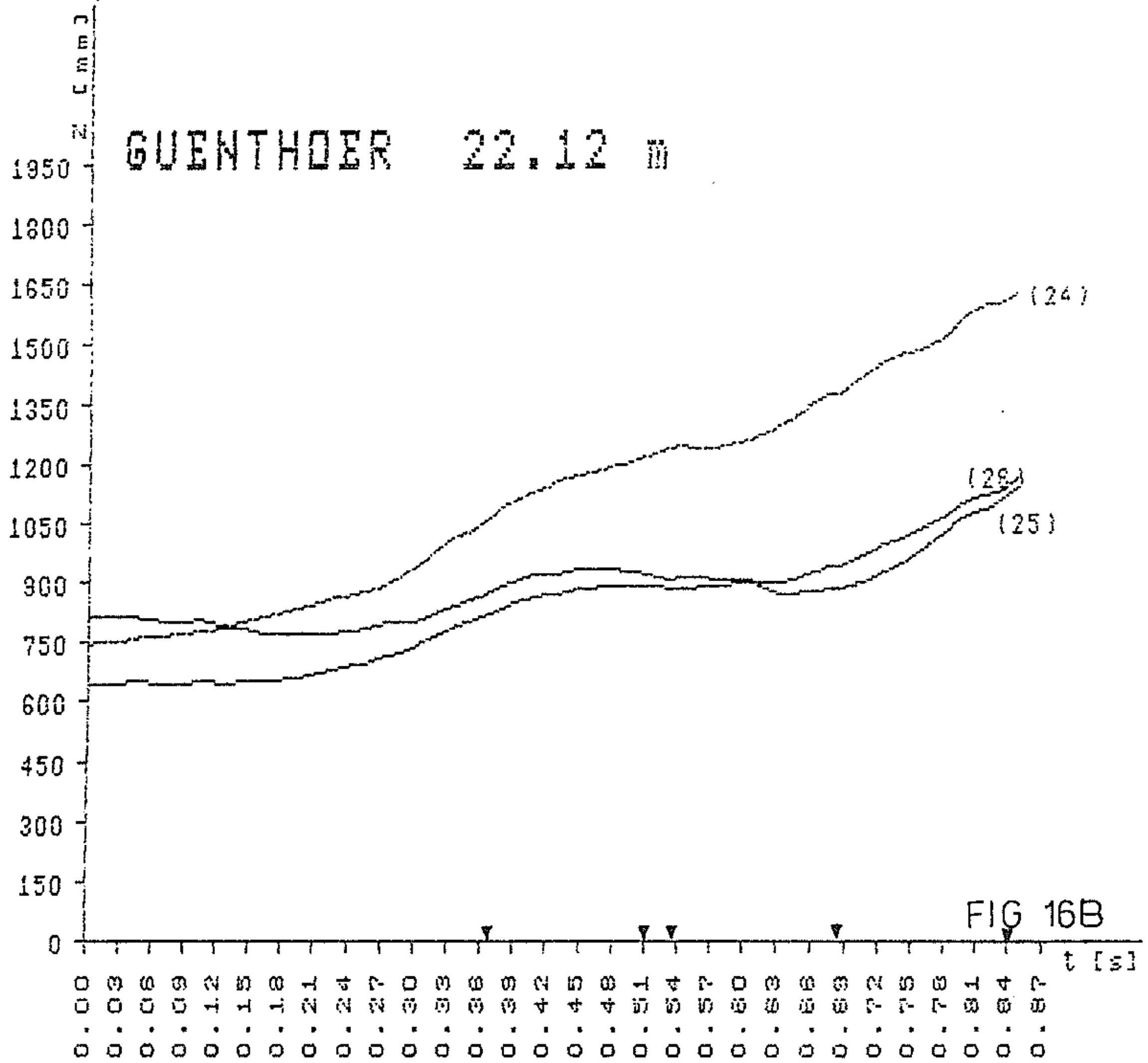


FIG 16B

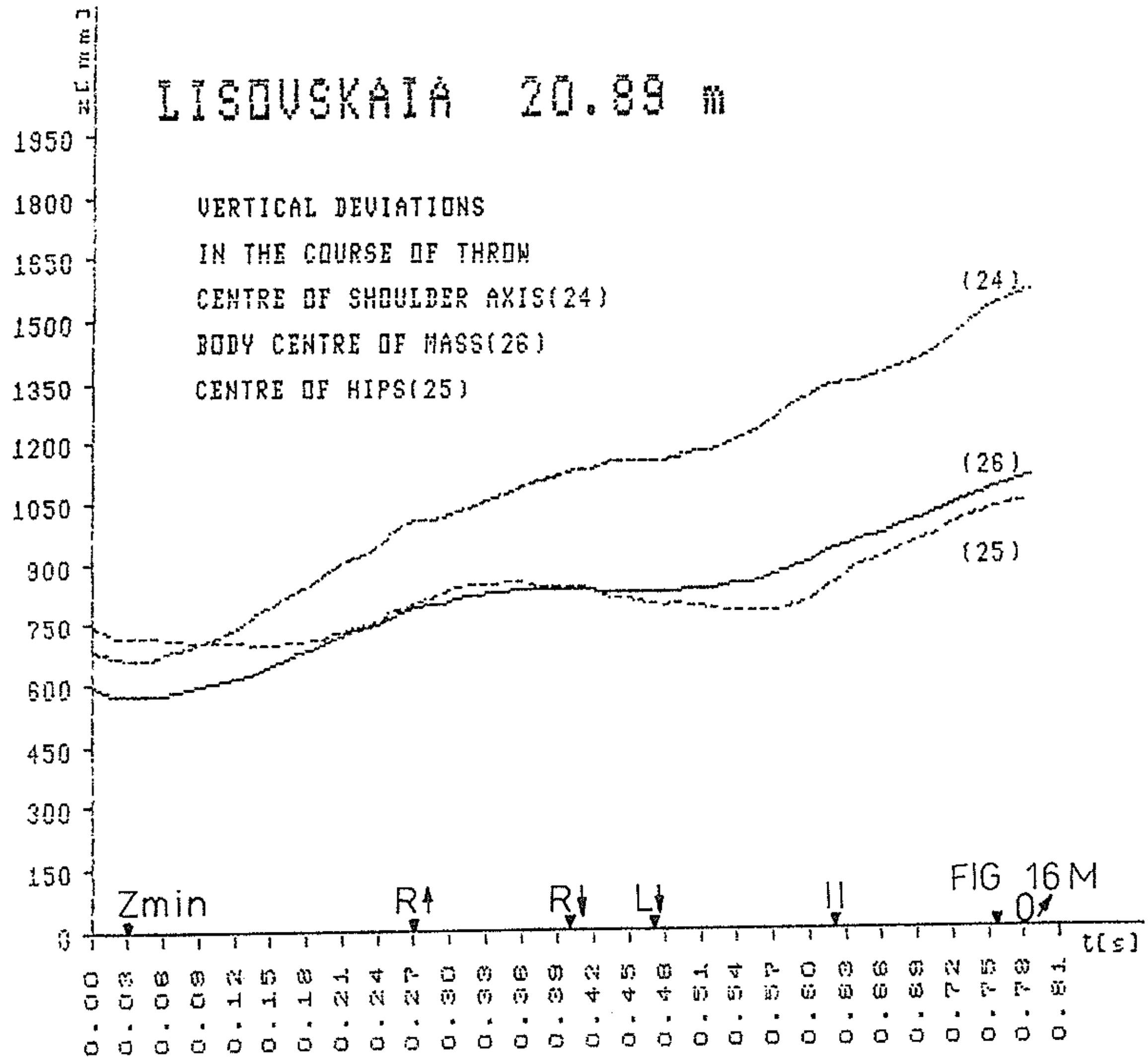


FIG 16 M

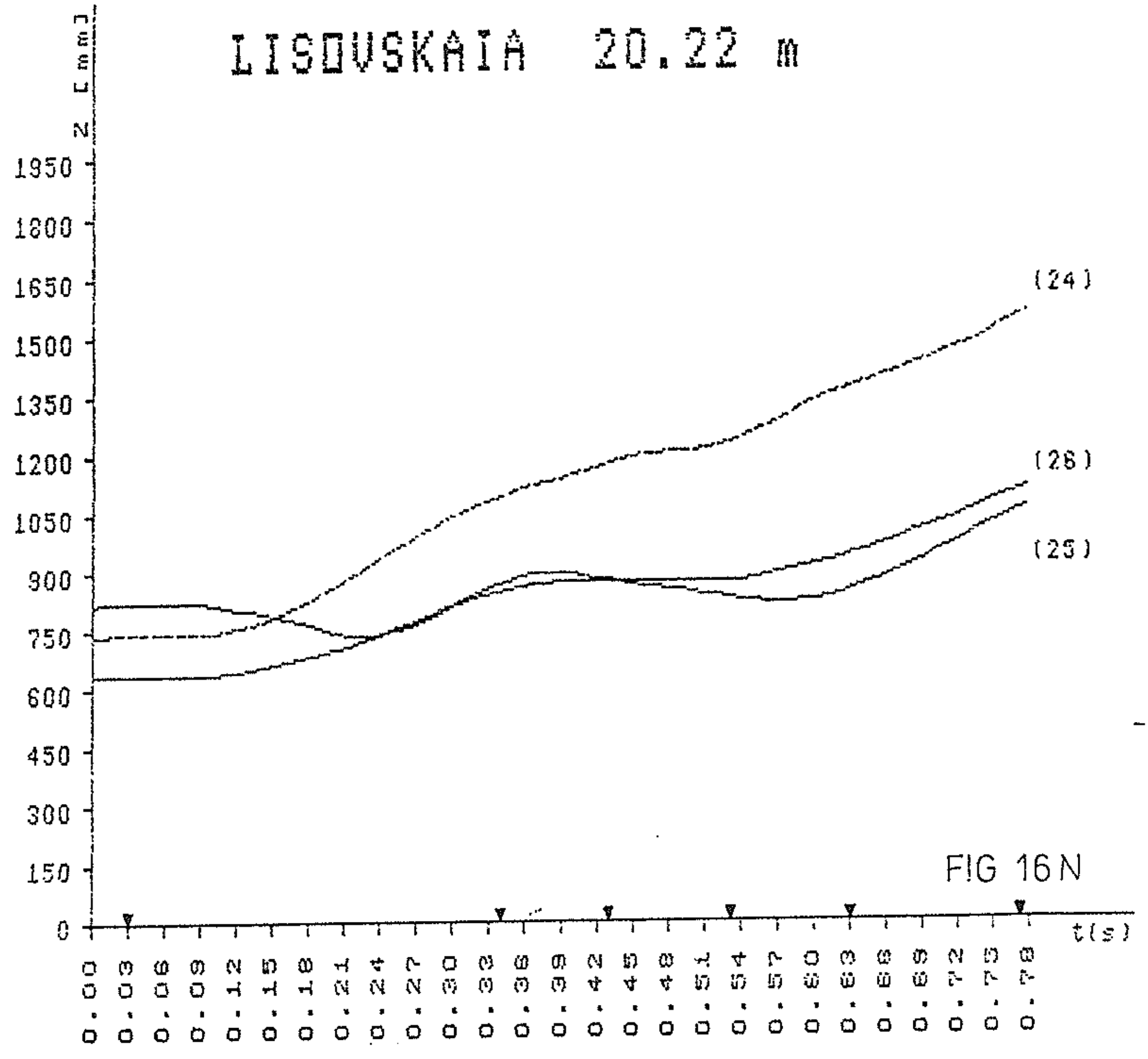


FIG 16 N

4.1.4. Deviation of the trunk in relation to the pelvis

(i.e. of the centre of the line connecting the shoulder joints in relation to the centre of the line connecting the hip joints in ground projection)

A comprehensive investigation of the characteristic traits of movements in the pelvis and shoulder area during the put can be provided by means of :

- the space angle betwen the shoulder axis and pelvic axis (17 A to Z);
- the x_i , y_i coordinates (of the centre of the line connecting the shoulder joints) in relation to the coordinate system introduced in the pelvic axis in ground projection (definition see Section 3, Fig. 5, definite values Fig. 18 A to Z);
- the changes in the position of the line connecting the centres of the shoulder joints projected into the elevation, front plane (Fig. 20 A) and ground plane (Fig. 21 A);
- the changes in the position of the line connecting the centres of the hip joints projected into the elevation, front plane (Fig. 22 A) and ground plane (Fig. 23 A);
- the space angles of pelvic axis and shoulder axis in relation to the planes XZ (Fig. 24 A), XY (Fig. 25 A) and XZ (Fig. 26 A).

Some relations need a greater spatial imagination and a broader and more simplified interpretation for application in practice. They are mentioned here only as examples (Figs 24 , 25 , 26 A). Similarly, in investigating the lines connecting the centres of shoulder and hip joints (Figs 20 A to 23 A), due to the limited possibilities, we confine ourselves to one example, namely Guenthoer's trial of 22.23m. Because all the relations mentioned above possess obvious information value, we suggest a further proceeding for their utilization in Section 5.

Magnitude of the space angle is influenced by:

- during the glide (R↑ - R↓), primarily by the rotation of the pelvis and possibly by premature rotation of the shoulder axis;
- after the glide end (R↓), by the rotation of the pelvis but primarily by the action of the left shoulder joint (6) (its lift and rotation with a simultaneous effort to maintain the lowered position ot the implement and the right shoulder (2));
- primarily after the landing of the left foot (L↓) (or even later) by pushing the shot and shifting the shoulder axis into the horizontal position (angle γ decreases).

Significant differences between putters and identical characteristic elements in various individual trials are demonstrated clearly in the following tables derived from Figs 17, 18 A to Z.

Differences in individual execution characterize the variance range in the selected key moments of the put.

For angle γ (°)

		MEN	WOMEN
	R↓	22° - 84°	27° - 102°
	L↓	18° - 84°	37° - 104°
	‖	18° - 44°	22° - 51°
	O/	-28° - 12°	-21° - 0°

Concerning the deviation of the centre of the line connecting the shoulder joints (24) in relation to the pelvic axis, similar differences can be found:

For y_i (m)	R↓	0.25 - 0.45	0.09 - 0.48
	L↓	0.17 - 0.39	0.07 - 0.28
	‖	-0.20 - -0.02	-0.21 - -0.05
	O/	0.00 - 0.10	-0.7 - 0.13

The shift of the centre of the line connecting the shoulder joints (24) in relation to the centre of the line connecting the hip joints (25) occurs in the following variation range:

For x_i (m)	R↓	0.12 - 0.30	0.17 - 0.47
	L↓	0.13 - 0.34	0.23 - 0.41
	‖	0.04 - 0.24	0.08 - 0.20
	O/	-0.15 - -0.01	-0.20 - -0.03

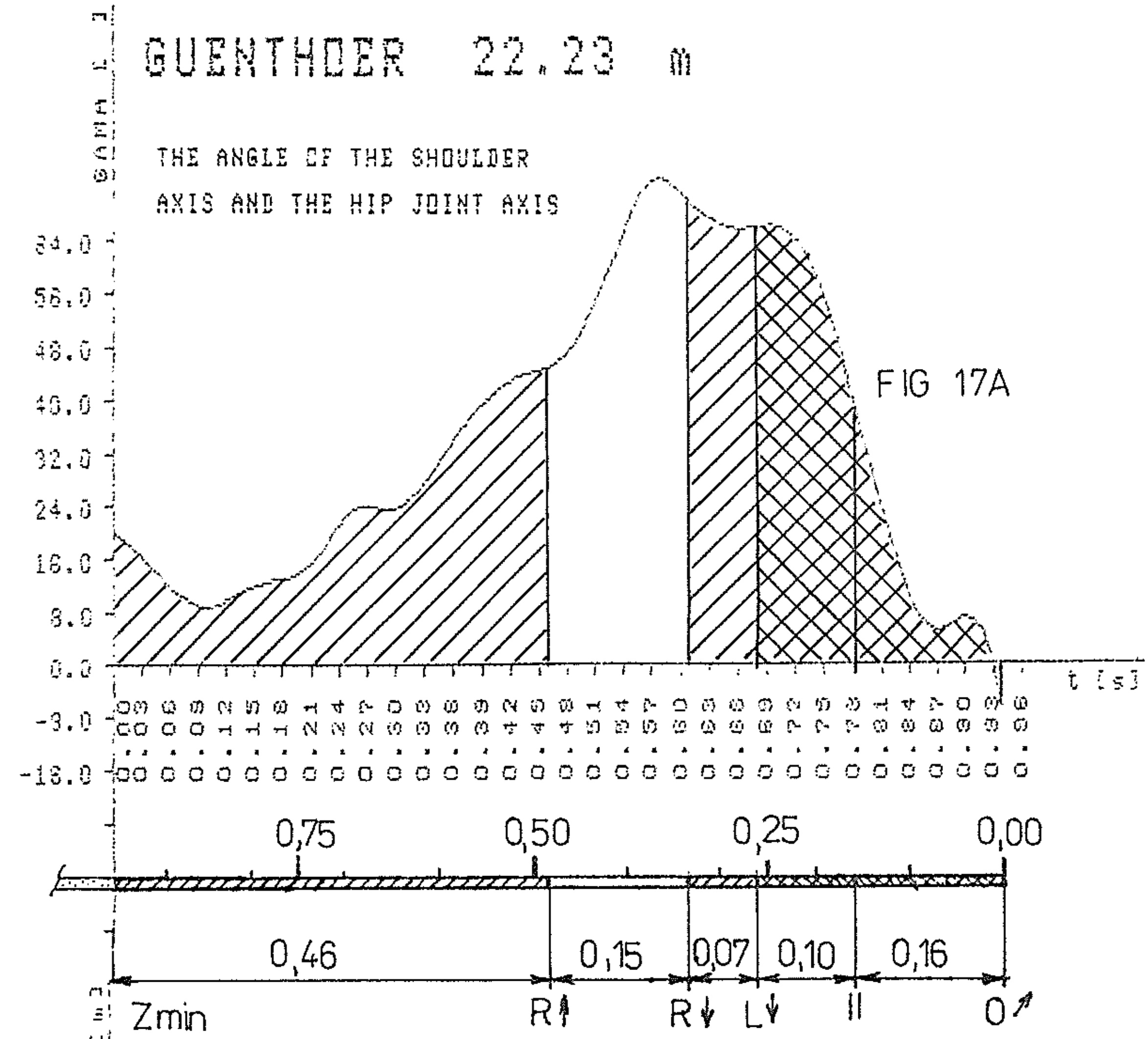
A great space deviation of the shoulder axis in relation to the pelvic axis (near R↓ greater than 70°) is reached by Guenthoer, Brenner and Beyer. Conversely Andrei, Machura, Timmermann and Lisovskaya reach a deviation of less than 50° in the course of the whole delivery. Active action of the trunk and shoulders followed up by the quick extension of the arm with the shot while the pelvic axis rotates approximately in the horizontal plane, is expressed by the step curve γ (t) in phases (L↓ - ‖ - O/). Differences between Guenthoer and Mueller and other putters are more than noticeable.

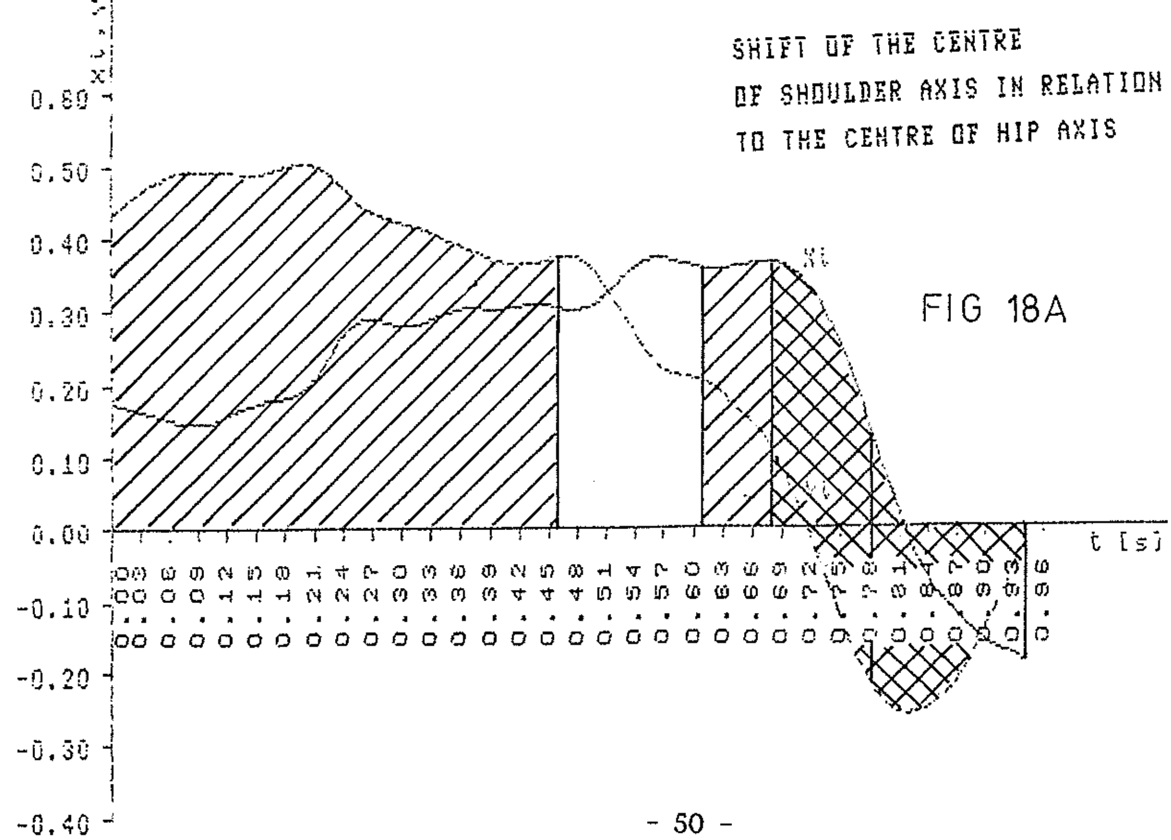
Simplifying to a certain extent we can ask the question: was the kinetic energy of the body transmitted into the kinetic energy of the implement? In a positive case the values of γ, y_i and probably x_i should approximate to zero or, in the case of x_i, to some constant value.

In the area of (‖), when the pelvic axis gets into a position parallel with the putting axis, the centre of the line connecting the shoulder joints (24) in relation to the pelvis indicates a moderate backward lean of the putter who, in the delivery phase, (‖ - O/) gets into the vertical position (y_i = 0). Where the putter' s trunk continues incorrectly in its movement, following the implement (see e.g. Beyer in Fig. 18 J), we find a greater increment of the positive component y_i.

Angle γ and the magnitude of the deviation x_i in the phases (L↓ - ‖ - O↗) indicate how much the trunk rotation and shot lift (x_i) were utilized for achieving a higher velocity in these phases and acceleration of the implement in the final phase of delivery. This is a distinctly different execution, a positive one in our opinion, which is demonstrated by Guenthoer in his trials.

In the final phase of delivery, the shift of the centre of the line connecting the shoulder joints (24) in relation to the centre of the line connecting the hip joints (25) (x_i value) makes it possible to conclude whether a shift of the shoulder axis occurred (in the direction of the pelvic axis) from the putting direction, or conversely the shift was halted.


GUENTHOER 22.23 m
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
FIG 17A
t [s]
0,75
0,50
0,25
0,00
0,46
0,15
0,07
0,10
0,16
Zmin
R
R
L
II
O


SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18A
t [s]

GUENTHOER 22.23 m

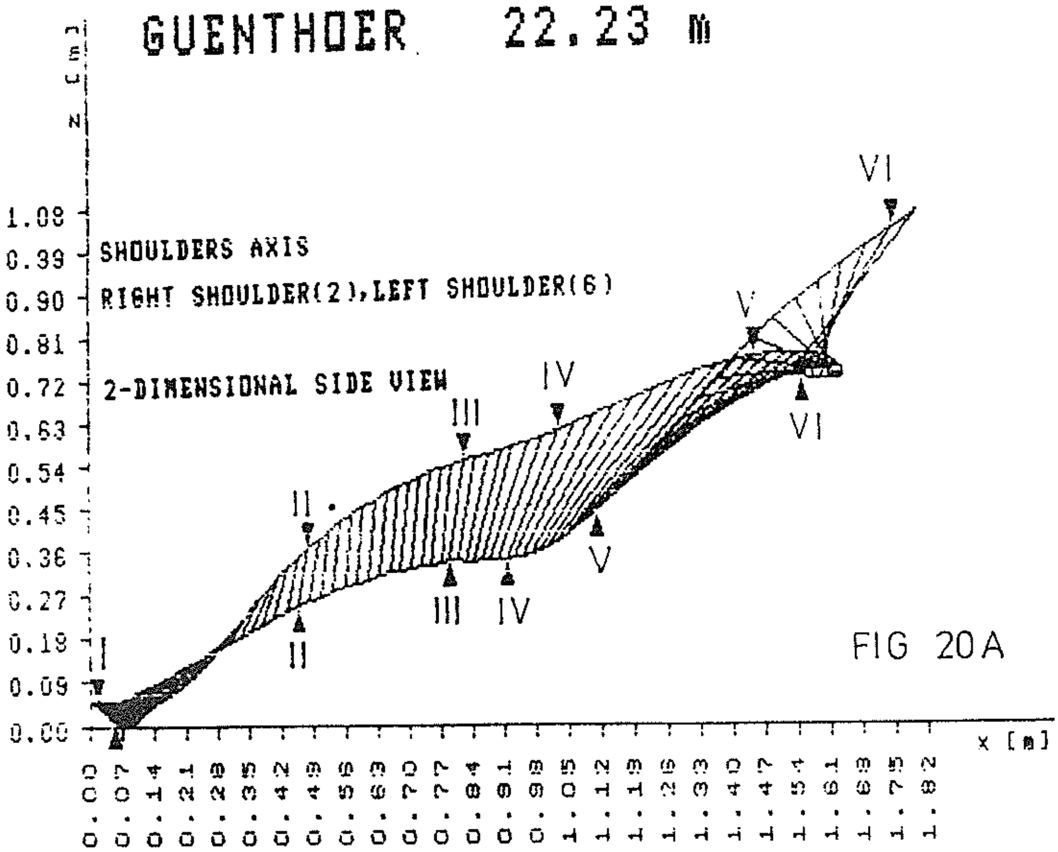


FIG 20A

SHOULDERS AXIS

RIGHT SHOULDER(2),LEFT SHOULDER(6)

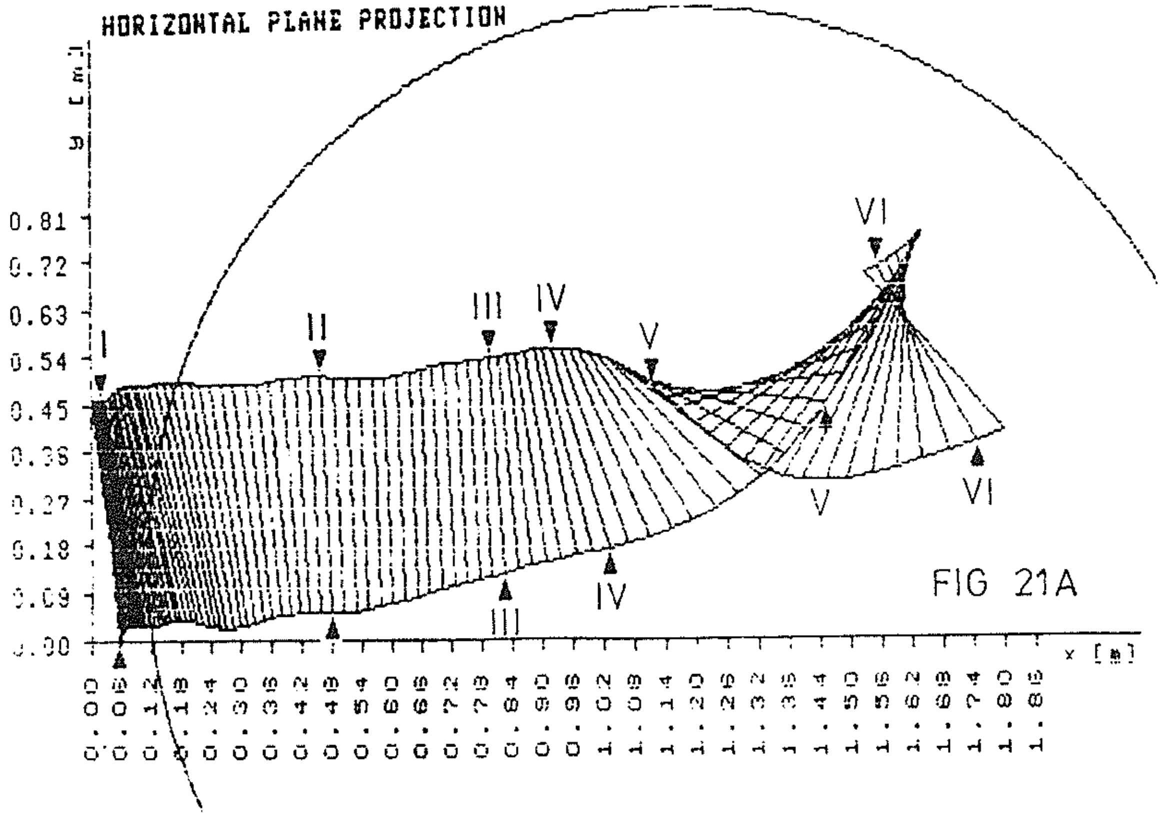


FIG 21A

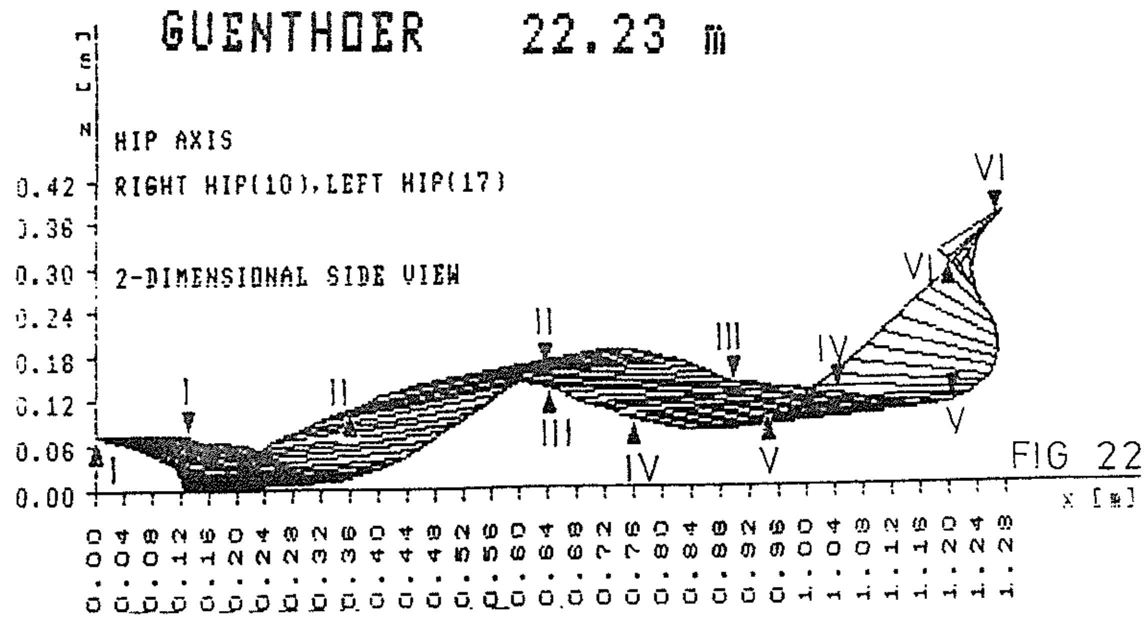


FIG 22A

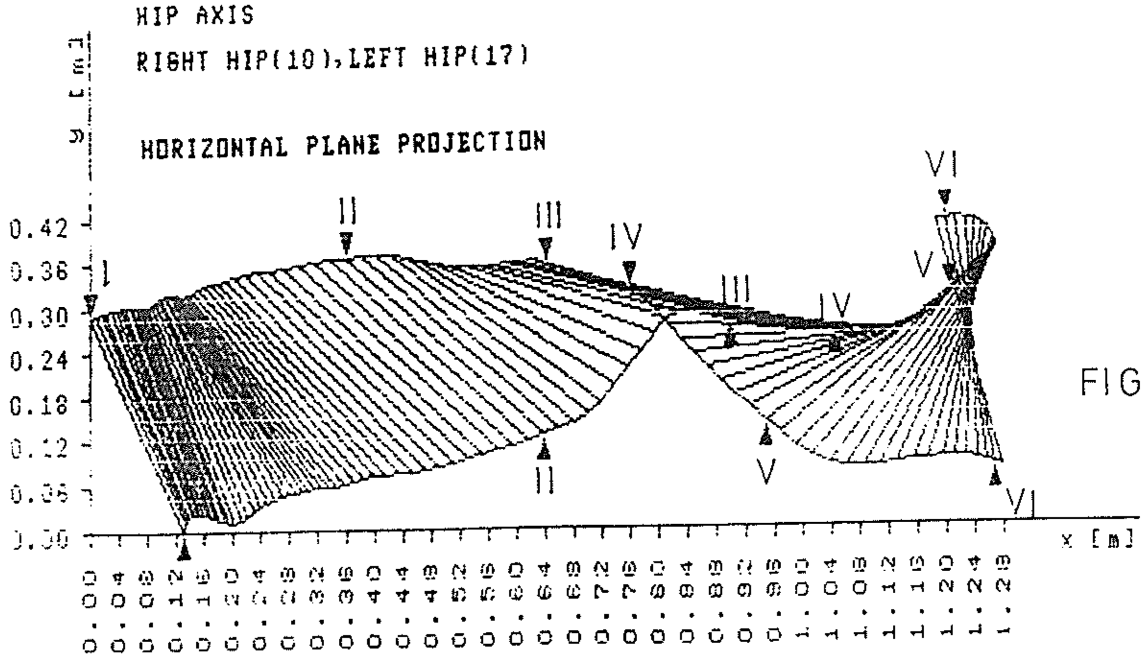


FIG 23A

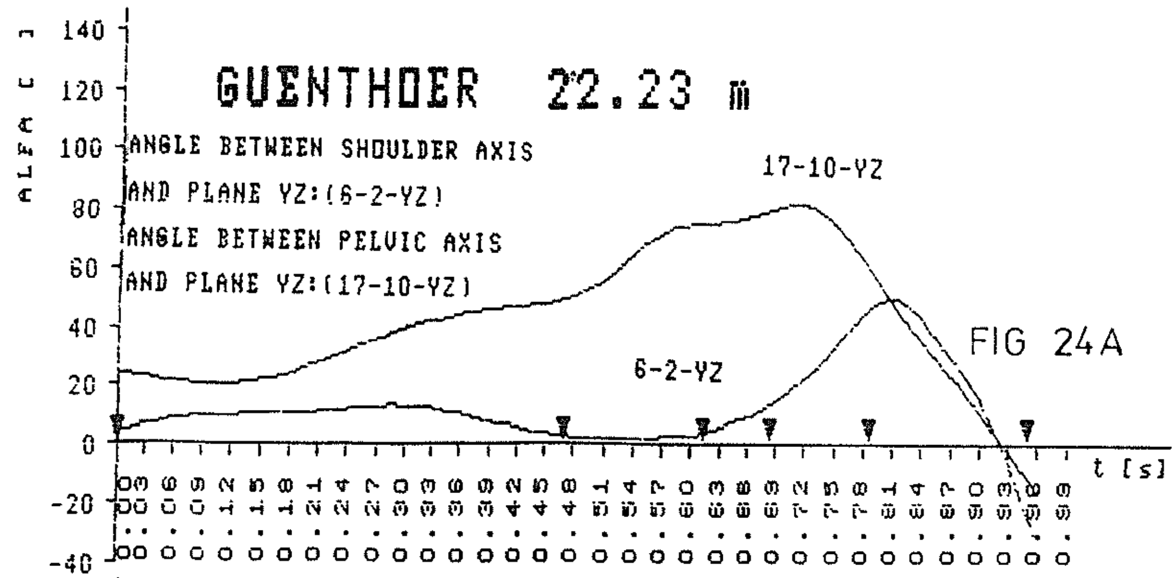


FIG 24A

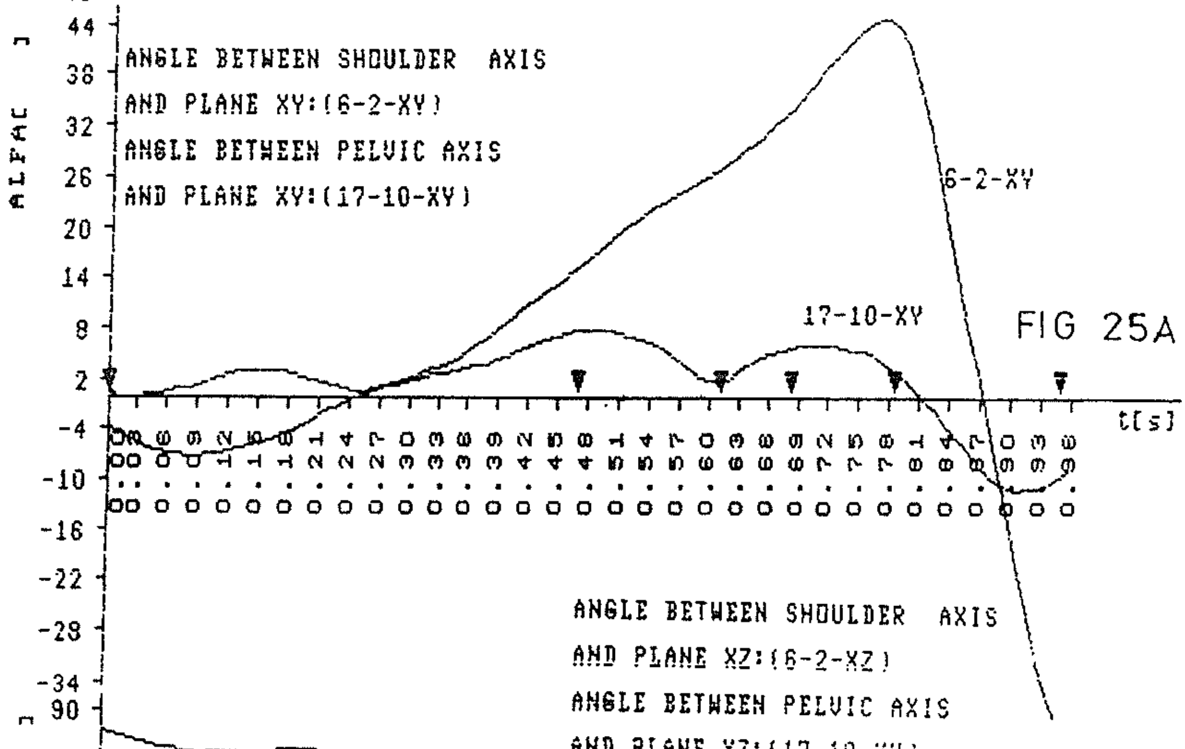


FIG 25A

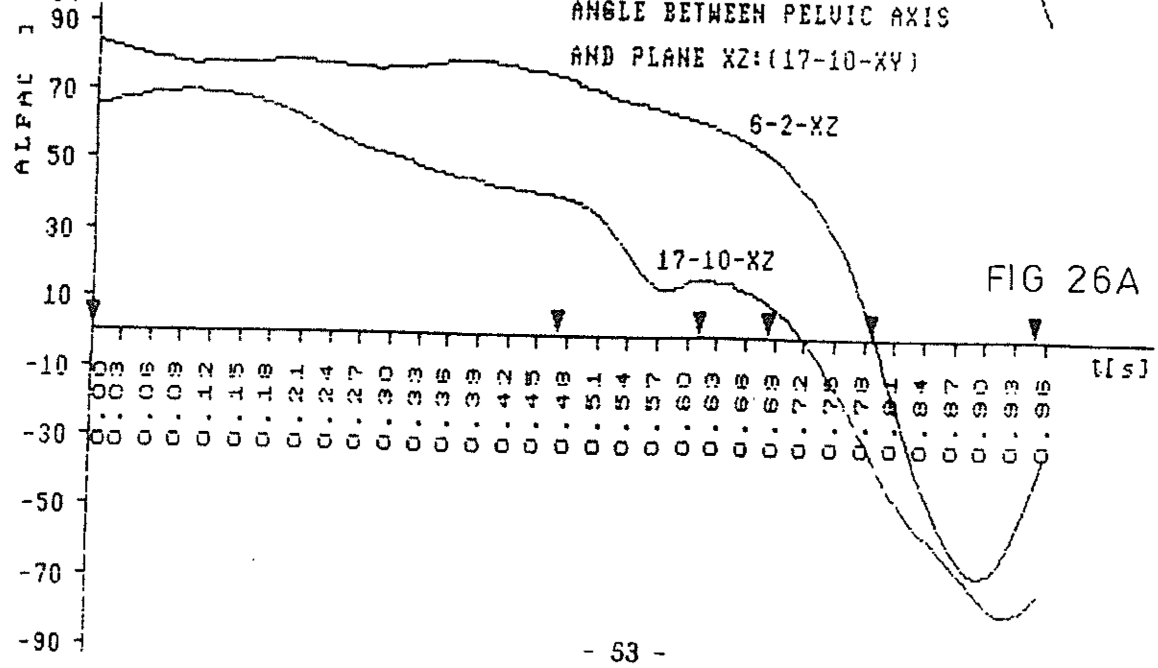
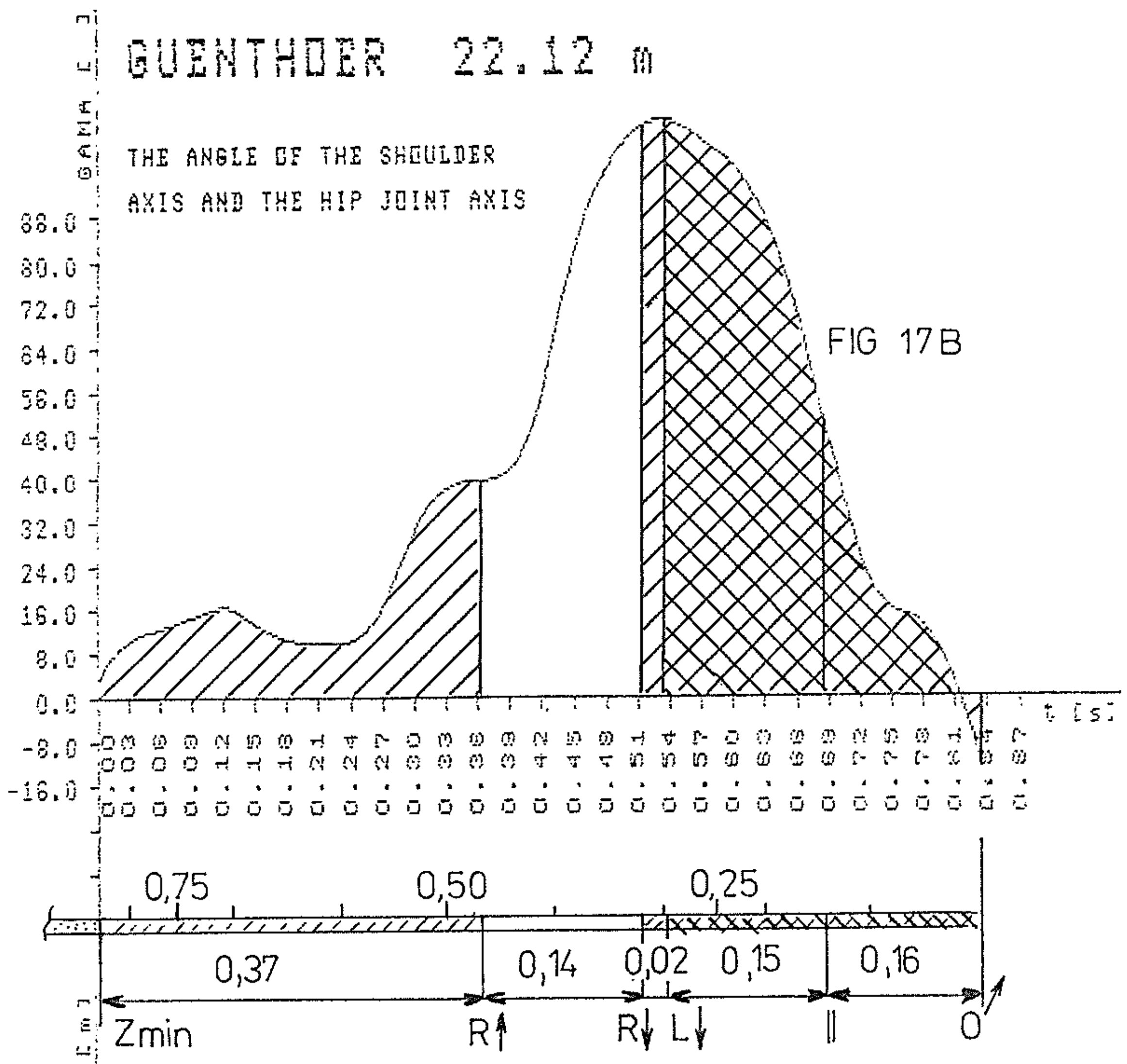
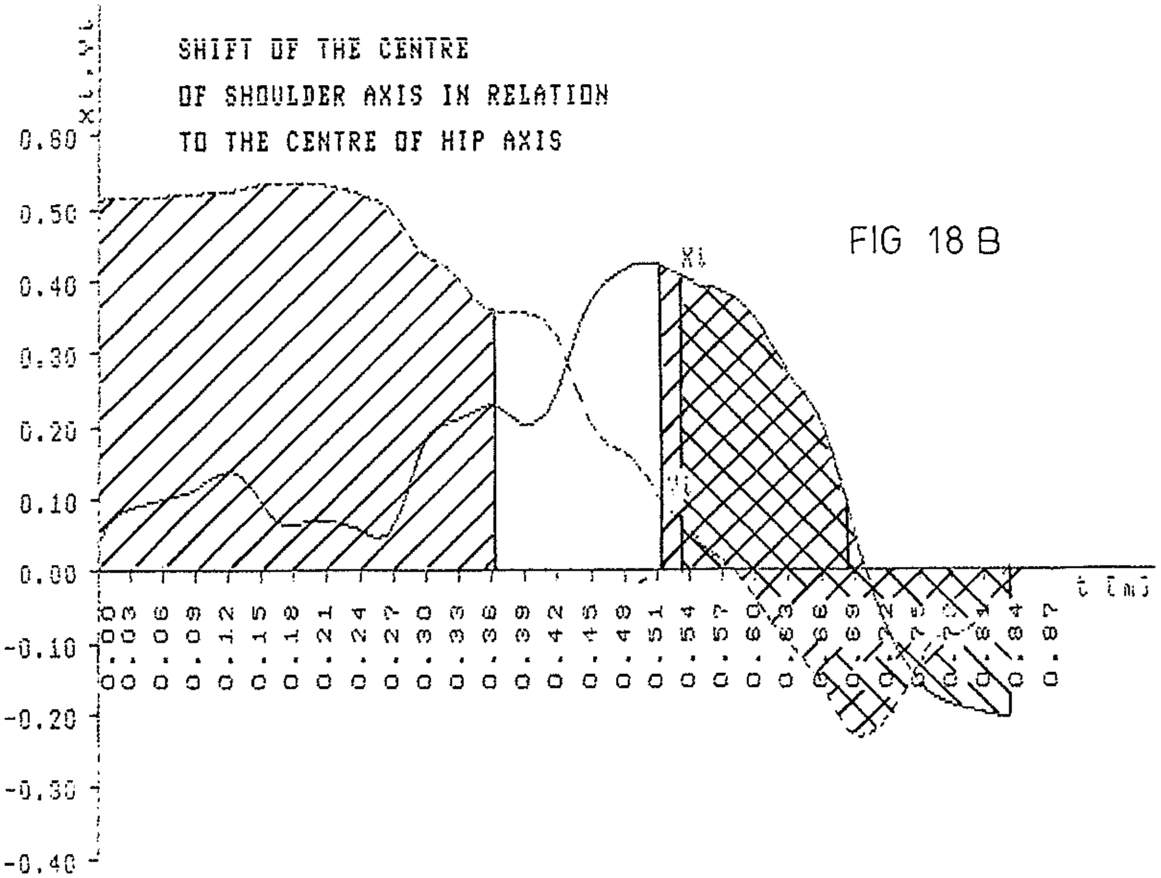


FIG 26A


GUENTHOER 22.12 m
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
GAMA [ ]
FIG 17B
t [s]
0,75
0,50
0,25
0,37
0,14
0,02
0,15
0,16
Zmin
R↑
R↓ L↓
‖
O↗


SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18 B

ANDREI 21.88 m

THE ANGLE OF THE SHOULDER AXIS AND THE HIP JOINT AXIS

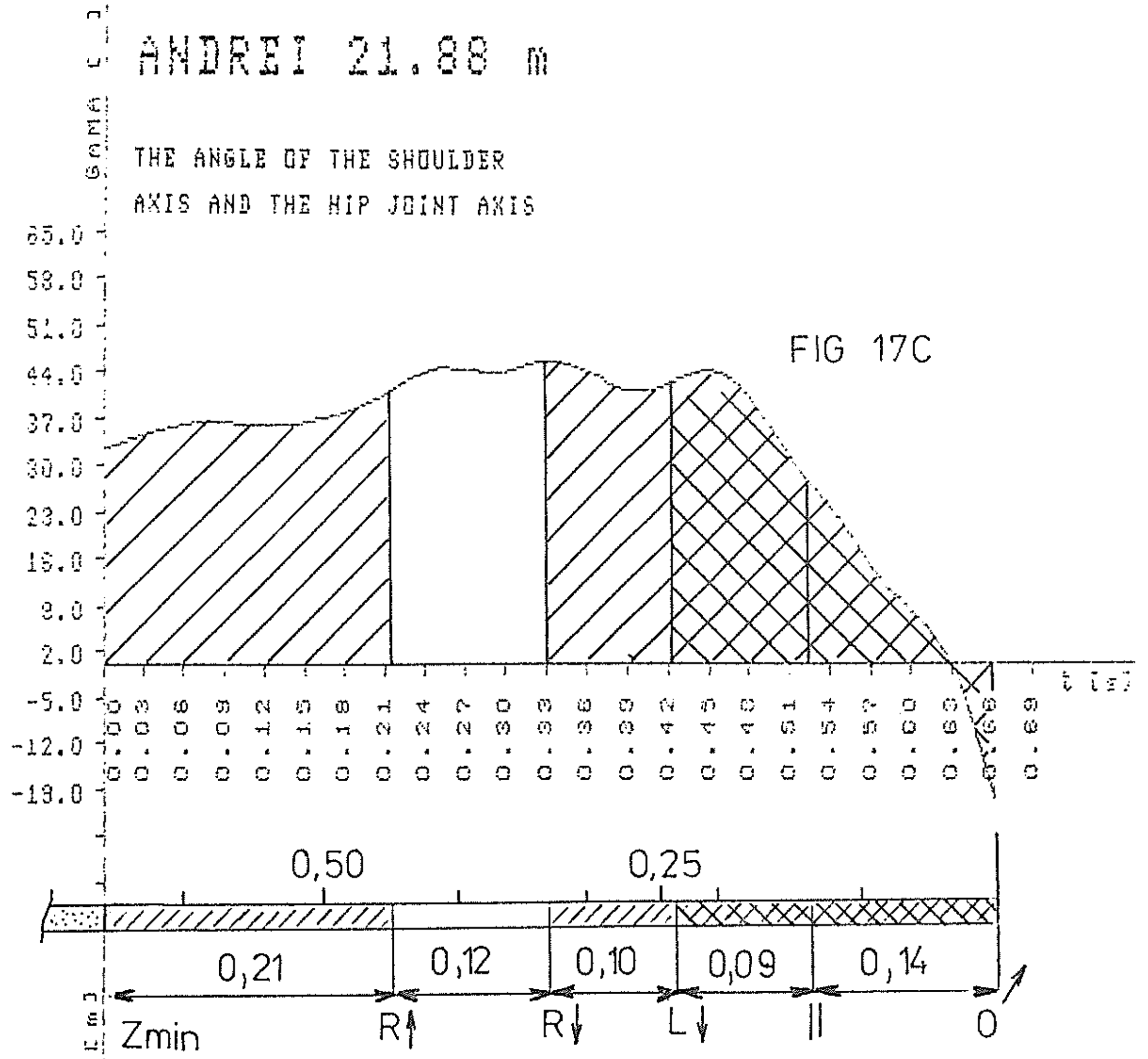


FIG 17C

SHIFT OF THE CENTRE OF SHOULDER AXIS IN RELATION TO THE CENTRE OF HIP AXIS

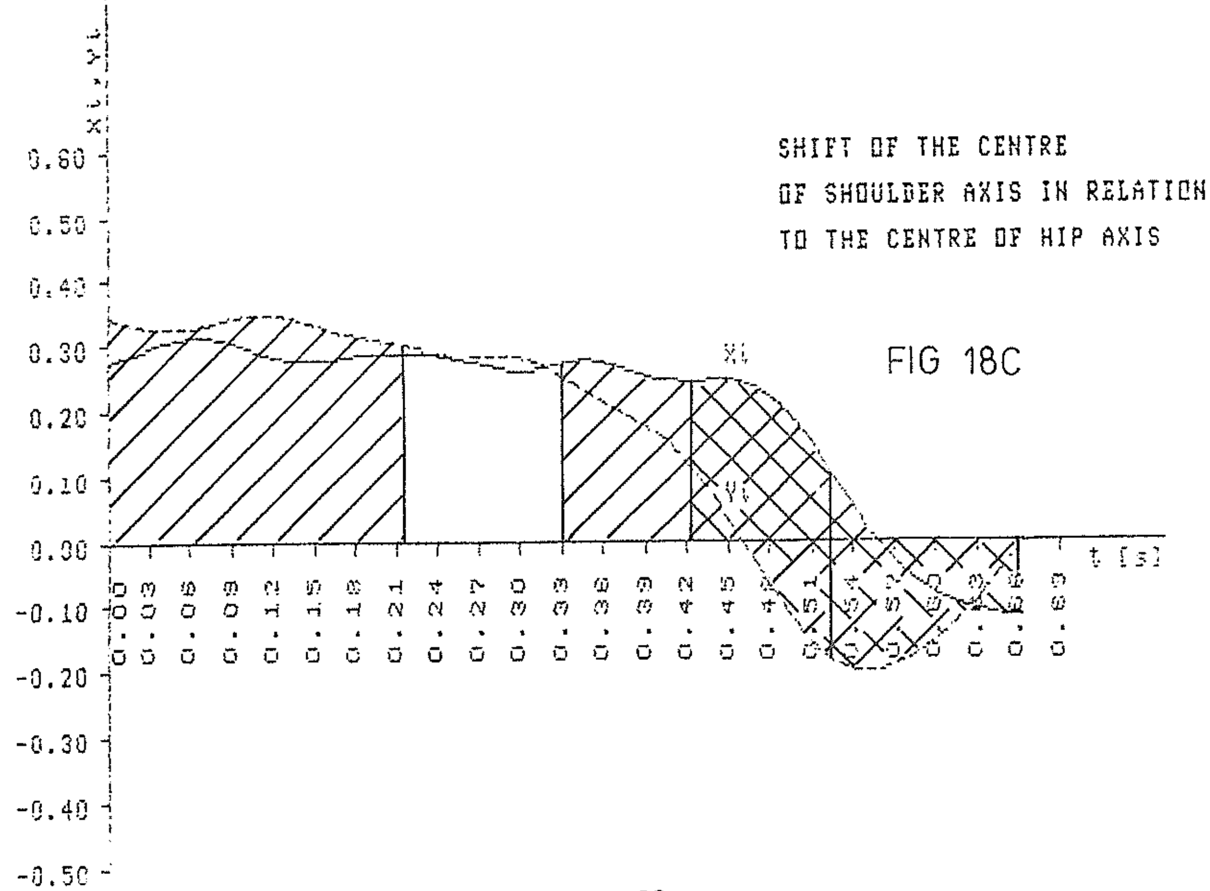
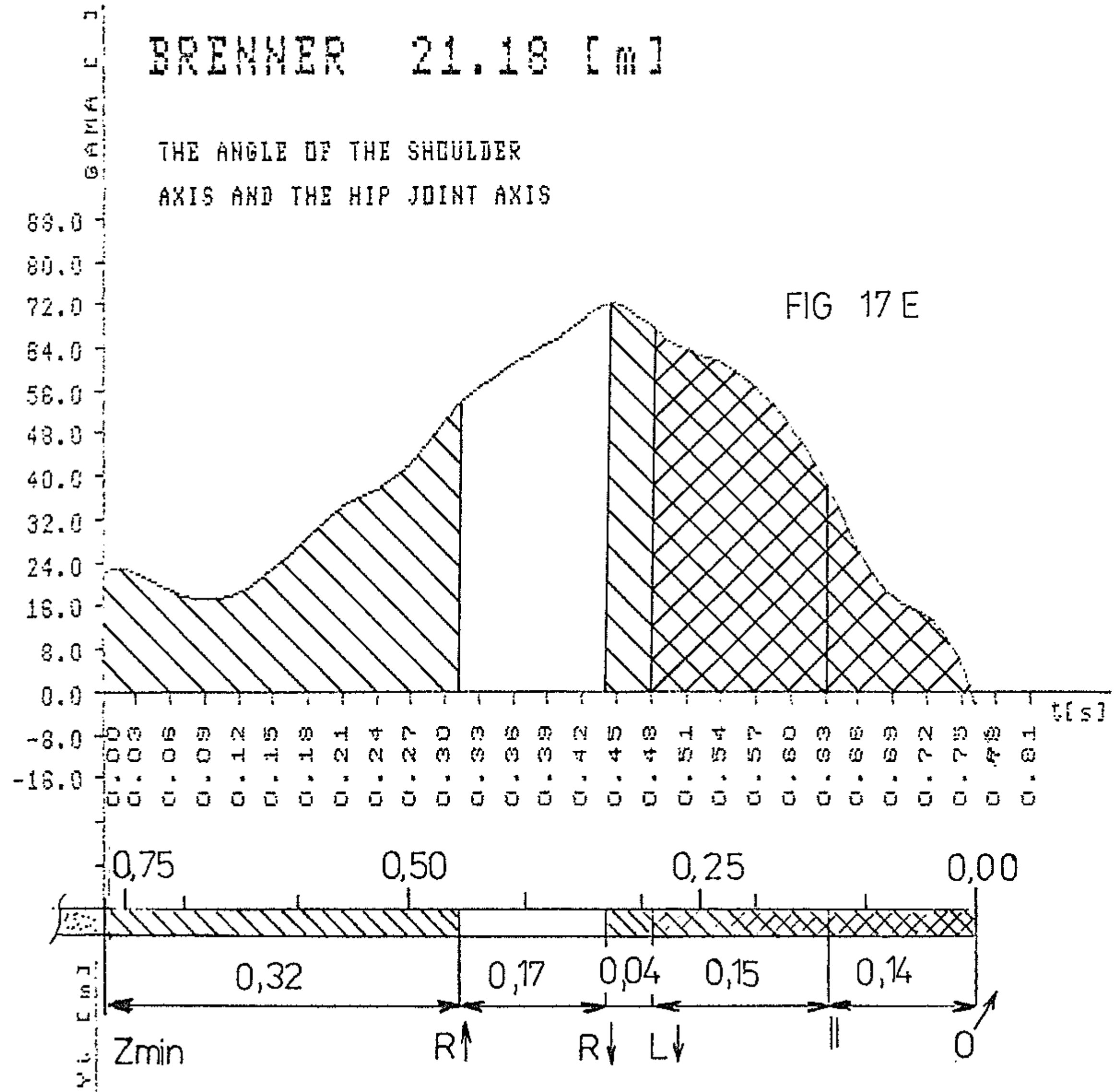
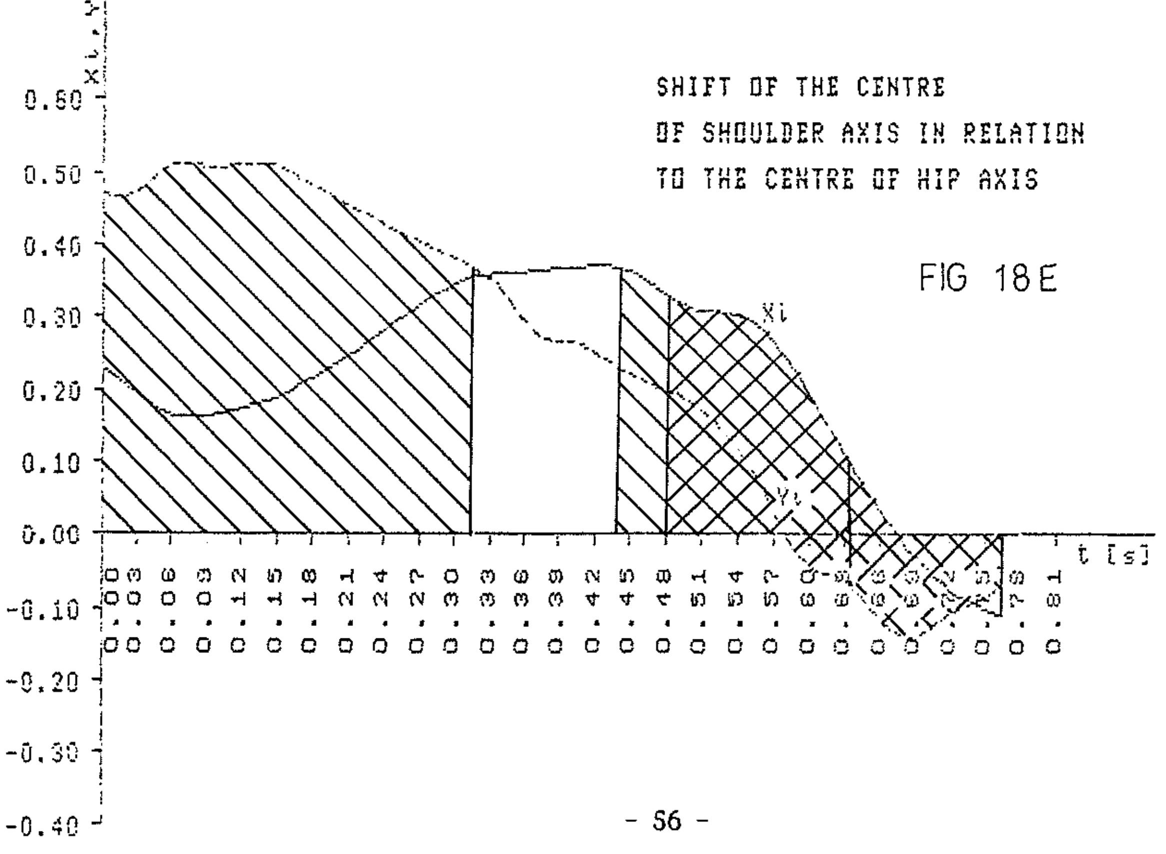


FIG 18C


BRENNER 21.18 [m]
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
GAMA [ ]
FIG 17 E
t[s]
0,75
0,50
0,25
0,00
0,32
0,17
0,04
0,15
0,14
Zmin
R↑
R↓
L↓
||
O


XL, YL [m]
SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18 E
Xi
Yi
t [s]

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J

BIOMECHANICAL ANALYSIS OF THE DISCUS THROW

Sušanka, P.; Dumbrovský, M.; Barac, F.; Štěpánek, J.; Nosek, M.

CONTENTS

1. INTRODUCTION

Biomechanical analyses of the final contests at the II WC confirmed that the levels of sports performance and of technique have stagnated at the present time.

The tendencies of perfomance development are shown in FIG.1 and 2.

Twenty years ago the throws of women were about 5m shorter in comparison with those of men. During the last 10 years they have closed the difference and today produce longer throws than men.

The reasons for the above can be as follows :
- different weight of competitive implement (50 %);
- relatively more advantageous aerodynamic properties of the women's discus;
- gradually decreasing difference in speed - strength dispositions between men and women; - probably due to the greater range of joint mobility of women;

FIG. 1 and 2 indicate the best performances in 1987. In the last two columns the placement at the II WC and the difference between the best performance of the year and the performance reached at the II WC is presented.

It can be noticed from the tables that only those throwers who were ranked among the first 20 in the world reduced ranking lists, with exception of Mikhalenko, started in both categories in the final contests. Medals were won by virtually the highest ranked athletes only: the "worst" ranking athlete on the world list 1987 to win a medal was Delis who was 5th ! !

The mean values of performance parameters of the finalists at the I WC 83 and II WC 87 (n=8) :

Men	Age	Best performance of the year	Performance at the WC	Difference
I WC 83	26.5	68.45	65.47	-2.98
II WC 87	30.5	68.10	65.88	-2.23
Women				
I WC 83	27.3	69.04	65.54	-3.50
II WC 87	26.0	70.45	67.15	-3.30

Indicated figures confirm the tendency towards performance stagnation even in the finalists of the WC. Only the women improved their performance in both parameters by about 1.5 m.

In the men's category the mean performance of the finalists at the WC is as little as 0.41 m better than at the WC 83. This fact is obviously influenced by the high average age of the throwers, - more than 30 years !

In both categories, the athletes reached a lower performance at the WC compared to their best performances of the year. This difference decreased by about 0.75 m in men, but by only 0.20 m in women; consequently, it is more than 1 m greater than in men today.

The differences between the best performances of the year and those attained at top competitions can be explained by consistent doping controls. Biochemization of the training process has influenced not only the volume and intensity of the training load, but the performance development as well. In addition to the unambiguously negative influence on the athletes' health it diverts the training process to the predominant development of strength dispositions.

According to the biomechanical analyses of the technique shown at the I and II WC we found not only a decrease in performance development, but in the development of technique as well.

Nevertheless we see further possibilities for an increase in the performance in technical events, namely through the better utilization of the applied biomechanical knowledge. The level of technique, the improvement of performance and success in competition can thus be influenced by technical means themselves.

MEN

FINAL 4/9 - 18.50

1.	487 Schult Juergen	60	GDR	68.74	65.80	68.74	66.18	67.36	66.74	65.94	CR
2.	1076 Powell John	47	USA	66.22	66.22	60.42	61.48	—	—	—	
3.	203 Delis Luis M.	57	CUB	66.02	63.30	64.18	X	X	65.66	66.02	
4.	356 Danneberg Rolf	53	FRG	65.96	65.14	60.92	64.30	65.42	65.96	63.80	
5.	1005 Zinchenko Vladimir	59	URS	65.60	65.60	63.04	65.26	64.78	64.04	X	
6.	1000 Ubartas Romas	60	URS	65.50	65.06	63.22	62.82	65.04	65.50	64.56	
7.	887 Bugar Imrich	55	TCH	65.32	X	63.12	65.32	62.16	X	X	
8.	965 Kidikas Vaclavas	61	URS	63.64	57.78	62.30	63.64	60.22	X	X	
9.	• 907 Valent Gejza	53	TCH	61.98	57.74	61.64	61.98	—	—	—	
10.	49 Cooper Bradley	57	BAH	61.94	61.94	56.96	60.32	—	—	—	
11.	365 Hannecker Alois	61	FRG	60.98	58.44	X	60.98	—	—	—	
12.	595 Martino Marco	60	ITA	60.60	60.60	58.30	60.04	—	—	—	

Ore/Time 20:38 — Temp.: +19 °C
Press.: 1013 mBar — Umidità/Humidity: 83%

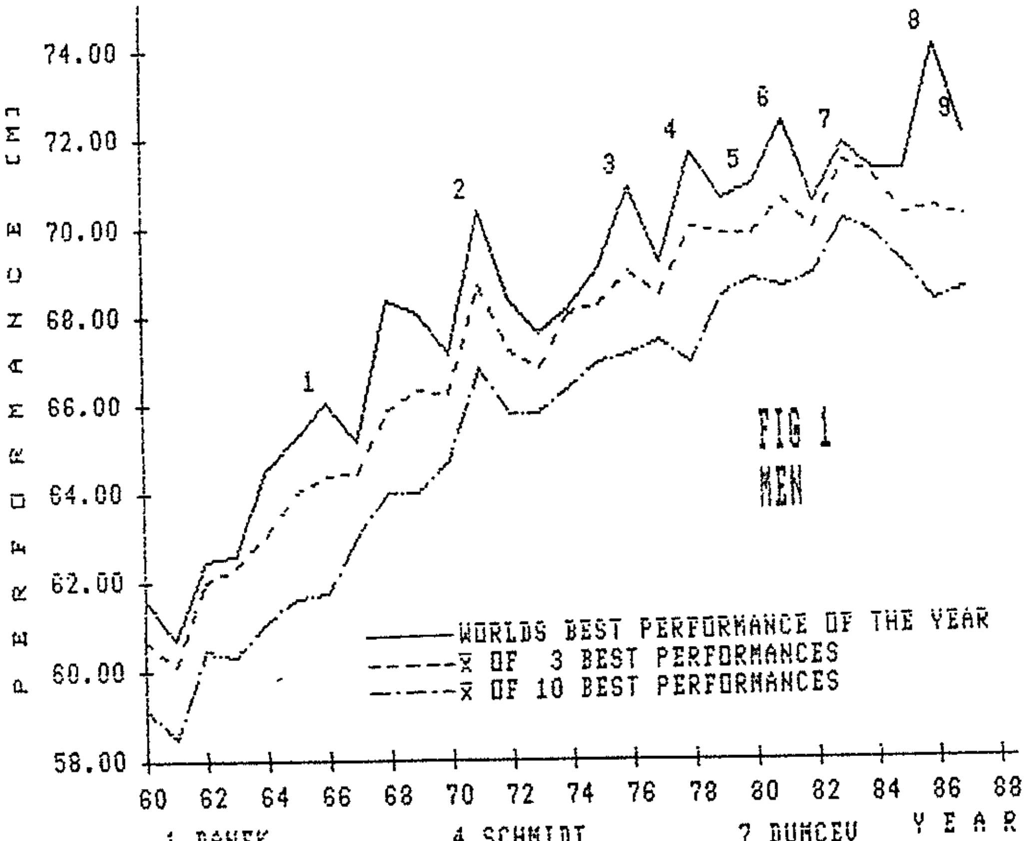
WOMEN

FINAL 31/8 - 18.00

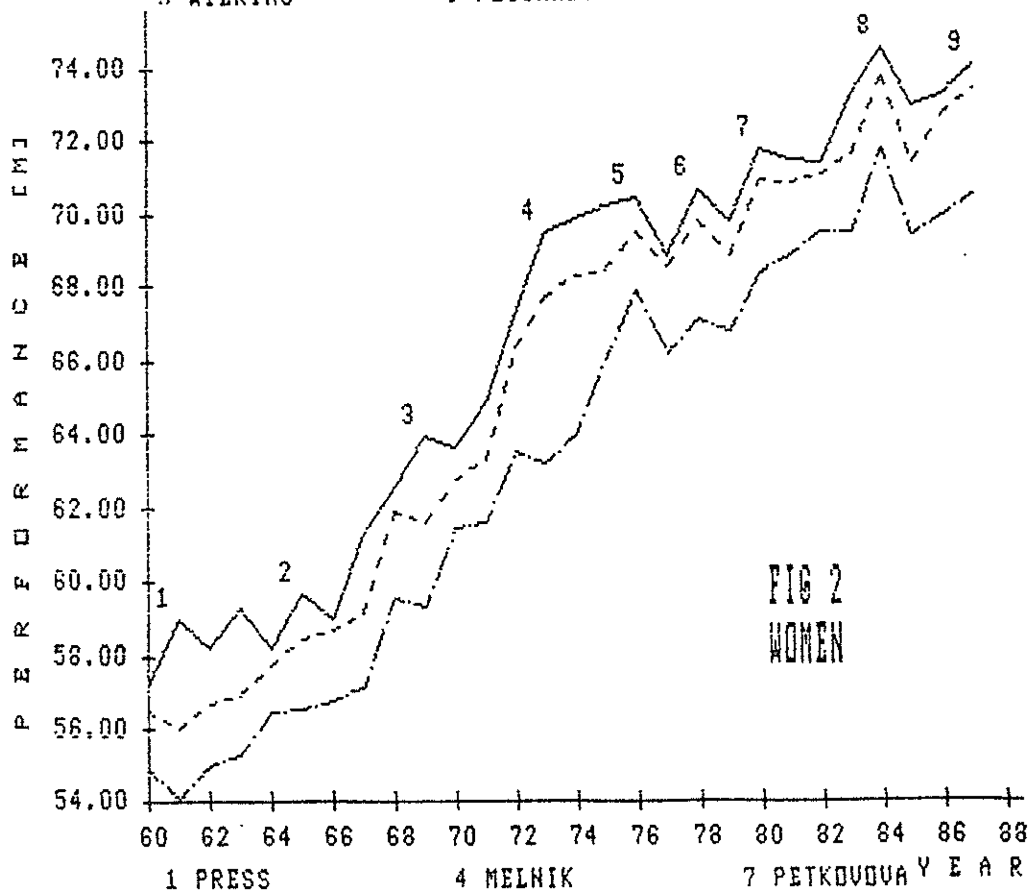
1.	297 Hellmann Martina 71.08 68.90 69.66 71.62 X 67.86	60	GDR	71.62	CR
2.	290 Gansky Diana 66.64 67.50 70.12 68.78 65.42 X	63	GDR	70.12	
3.	57 Khristova Tsvetanka 63.72 66.10 65.38 63.36 68.82 68.80	62	BUL	68.82	
4.	318 Wyludda Ilke 68.20 62.60 62.06 67.64 67.06 67.44	69	GDR	68.20	
5.	66 Mitkova Svetla 64.86 65.44 65.48 65.58 X 66.58	64	BUL	66.58	
6.	538 Silhava Zdenka 64.34 64.82 X 64.46 64.30 63.88	54	TCH	64.82	
7.	583 Mikhalchenko Larisa 64.18 64.72 59.72 63.66 60.68 63.54	63	URS	64.72	
8.	484 Ionescu-Lengyl M. 62.30 59.28 59.54 X 58.14 60.86	53	ROM	62.30	
9.	147 Marten Mariza 60.22 60.80 62.00 — — —	63	CUB	62.00	
10.	576 Korotkevich Larisa 60.74 59.96 60.12 — — —	66	URS	60.74	
11.	468 Katewicz Renata X 58.22 X — — —	65	POL	58.22	
12.	651 Price Connie	62	USA	DNC	

Ore/Time 19:45 — Temp.: +25 °C
Press.: 1017 mBar — Umidità/Humidity: 57%

TABLE 1



1 DANEK
2 SILVESTER
3 WILKINS
4 SCHMIDT
5 WILKINS
6 PLUCKNETT
7 DUMCEV
8 SCHULT
9 POWELL



1 PRESS
2 PRESS
3 WESTERMANN
4 MELNIK
5 MELNIK
6 JAHL
7 PETKOVOVA
8 SILHAVA
9 GANSKY

WORLD LIST 1987 (at 15th October 1987) DISCUS THROW MEN

72.08	John	Powell	47	USA	1	Klagshamn	1109	2.	-5.86
69.80	Stefan	Fernholm	59	SWE	1	Klagshamn	1308	N	-8.44
69.52	Jürgen	Schult	60	GDR	1	Neubrandenburg	1106	1.	-0.78
68.98	Mike	Buncic	62	USA	1	Stanford	2006	R	
67.92	Luis	Delis	57	CUB	1	Madrid	0406	3.	-1.90
67.80	Alwin	Wagner	50	FRG	1	Melsungen	0107	R	
67.70	Svein Inge	Valvik	56	NOR	1	Ylivieska	1207	N	-7.94
67.62	Randy	Heisler	61	USA	1	Bloomington	2906	N	-8.60
67.60	Rolf	Danneberg	53	FRG	1	W. Berlin	3105	4.	-1.64
67.58	Vladimir	Zinčenko	59	URS	1	Tallinn	2706	5.	-1.98
67.22	Imrich	Bugár	55	TCH	1	Nitra vHun,GB	3105	7.	-1.90
67.20	Vesteinn	Hafsteinsson	60	ISL	1	Klagshamn	1707	-	
66.90	Art	Burns	54	USA	1	Walnut MSR	2604	R	
66.80	Vaclavas	Kidikas	61	URS	1	Praha EP/A	2806	8.	-3.16
66.60	Juan	Martinez	58	CUB	2	Habana Barr	1403	-	
66.46	Göran	Svensson	59	SWE	2	Klagshamn	1308	dnc Q	
66.16	Georgi	Georgiev	61	BUL	1	Sofia	2305	N	-7.36
66.10	Romas	Ubartas	60	URS	2	Moskva Znam	0706	6.	-0.60
66.06	Dmitrij	Kovcun	55	URS	2	Brjansk NC	1907	R	
65.86	Knut	Hjeltnes	51	NOR	1	Tampere vFin	1706	N	-4.22
65.84	Erik	de Bruin	63	HOL	1	Leiden	0805	-	
65.82	Werner	Hartmann	59	FRG	1	Norden	0609	dns Q	
65.72	Gejza	Valent	53	TCH	1	Třinec NC	1608	9.	-3.74
65.52	Marco	Martino	60	ITA	1	Ostia	0506	12.	-4.92
65.42	Lars	Sundin	61	SWE	1	Helsingborg	1108	N	-5.98
65.32	Alois	Hannecker	61	FRG	1	Illertissen	2106	11.	-4.34
65.22	Georgi	Taušanski	57	BUL	1	Stara Zagora	0108	-	
65.16	Dariusz	Juzyszyn	57	POL	1	Poznań NC	1508	N	-3.78
65.04	Jevgenij	Burin	64	URS	1	Leningrad	0908	R	
64.94	Kamen	Dimitrov	62	BUL	1	Sofia NC	1408	N	-6.04
64.90	Olav	Jensen	62	NOR	2	Klagshamn	1707	-	
64.80	John	Brenner	61	USA	1	Point Loma	2205	N	-6.36
64.56	Bradley	Cooper	57	BAH	2	Indianapolis PAG	1208	10.	-2.62
					↑ 1			↑ 2	↑ 3

1 - PLACEMENT IN THE CONTENTS

2 - PLACEMENT IN THE II WC

R - REDUCED RANKING

N - DID NOT PASS THE QUALIFICATION II WC

3 - DIFFERENCE BETWEEN THE PERFORMANCE AT THE II WC AND THE BEST PERFORMANCE 1987

TABLE 2

WORLD LIST 1987 (at 15th October 1987) DISCUS THROW WOMEN

74.08	Diana	Gansky	63	GDR	1	K-Marx-St. vSov	2006	2.	-3.96
73.22	Cvetanka	Christova	62	BUL	1	Kazanlak	1904	3.	-4.40
72.92	Martina	Hellmann	60	GDR	1	Potsdam NC	2008	1.	-1.30
71.64	Ilke	Wyludda	69	GDR	2	Potsdam NC	2008	4.	-3.44
69.72	Svetla	Mitkova	64	BUL	2	Sofia NC	1608	5.	-3.14
69.52	Zdeňka	Šilhavá	54	TCH	1	Ostrava ZT	1006	6.	-4.70
69.34	Silvia	Madetzky	63	GDR	1	Halle WCT	2606	R	
68.98	Irina	Meszynski	62	GDR	4	Potsdam NC	2008	R	
67.90	Hilda	Ramos	64	CUB	1	Habana Barr	1403	-	
67.82	Tatjana	Belova	61	URS	1	Irkutsk	-0908	R	
67.62	Mariana	Lengyel	53	ROM	1	Poiana Brasov	2607	8.	-5.32
67.34	Irina	Šabanova	64	URS	1	Krasnodar	1508	R	
67.32	Olga	Chval	62	URS	1	Moskva	1508	R	
67.18	Gabriele	Reinsch	63	GDR	1e2	K-Marx-St.	2006	R	
67.18	Galina	Jermakova	53	URS	2	Moskva	1508	R	
67.00	Jana	Günther	68	GDR	6	Potsdam NC	2008	R	
66.84	Florenta	Craciunescu	55	ROM	1	Bucuresti IntC	1306	-	
66.76	Yu	Houren	63	PRC	1	Beijing	2703	N	-10.06
66.34	Franka	Dietzsch	68	GDR	2	St. Denis	1106	R	
65.74	Anne	Chorina	59	URS	1	Brjansk NC	1807	N	-7.98
65.58	Maritza	Marten	63	CUB	1	Indianapolis PAG	1008	9.	-3.58
65.00	Elju	Kubi	51	URS	1	Tallinn	2608	R	
64.94	Larisa	Korotkevič	66	URS	Q	Brjansk NC	1707	10.	-4.20
64.88	Larisa	Michalčenko	63	URS	Q	Brjansk NC	1707	7.	-0.16
64.82	Connie	Price	62	USA	Q	San Jose TAC	2506	dnc	(-4.92)
64.62	Irina	Dmitrijeva	59	URS	2	Leselidze	1305	R	
64.56	Renata	Katewicz	65	POL	2	Lodź Kuso	1606	11.	-6.34
64.12	Galina	Murašova	55	URS	4	Brjansk NC	1807	R	
64.18	Larisa	Baranova	61	URS	1	Baku	1309	R	
64.04	Hou	Xuemei	62	PRC	3	Zagreb WUG	1307	N	-5.78

↑ 1 ↑ 2 ↑ 3

1 - PLACEMENT IN THE CONTENTS

2 - PLACEMENT IN THE II WC

R - REDUCED RANKING

N - DID NOT PASS THE QUALIFICATION II WC

TABLE 3

3 - DIFFERENCE BETWEEN THE PERFORMANCE AT THE II WC AND THE BEST PERFORMANCE 1987

2. METHODS AND PROCEDURES

For analyzing the discus throw high speed kinematography was used. The action was shot by synchronized Photosonics 500 cameras at a frequency of 200 frames per second. The coordinate system 0,x,y,z is directed to the centre of the circle and located in relation to the throwing direction so that the x axis is identical with the axis of the throwing sector (FIG.3).

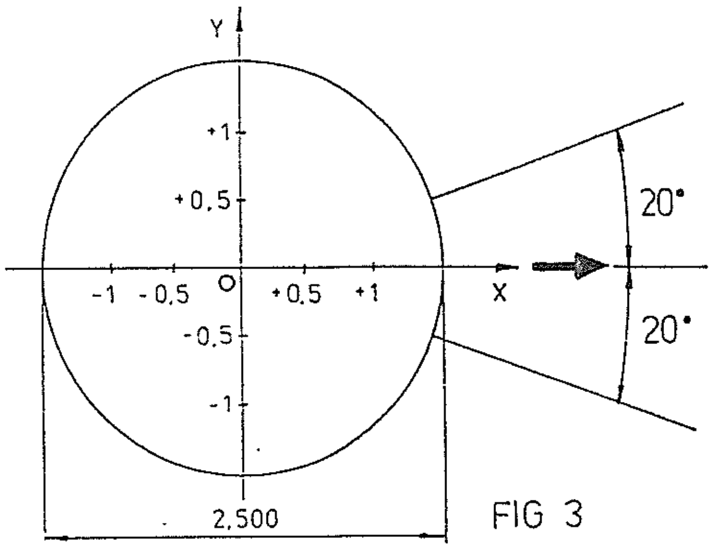


FIG 3

Conditions existing during the final contests of the discus throw made it impossible to shoot the action in the direction of the x and y axes of the located coordinate system. In these shooting directions, various obstacles shaded the athletes' actions. For this reason, the shooting was made after the axes of cameras K_1 and K_2 had been turned by 20^o, when K_2 camera had been located in the extension of the right edge of the throwing sector. The objective axes of both cameras K_1 and K_2 contained the 90^o angle (FIG. 4) .

For computing the three dimensional coordinates, generally known procedures of analytic geometry were used. Having obtained three dimensional coordinates of anthropometric points and of the implement CM, they were transformed into the coordinate system 0,x,y,z.

For better orientation in the text, pictures and analyses which were made, we introduced the division of the whole motor manoeuvre into separate phases by means of so called key moments:

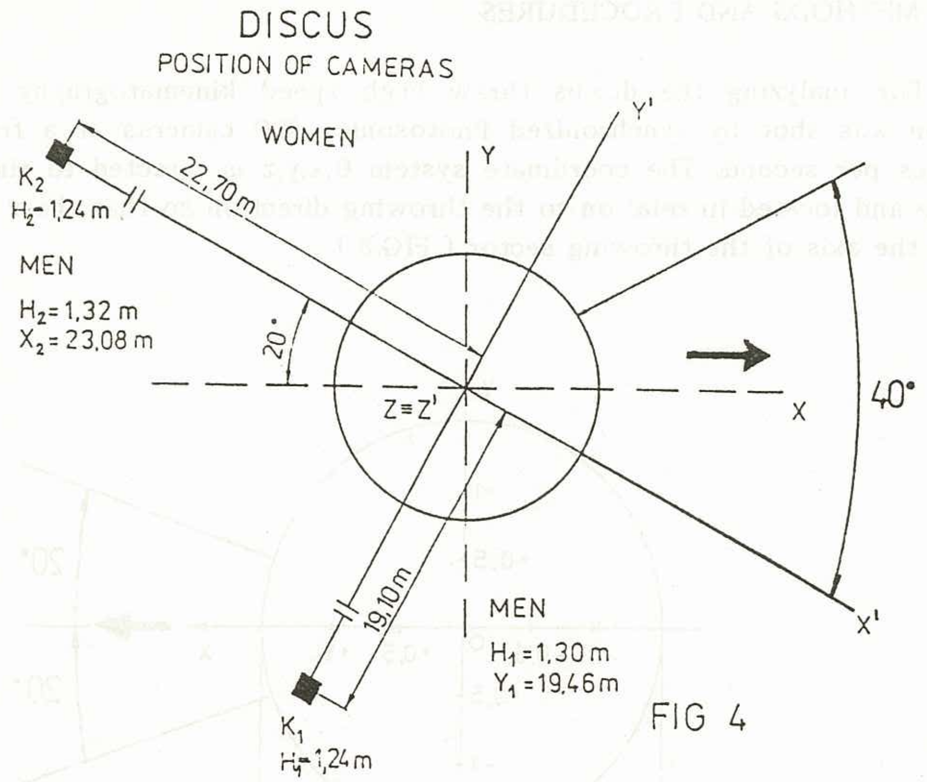


FIG 4

Z_O ...... farthest position of the discus (moment of the direction change after the last preliminary swing) . We do not take this position into consideration; preliminary swings and the preparatory phase (Z_O - R↑) have probably no substantial influence on following movements.

R↑....... moment when right foot leaves the ground

Z_{mini}.. moment when the discus reaches its first minimum in the vertical direction

L↑....... moment when the left foot leaves the ground

R↓....... moment of the first contact of the right foot with the ground

Z_{max}...moment when the discus reaches its maximum in the vertical direction

L↓........moment of the first contact of the left foot with the ground

Z_{min2}..moment when the discus reaches it second minimum in the vertical direction

O↑.......moment when the discus leaves the thrower's fingers

As was already mentioned in the analysis of the shot put, in all throwing events we consider the action of the upper body during the throwing action to be of extreme importance. To make the point more clearly, we introduced an auxiliary coordinates system 0,x',y' into the centre of the line connecting both hip joints, where the x' axis is identical with the pelvic axis running through the centres of rotation of the hip joints (FIG. 5)

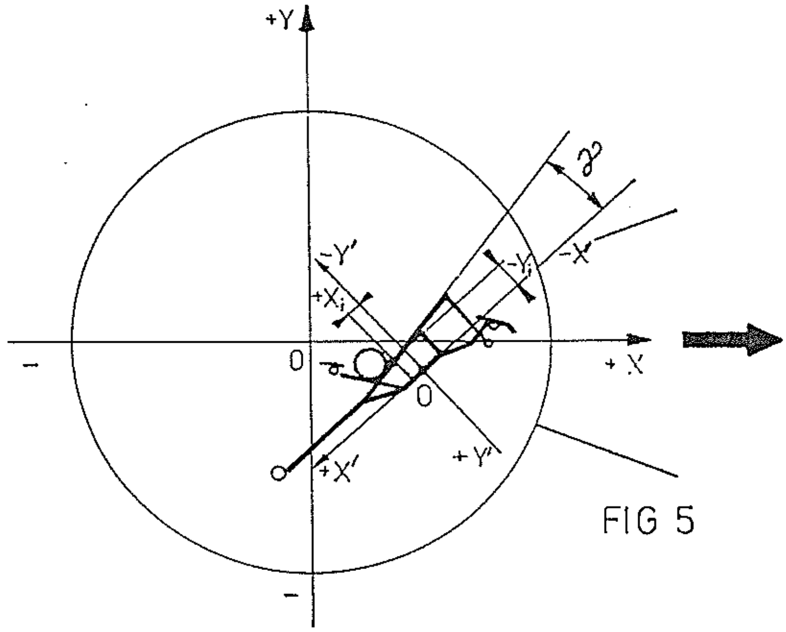


FIG 5

Defined in this way, this coordinates system enables us to visualise, in ground projection, the position of the centre of the line connecting the shoulder joints in relation to the centre of the line connecting the hip joints.

Further, the magnitude changes of the β and γ angles are observed during the throwing action:

β .... angle with the apex in the centre of rotation of the right shoulder joint which is defined by two half-lines; one half-line runs through the centres of both shoulder joints, the second one through the centre of the right shoulder joint and the CM of the implement; it can be identically defined in the ground projection.

γ .... angle between the shoulder axis and the pelvic axis.

3. ANALYSIS OF THE DISCUS THROW COMPETITION AT II WORLD CHAMPIONSHIPS IN ATHLETICS

In spite of measures taken concerning the location of the cameras, a great deal of shots were impaired by too many officials moving in the area of the throwing competition.

For biomechanical analysis, 8 trials in the men's category (with performances 64,18m - 68,74m) and 10 trials in the women's category (62,30m - 69,66m) were chosen.

On the basis of the three dimensional reconstruction of movements of separate anthropometric points and the CM of the implement, we chose some geometric and kinematic parameters that can help to make objective the evaluation of the level of execution of the given motor manoeuvre - the Discus Throw.

3.1. Parameters of Kinematic Geometry

3.1.1. Time Characteristic of the Discus Thrower's Action

Principal terms:

As we have mentioned in chapter 2, we divide the thrower's action into separate key points. These define his action in separate phases.

For fast information during the training process we use a simplified division into separate phases according to the thrower's action:

Preparatory	Z_o	-	R↑
Starting	R↑	-	L↑
Flight	L↑	-	R↓
Transitory	R↓	-	L↓
Delivery	L↓	-	O↗

Three dimensional kinematography makes possible a more detailed division from the point of view of the motor action of the thrower and, at the same time, of the implement itself.

Preparatory		Z_o	-	R↑
Starting	- descending	R↑	-	Z_{min1}
	- ascending	Z_{min1}	-	L↑
Flight ascending		L↑	-	R↓
Transitory	- ascending	R↓	-	Z_{max}
	-descending	Z_{max}	-	L↓
Delivery	- descending	L↓	-	Z_{min2}
	- ascending	Z_{min2}	-	O↑

The observed parameter is the time difference Δ_{t1} between the individual subsequent key points (R↑, $Z_{min\ 1}$, L↑, R↓, Z_{max}, L↓, $Z_{min\ 2}$, O/ ; or between R↑, L↑, R↓, L↓, O/).

The method of high speed kinematography limits the information value in direct dependence on the frame frequency used.
With respect to the duration of individual phases, and the ability of estimating the separate positions by the person analyzing film shots etc., we consider the lowest usable frame frequency 200 frames per second.

But even in this case we must assume that the data are estimated with an accuracy of ± 5 ms at the best. Data rounded-off to 5 ms are quoted just for orientation, lest differences may result between the sum of individual intermediate times and the final duration of the whole action. According to the method applied, rounding-off to hundredths of a second would be matched-up at most.

Accuracy of measurement improves markedly by using a frame frequency of 400 - 500 frames per second (when the time step between the motion moments is Δt = 2,5 or 2 ms) . At the same time the consumption of film material increases considerably and the laboriousness of the kinematographic analysis and the financial costs as well are much greater.

From the point of view of action timing it can be stated that the published data concerning the total time of the throw duration are meaningless.

Time data of separate movement phases of the trials observed indicate:

- at the successful trials of individual athletes, the movement phases observed are carried out in the same time or with a minimum difference 1 - 3 ms. (See TAB 5 and results of our previous observations. Of course, with the proviso that the climate condition during the competition are relatively constant, especially wind direction and wind velocity...)
- duration of chosen action phases at the finalists of the II WC (TAB. 4, 5) :

	MEN	WOMEN
R↑ L↑	〈 0.36 - 0.55 〉	〈 0.25 - 0.44 〉
L↑ R↓	〈 0.02 - 0.14 〉	〈 0.02 - 0.10 〉
R↓ L↓	〈 0.13 - 0.33 〉	〈 0.13 - 0.23 〉
L↓ O/	〈 0.11 - 0.16 〉	〈 0.10 - 0.16 〉

- variance range of the duration of the delivery phase is practically in agreement for men and women;
- significant differences exist in the timing of separate action phases among individual throwers.

These time differences are attended by a different concept of execution of the motor manoeuvre. Consequences are varying increments of the discus path and deviations in discus velocity increments resulting from it in separate action phases; the differences found are smaller for men than for women.

Comment :

Acceleration of the starting phase (R↑, L↑) - (by coincidence the variance range of the duration of the starting phase in men and women in the final contest at the II WC is identical - 0,19 s) need not affect the final performance positively. Exceedingly shortened duration of the starting phase has an unfavourable influence on the execution of the following movements.

Shortening of the flight phase (L↑, R↓) makes possible well timed active acting on the implement on the one hand, but on the other hand, makes more difficult a sufficient torsion of the upper body in relation to the pelvis (lower extremities) and a sufficient "getting ahead" of legs in relation to the implement (the angle between the shoulder axis and the right arm - discus - β).

In the transistory phase (R↓ L↑) we measured maximum differences of 0.2 s in women and 0.1 s in men. Longer duration of this phase is caused by the late landing of the left foot. This is due to the movement of the left leg on a path farther from the rotation axis or to the movement of the left foot high over the circle.

In the delivery phase (L↓ O↗) the measured differences are the smallest - 0.05-0.06 s. It is reasonable to judge the differences among athletes only in connection with the discus trajectory on the descending (L↓ Z_{min2}) and ascending part (Z_{min2} O↗).

MEN

NAME	PERF.	$t_{R\uparrow}$	t_{Z1min} $\Delta t(1)$ $\Delta s(1)$	$t_{L\uparrow}$	$t_{R\downarrow}$ $\Delta t(2)$ $\Delta s(2)$	t_{Zmax} $\Delta t(3)$ $\Delta s(3)$	$t_{L\downarrow}$	t_{Z2min} $\Delta t(4)$ $\Delta s(4)$	$t_{O\nearrow}$
SCHULT JUERGEN	68.74	0.000	0.320 0.400 2.25	0.400	0.480 0.080 0.65	0.600 0.225 1.98	0.705	0.780 0.150 2.52	0.855
SCHULT JUERGEN	66.74		0.225 0.300 2.17	0.300	0.360 0.060 0.52	0.465 0.170 1.88	0.530	0.600 0.120 2.19	0.650
POWELL JOHN	66.22		0.170 0.340 2.20	0.340	0.415 0.075 0.65	0.460 0.180 1.41	0.595	0.680 0.160 2.27	0.755
DELIS LUIS	66.02		0.220 0.320 2.83	0.320	0.405 0.085 0.95	0.450 0.130 1.26	0.535	0.595 0.110 2.03	0.645
DELIS LUIS	64.18		0.310 0.440 2.73	0.440	0.535 0.095 0.78	0.575 0.180 1.14	0.715	0.800 0.150 2.34	0.865
DANNEBERG ROLF	65.96		0.115 0.255 2.53	0.255	0.330 0.075 1.09	0.360 0.130 1.43	0.460	0.525 0.110 2.10	0.570
ZINCHENKO VLADIMIR	64.78 *	x	x x x	0.000	0.025 0.025 0.30	0.070 0.170 1.82	0.195	0.240 0.100 1.93	0.295
UBARTAS ROMAS	65.08	0.000	0.110 0.360 2.38	0.360	0.450 0.090 0.93	0.550 0.215 1.77	0.665	0.760 0.155 2.35	0.820

* t 0.000 u L CAMERA SWITCHED ON LATER

t_R ; t_{Z1min} ; t_L ; t_R ; t_{Zmax} ; t_L ; t_{Z2min} ; t ...... [s]

$\Delta t(i)=1,2,3,4$ .... [s]

$\Delta s(i)=1,2,3,4$ .... [m]

TABLE 4

WOMEN

NAME	PERF.	$t_{R\uparrow}$	t_{Z1min} $\Delta t(1)$ $\Delta s(1)$	$t_{L\uparrow}$	$t_{R\downarrow}$ $\Delta t(2)$ $\Delta s(2)$	t_{Zmax} $\Delta t(3)$ $\Delta s(3)$	$t_{L\downarrow}$	t_{Z2min} $\Delta t(4)$ $\Delta s(4)$	$t_{O\nearrow}$
HELLMANN MARTINA	69.66		0.260 0.455 2.74	0.455	0.510 0.055 0.43	0.560 0.240 1.59	0.750	0.840 0.155 2.31	0.905
HELLMANN MARTINA	67.86		0.250 0.485 2.88	0.485	0.525 0.040 0.30	0.640 0.245 1.56	0.770	0.860 0.155 2.18	0.925
GANSKY DIANA	67.50		0.280 0.460 x	0.460	0.500 0.040 x	0.610 0.320 x	0.820	0.890 0.130 x	0.950
GANSKY DIANA	65.42		0.310 0.450 2.13	0.450	0.470 0.020 0.13	0.610 0.330 2.15	0.800	0.890 0.140 2.17	0.940
KHRISTOVA TSVETANKA	68.82		0.230 0.370 2.80	0.370	0.490 0.120 0.93	0.490 0.130 1.20	0.620	0.685 0.110 2.00	0.730
KHRISTOVA TSVETANKA	68.80	0.000	0.220 0.360 2.78	0.360	0.470 0.110 0.86	0.470 0.130 1.15	0.600	0.665 0.125 2.01	0.725
WYLLUDA ILKE	68.20		0.265 0.425 2.22	0.425	0.510 0.085 0.53	0.565 0.200 1.41	0.710	0.785 0.135 2.20	0.845
MITKOVA SVETLA	66.58		0.300 0.545 2.47	0.545	0.575 0.030 0.20	0.660 0.235 1.34	0.810	0.905 0.160 2.16	0.970
SILHAVA ZDENKA	64.82		0.250 0.430 1.72	0.430	0.565 0.135 0.92	0.670 0.195 1.69	0.760	0.860 0.155 2.32	0.915
IONESCU LENGYEL M.	62.30		0.140 0.360 x	0.360	0.485 0.125 x	0.490 0.155 x	0.640	0.690 0.125 x	0.765

t_R ; t_{Z1min} ; t_L ; t_R ; t_{Zmax} ; t_L ; t_{Z2min} ; t ...... [s]

$\Delta t(i)$=1,2,3,4 .... [s]

$\Delta s(i)$=1,2,3,4 .... [m]

TABLE 5

3.1.2. Trajectory of the Body and Implement Centre of Mass during the Throw

The basic terms:

We observe the discus position in the local extremes of the 3-dimensional curve of the discus path Z_{min1}; Z_{max}; Z_{min2}; O'. The division of the throwing action into the key moments - see section 2. and 3.1.1.

We deal with the trajectory of body and implement centre of mass from the point of view of the 3-dimensional execution.

Problems discussed are graphically shown for throwers observed under marking A - S; see explanatory notes p. 19 - 31.

FIG. 8 - 3-dimensional trajectory of the discus centre of mass,
FIG. 11 - discus centre of mass in the ground projection,
FIG. 9 - 3-dimensional trajectory of the body centre of mass,
FIG. 10 - body centre of mass in the ground projection,
FIG. 12 - lines connecting body centre of mass and discus centre of mass in the ground projection (points 26 - 5).
FIG. 13 - the same in the front view projection.

Observed parameters:

Increments of trajectory Δs [m] of the implement and body centers of mass in the space between subsequent key moments (chap. 3.1.1.).

Vertical deviations of the discus centre of mass Z_i [m] during the action and its local extremes.

Movement of the system thrower - implement in the restricted space of the throwing circle demonstrated in the defined coordinates system 0,x,y,z (FIG. 3) by the coordinates of the observed points in the ground projection (x_i; y_i) ... [m].

The use of 3- dimensional kinematography enables us to examine the action of the thrower-implement system which was impossible in the recent past without usage of contemporary hardware and software.

With respect to the real possibilities of our investigation and extent of this report we applied, as a first step, observation of the 3-dimensional movement of the line connecting the body and implement centres of mass.

Results:

Three dimensional kinematography makes it possible to visualise the length and character of the discus path in the individual phases of the throw, bounded by the key moments.

The discus path in the single-support phase, in the flight phase, in the single-support and double support positions in the course of the delivery (TAB.6 - men, TAB.7 - women). Δs_i ... i=1,2,3,4,... [m].

For performances:

	MEN	WOMEN
	⟨65.96; 68.74⟩	⟨67.50; 69.66⟩

this variance range of separate parts of the discus trajectory ΔS_i was established:

	MEN	WOMEN
R↑ L↑	⟨2.17; 2.83⟩	⟨2.22; 2.88⟩
L↑ R↓	⟨0.52; 1.09⟩	⟨0.30; 0.93⟩
R↓ L↓	⟨1.26; 1.98⟩	⟨1.15; 1.59⟩
L↓ O↗	⟨2.03; 2.52⟩	⟨2.00; 2.31⟩

and vertical discus positions z_i...[m]:

	MEN	WOMEN
z_{1min}	⟨0.97; 1.23⟩	⟨0.75; 1.19⟩
z_{max}	⟨1.46; 1.86⟩	⟨1.45; 1.68⟩
z_{2min}	⟨0.71; 1.07⟩	⟨0.60; 0.94⟩
$z_{O↗}$	⟨1.18; 1.67⟩	⟨1.03; 1.52⟩

Conversely -

a different concept of technique is manifested in the different course of the discus path. The differences are unambiguosly demonstrated on FIG. 8 - 13.

MEN

NAME	PERF.	Z_{1min} DISCUS [m]	Z_{max} CENTER [m]	Z_{2min} OF MASS [m]	$Z_{O↗}$ (5) [m]
SCHULT JUERGEN	68.74	1.15	1.85	0.95	1.67
SCHULT JUERGEN	66.74	1.23	1.86	0.97	1.49
POWELL JOHN	66.22	0.97	1.70	0.83	1.52
DELIS LUIS	66.02	0.97	1.46	0.71	1.18
DELIS LUIS	64.18	0.95	1.40	0.71	1.24
DANNEBERG ROLF	65.96	1.14	1.62	1.07	1.54
ZINCHENKO VLADIMIR	64.78	0.94	1.58	0.88	1.34
UBARTAS ROMAS	65.06	1.00	1.54	0.84	1.36

TABLE 6

WOMEN

NAME	PERF.	Z_{1min} DISCUS [m]	Z_{max} CENTER [m]	Z_{2min} OF MASS [m]	$Z_{0↗}$ (5) [m]
HELLMANN MARTINA	69.66	0.78	1.68	0.88	1.46
HELLMANN MARTINA	67.86	0.75	1.64	0.89	1.43
GANSKY DIANA	67.50	1.19	1.46	0.94	1.19
GANSKY DIANA	65.42	1.15	1.40	0.80	1.45
KHRISTOVA TSVETANKA	68.82	0.84	1.55	0.60	1.03
KHRISTOVA TSVETANKA	68.80	0.86	1.55	0.65	1.07
WYLLUDA ILKE	68.20	1.01	1.45	0.81	1.52
MITKOVA SVETLA	66.58	0.90	1.42	0.73	1.29
SILHAVA ZDENKA	64.82	1.16	1.43	0.72	1.18
IONESCU LENGYEL M.	62.30	0.89	1.56	0.67	1.30

TABLE 7

Comment:

In the case of individual throwers, differences between increments of the discus path at individual trials in given phases of action, and differences in vertical deviations of discus centre of mass, are of minimum value. They manifest themselves only in the delivery phase more markedly (to 0.32m). In remaining phases they do not exceed ca. 0.1 m. Differences in vertical deviations of discus centre of mass in separate key moments are even smaller - 0.00 - 0.06m.(See Hellmann, Khristova, Schult, Delis).

This demonstrates the ability of the best athletes to produce the given motor manoeuvre practically in the same manner. This fact is one of the basic preconditions for the creation of optimal conditions for the final part of the delivery.

From the take-off of the left foot (L↑) the trajectory of the body centre of mass projected into the horizontal plane moves practically along a straight line. The difference in the vertical movement in the course of the turn (R↑ - $Z_{2\,min}$) fluctuates in the range 0.05 - 0.12 m.

Vertical deviations are even smaller in phases from the take-off of the left foot to its landing - before the beginning of the delivery phase, (L↓ - L↑) (e.g. Hellmann 0.04 m).

The projection of the discus path in the horizontal plane enables us to examine the range and progress of discus motion in the key movements of the throw.

A more energetic lead into the turn (L↑) and a forward bend of the trunk gives a better chance of accelerating the implement along a longer path.

On the contrary, the double support position taken in time, with the implement above the shoulders, prolongs the discus path in the delivery stage.

Of course, the shortening of time needed for assuming the double support stance (landing of the left foot L↓) might not be executed, to the detriment of the length of rotation radius of the right shoulder and the dynamic balance of the discus thrower manifested by his open delivery position.

A pronounced bend of the trunk, and the shifting of body weight to the right leg makes it possible to extend the path of the discus in the final phase of the throw.

SCHULT 68.74 m

DISCUS CENTRE OF MASS(5)

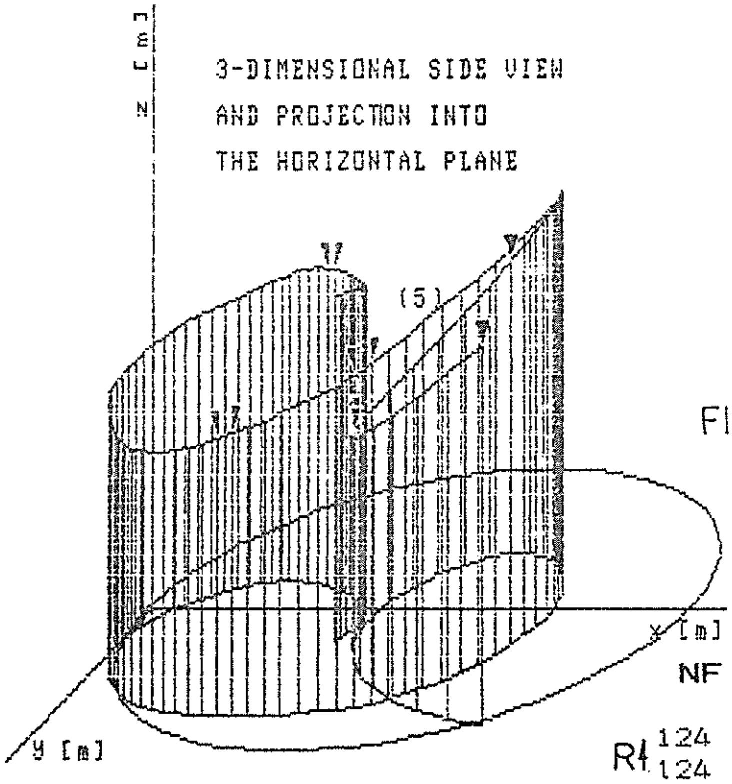


FIG 8A

3-DIMENSIONAL COORDINATES

	NF	TIM	IP	X:	Y:	Z:
R↑	124	0.17	5	-494	202	1414
	124	0.17	26	-813	-373	1051
L↑	202	0.56	5	-414	-945	1242
	202	0.56	26	-326	-359	1092
R↓	218	0.64	5	171	-839	1490
	218	0.64	26	-157	-342	1110
L↓	263	0.87	5	192	492	1309
	263	0.87	26	371	-222	1060
Zmin	278	0.94	5	-154	-260	926
	278	0.94	26	512	-173	1086
O↗	293	1.02	5	807	-1006	1675
	293	1.02	26	574	-151	1134

BODY CENTRE OF MASS(26)

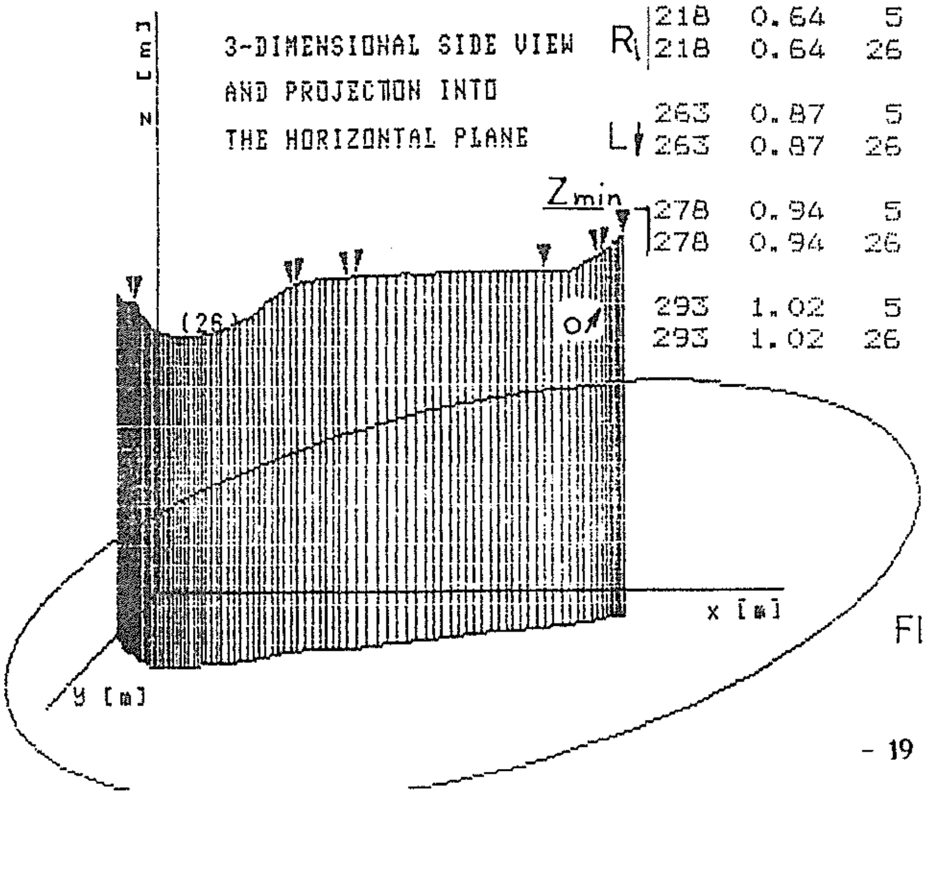
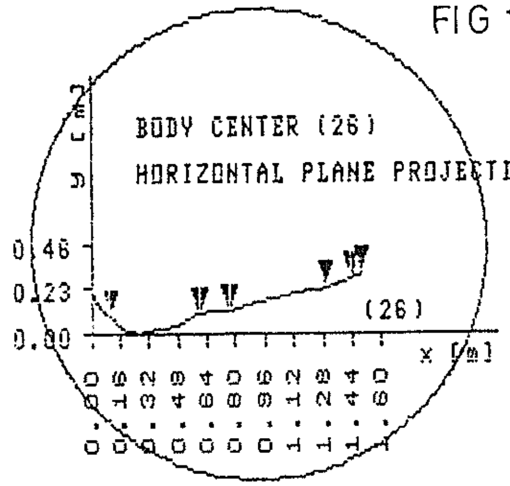
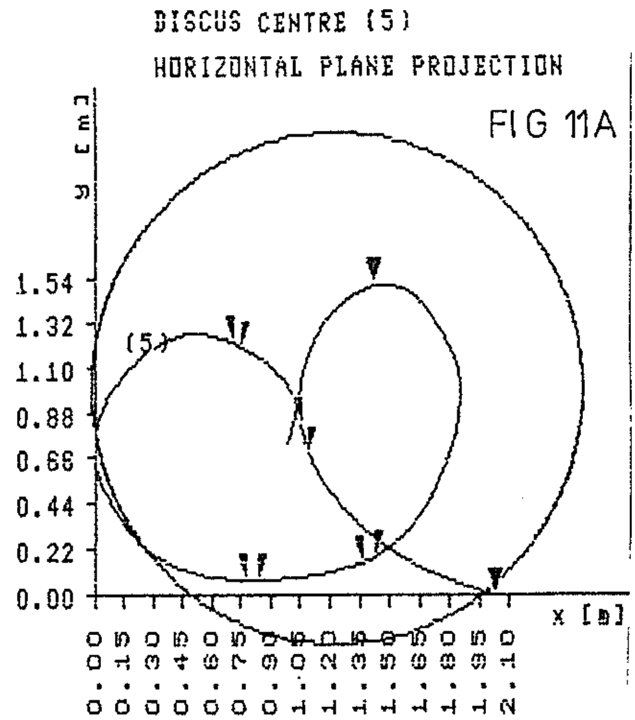
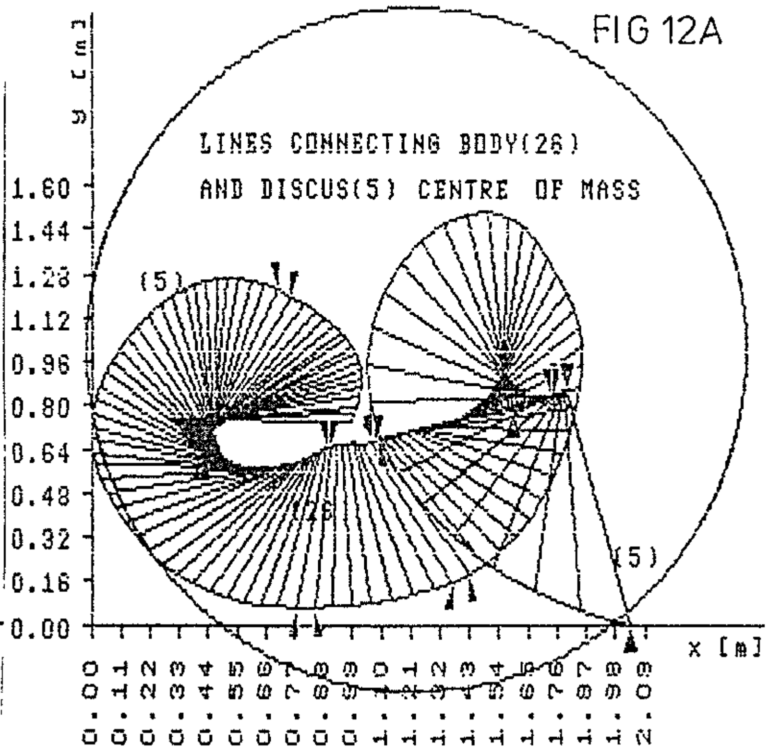


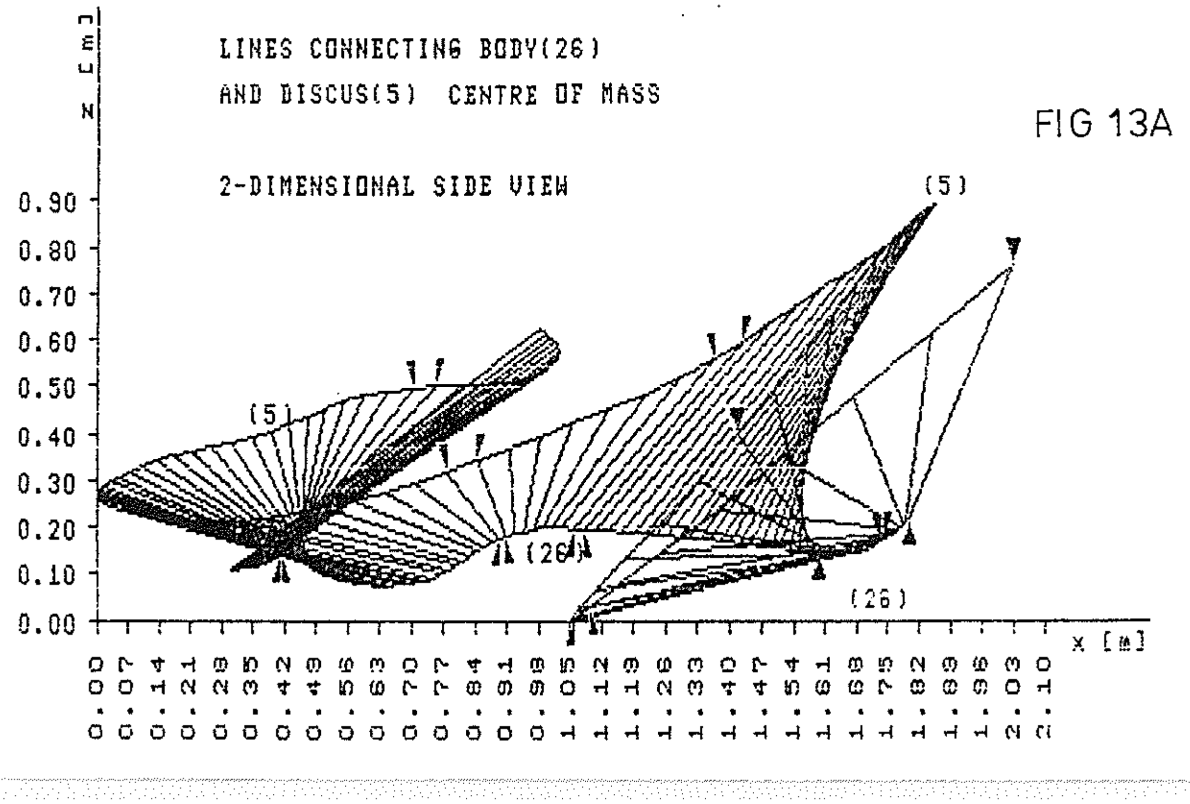
FIG 9A

FIG 10A SCHULT 68.74 m









POWELL 66.22 m

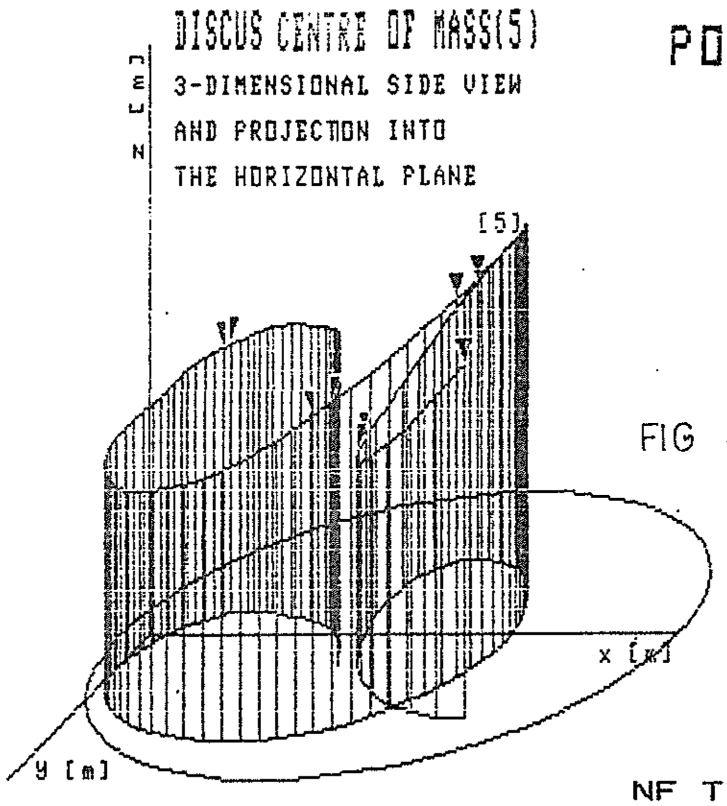


FIG 8C

3-DIMENSIONAL COORDINATES

	NF	TIM	IP	X:	Y:	Z:
R↑	104	0.24	5	-866	199	1160
	104	0.24	26	-676	-446	1023
L↑	172	0.58	5	72	-822	1387
	172	0.58	26	-301	-274	1061
R↓	187	0.66	5	439	-356	1637
	187	0.66	26	-155	-191	1067
L↓	225	0.84	5	21	661	1201
	225	0.84	26	243	-18	1006
Zmin	242	0.93	5	-145	-34	836
	242	0.93	26	418	37	1055
O↗	257	1.00	5	649	-704	1521
	257	1.00	26	481	76	1131

BODY CENTRE OF MASS(26)
3-DIMENSIONAL SIDE VIEW
AND PROJECTION INTO
THE HORIZONTAL PLANE

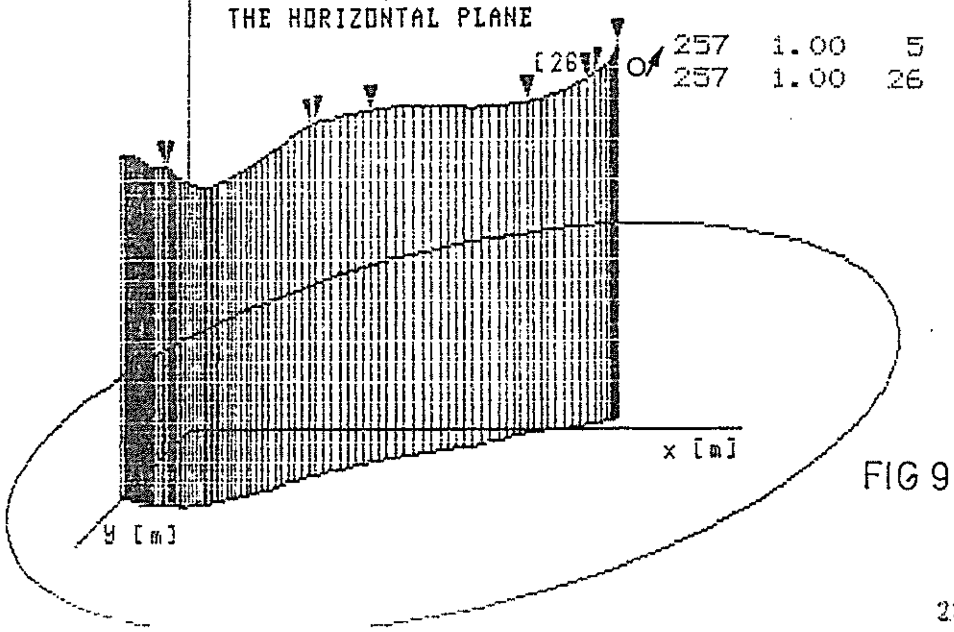


FIG 9C

POWELL 66.22 m

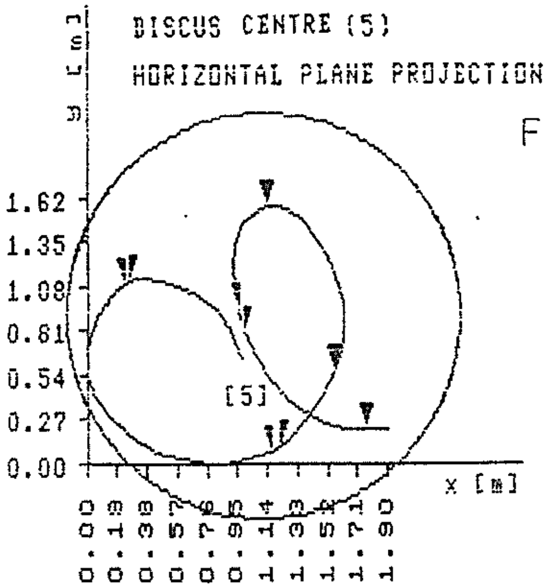


FIG 11 C

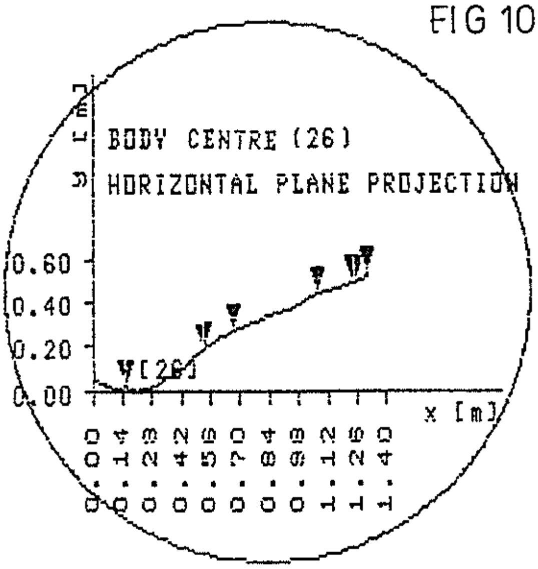


FIG 10 C

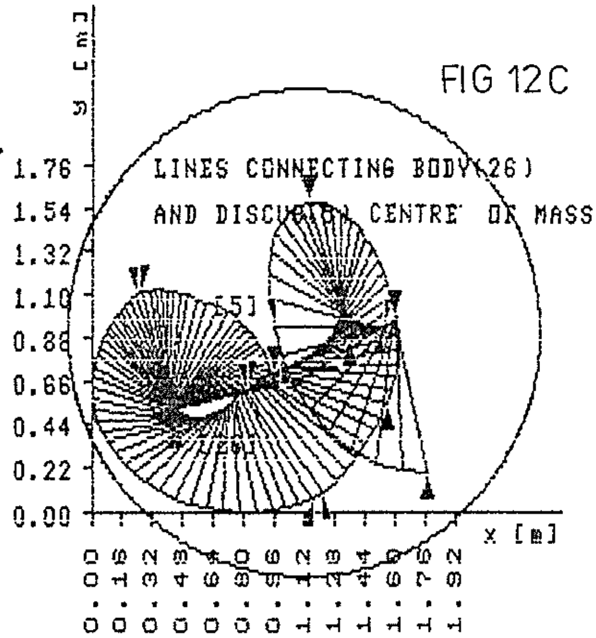


FIG 12 C

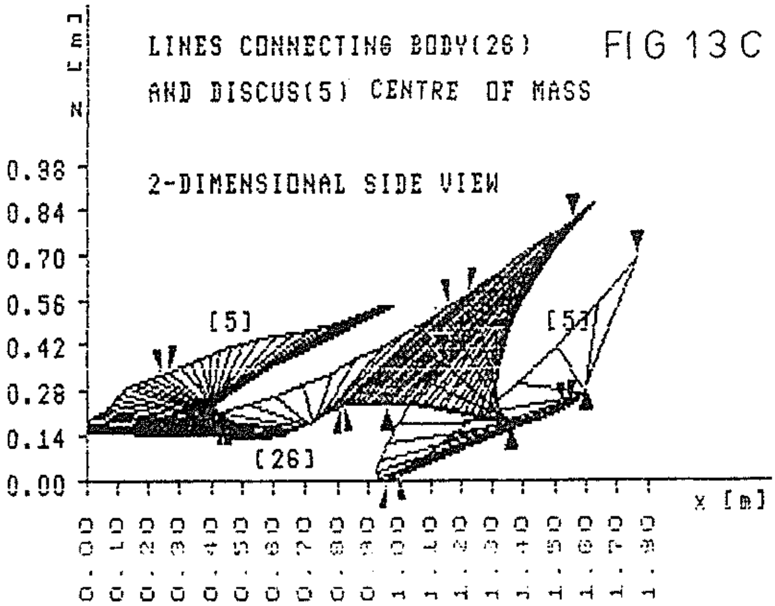


FIG 13 C

DELIS 66.02 m

DISCUS CENTRE OF MASS(5)

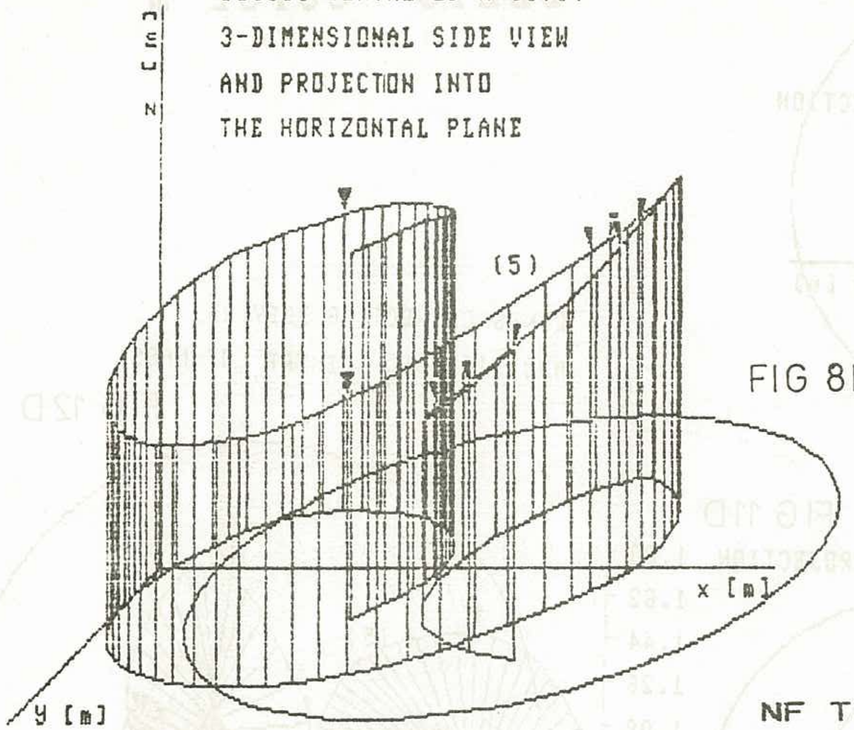


FIG 8D

BODY CENTRE OF MASS(26)

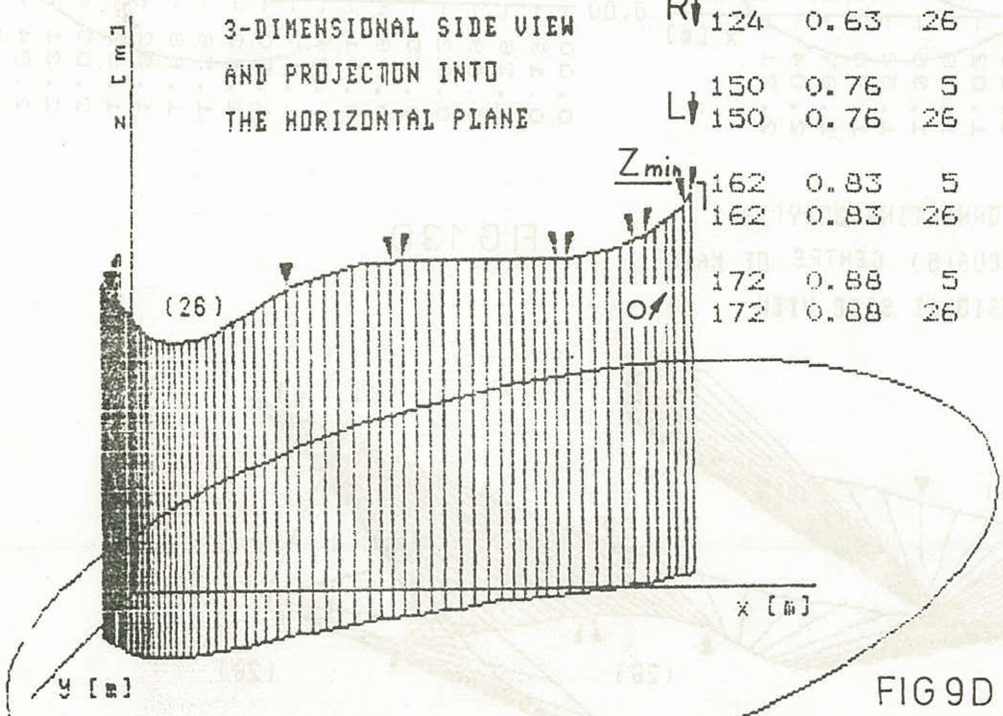


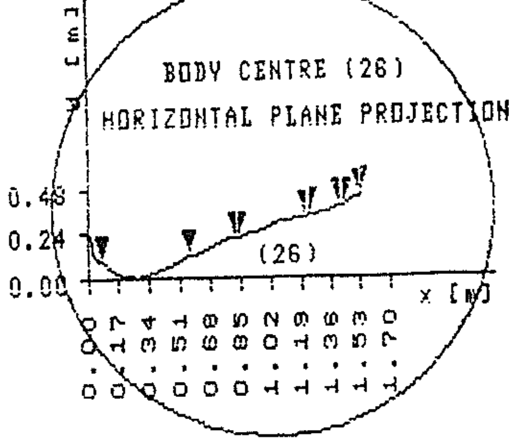
FIG 9D

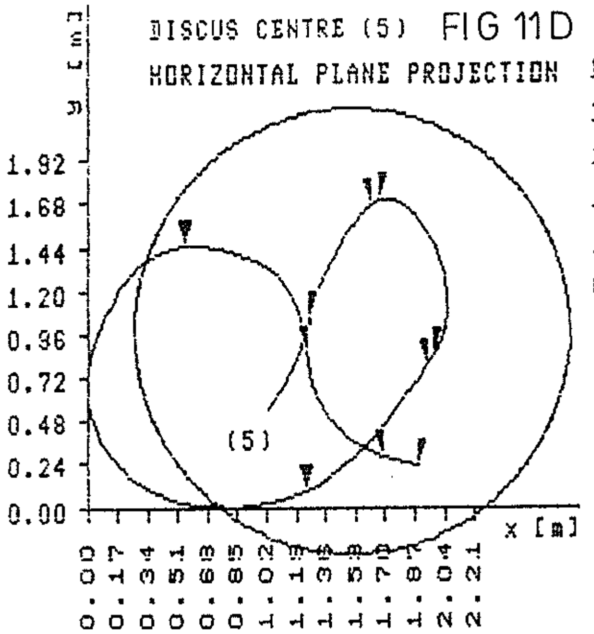
3-DIMENSIONAL COORDINATES

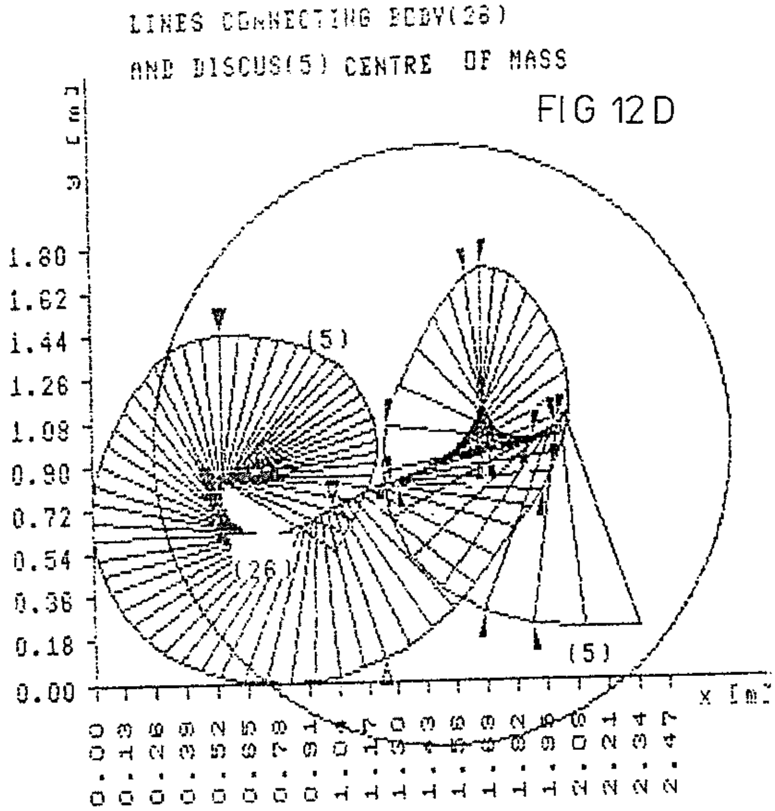
	NF	TIM	IP	X:	Y:	Z:
	45	0.23	5	-953	474	1229
R↑	45	0.23	26	-957	-280	957
L↑	107	0.54	5	-255	-880	1134
	107	0.54	26	-477	-247	952
R↓	124	0.63	5	456	-152	1411
	124	0.63	26	-211	-146	977
L↓	150	0.76	5	142	720	1016
	150	0.76	26	192	-33	923
Zmin	162	0.83	5	-254	-13	708
	162	0.83	26	383	22	951
O	172	0.88	5	276	-725	1183
	172	0.88	26	492	82	1025

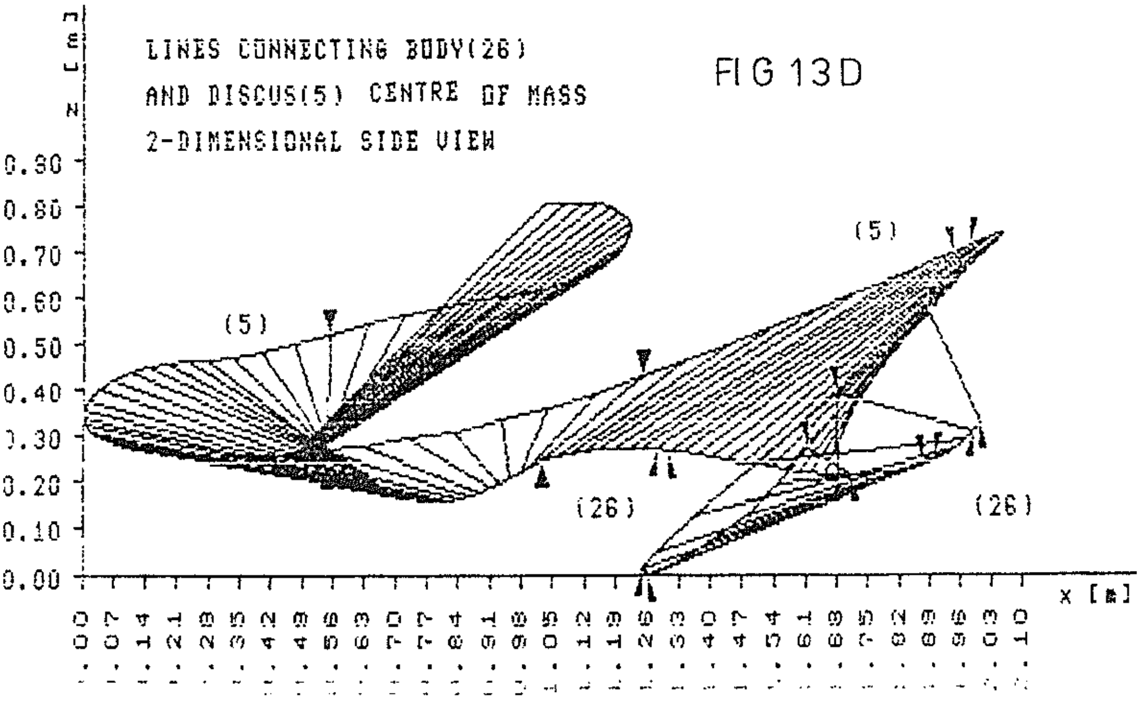
DELIS 66.02 m

FIG 10D









HELLMANN 69.66 m

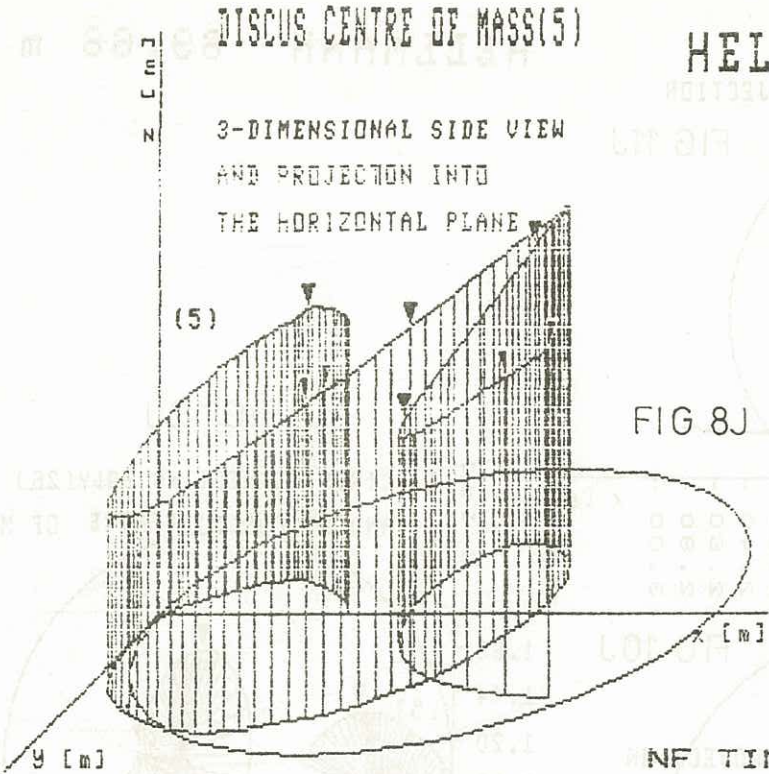


FIG 8J

3-DIMENSIONAL COORDINATES

	NF	TIM	IP	X:	Y:	Z:
R↑	21	0.10	5	-734	286	1189
	21	0.10	26	-887	-330	938
L↑	112	0.56	5	-99	-920	1394
	112	0.56	26	-353	-326	956
R↓	123	0.61	5	194	-658	1566
	123	0.61	26	-217	-286	987
L↓	171	0.85	5	140	607	1304
	171	0.85	26	269	-27	952
	189	0.94	5	-114	-87	877
	189	0.94	26	424	42	989
O↗	202	1.01	5	768	-743	1458
	202	1.01	26	478	68	1070

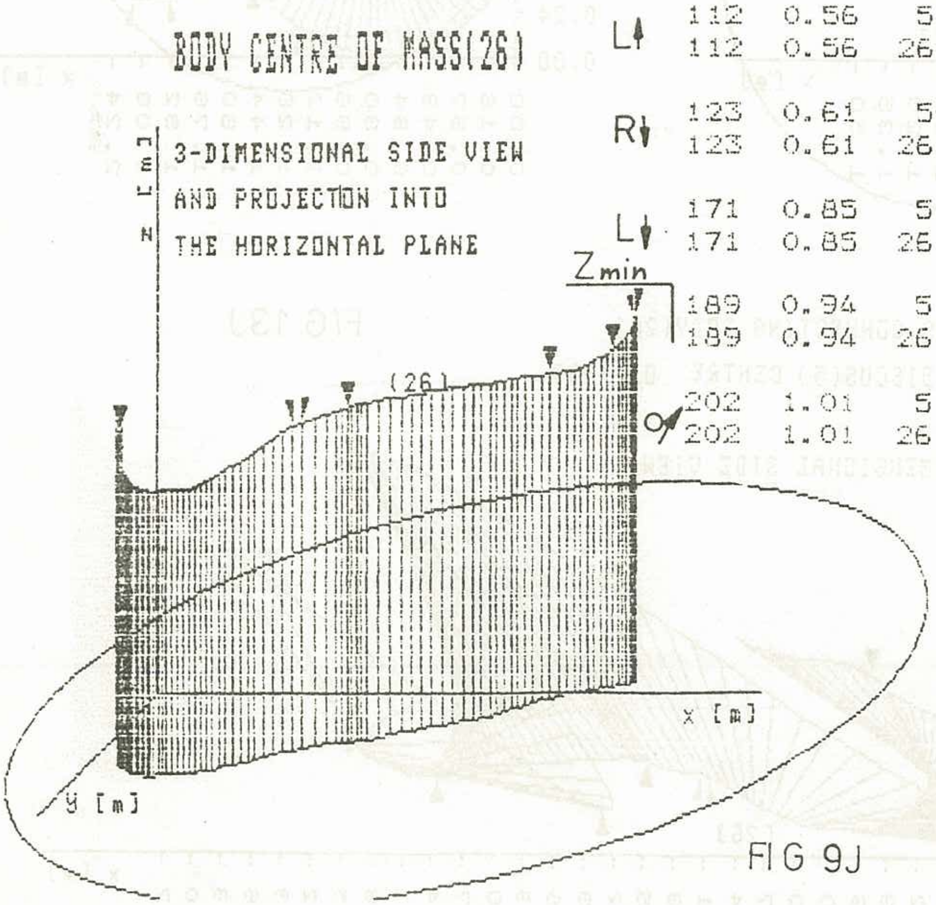


FIG 9J

HELLMANN 69.66 m

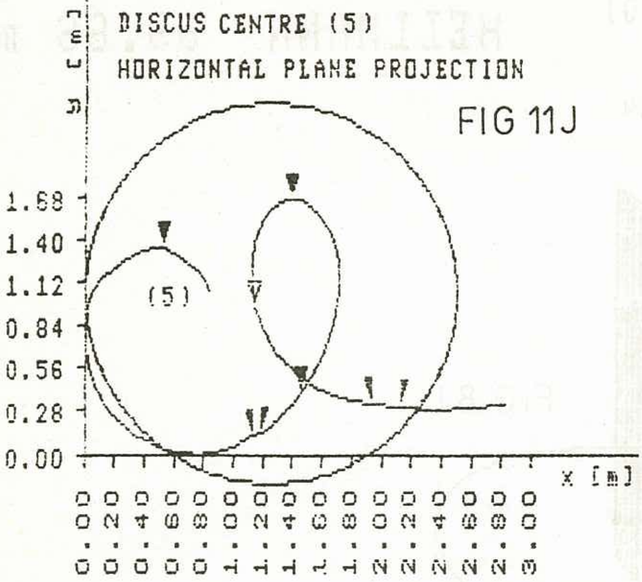


FIG 11J

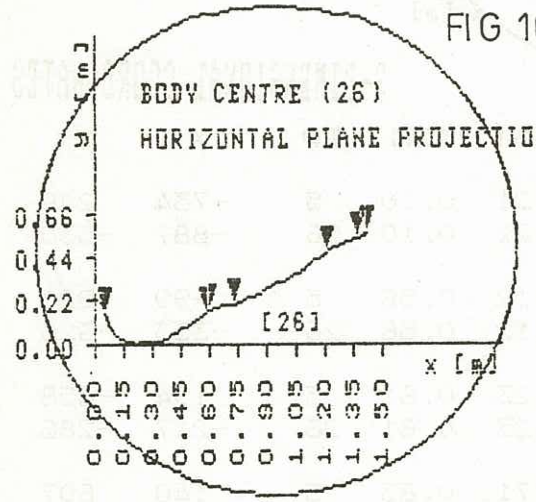


FIG 10J

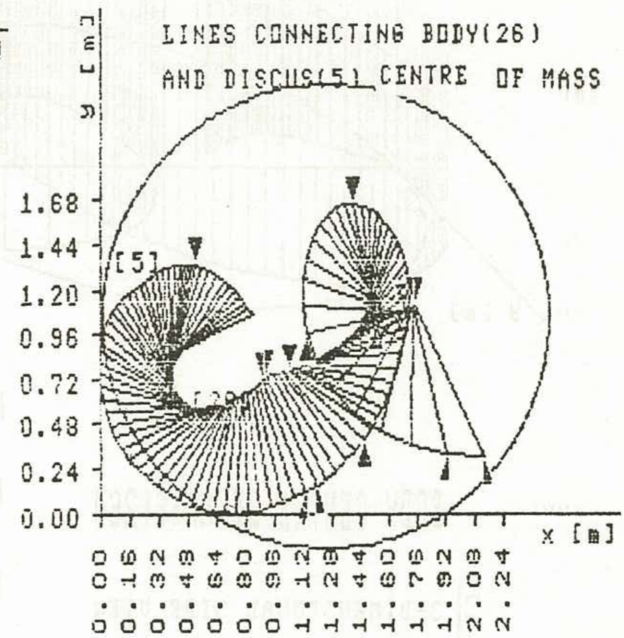


FIG 12J

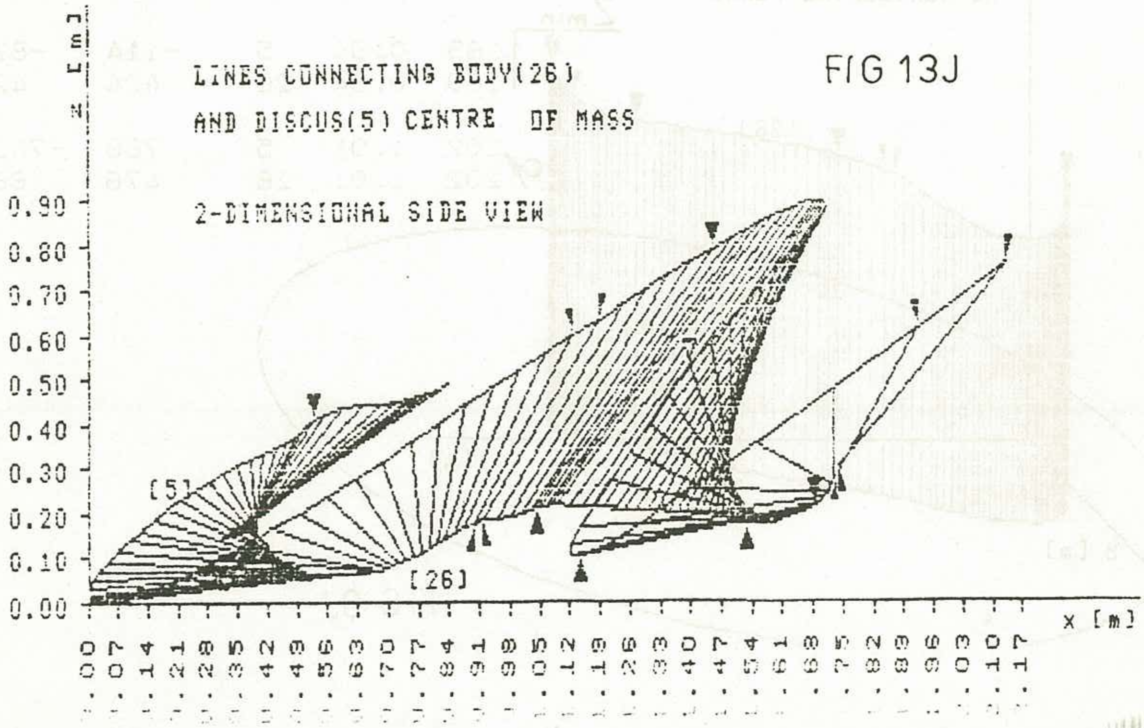


FIG 13J

GANSKY 67.50 m

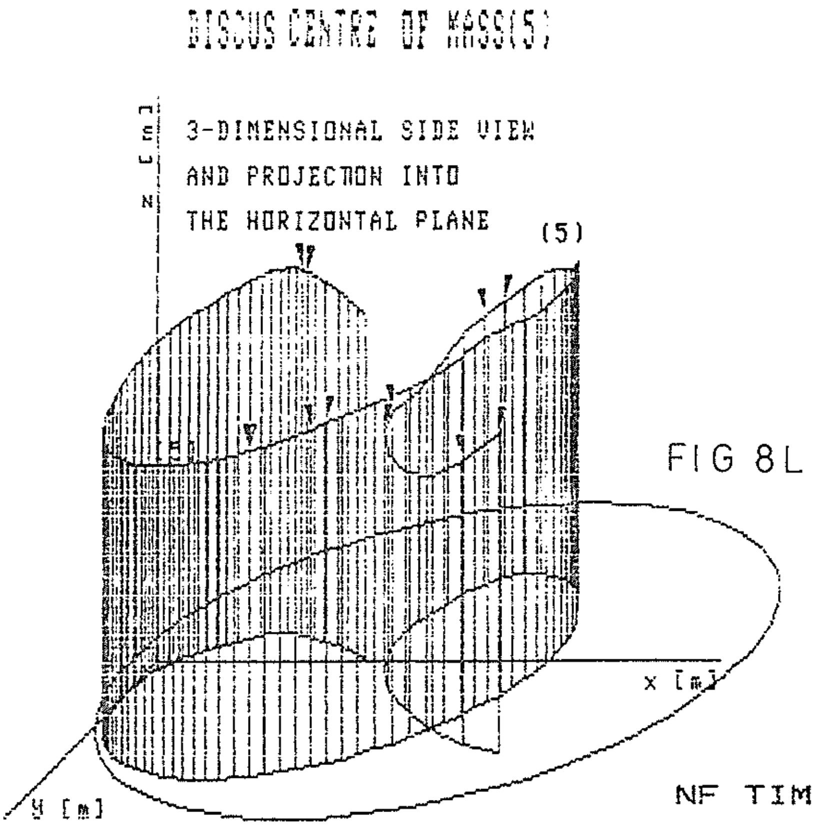


FIG 8L

3-DIMENSIONAL COORDINATES

	NF	TIM	IP	X:	Y:	Z:
R↑	116	0.07	5	-644	200	1444
	116	0.07	26	-750	-443	1056
L↑	207	0.53	5	-313	-906	1284
	207	0.53	26	-375	-420	937
R↓	216	0.57	5	-77	-811	1336
	216	0.57	26	-293	-375	961
L↓	280	0.89	5	-90	635	1074
	280	0.89	26	283	34	940
Z_{min}	294	0.96	5	-224	33	939
	294	0.96	26	402	94	954
O↗	304	1.02	5	522	-699	1189
	304	1.02	26	449	128	979

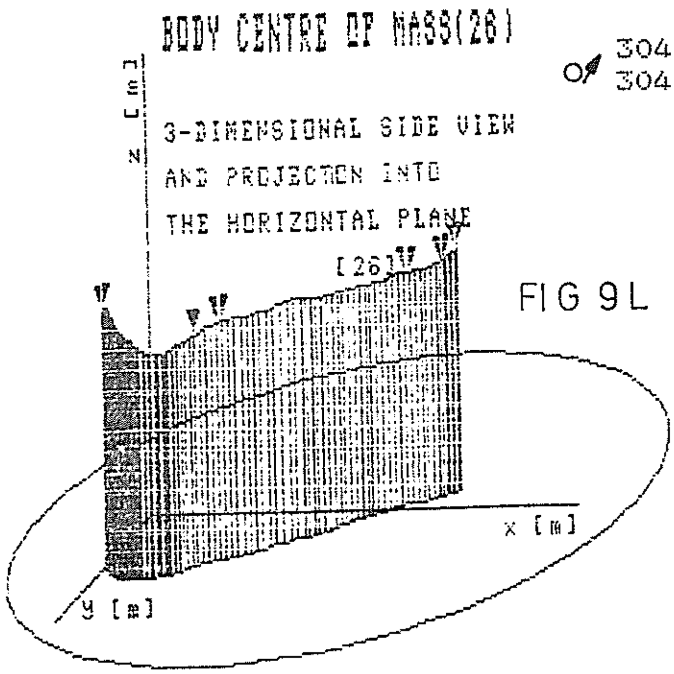


FIG 9L

GANSKY 67.50 m

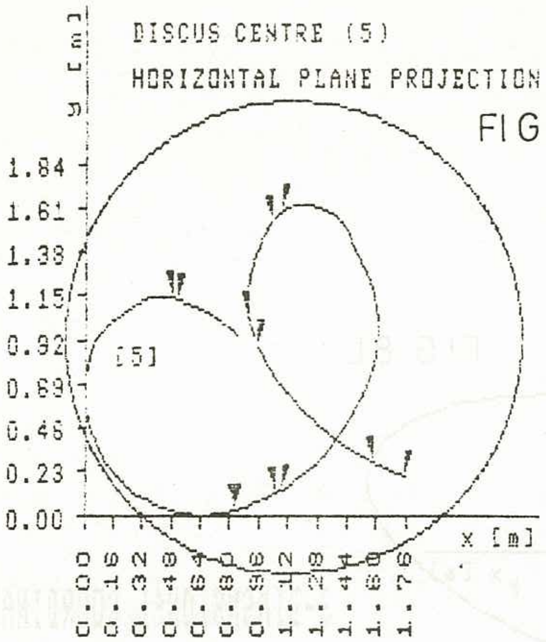


FIG 11L

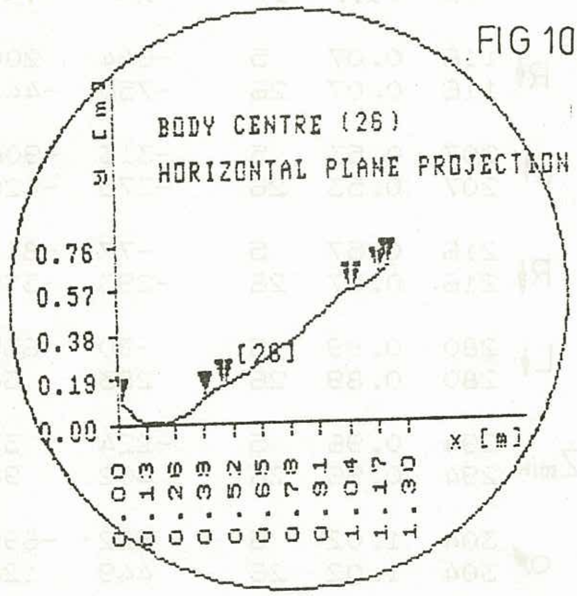


FIG 10L

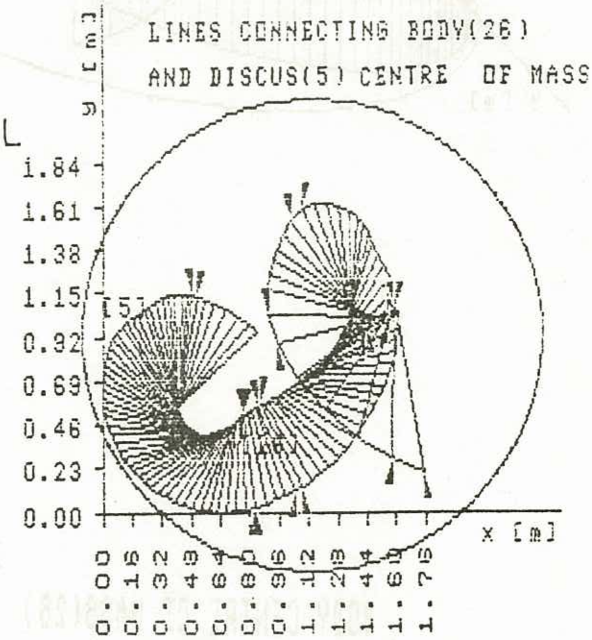


FIG 12L

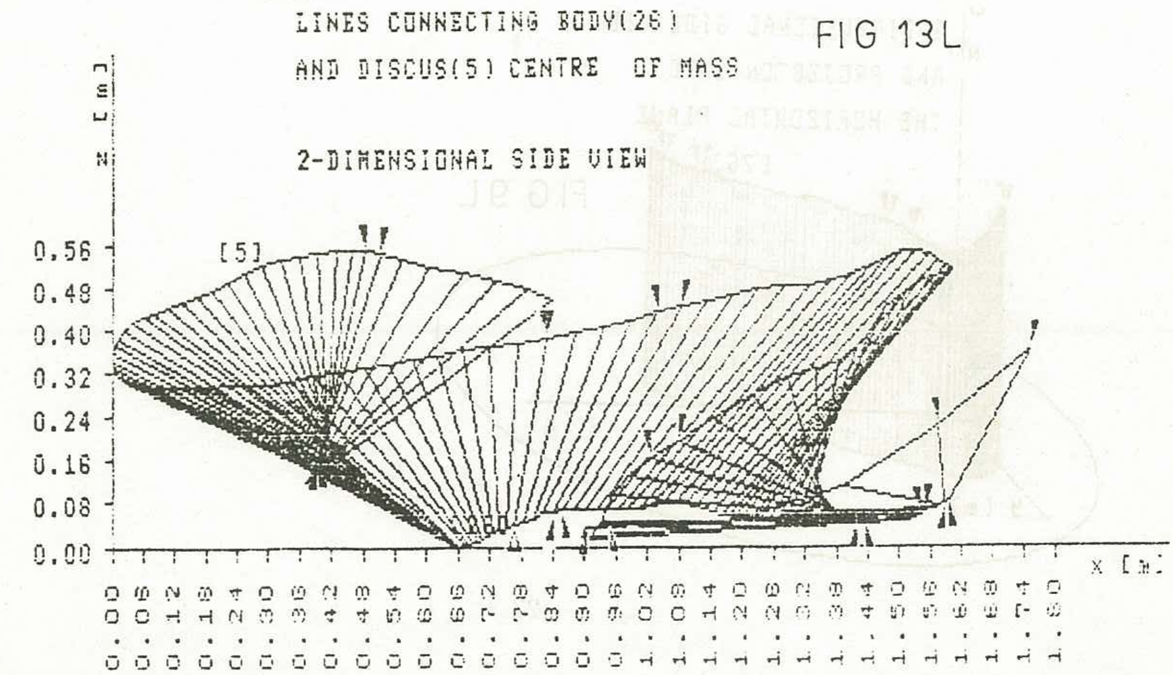


FIG 13L

KHRISTOVA 68.82 m

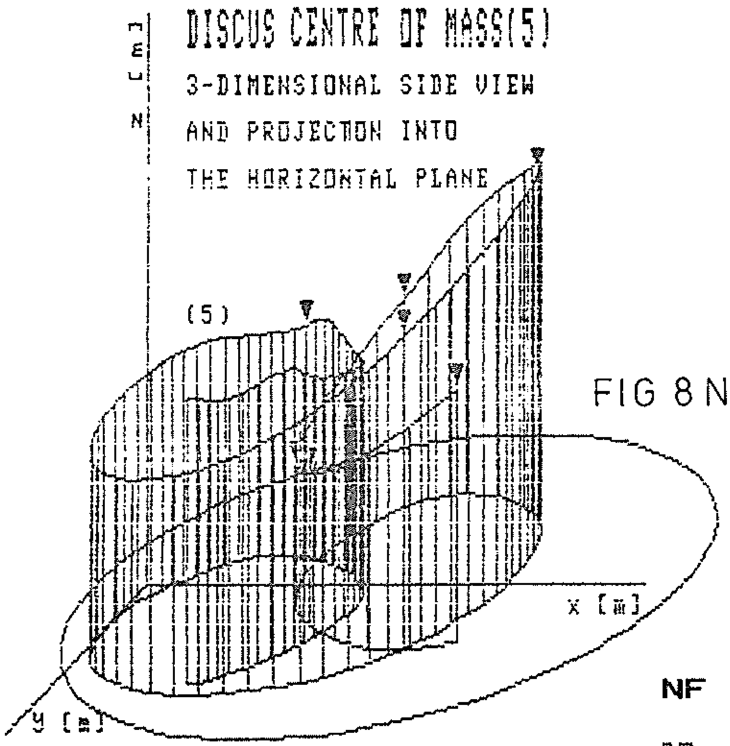


FIG 8 N

3-DIMENSIONAL COORDINATES

	NF	TIM	IP	X:	Y:	Z:
R↑	89	0.28	5	-472	236	962
	89	0.28	26	-558	-410	861
L↑	163	0.65	5	323	-510	1289
	163	0.65	26	-170	-187	879
R↓	187	0.77	5	467	335	1542
	187	0.77	26	4	9	880
L↓	213	0.90	5	-255	640	871
	213	0.90	26	223	193	819
Zmin	226	0.97	5	-235	-266	602
	226	0.97	26	343	273	804
O↗	235	1.01	5	521	-460	1033
	235	1.01	26	405	309	797

BODY CENTRE OF MASS(26)

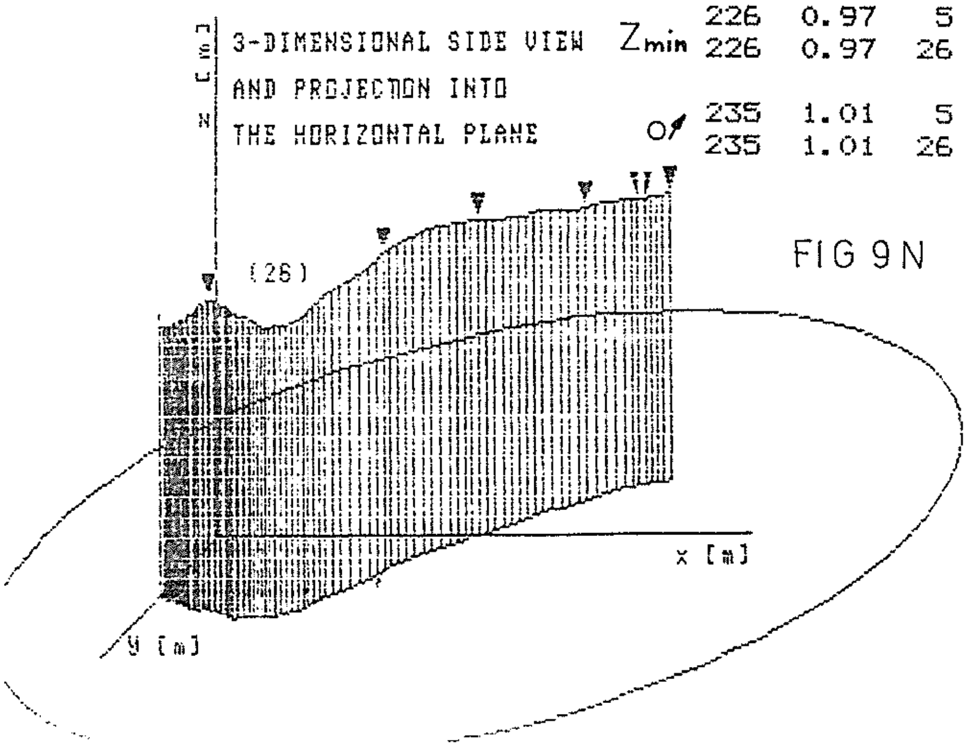


FIG 9 N

KHRISTOVA 68.82 m

FIG 11 N

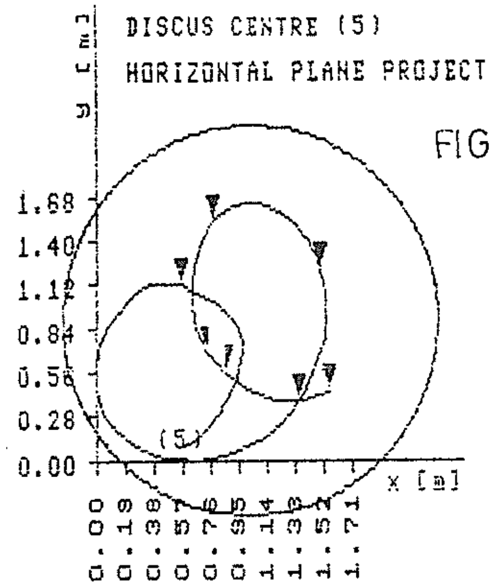


FIG 12 N

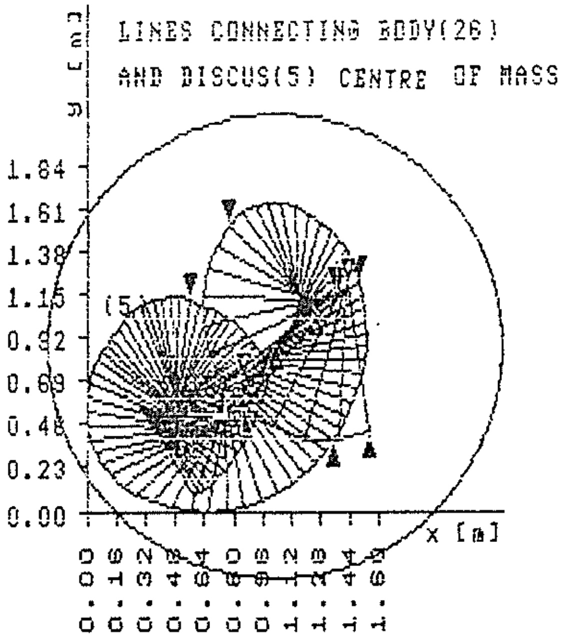


FIG 10 N

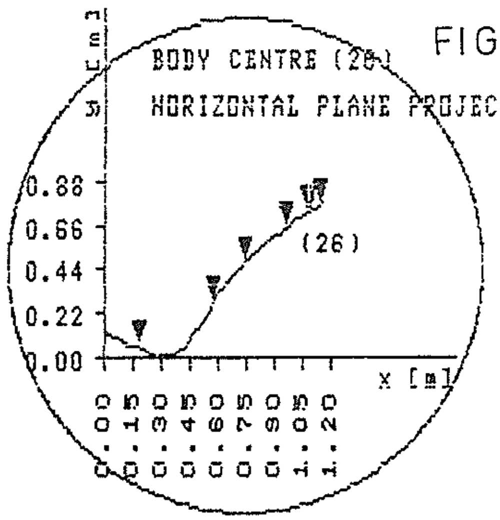
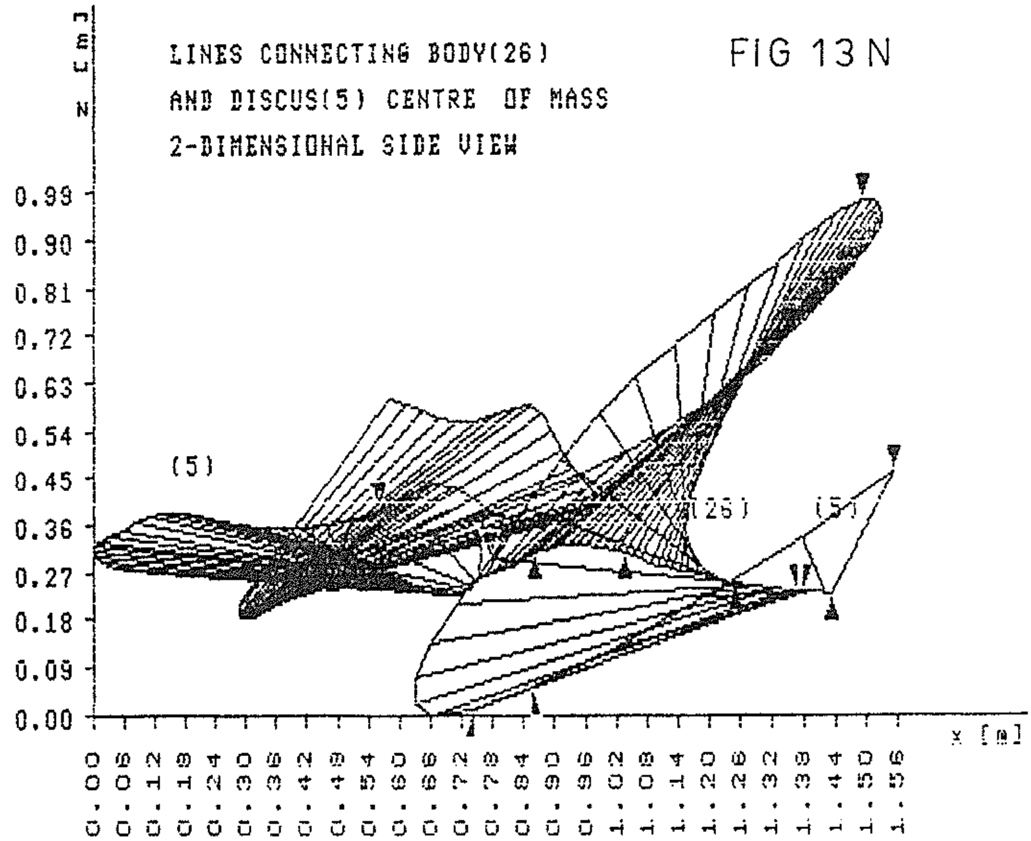


FIG 13 N



3.1.3. Accompanying Movements of the Lower Extremities

Accompanying movements of the lower extremities are of basic significance in the execution of the whole motor manoeuvre.

Deviations in the movements of lower extremities are considerable and witness totally different concepts of technical execution of the throw among individual athletes.

Observed parameters were the coordinates of points 16, 23 .... (x, y, z) ...[m] of the tips of the toes of the right and left foot.

Comment:

Totally different concepts of the movement of the lower extremities can be demonstrated on the example of the functional course of the z–component (vertical deviation) of points 16, 23 in the time of execution of the whole action (Hellmann on FIG. 6K, Mitkova on FIG. 6Q) . *

The movement range of points 16, 23 in the horizontal plane is manifested by the change of positions of the line connecting points 16, 23. **

An energetic lead into the turn(L↑)- (Shult, Delis, Hellman FIG.7 A, D, J) and a forwards bend of the trunk in the direction of the throw (R↓) gives a better chance of accelerating the discus along a long path.

The flight phase (L↑ - R↓) is shortened by accelerating the second part of the starting phase (R↑ - L↑). On average, the flight phase in throwers with higher performances is markedly shorter than in those with lower performances (0.02~0.06 s ; in men as much as 0.09 s).

Acceleration can be attained, among other means , by leading the right leg closer to the rotation axis (FIG.7 A, C, D, J, L, N, - see the change of distance between the point 16 and 23) in phases R↑ - R↓.

Remark:

* - In FIG.6 K,Q, the error range of the method we apply can be followed in the course of the observation of the three dimensional movement of separate anthropometric points. Z-component of point 23 should gain a zero-value (error 0~2 cm) in the interval (R↑ - L↑) ; that of point 16 (error 0~2 cm) in the interval (R↓ - O↗).

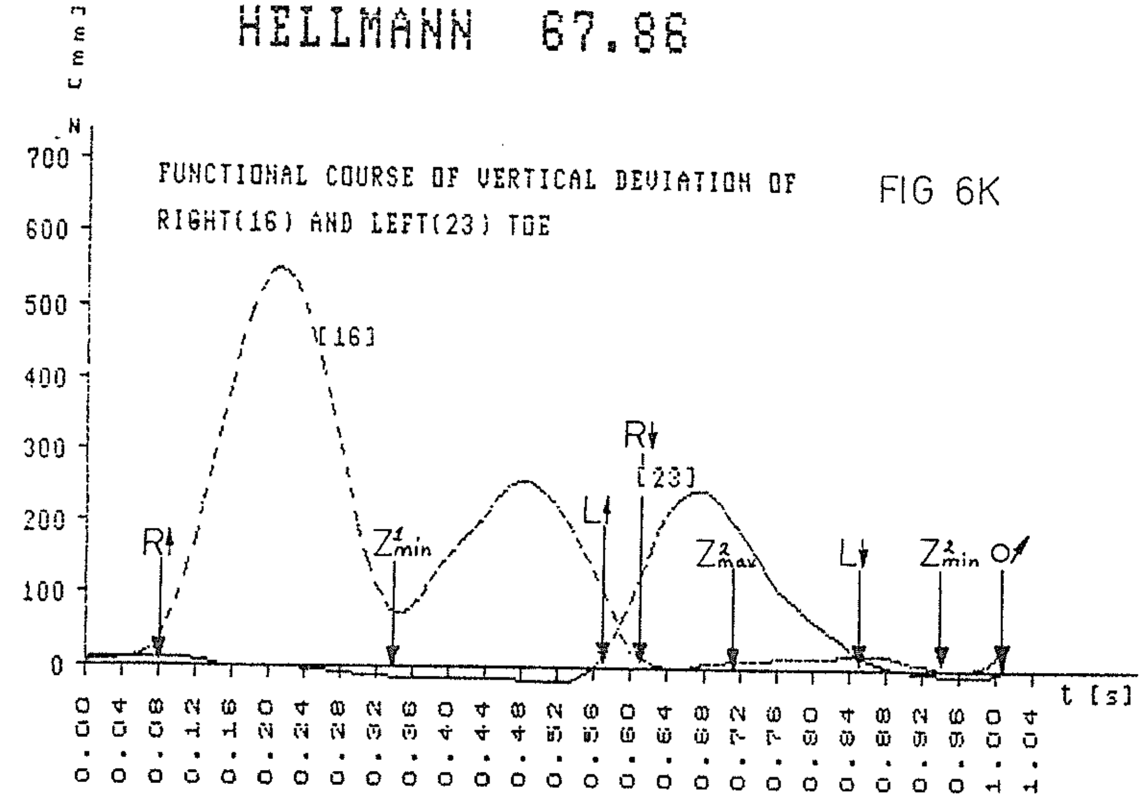
** - The ground projection of points 16, 23 indicates, among other things, the utilization of the restricted space of the throwing circle and of its vicinity for the execution of the given motor manoeuvre by individual athletes and, for orientation, also the utilization of physical consequences of the changes in inertia moments caused by leading the swing leg nearer to or more away from the momentary rotation axis, which in our case, for orientation only, is represented by the points of the support .

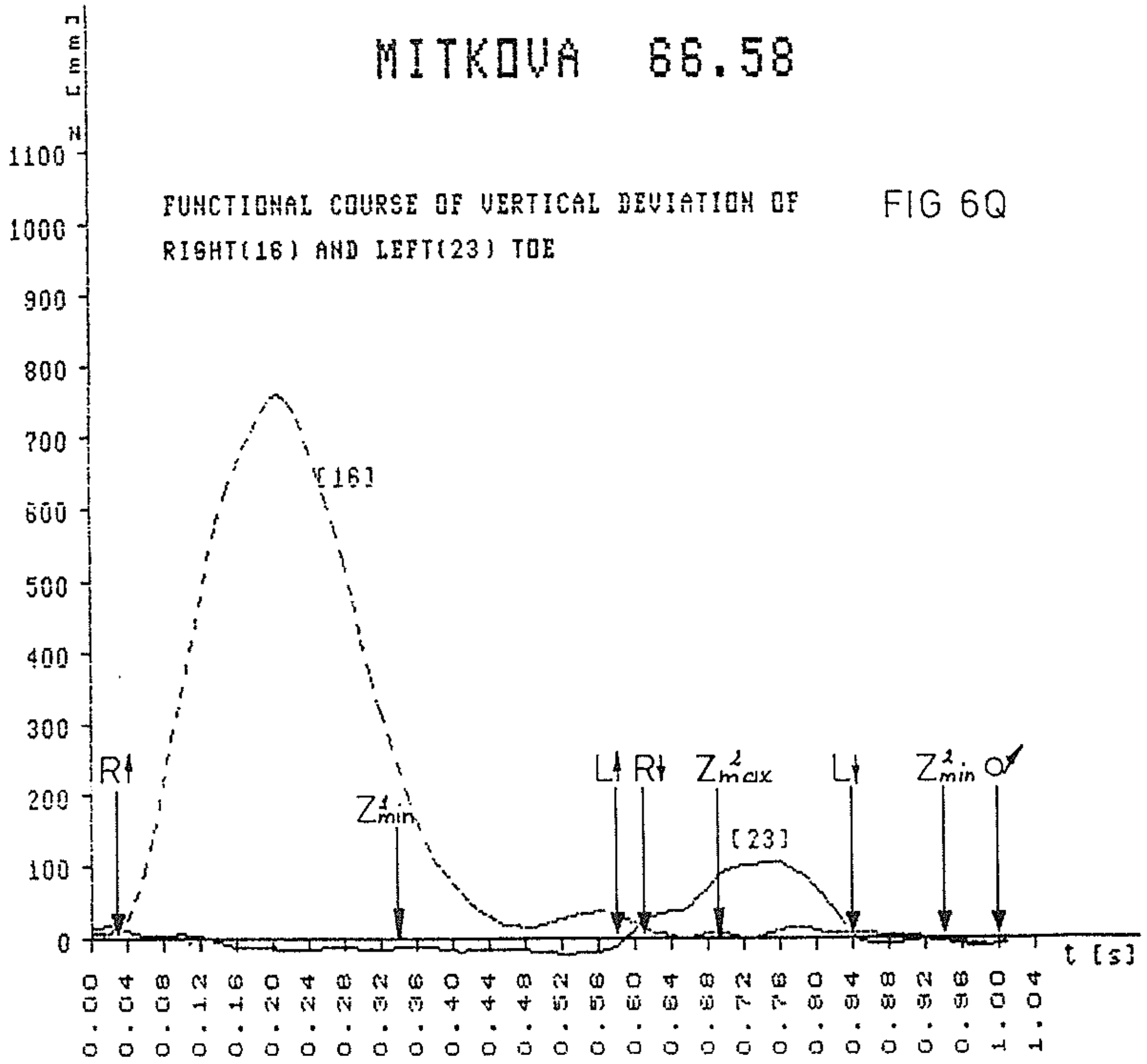
The pronounced lift of the left foot in the first part of the starting phase (R↑ - L↑) as high as 80 cm above the plane of the circle (see Mitkova), perhaps with the aim of the posibility of the subsequent swing of the foreleg, needs deeper analysis. But at least for the purpose of simplification and more economic execution of all accompanying movements, the high lift seems to be disadvantageous.

It is necessary to move the left leg in the flight phase (L↑ - R↓) and transistory phase (R↓ - L↑) so that the thrower will be able to assume a wider and more open delivery stance in order to have a better chance to hold dynamic balance in the delivery phase.

If the thrower's foot lands more to the right, he gets into a very narrow and very closed delivery positon which in addition prevents the optimal pre-tension of the trunk muscles. At the same time, as was mentioned above, as a result of it, the path radius of the right shoulder and discus centre of mass is shortened.

Differences in the concept and execution of the throw manifest themselves in FIG.7 A,D,J,L; on the contrary see the closed position in FIG.7 N,C.


HELLMANN 67.86
Z [mm]
FUNCTIONAL COURSE OF VERTICAL DEVIATION OF
RIGHT(16) AND LEFT(23) TOE
FIG 6K
[16]
[23]
R↑
Z^1_{min}
L↑
R↓
Z^2_{max}
L↓
Z^2_{min}
O↗
t [s]


MITKOVA 66.58
Z [mm]
FUNCTIONAL COURSE OF VERTICAL DEVIATION OF
RIGHT(16) AND LEFT(23) TOE
FIG 6Q
[16]
[23]
R↑
Z^1_{min}
L↑
R↓
Z^2_{max}
L↓
Z^2_{min}
O↗
t [s]

SCHULT 68.74 m

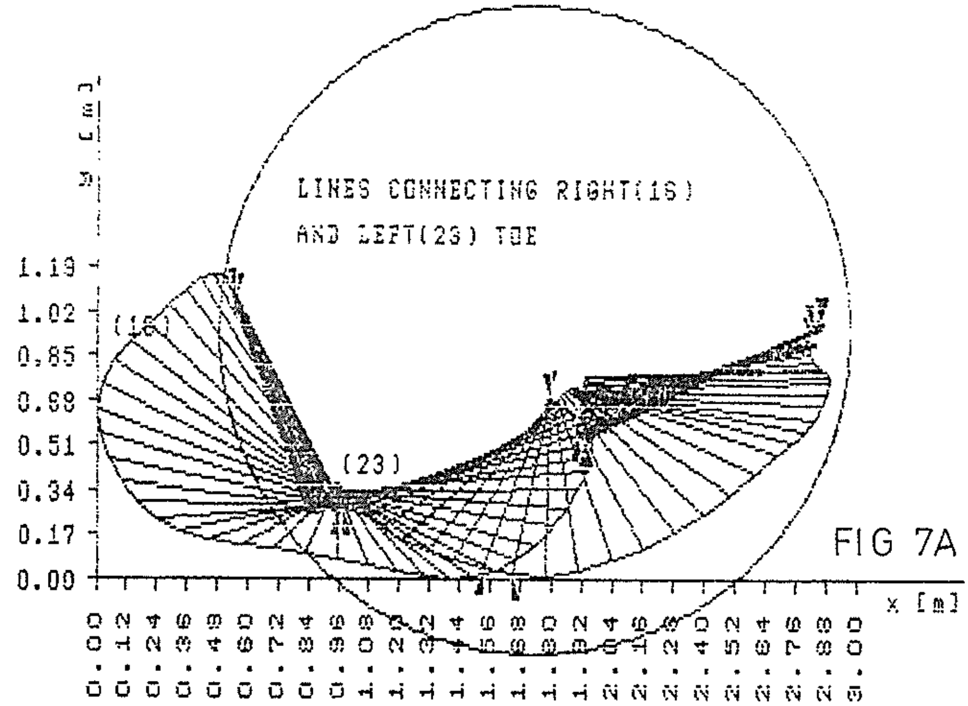


FIG 7A

POWELL 66.22 m

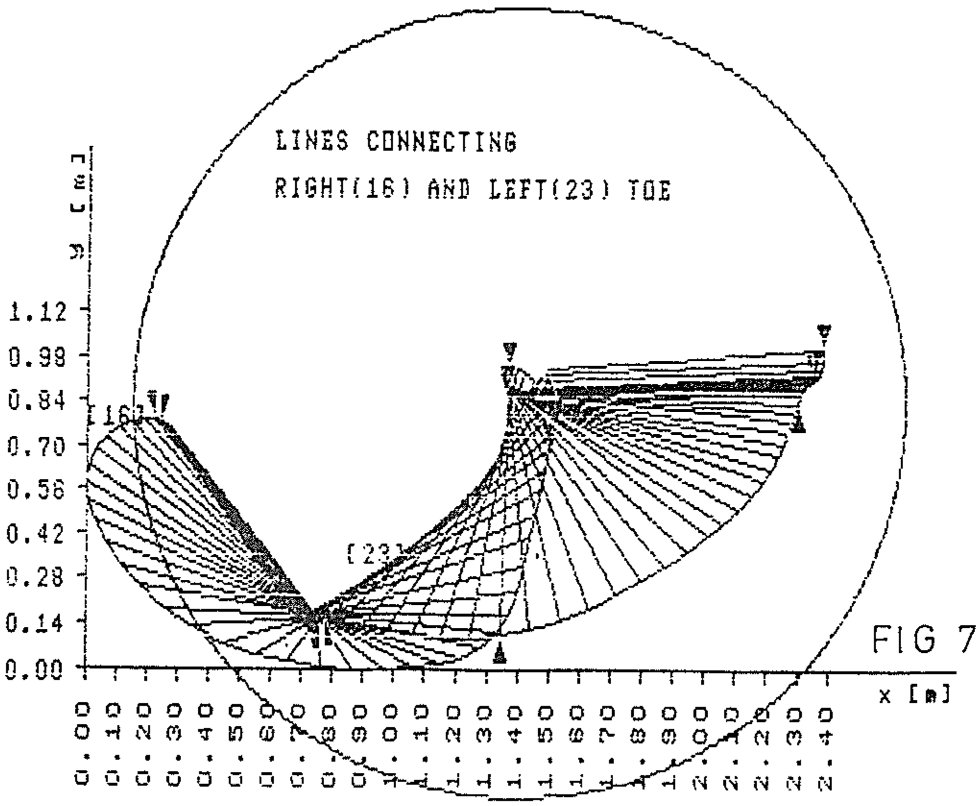


FIG 7C

GANSKY 67.50 m

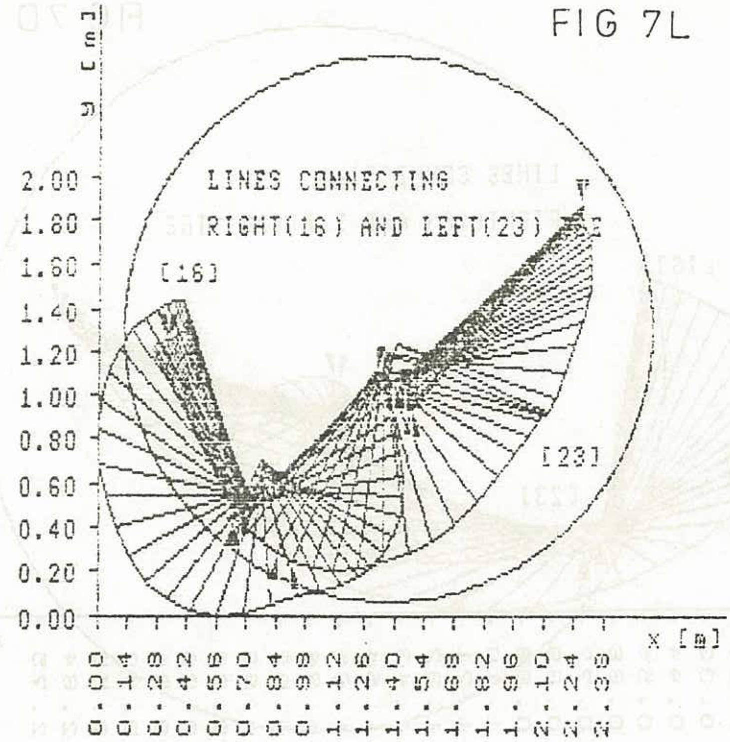


FIG 7L

KHRISTOVA 68.82 m

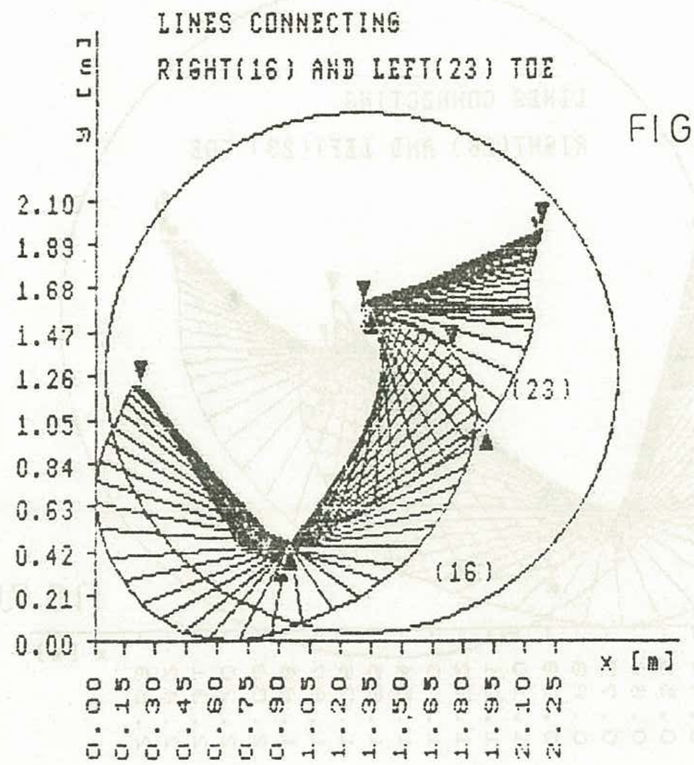


FIG 7N

DELIS 66.02 m

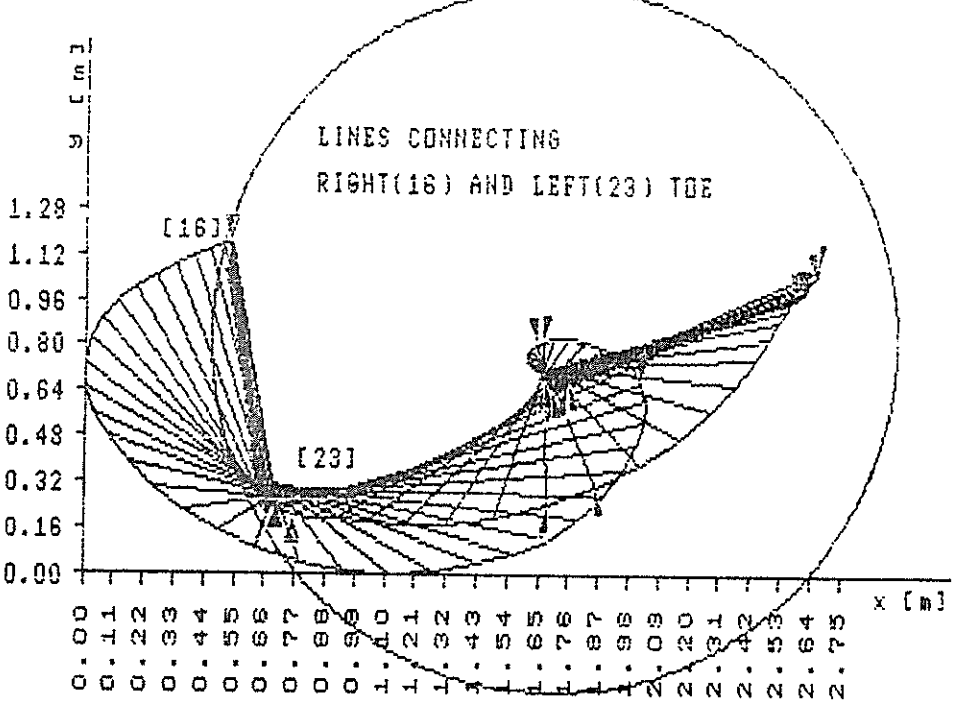


FIG 7D

HELLMANN 69.66 m

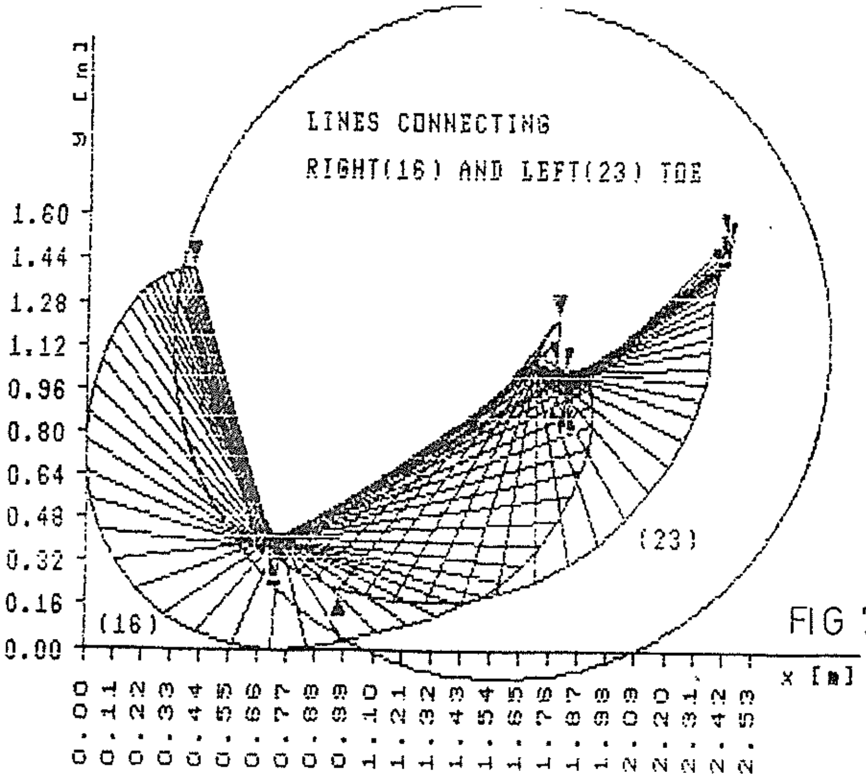


FIG 7J

3.1.4. Deviation of the Trunk in Relation to the Pelvis

Description of the investigation of the deviations of the trunk in relation to the pelvis can be found in chap. 2 - Methods and Procedures.

Observed parameters:

γ [^{o}].....angle between the pelvis axis and shoulder axis characterizes, in the case of its positive value, the "getting ahead" of shoulders in relation to the pelvis movement. In the case of an athlete throwing with the right arm, the attention is concentrated on the right shoulder movement (see FIG.17).
(x_i; y_i) ...[m] ....coordinates of the centre of the line connecting the shoulder joints in relation to the coordinates system introduced in the pelvis area; see description in chap.2, FIG.5.
x_i.....x-coordinate demonstrates the extent of the trunk side bend in relation to the pelvis. Positive values of the x-coordinate indicate the magnitude of the trunk bend to the right and negative values the magnitude of the trunk bend to the left.
y_i......y-coordinate demonstrates the extent of the forward bend of the trunk in relation to the pelvis. Positive values of the y-coordinate indicate the magnitude of the forward bend. Negative values indicate the magnitude of the backward bend.

Results:

With respect to the extent of this publication and the fact that we demonstrate the functional courses during the whole motor manoeuvre in medallists on FIG.17, 18 and in remaining throwers in the Appendix, we specify only these values :

- for y-angle extreme values of the variance range and the position of the shoulders in the release moment $\gamma O\nearrow$.
- the magnitude of the backward and sideward bend of the trunk at the moment of delivery ($O\nearrow$) is indicated by the coordinates x_i; y_i on TAB. 8,9.

Comment:

With the aim of an effective utilization of the trunk muscles, it seems advantageous to reach a pronounced torsion of the trunk at the moment of the left foot landing L↓.

In this way the pre-condition is created for utilization of the rotational strength of the trunk for accelerating the implement on its path in the delivery phase (L↓ - Z_{min2} - $O\nearrow$).

In the release moment there should be a parallel position of the shoulders and the body (γ=0 ^{o}) this proving that all the kinetic energy has been transferred into the implement in the maximum possible degree. Schult in FIG. 17 A and Hellmann in FIG. 17 J fulfil the quoted pre-conditions.

In the case of Delis in FIG. 17 D, the shoulder axis gets markedly ahead in relation to the pelvis axis in the final phase of the delivery; in less successful trials by 40^{o} and in the trial 66,02 m by 22^{o} which can be considered a technical fault.

On the other hand, early release of the discus, when the shoulders axis is considerably delayed behind the pelvis axis (e.g.Wyllnda-Appendix,FIG.17P,γ O$\nearrow$=-28^{o}) gives evidence that the trunk rotation has not been utilized sufficiently.

From the standpoint of contemporary theoretical views on the throwing action, the magnitudes of the coordinates of the centre of shoulders, x_i; y_i, are of special interest to us primarily in the course of the transitory (R$\downarrow$ L$\downarrow$) and delivery (L$\downarrow$ O$\nearrow$) phase. In these phases, the position of the centre of the shoulders in relation to the pelvis affects the length of the path of implement centre of mass and at the moment of the discus release demonstrates the level of stability in the delivery position. In the delivery position the magnitudes of the coordinates x_i; y_i should fluctuate around zero-value.

Values of Christova and Delis can be considered atypical.

WOMEN

NAME	PERF.	γ_{max} R↑O↗	γ_{min} R↑L↓	$\gamma_{O↗}$	β_{max}	β_{min}	$X_{iO↗}$	$Y_{iO↗}$	Z^* max-min	$\alpha_{O↗}$
HELLMANN MARTINA	69.66	64	2	3	238	190	0.03	-0.05	0.20	34.3
HELLMANN MARTINA	67.86	76	19	16	252	194	-0.06	-0.03	0.26	36.4
GANSKY DIANA	67.50	100	13	20	257	204	-0.09	-0.15	0.18	39.4
GANSKY DIANA	65.42	90	17	10	254	205	-0.14	-0.10	0.16	40.4
KHRISTOVA TSVETANKA	68.82	65	23	-12	236	196	0.24	-0.17	0.14	37.4
KHRISTOVA TSVETANKA	68.80	68	16	- 8	241	175	0.19	-0.15	0.15	37.0
WYLLUDA ILKE	68.20	80	0	28	242	193	-0.08	-0.08	0.10	x
MITKOVA SVETLA	66.58	80	6	4	236	185	-0.02	-0.15	0.17	40.8
SILHAVA SVETLA	64.82	90	21	-20	237	x	0.17	-0.10	0.12	x
IONESCU LENGYEL M.	62.30	95	22	11	241	192	-0.02	-0.18	0.14	39.9

α, β, γ .... (°)

* BODY CENTRE OF MASS (26)

TABLE 9

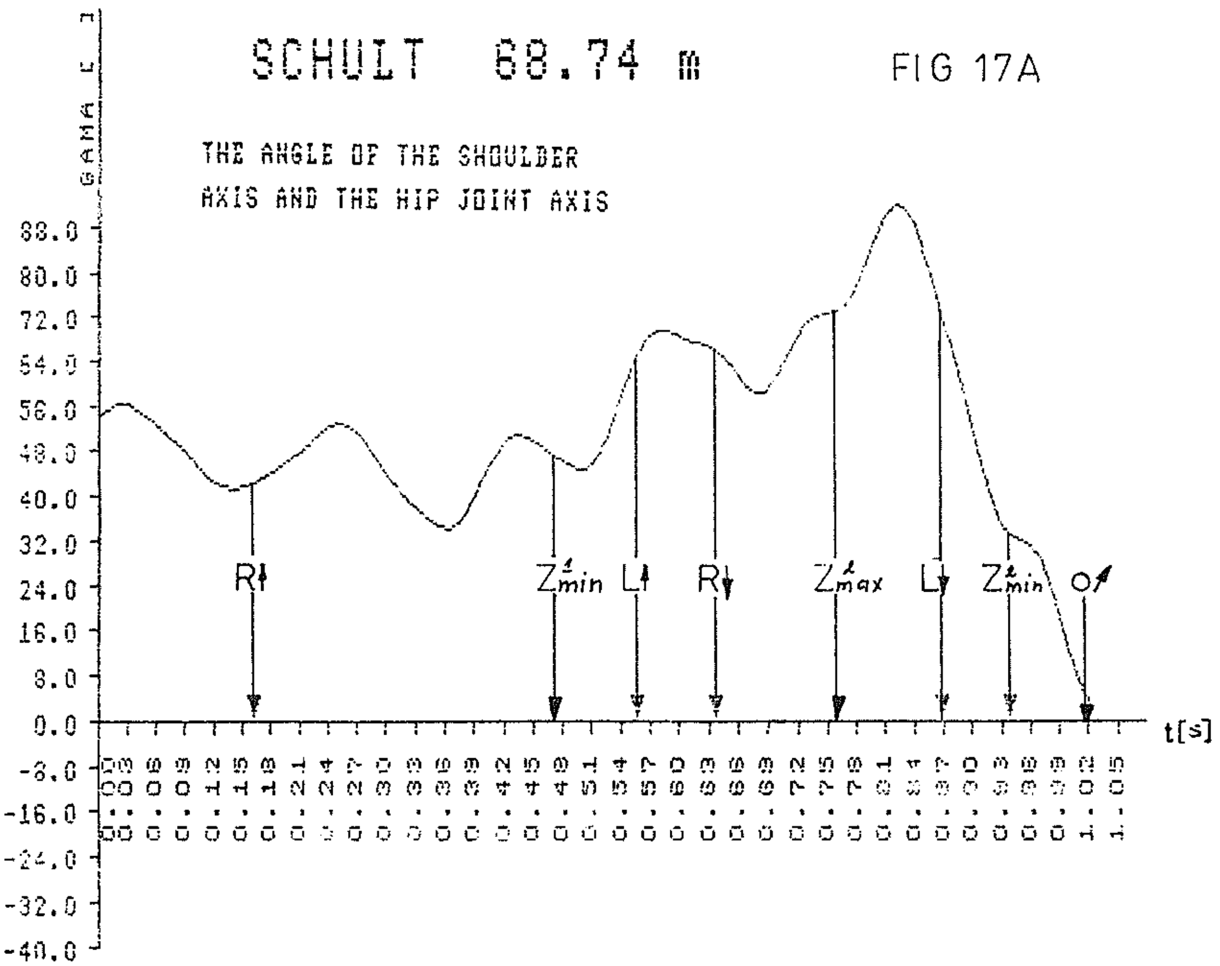


FIG 17A

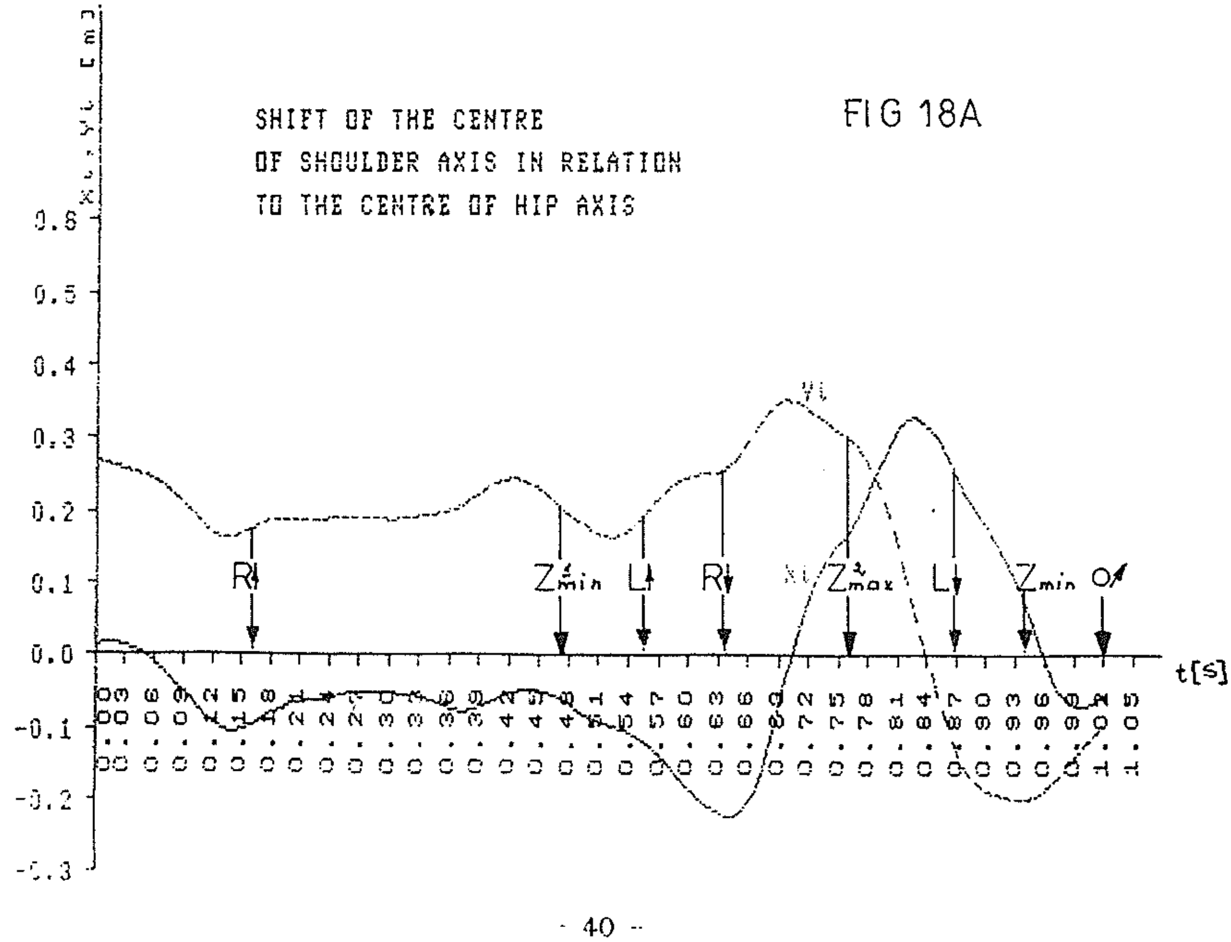
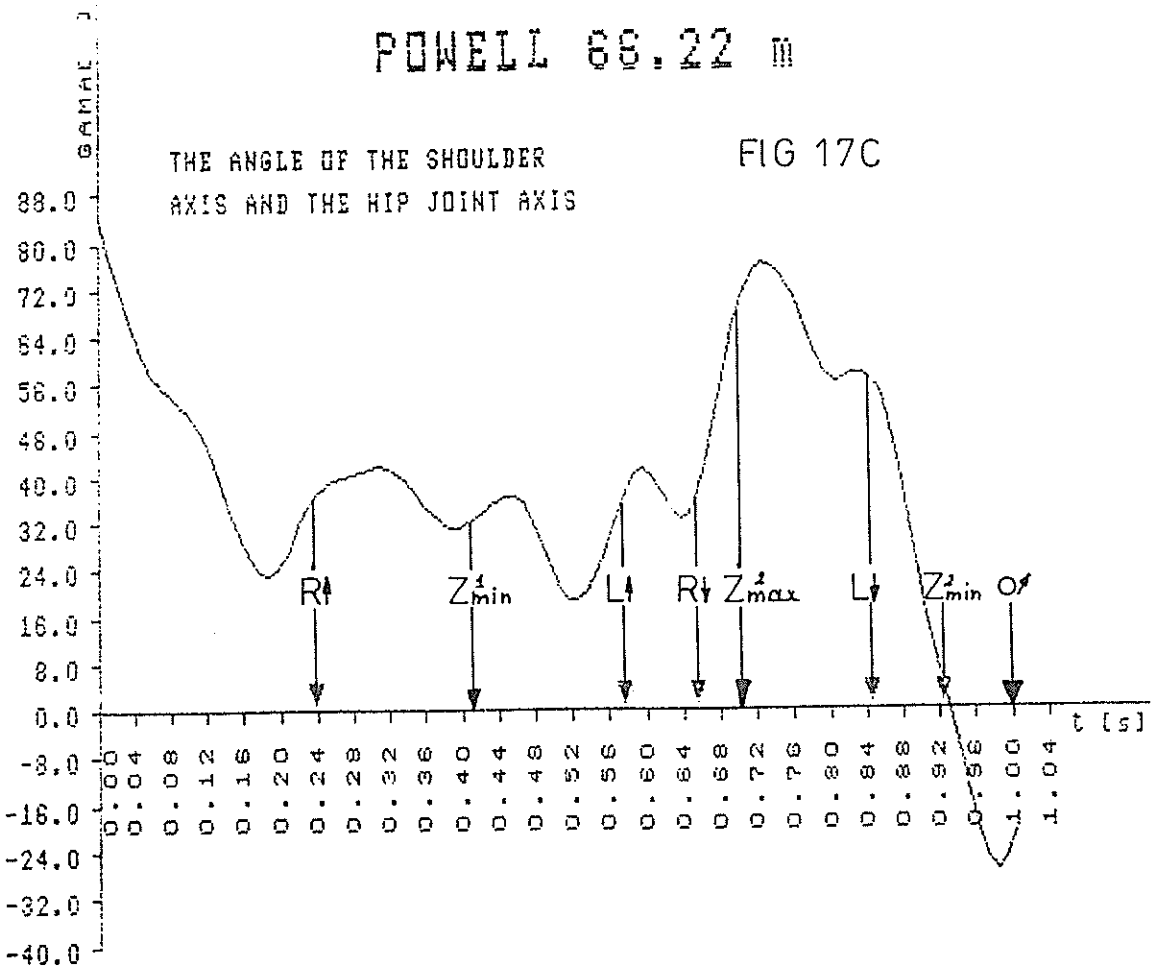


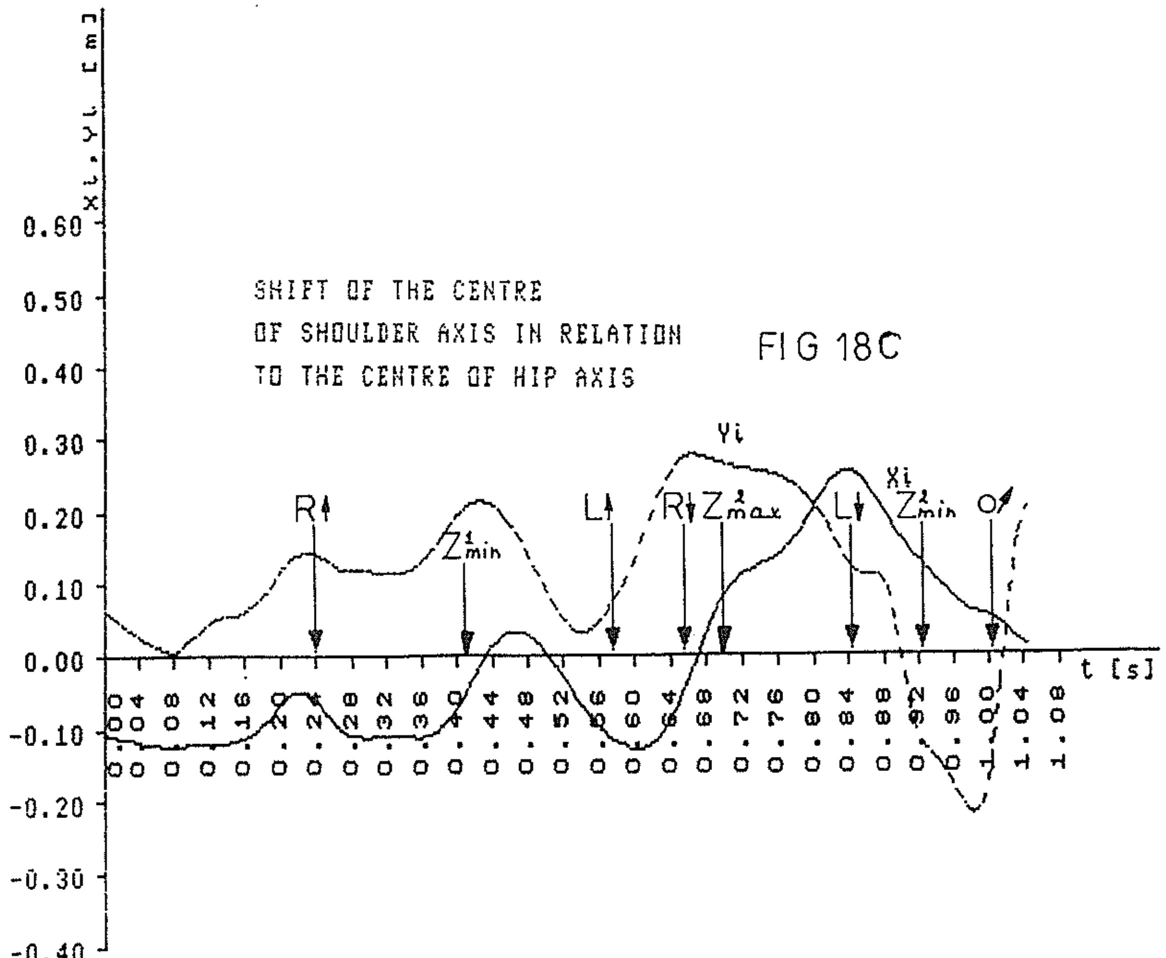
FIG 18A

POWELL 68.22 m



THE ANGLE OF THE SHOULDER AXIS AND THE HIP JOINT AXIS

FIG 17C

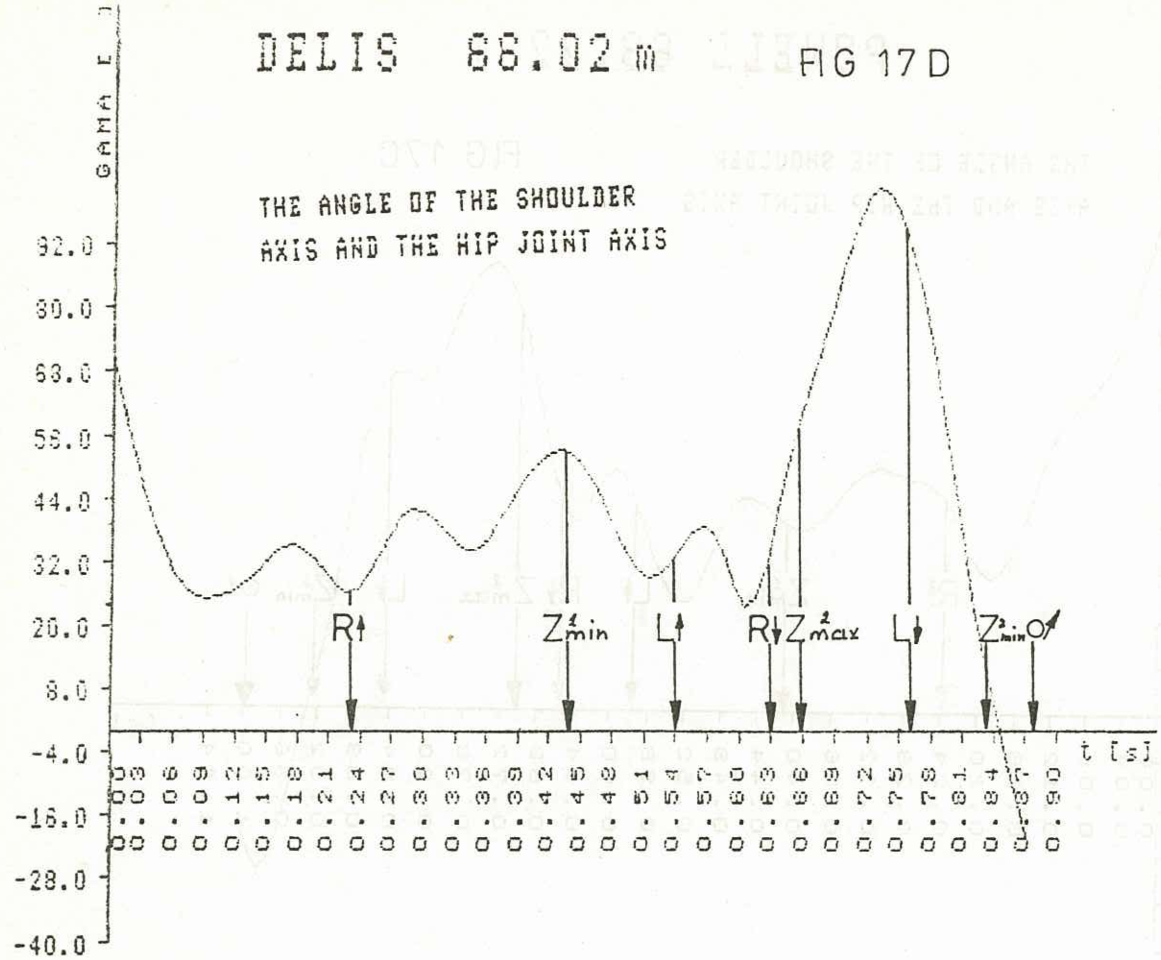


SHIFT OF THE CENTRE OF SHOULDER AXIS IN RELATION TO THE CENTRE OF HIP AXIS

FIG 18C

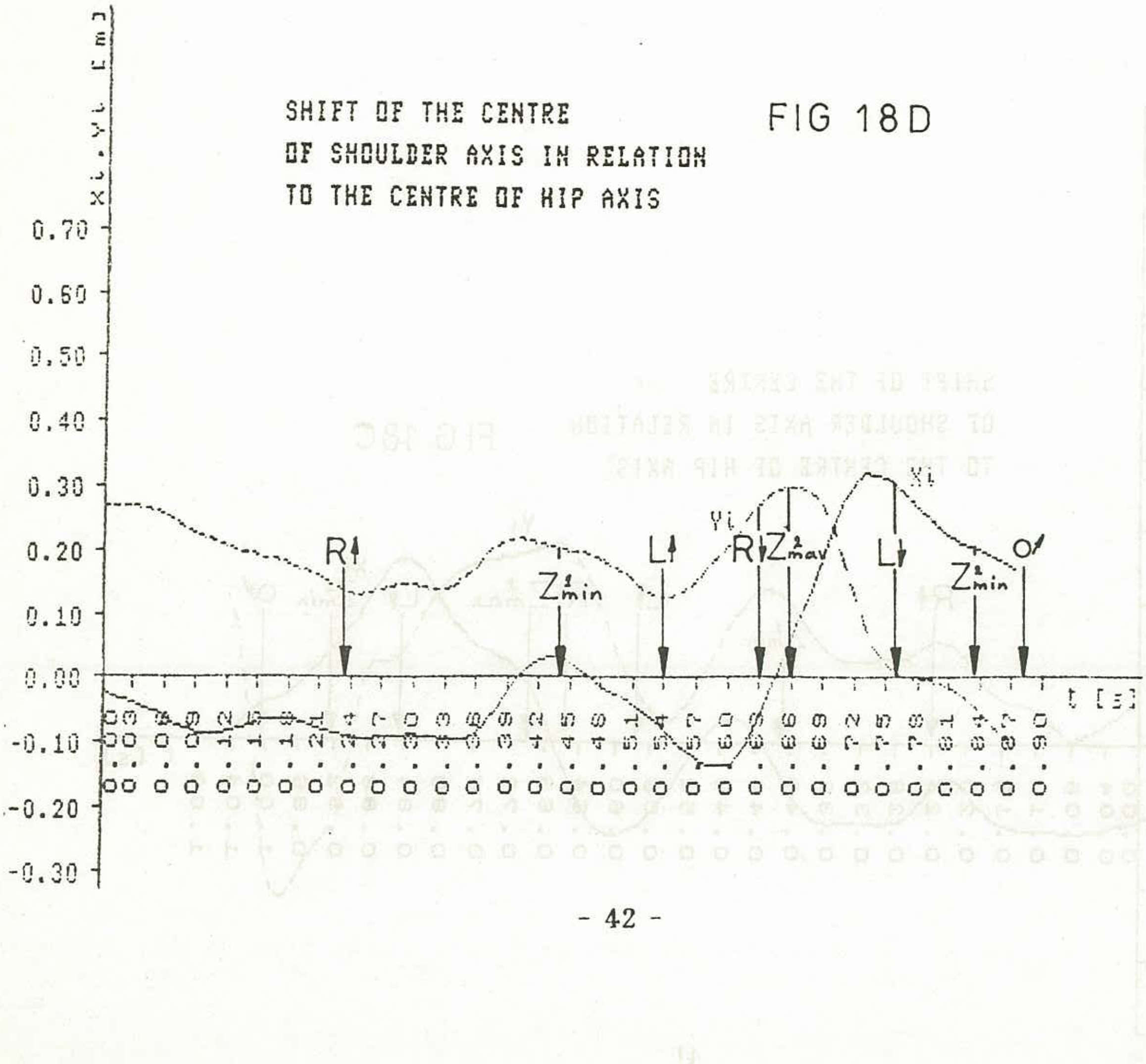
DELIS 88.02 m FIG 17D

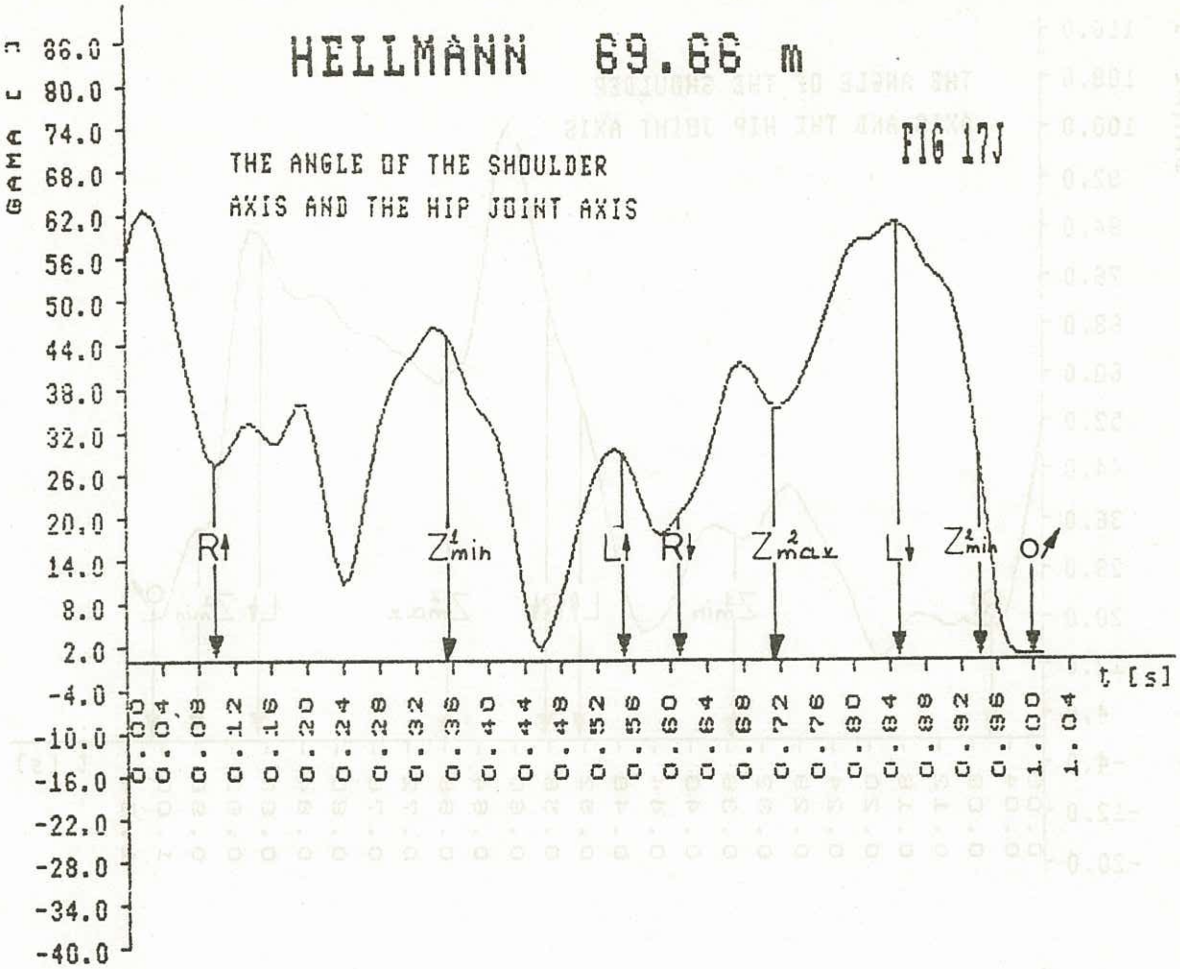
THE ANGLE OF THE SHOULDER AXIS AND THE HIP JOINT AXIS

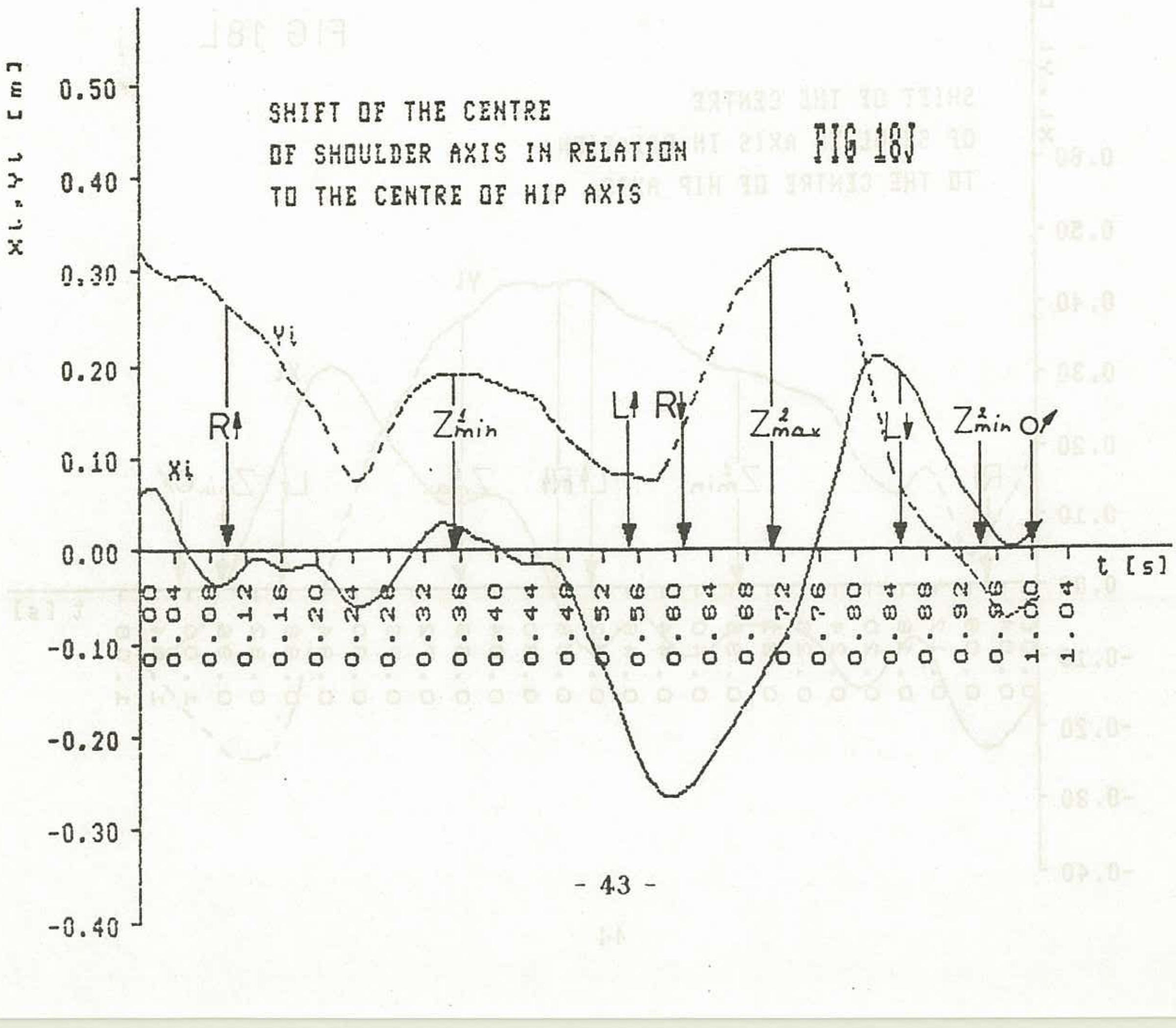


SHIFT OF THE CENTRE OF SHOULDER AXIS IN RELATION TO THE CENTRE OF HIP AXIS

FIG 18D




HELLMANN 69.66 m
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
FIG 17J
GAMA [ ]
t [s]


SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18J
XL, YL [m]
t [s]

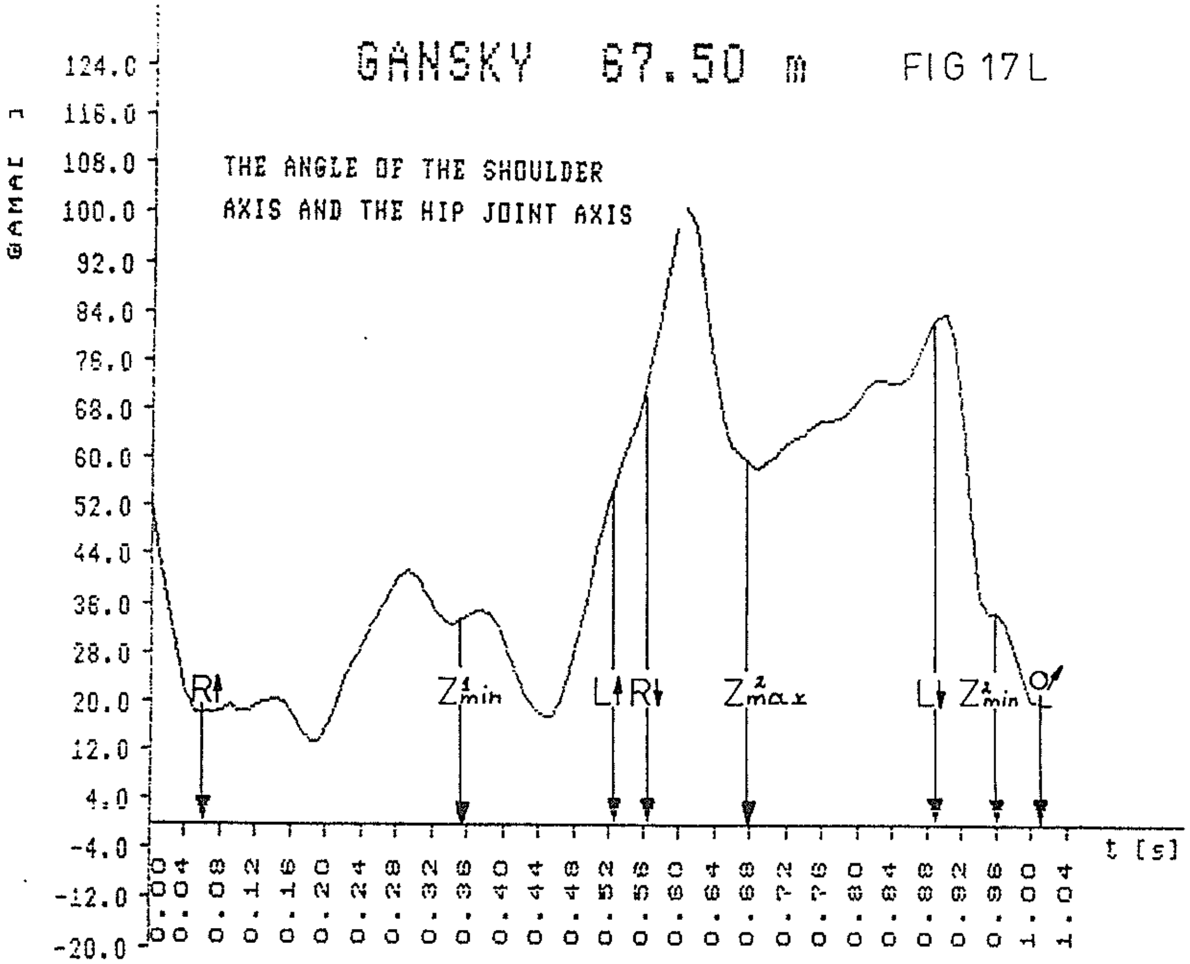


FIG 17L

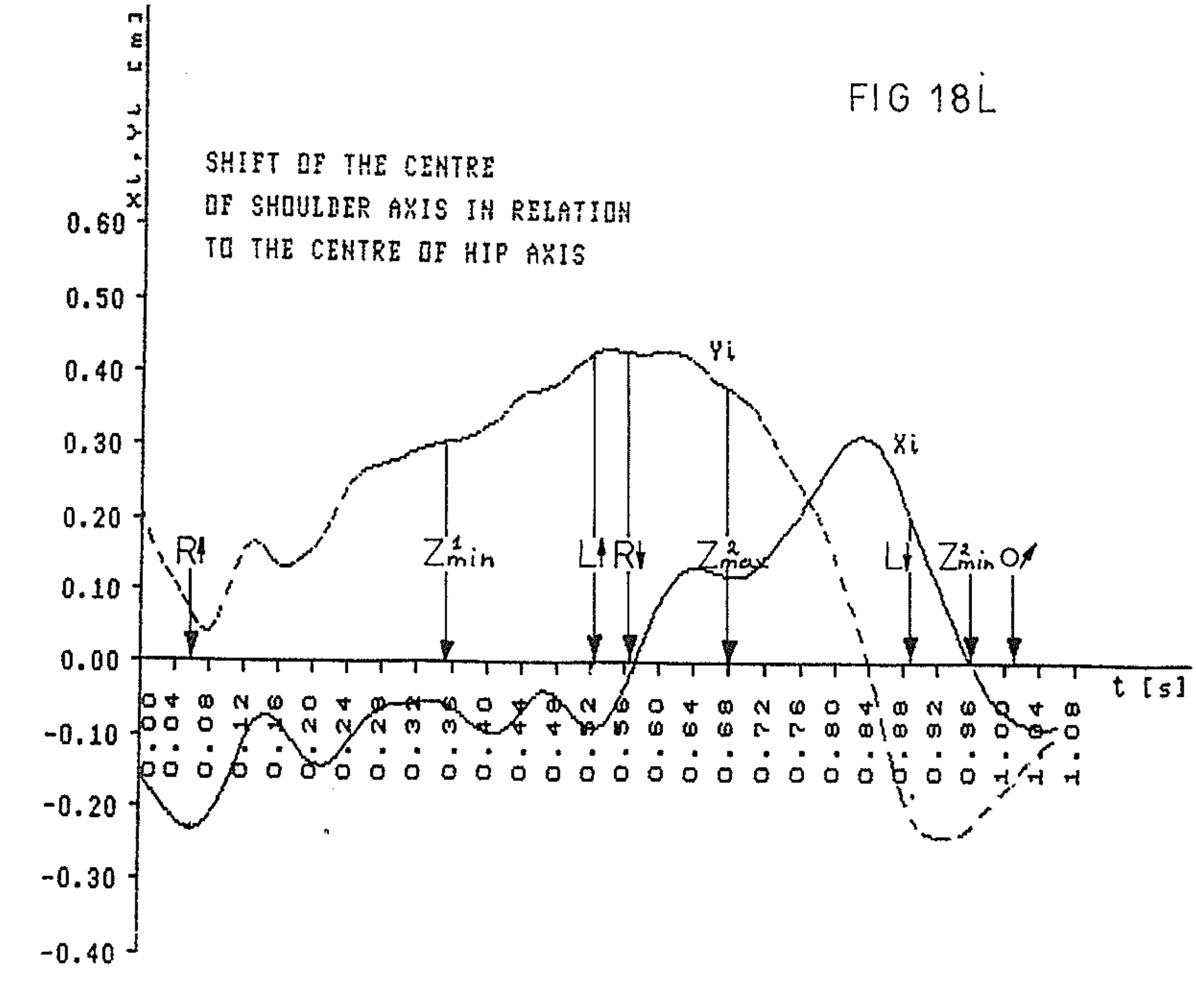
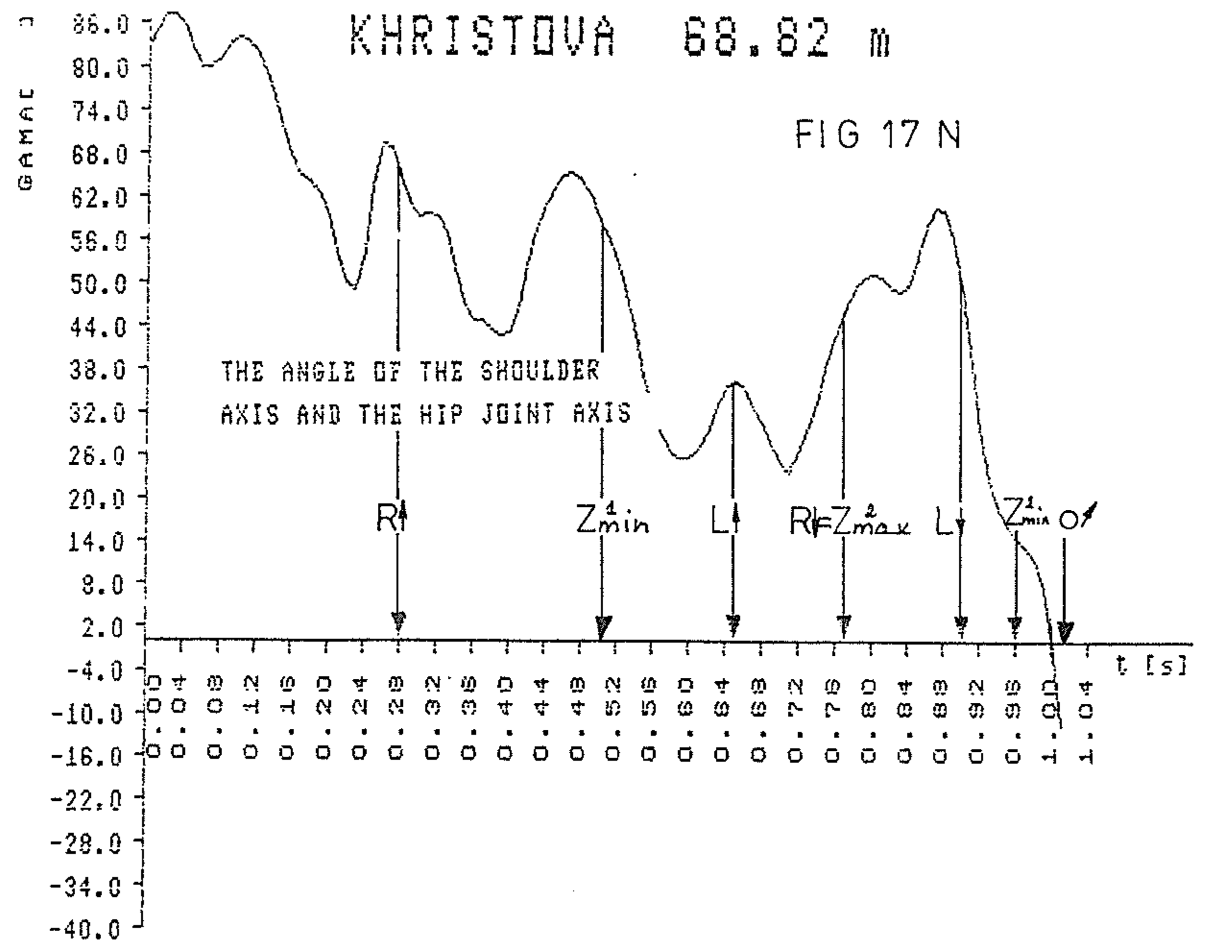
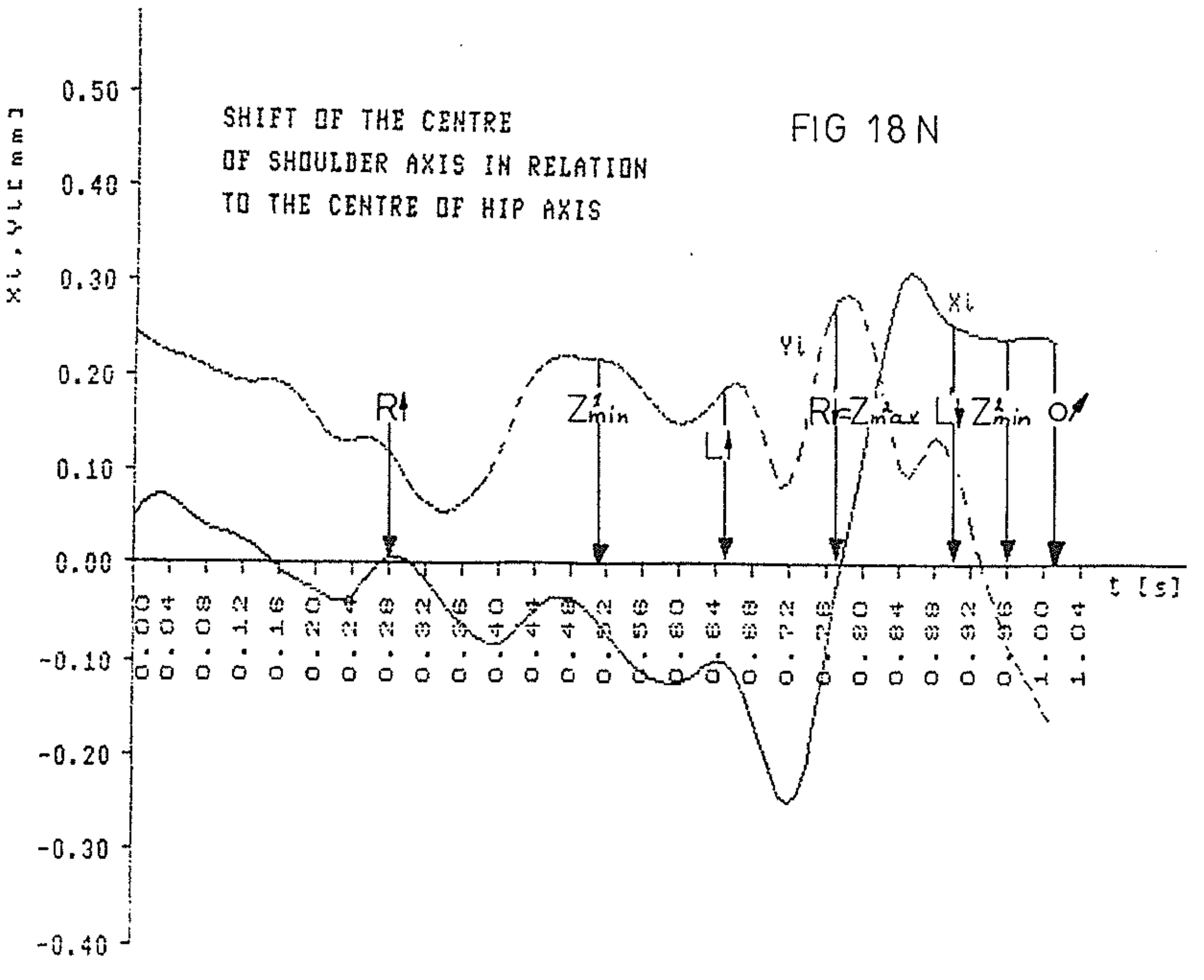


FIG 18L


KHRISTOVA 68.82 m
FIG 17 N
GAMA [ ]
THE ANGLE OF THE SHOULDER
AXIS AND THE HIP JOINT AXIS
R
Z^1_{min}
L
R
Z^2_{max}
L
Z^1_{min}
O
t [s]


SHIFT OF THE CENTRE
OF SHOULDER AXIS IN RELATION
TO THE CENTRE OF HIP AXIS
FIG 18 N
Yi
Xi
R
Z^1_{min}
L
R
Z^2_{max}
L
Z^1_{min}
O
t [s]

3.1.5. Position of the Implement Centre of Mass, Flight Upper Extremity, and Shoulder Axis (ß angle) .

Observed parameters :

ß...angle between the shoulder axis and the right upper extremity or the same angle in the ground projection (ß')

Results :

In FIG. 8, 9 maximum and minimum values of ß-angle are indicated.

For information we indicate, in addition, the release angle and the lift of the body centre of mass in respective trials (difference of the minimal and maximum deviation of the body centre of mass).

In FIG. 16 the functional course of the ground projection of the ß' -angle in time (ß'(t)) is given .

In FIG. 15 the functional course of the three dimensional ß-angle in the course of the throw is given (ß (t)) .

In order to make possible the comparison of functional changes of the ß-angle with the course of the thrower's body centre of mass and the implement centre of mass we show on the same side the functional courses of the vertical deviations of the body centre of mass (26) and the implement centre of mass (5) and increments of the discus path in the course of the throw [5 (t); 26 (t); s (t)] - see FIG. 14.

In the course of the whole throwing action the three dimensional ß-angle including its ground projection ß' assumes - in agreement with the expectation - markedly greater values than 180°. Maximum values of ß-angle are in a relatively small range in men compared to women (women cca 235 - 255°; men cca 220 - 240°).

Considerable differences recorded in the values of the local extremes and magnitudes of ß and ß'-angles in the release moment call for a deeper study, including the analysis of the record made by means of synchronized cameras with frequencies of 500 (at least 400) frames per second.

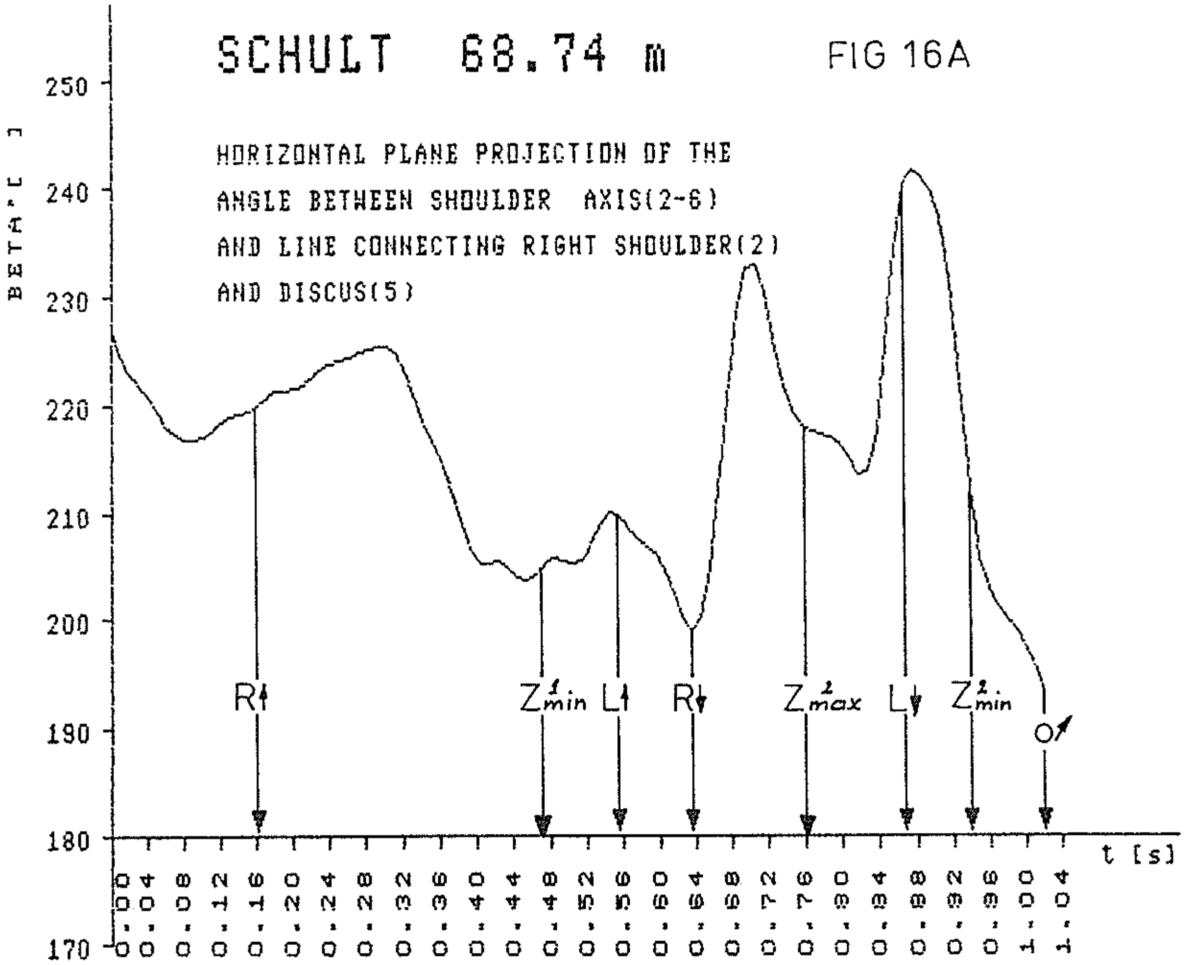


FIG 16A

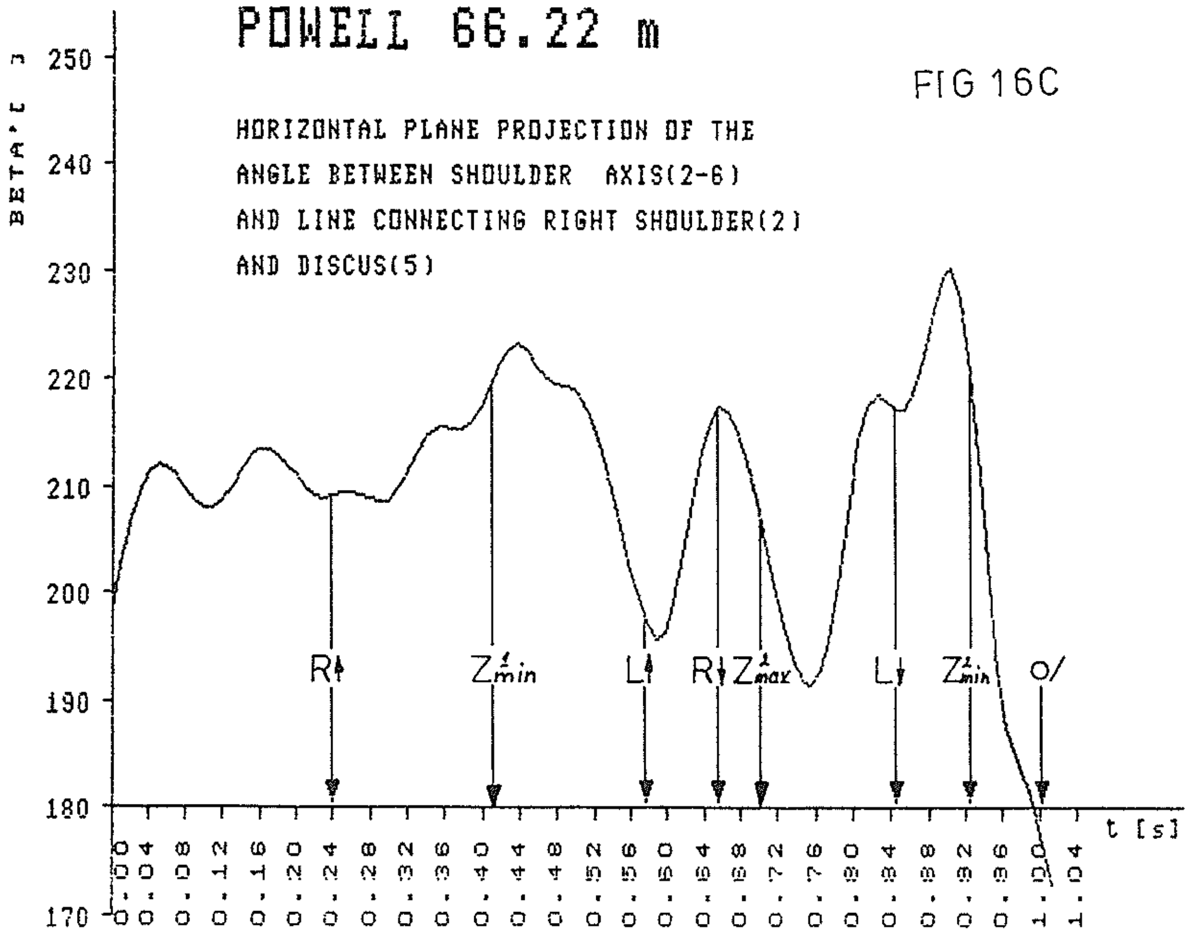


FIG 16C

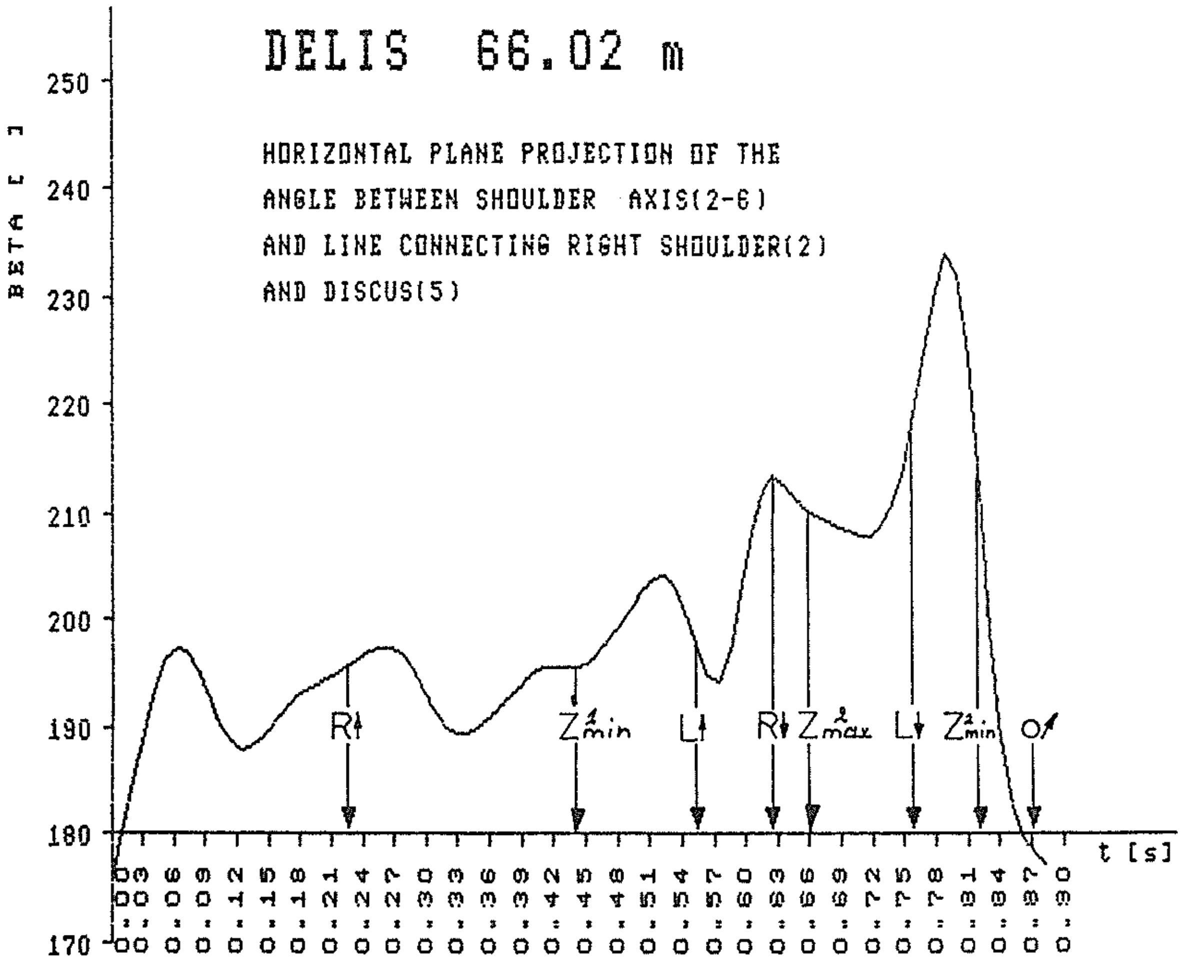

DELIS 66.02 m
HORIZONTAL PLANE PROJECTION OF THE
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
BETA [ ]
250
240
230
220
210
200
190
180
170
R↑
Z¹min
L↑
R↓
Z²max
L↓
Z²min
O↗
t [s]
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.30
0.33
0.36
0.39
0.42
0.45
0.48
0.51
0.54
0.57
0.60
0.63
0.66
0.69
0.72
0.75
0.78
0.81
0.84
0.87
0.90

FIG 16D

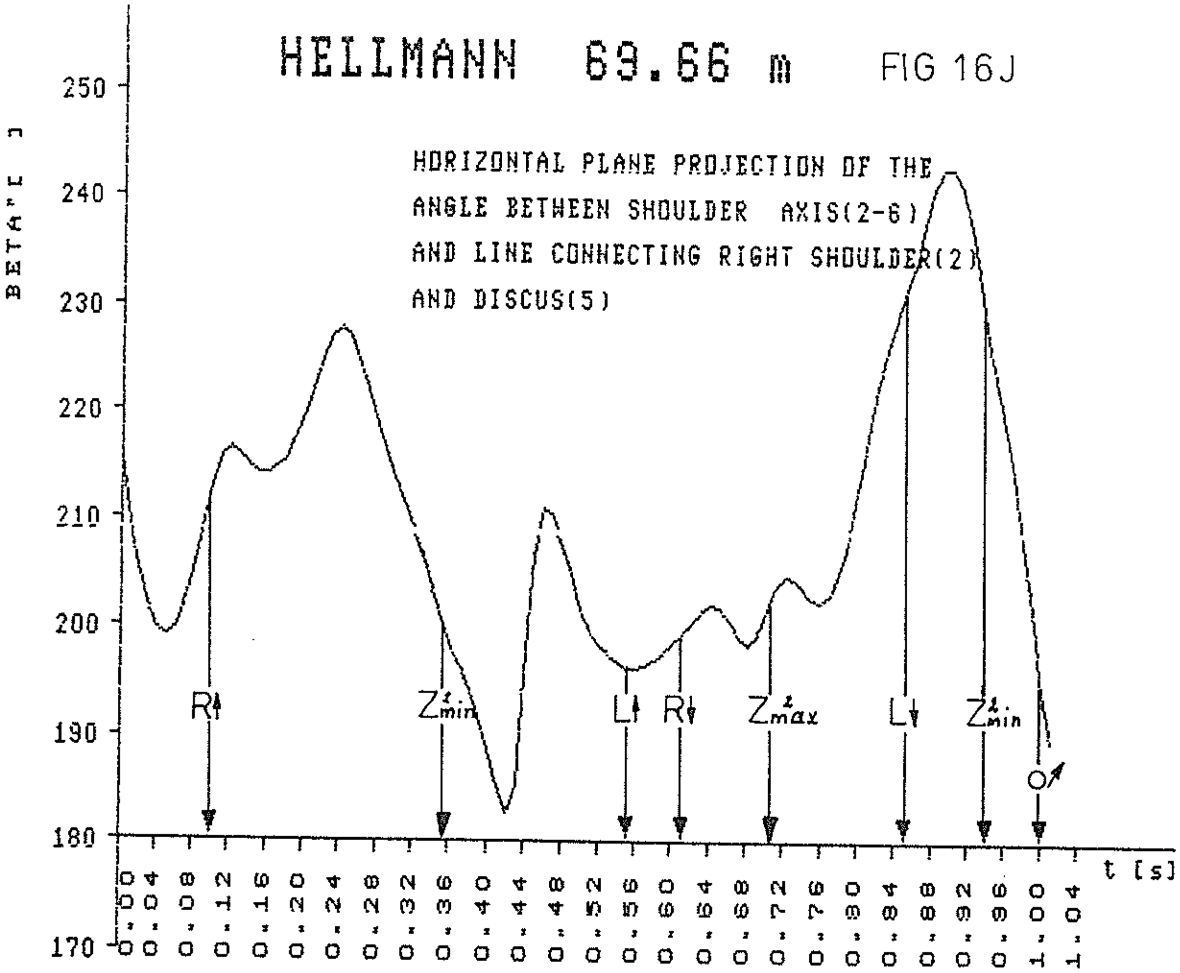


FIG 16J

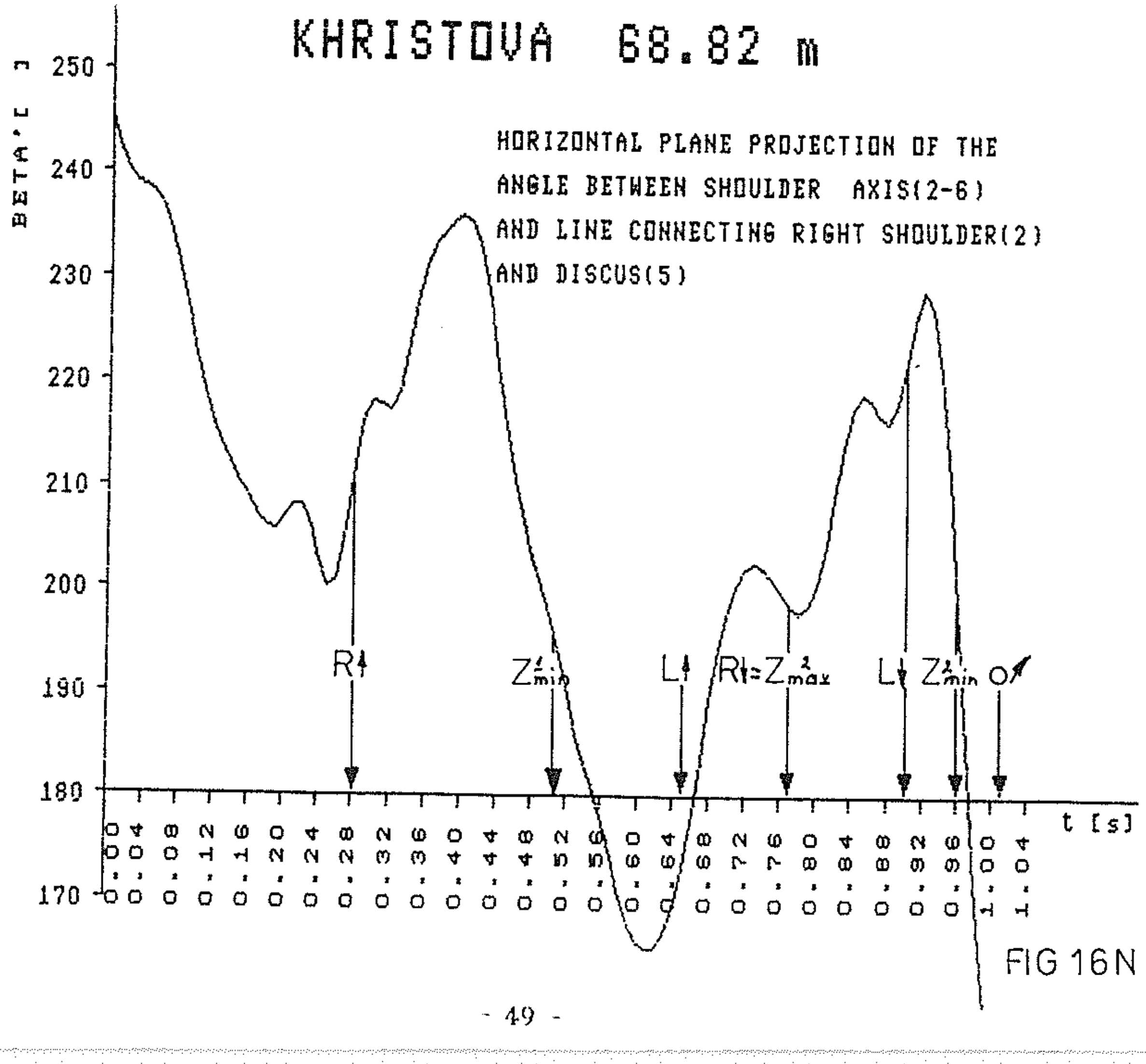


FIG 16N

SCHULT 68.74 m

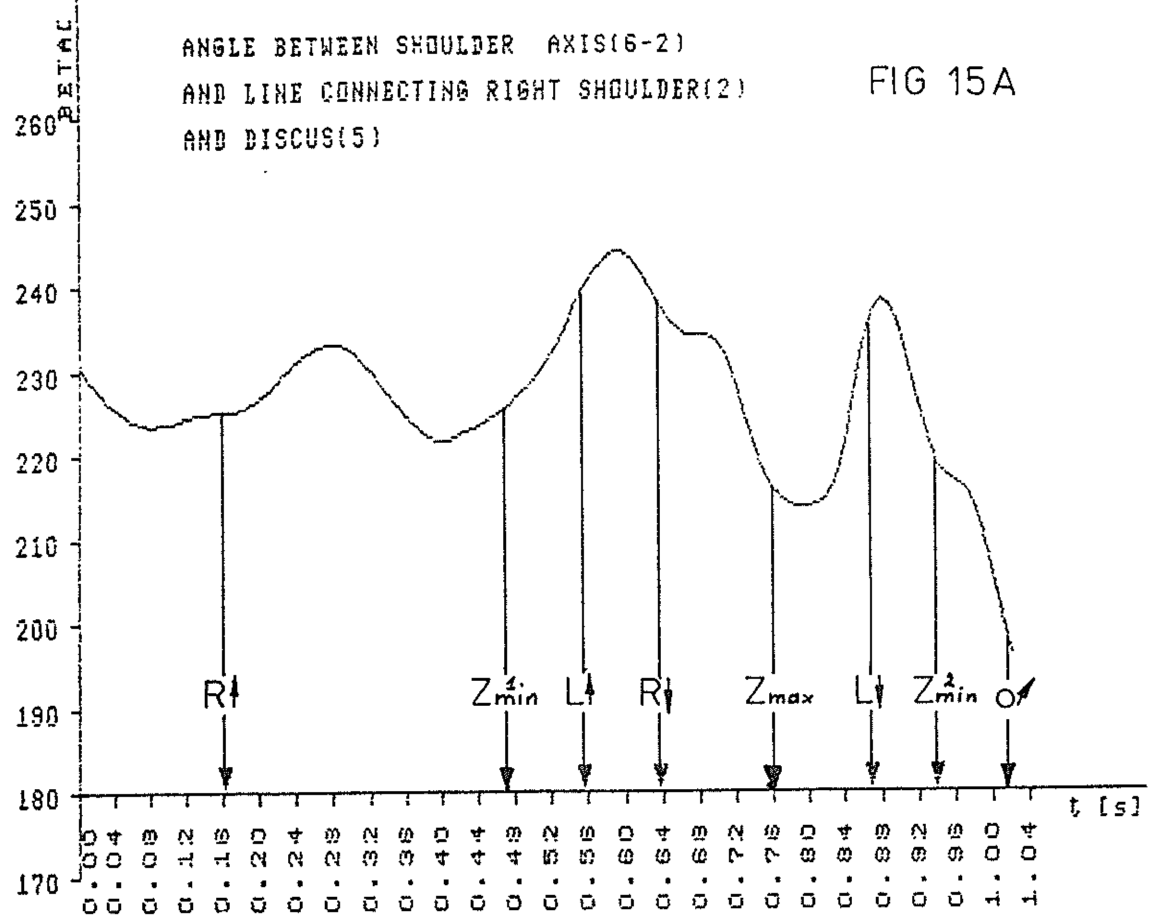


FIG 15A

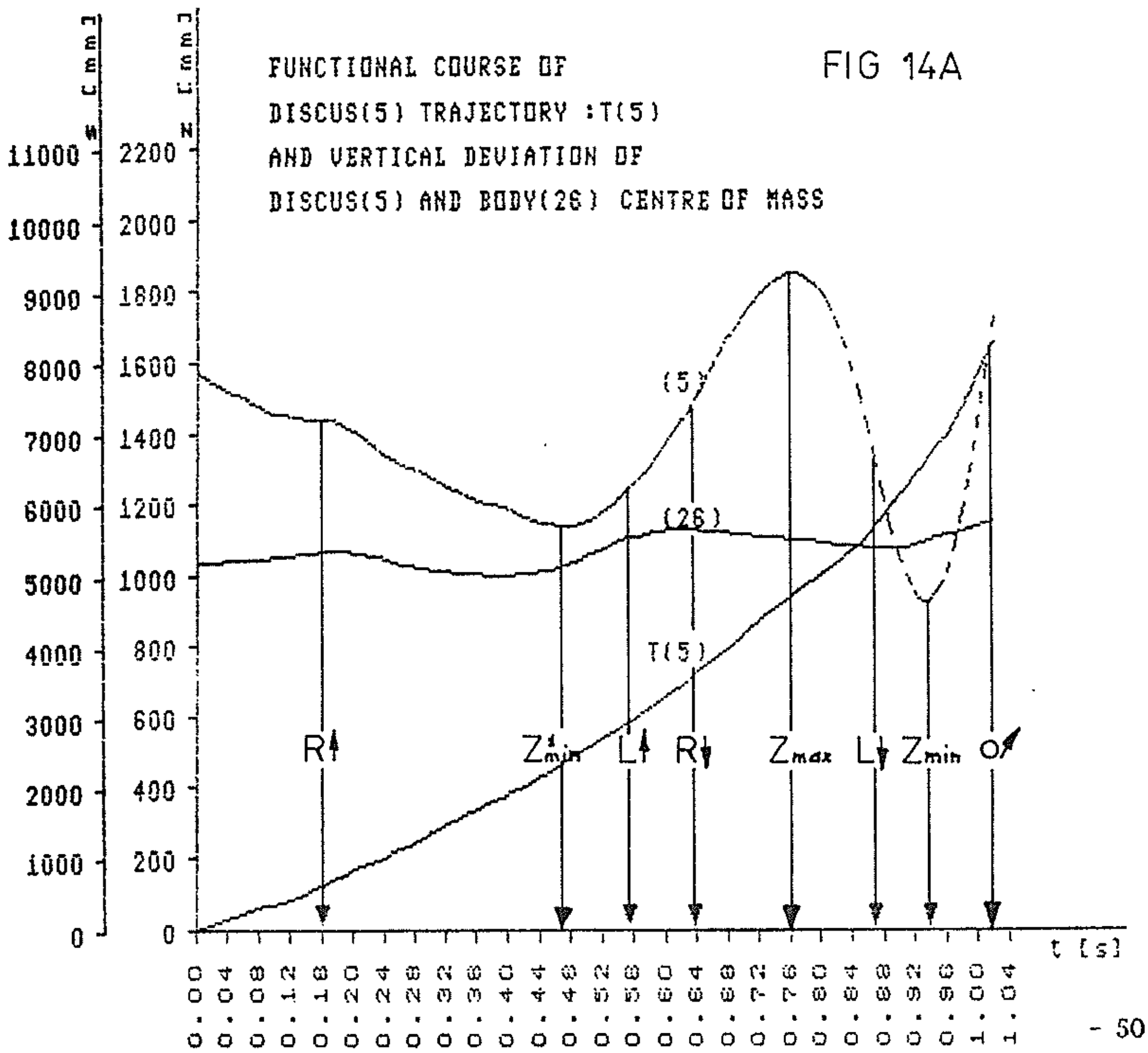
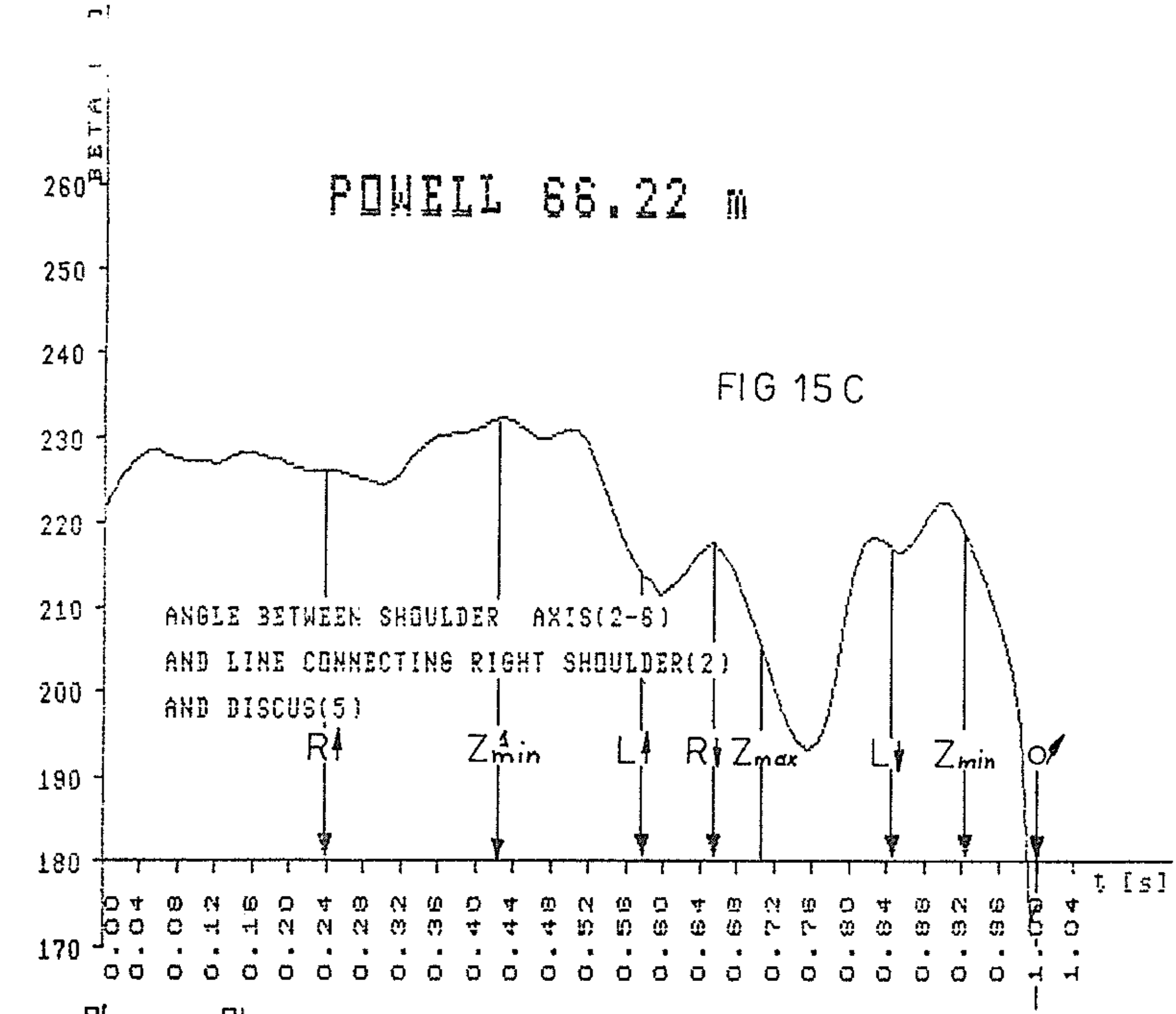
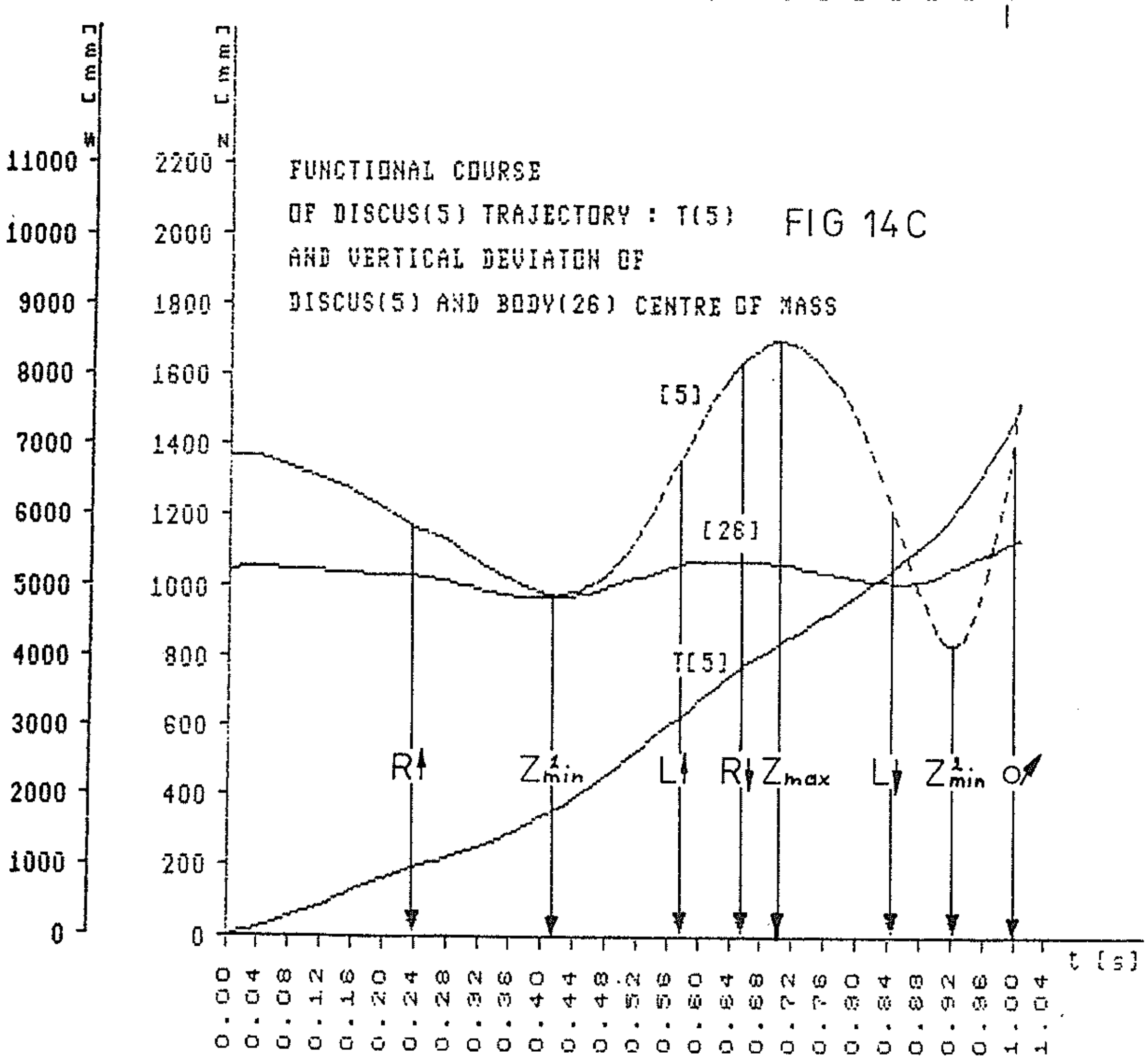
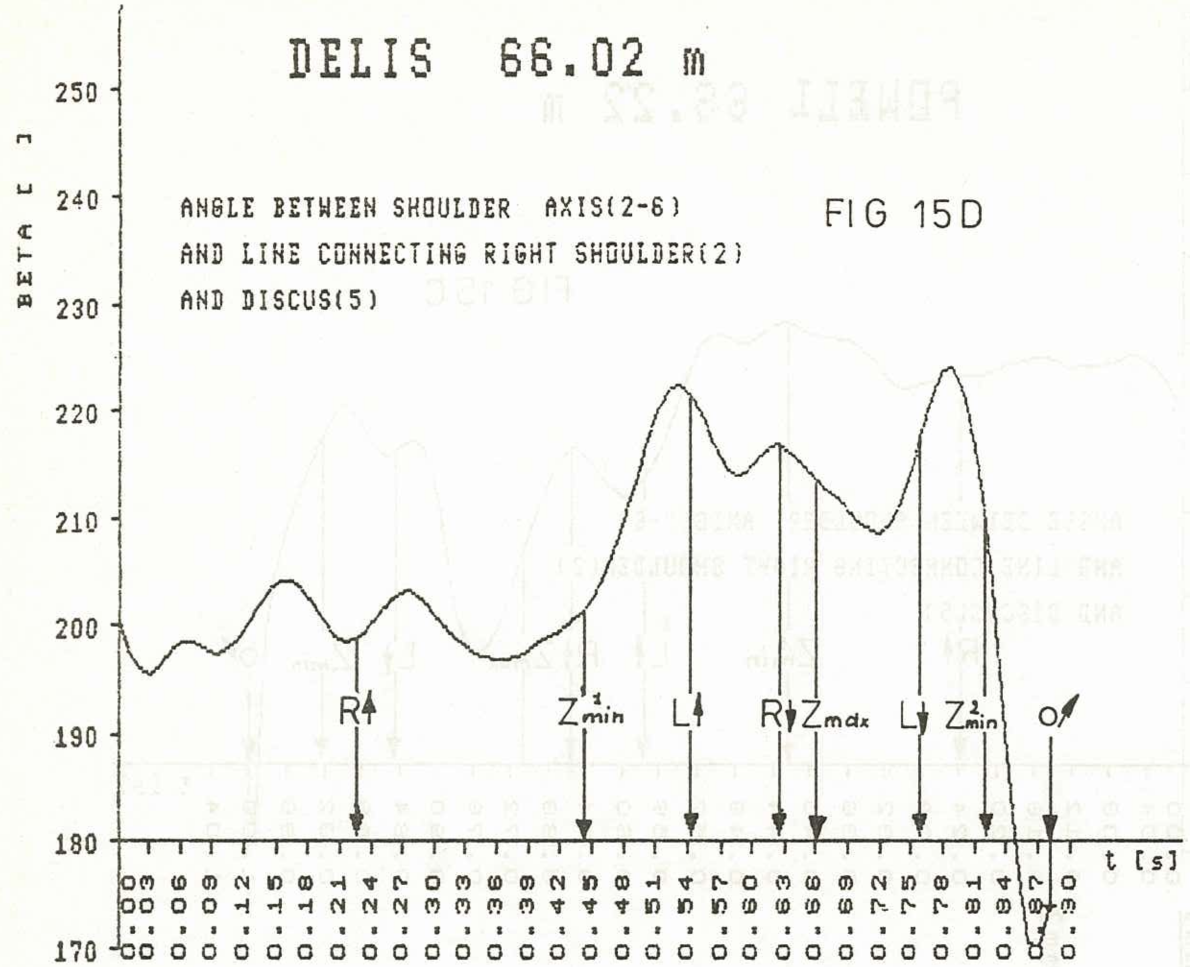
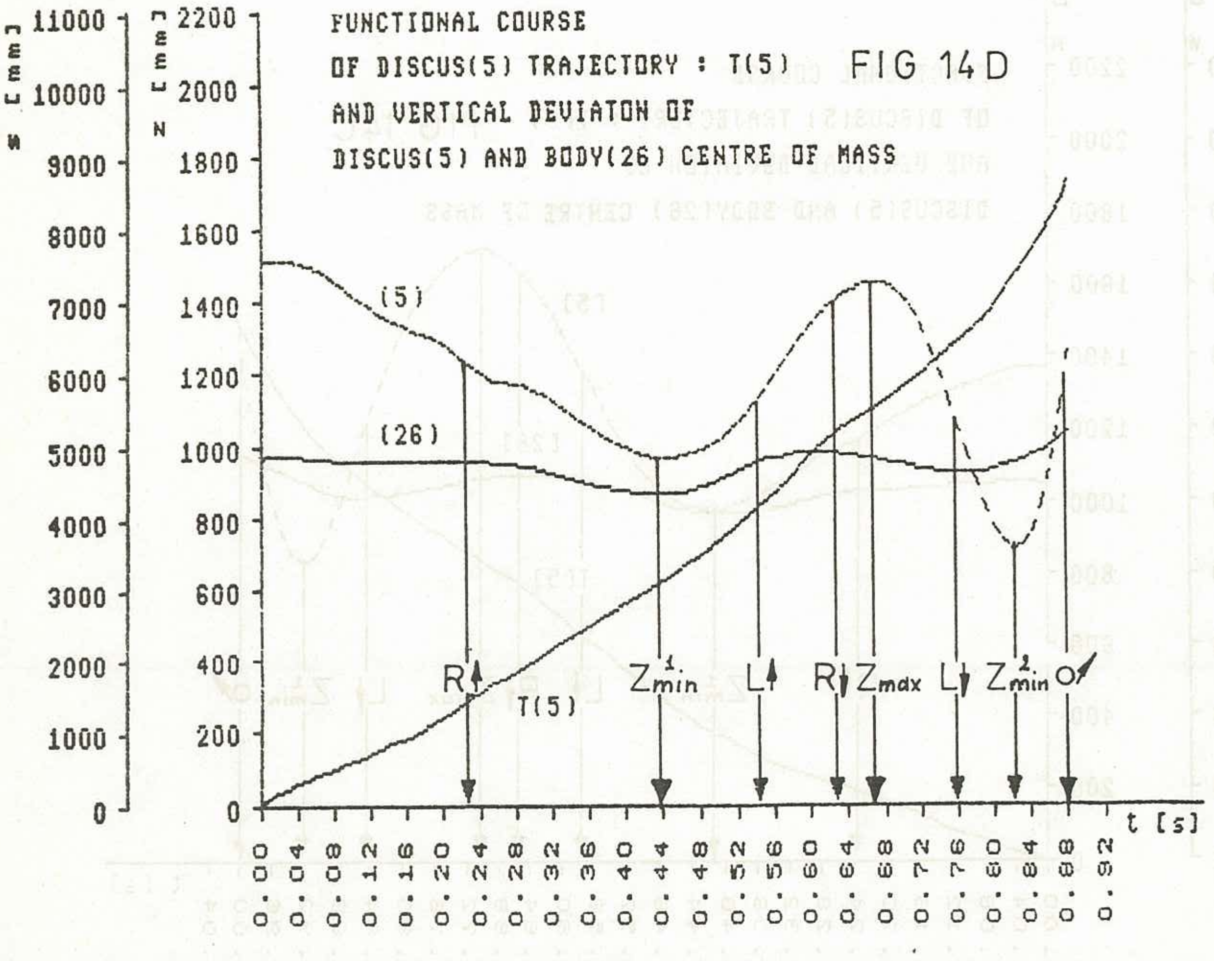


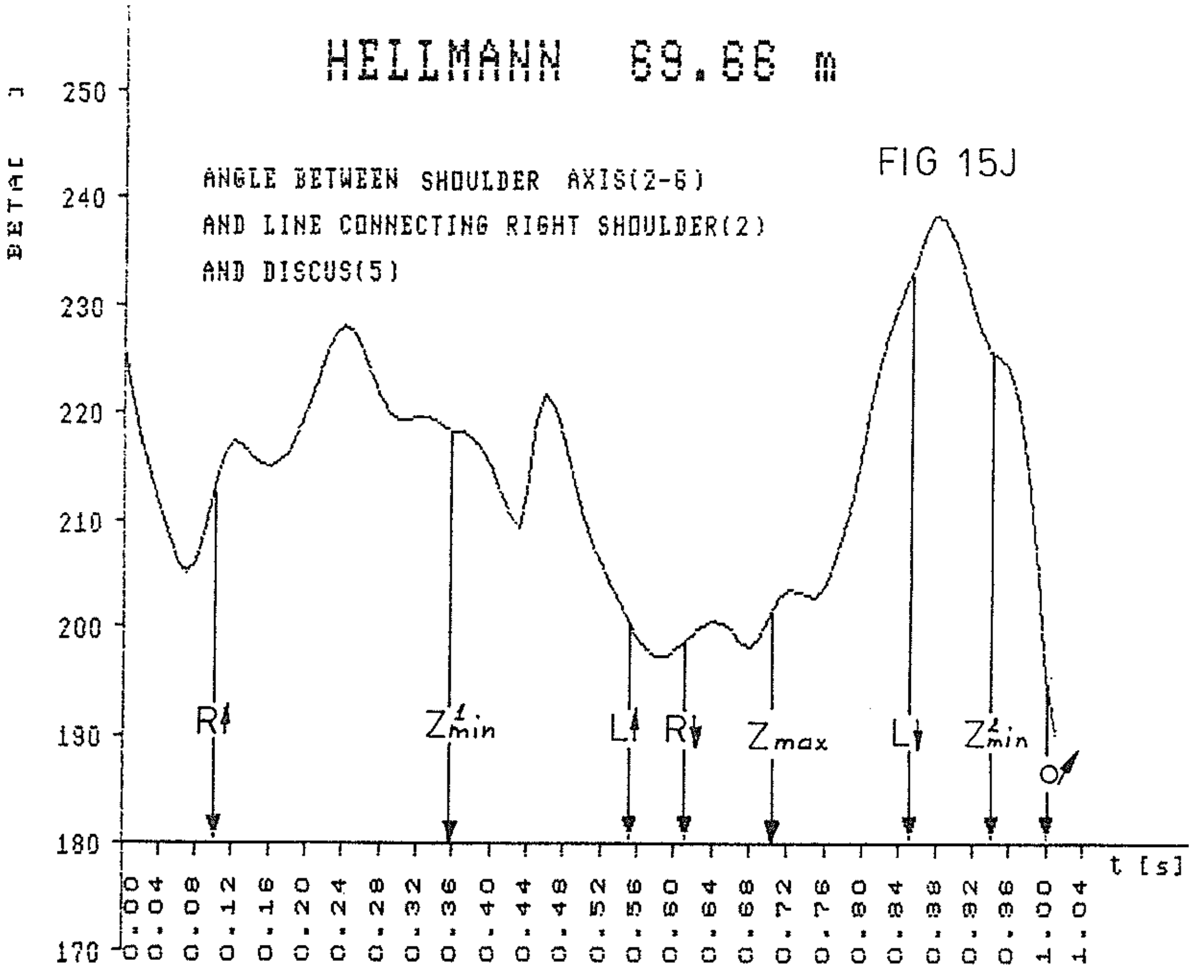
FIG 14A


POWELL 66.22 m
FIG 15 C
BETA
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
R↑
Z¹min
L↑
R↓
Zmax
L↓
Zmin
O↗
t [s]


FUNCTIONAL COURSE
OF DISCUS(5) TRAJECTORY : T(5)
AND VERTICAL DEVIATON OF
DISCUS(5) AND BODY(26) CENTRE OF MASS
FIG 14C
[5]
[26]
T[5]
R↑
Z¹min
L↑
R↓
Zmax
L↓
Z¹min
O↗
t [s]


DELIS 66.02 m
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
FIG 15D
BETA [ ]
250
240
230
220
210
200
190
180
170
R↑
Z¹min
L↑
R↓Zmax
L↓
Z²min
O↗
t [s]


FUNCTIONAL COURSE
OF DISCUS(5) TRAJECTORY : T(5)
AND VERTICAL DEVIATON OF
DISCUS(5) AND BODY(26) CENTRE OF MASS
FIG 14D
s [mm]
z [mm]
(5)
(26)
T(5)
R↑
Z¹min
L↑
R↓Zmax
L↓
Z²min
O↗
t [s]


HELLMANN 69.66 m
FIG 15J
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
BETAL]
t [s]
R
Z^1_{min}
L
R
Z_{max}
L
Z^2_{min}
O

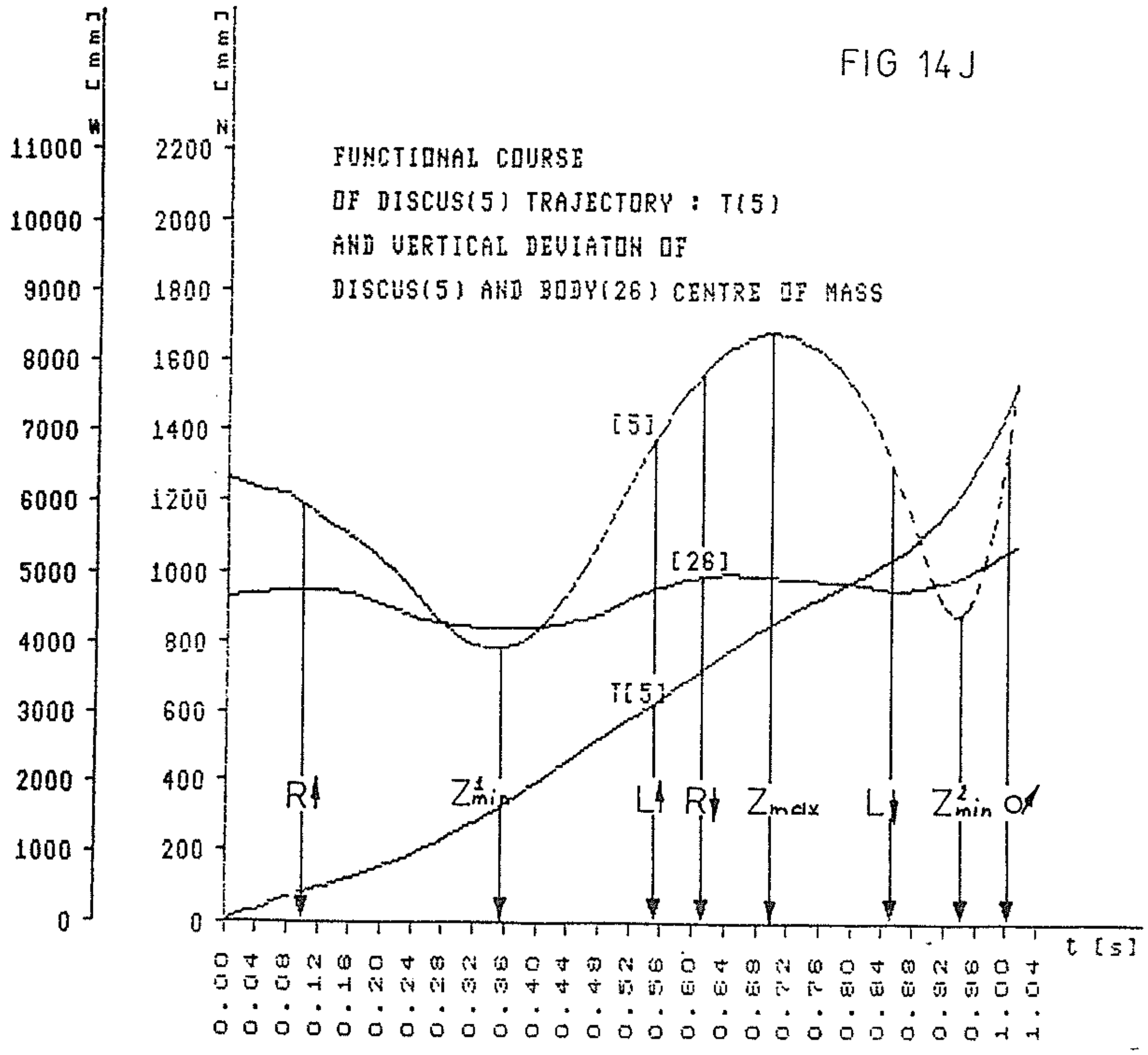
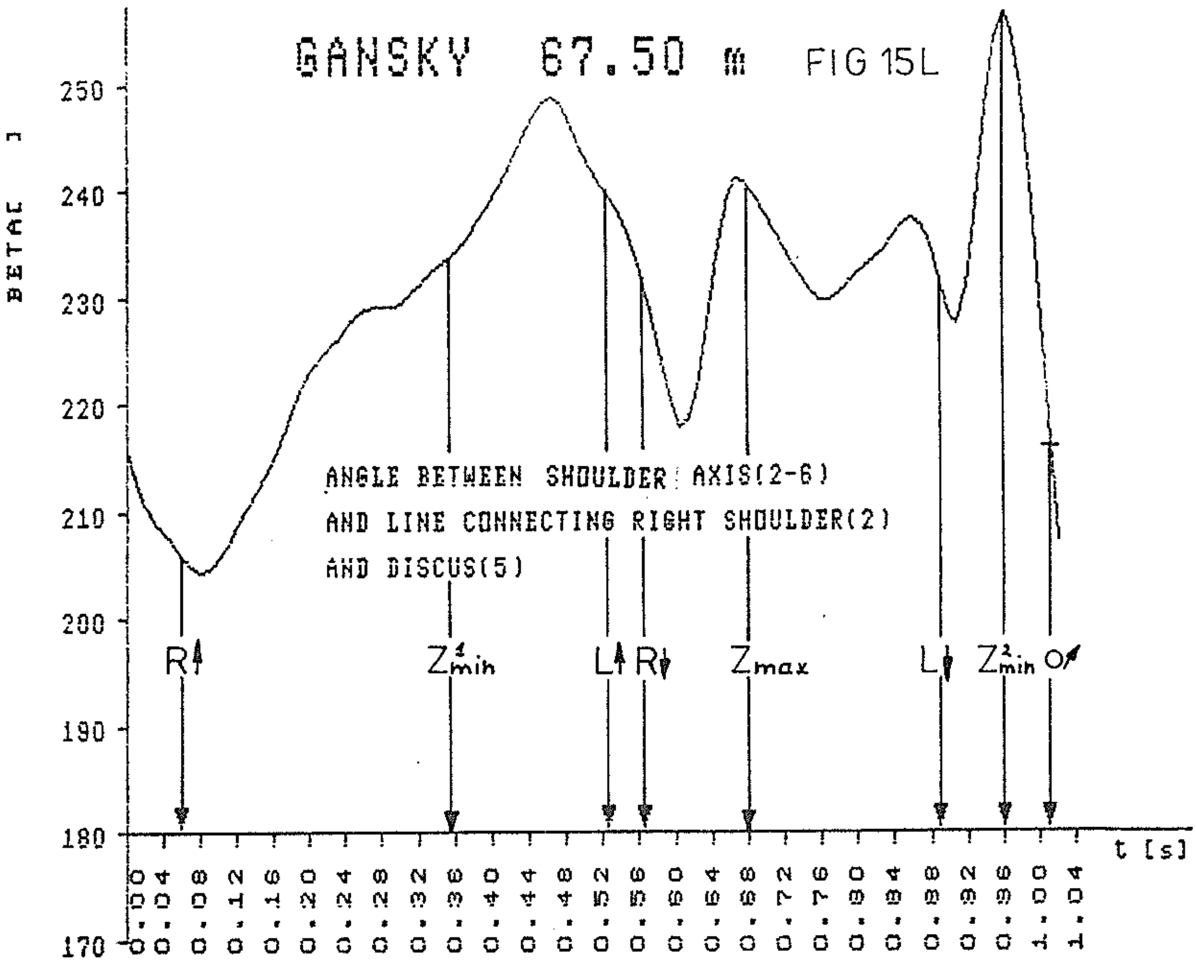
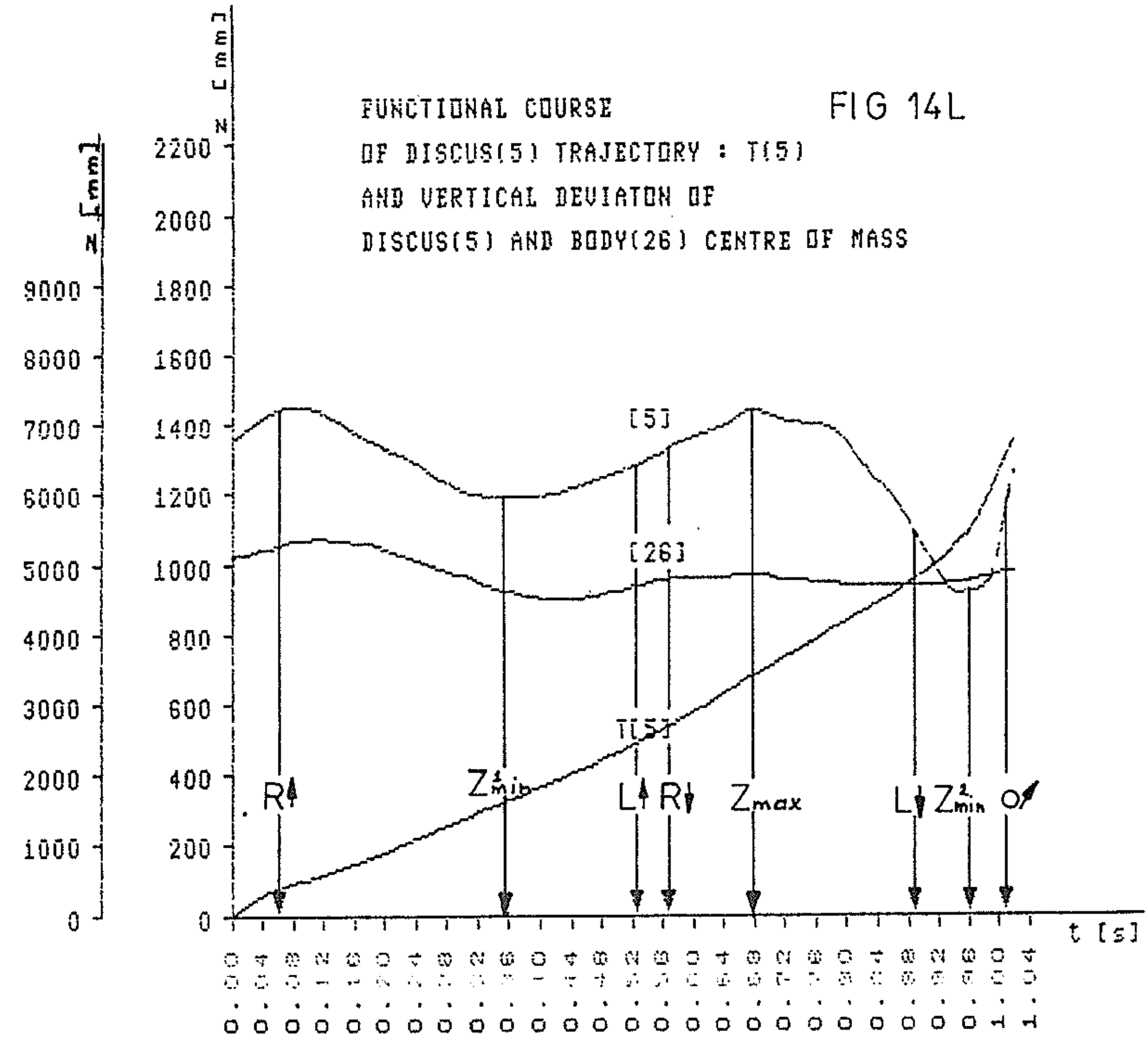
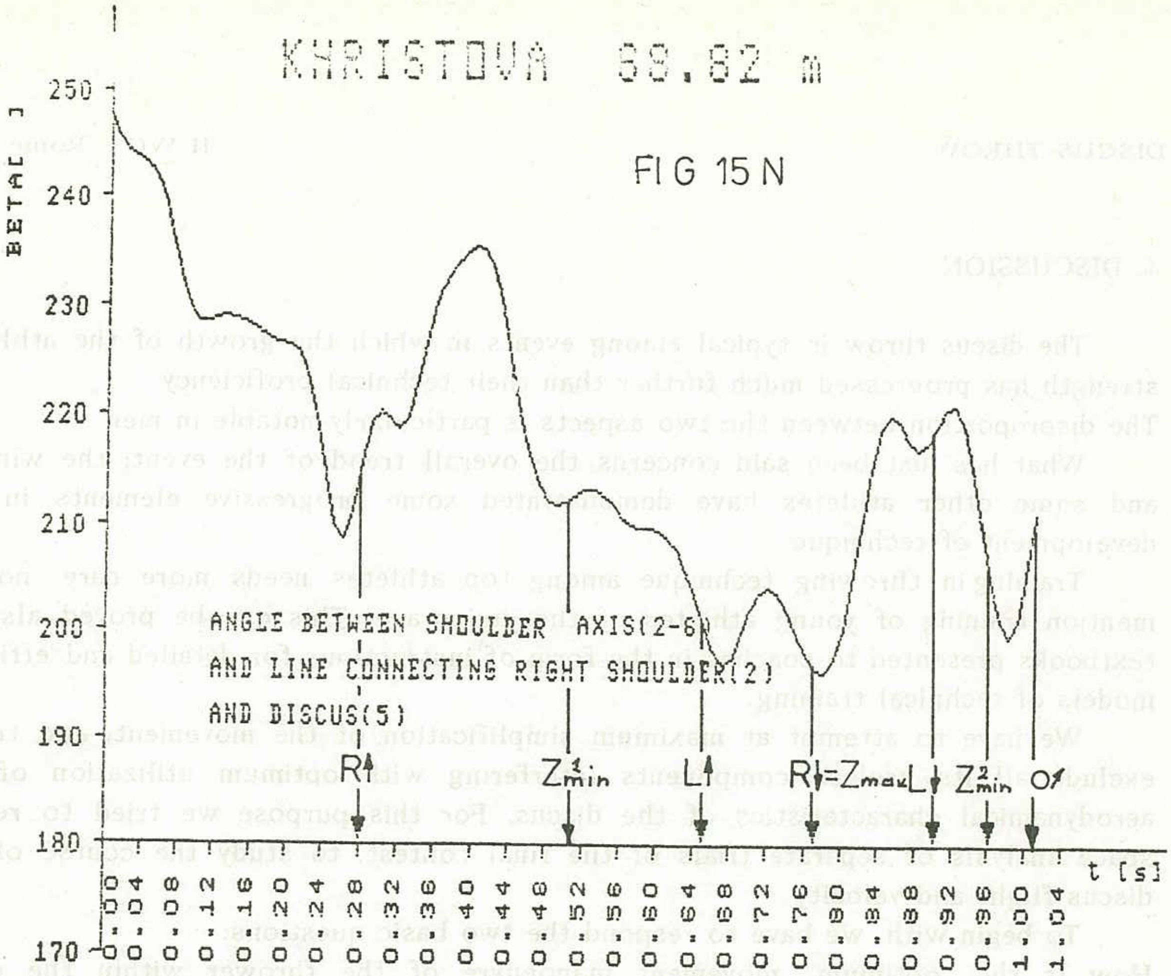
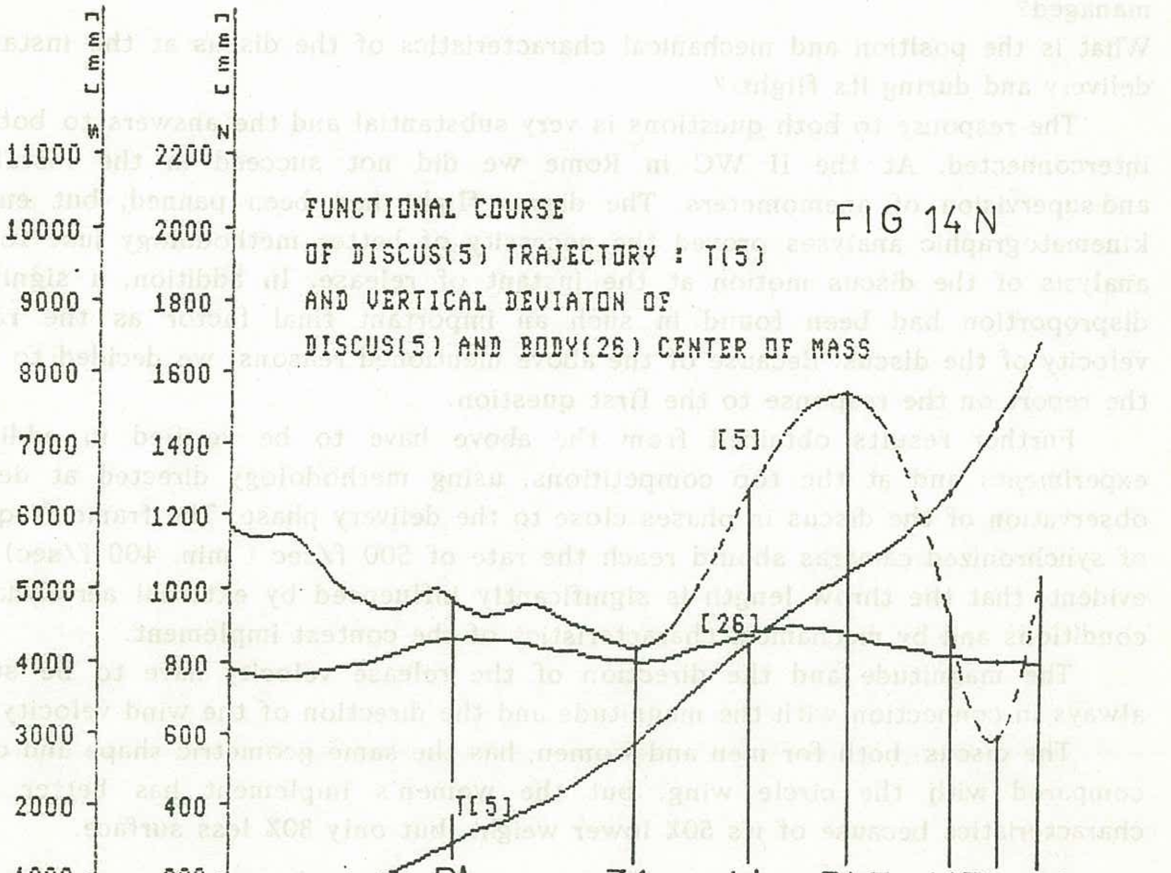


FIG 14J
FUNCTIONAL COURSE
OF DISCUS(5) TRAJECTORY : T(5)
AND VERTICAL DEVIATON OF
DISCUS(5) AND BODY(26) CENTRE OF MASS
W [mm]
Z [mm]
[5]
[26]
T[5]
t [s]
R
Z^1_{min}
L
R
Z_{max}
L
Z^2_{min}
O


GANSKY 67.50 m FIG 15L
BETA[ ]
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
R
Z¹min
L R
Zmax
L
Z²min
O
t [s]


FUNCTIONAL COURSE
OF DISCUS(5) TRAJECTORY : T(5)
AND VERTICAL DEVIATON OF
DISCUS(5) AND BODY(26) CENTRE OF MASS
FIG 14L
z [mm]
[5]
[26]
T[5]
R
Z¹min
L R
Zmax
L
Z²min
O
t [s]


KHRISTOVA 68.82 m
FIG 15 N
BETA[ ]
250
240
230
220
210
200
190
180
170
ANGLE BETWEEN SHOULDER AXIS(2-6)
AND LINE CONNECTING RIGHT SHOULDER(2)
AND DISCUS(5)
R↑ Z¹min L↑ R↓=Zmax L↓ Z²min O↗
t [s]
0.00 0.04 0.08 0.12 0.16 0.20 0.24 0.28 0.32 0.36 0.40 0.44 0.48 0.52 0.56 0.60 0.64 0.68 0.72 0.76 0.80 0.84 0.88 0.92 0.96 1.00 1.04


S [mm]
Z [mm]
FUNCTIONAL COURSE
OF DISCUS(5) TRAJECTORY : T(5)
AND VERTICAL DEVIATON OF
DISCUS(5) AND BODY(26) CENTER OF MASS
FIG 14 N
11000 10000 9000 8000 7000 6000 5000 4000 3000 2000 1000 0
2200 2000 1800 1600 1400 1200 1000 800 600 400 200 0
[5]
[26]
T[5]
R↑ Z¹min L↑ R↓=Zmax L↓ Zmin O↗
t [s]
0.00 0.04 0.08 0.12 0.16 0.20 0.24 0.28 0.32 0.36 0.40 0.44 0.48 0.52 0.56 0.60 0.64 0.68 0.72 0.76 0.80 0.84 0.88 0.92 0.96 1.00 1.04

4. DISCUSSION

The discus throw is typical among events in which the growth of the athletes' strength has progressed much further than their technical proficiency.
The disproportion between the two aspects is particularly notable in men.

What has just been said concerns the overall trend of the event; the winners and some other athletes have demonstrated some progressive elements in the development of technique.

Training in throwing technique among top athletes needs more care, not to mention training of young athletes of the junior age. This can be proved also by textbooks presented to coaches in the form of instructions for detailed and efficient models of technical training.

We have to attempt at maximum simplification of the movement, and try to exclude all its useless components interfering with optimum utilization of the aerodynamical characteristics of the discus. For this purpose we tried to realize space analysis of separate trials of the final contest, to study the course of the discus flight and velocity.

To begin with, we have to respond the two basic questions:
How is the "optimum" movement manoeuvre of the thrower within the circle managed?
What is the position and mechanical characteristics of the discus at the instant of delivery and during its flight ?

The response to both questions is very substantial and the answers to both are interconnected. At the II WC in Rome we did not succeed in the instalation and supervision of anemometers. The discus flight had been panned, but ensuing kinematographic analyses proved the necessity of better methodology just for the analysis of the discus motion at the instant of release. In addition, a significant disproportion had been found in such an important final factor as the release velocity of the discus. Because of the above mentioned reasons, we decided to focus the report on the response to the first question.

Further results obtained from the above have to be verified in additional experiments and at the top competitions, using methodology directed at detailed observation of the discus in phases close to the delivery phase. The frame frequency of synchronized cameras should reach the rate of 500 f/sec (min. 400 f/sec). It is evident, that the throw length is significantly influenced by external aerodynamical conditions and by mechanical characteristics of the contest implement.

The magnitude and the direction of the release velocity have to be studied always in connection with the magnitude and the direction of the wind velocity.

The discus, both for men and women, has the same geometric shape and can be compared with the circle wing, but the women's implement has better flying characteristics because of its 50% lower weight, but only 30% less surface.

The rotation of the discus is important for usage of gyroscopic effect. At the same time the positioning of the whole mass of the discus is critical. This all affects the discus flying stability. This stability grows with the magnitude of its momentum.

The observation of discus flight in final trials at the II WC in Rome proves the high percentage of attempts with insufficient stability of the implement and incorrect angle of the air flow.

In some cases we examined the considerable clockwise rotation of the discus during the flight (viewed from the circle in the direction of the throw).

In a great number of trials the disproportionate tension of the discus round its longitudional axis occured. This is due to the air resistance, which creates the moment of rotation, whose magnitude depends again on the stability of the discus (on its inertia momentum in regard to the transverse axis of the discus). At the same time, obviously, the conditions for the discus position at the instant of its release were not fulfilled. In the second half of its flight the discus lost its balance and got into a position with the frontal plane against the flight direction. This fact is considerably affected by the angle of release and the angle of the air flow. Under the given conditions of the wind against the throw, the angle of release should be lower and the angle of the air flowing contrary greater.

The above mentioned problems moved us to elaborate the study following this report, which will deal with the discus flight from release till landing. On the basis of already published information the elaborated theoretical considerations should be verified in some top contest in 1988/89.

5. CONCLUSIONS

The report is focused on biomechanical analysis of the phases of the discus throwers' action till the instant of the release.

From the point of view of geometry of movement we discovered a remarkable identity of movement in observed succesful trials. On the other hand there are significant differences between athletes in the execution of the whole movement manoeuvre and its phases. We found considerable technical weaknesses in the selection of the best athletes - finalists of the II WC.

Analysis of movement timing has proved that comparison of total times of the duration of the attempts is of no use.

In longitudional investigation both of the individual and interpersonal comparisons of timing, attention has to be concentrated on separate phases and partial movements, particularly in the delivery phase $((L\downarrow - Z_{2min}) + (Z_{2min} - O\nearrow))$ even in connection with attained increments of the discus CM trajectory Δs_i.

Observation of partial trunk movements related to the coordinate system implanted in the region of the pelvis had been carried out by us for the first time at the hammer throw in 1983. The methodology has been proved right. The discus analysis from the II WC has also proved that these parameters, torsion of shoulder against the pelvis, forward bend and sideward bends, have unambiguous informative value.

The given methodology is of course insufficient for investigation of all necessary phenomena at the instant of delivery.

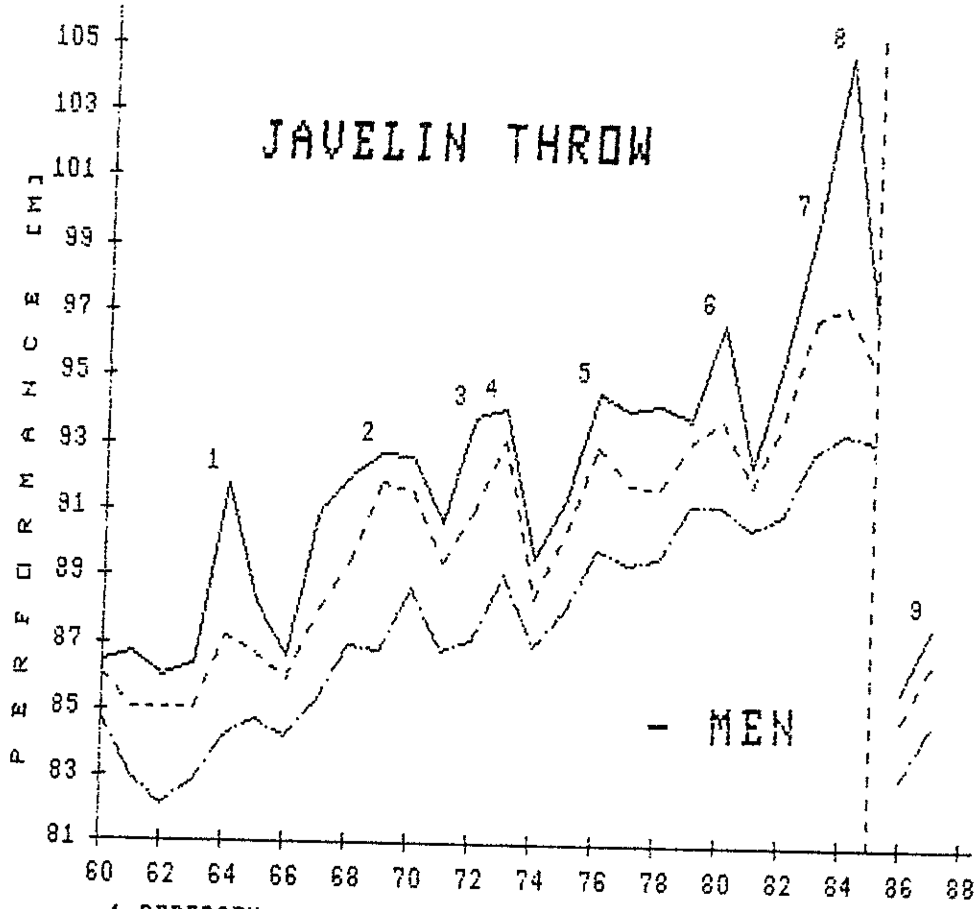
K

BIOMECHANICAL ANALYSIS OF THE JAVELIN THROW

Menzel, H.-J.

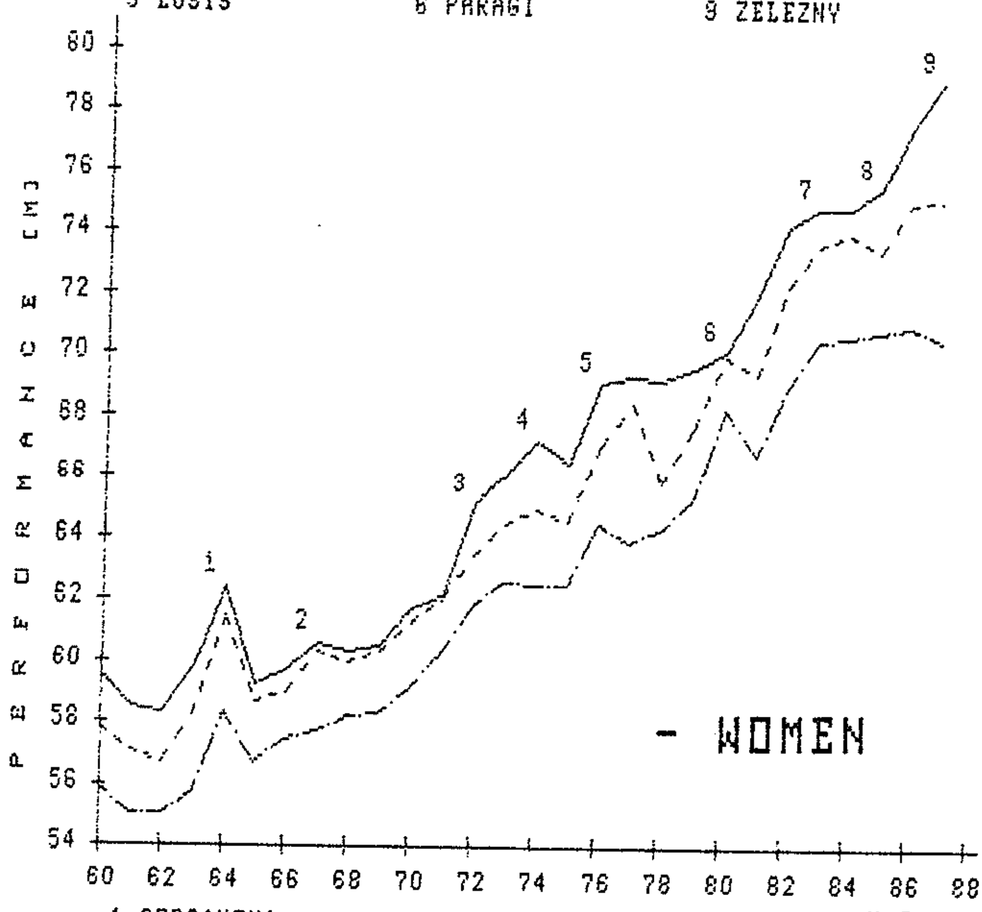
JAVELIN THROW

FIG 1.



1 PEDERSEN
2 KINNUNEN
3 LUSIS
4 WOLFERMANN
5 NEMETH
6 PARAGI
7 PETRANOFF
8 HOHN
9 ZELEZNY

FIG 2.



1 GORCAKOVA
2 PENES
3 FUCHS
4 FUCHS
5 FUCHS
6 BIRJULINA
7 LILLAK
8 FELKE
9 FELKE

INTRODUCTION

The development of the men's and women's javelin events have shown different characteristic rising trends in the years 1960 to 1988 as shown in Fig. 1 and 2. The solid lines which indicated the best performance for each year and the other two lines which indicated the course of the means of the maximum performance of the top 3 and top 10 athletes show taht the women's event has seen a steady rising trend. This is probably due to the improvements of methods and knowledge in the areas of conditioning and strenght training. The men's event displayed a less steep rise in the years 1960-1980. From 1980 to 1985 the trend was extremely steep due to the outstanding performances of PETRANOFF (USA) and HOHN (GDR). In 1986 the design of the men's javelin was changed and the distances achieved by the world's top throwers were reduced so that the results are now equal to those performances achieved by throwers in the year 1960. This print is marked on Fig. 1 by a vertical line.

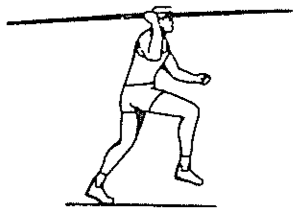
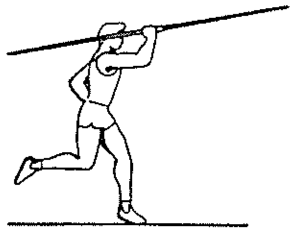
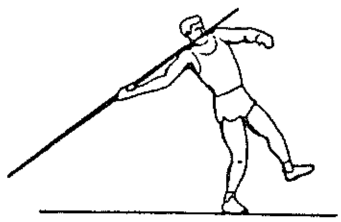
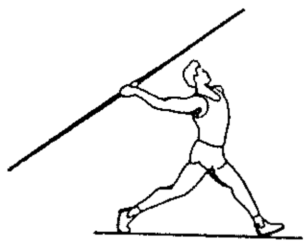
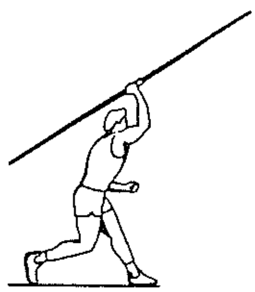
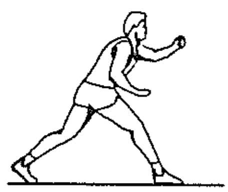
1 THROWING ELEMENTS AND THROWING PHASES

The objective of javelin throwing is to attain the greatest possible throwing distance. The athlete tries to achieve this objective, which is generally called the "maximization of throwing distance", via the following throwing elements:

- Approach run
- Release
- Recovery

The approach run and the release are divided into the throwing phases shown in table J-1.
The transmission of momenta leads to angular accelerations and decelerations of the relative orientation angles of the hip axis, trunk axis, upper arm axis and forearm axis.
The objective "maximization of throwing distance" requires an optimal approach velocity at the end of the acceleration phase of the approach run, an optimal position of the body segments and the javelin at the end of the transition phase and at the end of the preparatory phase, a maximal velocity of release as well as an optimal angle of release and attitude of the javelin at the end of the delivery phase. A maximal velocity of release requires an optimal transmission of momenta of the segment chain "hip - trunk - throwing arm - javelin" during the delivery phase.

Table J-1 Throwing elements and respective throwing phases of the javelin thrower's movement.

Throwing elements	Throwing phases	Limits of phases	
		Beginning of approach run	
Approach run	1. Acceleration phase (cyclic approach phase)		
		Start of the javelin with-drawal (generally the fifth from the last stride)	
	2. Transition phase (acyclic approach phase, release preparatory phase)		
		Planting of the throwing-arm side leg	
Release	1. Preparatory phase (one-legged-support phase)		
		Planting of the bracing leg	
	2. Delivery phase (two-legged-support phase)		
		Release of the javelin	
Recovery	Recovery phase		
		Standing in front of the foul line	

2 METHODS

2.1 MODEL OF THE JAVELIN THROWER

Most of the present studies of the delivery phase are two-dimensional analysis which do not consider the lateral deviation of the trunk and throwing arm in this phase. Only a very few contributions contain two-dimensional analysis from behind and from the throwing arm side (e.g. RICH et al. 1984).
In order to describe the three-dimensional rotation of the hip axis, trunk axis and throwing arm, a 6-segment-model of the thrower's body has been constructed (Fig. J-1, Tab. J-2).

Table J-2 Segments of the three-dimensional 6-segment model.

SH	-	Shank of the bracing leg
TH	-	Thigh of the bracing leg
HI	-	Hip axis (axis between the right and the left hip)
TR	-	Trunk axis (axis between the hip and shoulder on the throwing arm side)
UA	-	Upperarm
FA	-	Forearm

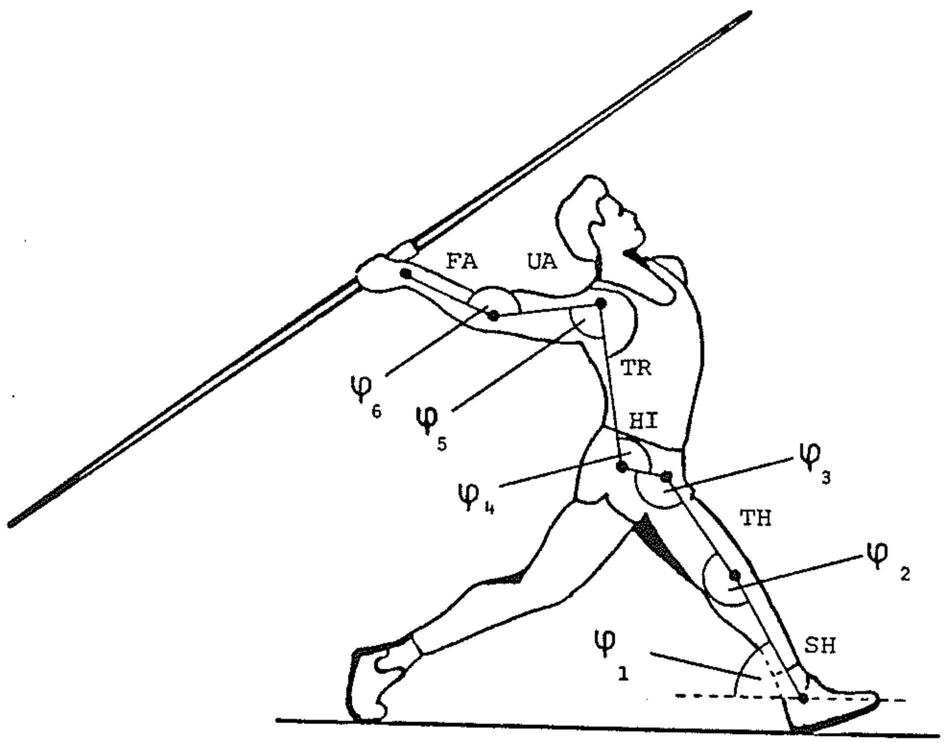


Figure J-1 6-segment-model of the thrower's body.

This model consists of six segments representing the shank and thigh of the bracing leg, the hip axis, the trunk axis on the throwing arm side (axis between hip and shoulder) and the upper arm and forearm of the throwing arm.
By determination of the three-dimensional angles φ_i between these axes and the angular velocities ω_i of the three-dimensional rotations of these axes, regression equations of the release velocity could be evaluated for differently qualified female groups of javelin throwers (MENZEL 1987 b).
Based on these findings the three-dimensional 6-segment-model is also used in this research.

2.2 DESIGN OF THE RESEARCH

The javelin events were filmed by two high-speed cameras (LOCAM) using 16 mm film. One moving camera was located on the right side 60 m from the run-up line, a second fixed camera was 50 m behind the foul line. Both cameras worked at 200 frames/s.
The recorded section was about 5 m wide and 4 m high.
This design allowed two-dimensional analysis of the approach and three-dimensional analysis of the delivery phase.
Throws of the male and female finalists have been analysed.

3 BIOMECHANICAL ANALYSIS

The present report is divided according to the throwing phases. The biomechanical fundamentals of the throwing phases will be presented followed by the results including interpretation of the analysed throws.

3.1 APPROACH

The approach run consists of the acceleration phase (cyclic approach phase) and the transition phase (acyclic approach phase, release preparatory phase).

3.1.1 ACCELERATION PHASE

Beginning: Beginning of approach run
End : Start of the javelin withdrawal
Objective: Achievement of an optimal approach velocity

The approach velocity shows an individual different optimal trend, going beyond or falling short of this range has a negative effect on performance.
Findings of different authors prove that there is a covariation between the optimal approach velocity and the throwing distance. For women the optimal approach velocity is between 5.7 and 6.5 m/s for throws of about 50-60 m, for men the optimal approach velocity is between 6.3 and 7.3 m/s for throws of about 70-80 m.

Table J-3 Approach velocity of different groups of throwers.

P [m]	V_{AP} [m/s]	Group of throwers	Author/Year	
>65	6.0-6.5	Female specialists	Bauersfeld/Schröter	1980
52.36-60.76	5.8-6.6	Female specialists	Menzel	1986
33.06-43.28	5.3-6.1	Pentathletes	Menzel	1986
>85	8.0-8.5	Male specialists	Bauersfeld/Schröter	1980
67.26-81.16	6.2-7.3	Male specialists	Menzel	1986
77.84	6.5	Male specialists	Kollath	1983
51.26-68.90	5.4-7.0	Beginners and advances throwers	Ikegami	1981
50.92-67.06	6.1-6.8	Decathletes	Menzel	1986

P - Performance (throwing distance)
V_{AP} - Approach velocity

As with the optimal approach velocity the optimal length of the acceleration path also depends on the level of performance. According to BAUERSFELD/SCHRÖTER (1980) and TERAUDS (1985) the optimal length of acceleration path is between 8-12 strides.

3.1.2 TRANSITION PHASE

Fundamentals

Beginning: Start of the javelin withdrawal
End : Planting of the throwing-arm side leg
Objective: Establishment of biomechanical release conditions which contribute to attaining a great throwing distance

Indicators for the optimal body position at the end of the transition phase (planting of the throwing arm leg) are the inclination angle of the longitudinal axis of the body ε, the knee angle of the landing leg τ, the elbow angle of the throwing arm E_1 and the javelin's angle of attitude β_1 (Fig. J-2).
According to BAUERSFELD/SCHRÖTER (1980) the optimum values for the inclination angle and the angle of attitude are between 30°-35°. The knee angle of the landing leg should be 150°-160° and the elbow joint should be stretched.
Concerning the approach velocity during the transition phase, the investigations of KOLLATH (1983) and MENZEL (1986) show that there is a variation of the approach velocity and that the reduction of approach velocity should be as slight as possible (Tab. J-6).

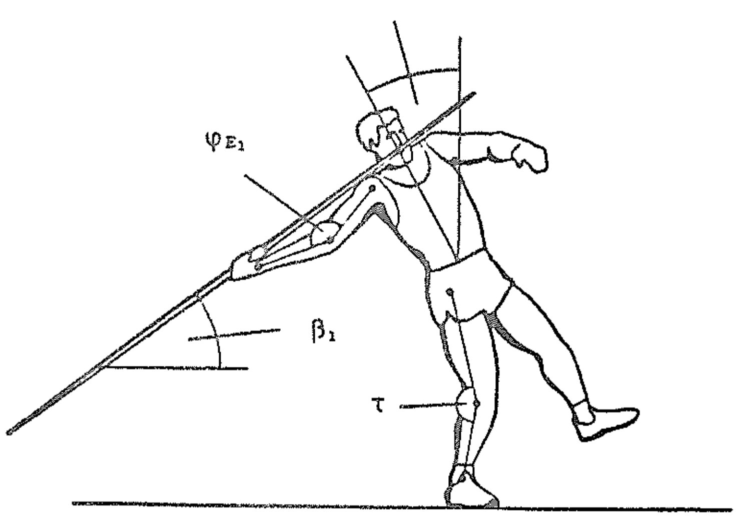


Figure J-2 Variables determining optimal body position at the end of the transition phase.

Table J-6 Mean values of velocities v_i (i = 5, ... 1) of the fifth from the last to the last approach stride (impulse stride) (MENZEL 1986).

Perf. [m]	v_5 [m/s]	v_4 [m/s]	v_3 [m/s]	v_2 [m/s]	v_1 [m/s]	Throwers
56.32	6.0	5.8	6.1	6.0	5.6	female
74.64	6.6	6.4	6.6	6.5	6.5	male

Results

The following variables of the transition phase have been analysed (Fig. J-2):

V_3, ..., V_1 - Velocities of the third from the last to the last approach stride (impulse stride) [m]

l_3, ..., l_1 - Stride length of the third from the last to the last approach stride (impulse stride) [m]

ε - Inclination angle between the longitudinal axis and the vertical line [°]

τ - Knee angle of the landing leg at [°]

φE_1 - Elbow angle of the throwing arm [°]

β_1 - Angle of attitude [°]

Table J-7 Results of the transition phase (men).

Name	Perf. [m]	v_3	v_2	v_1	l_3	l_2	l_1	ε	T	φ_{E1}	β_1
RATY	82.32	6.8	6.7	6.3	1.42	1.70	2.29	14	160	158	32
ZELESNY	82.20	6.9	7.2	6.8	1.52	1.81	1.56	19	162	147	43
PETRANOFF	80.46	7.2	7.0	7.1	1.35	1.68	2.25	28	175	154	44
YEVSYUKOV	80.34	6.6	6.9	6.3	1.89	2.18	2.74	36	162	151	21
HILL	78.14	7.0	7.2	7.3	1.68	1.86	2.40	18	156	163	28
MIZOGUSHI	77.78	7.6	7.6	7.6	1.72	2.06	1.26	35	161	167	37
WENNLUND	76.76	6.2	5.5	5.7	1.57	1.63	1.41	22	130	147	30
SHATILO	71.42	7.2	7.5	7.5	2.10	1.92	2.64	24	156	156	24

Table J-8 Results of the transition phase (women).

Name	Perf. [m]	v_3	v_2	v_1	l_3	l_2	l_1	ε	τ	φ_{E1}	β_1
WHITBREAD	76.64	6.6	6.9	6.5	1.63	1.56	1.87	27	156	165	30
FELKE	71.76	6.5	7.0	6.4	1.42	1.68	2.17	21	159	171	27
PETERS	68.82	6.7	6.8	6.3	1.57	1.94	1.95	26	160	165	30
SANDERSON	67.54	6.8	7.0	6.4	1.53	1.78	1.84	23	166	157	35
LILLAK	66.82	5.9	6.2	5.7	1.32	1.47	1.52	23	169	161	40
ERMOLOVICH	65.52	6.6	6.7	6.0	1.51	1.91	2.19	28	177	168	39
LEAL	64.90	6.4	6.8	6.0	1.66	2.06	2.08	28	147	149	36
JUNG	57.96	6.5	6.7	6.0	1.42	1.78	1.87	24	151	166	19

Interpretation:

Men

The approach velocity of the transition phase varies inter-individually between 5.5 m/s and 7.6 m/s and intra-individually up to 0.6 m/s.
The fastest approach velocity was realised by MIZOGUSHI who had a constant velocity during the last three steps of 7.6 m/s.
The slowest approach velocity of the impulse step (last approach step) was 5.7 m/s (WENNLUND).
Concerning the stride length of the last three steps, the stride length of the impulse step tends to be the longest, although three athletes have a longer stride length of the second from the last approach stride.
The inclination angle between the longitudinal axis and the vertical (ε) usually is less than reported in the literature. It was found that the inclination angle usually is between 15 - 25°.
The values of the elbow angle, which should be stretched at the end of the transition phase, are between 147 - 167°.

Women

The approach velocity of the transition phase varies inter-individually between 5.7 m/s and 7.0 m/s, intra-individually up to 0.8 m/s. The fastest approach velocity at the end of the transition phase was realised by WHITBREAD (6.5 m/s), FELKE (6.4 m/s), SANDERSON (6.4 m/s) and PETERS (6.3 m/s), the slowest approach velocity of the impulse step was 5.7 m/s (LILLAK).
Concerning the stride length of the last three steps, the stride length of the impulse step is the longest for all female athletes.
The inclination angle between the longitudinal axis and the vertical line (ε) is between 20° - 30°, which is less than reported in the literature. The values of the elbow angle, which should be stretched at the end of the transition phase, are between 149° - 171°.

3.2 RELEASE

3.2.1 PREPERATORY PHASE (SINGLE-SUPPORT PHASE)

Fundamentals

Beginning: Planting of the throwing-arm side leg
End : Planting of the bracing leg
Objective: Establishment of optimal biomechanical conditions for the delivery

During the preparatory phase the stride length of the bracing step is determined. According to TERAUDS (1985) the optimal relationship between the stride length of the last approach step (impulse step) and the bracing step is 1.62 : 1.
At the end of this phase the thrower should have realized an optimal stride length of the bracing stride and optimal conditions for the path of acceleration, which requires a stretched throwing arm at the time of planting the bracing leg.
The attitude angle of the javelin should be about 30°-35° (Fig. J-3).

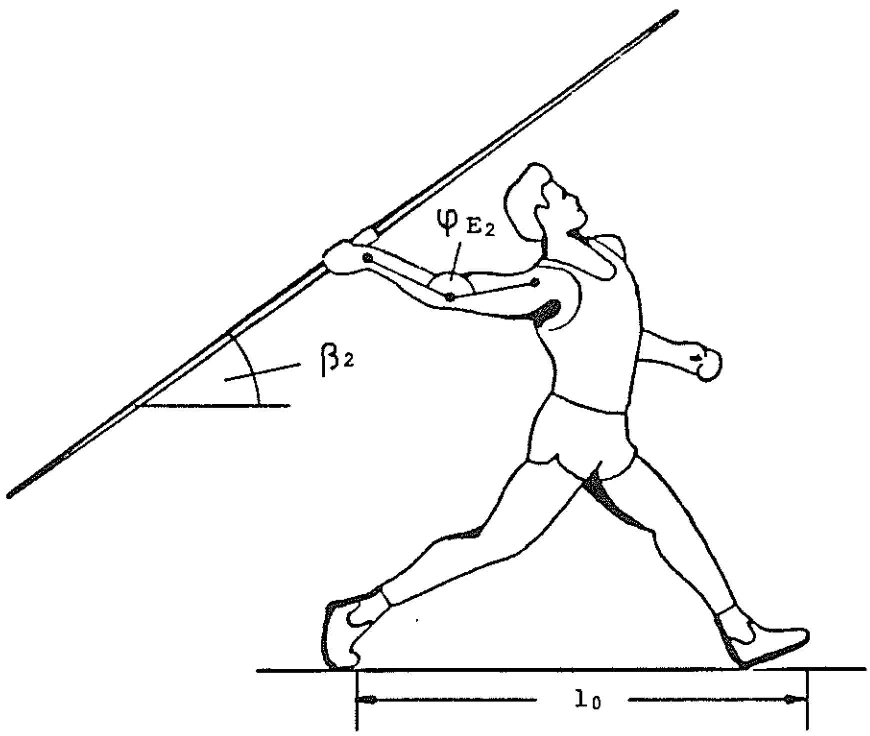


Figure J-3 Variables determining optimal body position at the end of the preparatory phase (single-support phase).

Results

The following variables of the preparatory phase are analysed (Fig. J-3):

Δt_p - Duration of the preparatory phase (single-support phase) [s]

l_0 - Stride length of the bracing stride [m]

$\frac{l_1}{l_0}$ - Relationship between the stride length of the impulse step and the bracing stride

φ_{E2} - Elbow angle of the throwing arm at the time of planting the bracing leg [°]

$\beta 2$ - Angle of attitude at the time of planting the bracing leg [°]

Table J-9 Results of the preparatory phase (men).

Name	Perf. [m]	Δt_p	l_0	$\frac{l_1}{l_0}$	φ_{E2}	β_2
RATY	82.32	0.195	1.54	1.48	131	32
ZELESNY	82.20	0.160	1.42	1.10	116	39
PETRANOFF	80.46	0.190	1.54	1.46	137	40
YEVSYUKOV	80.34	0.275	1.47	1.86	117	32
HILL	78.14	0.215	1.54	1.56	135	36
MIZOGUSHI	77.78	0.305	1.51	0.83	126	37
WENNLUND	76.76	0.130	1.43	0.99	123	30
SHATILO	71.42	0.240	1.57	1.68	127	35

Table J-10 Results of the preparatory phase (women).

Name	Perf. [m]	Δt_p	l_0	$\frac{l_1}{l_0}$	φ_{E2}	β_2
WHITBREAD	76.64	0.178	1.47	1.27	135	30
FELKE	71.76	0.202	1.33	1.63	107	27
PETERS	68.82	0.212	1.52	1.28	107	30
SANDERSON	67.54	0.256	1.50	1.23	123	35
LILLAK	66.82	0.197	1.62	0.94	114	38
ERMOLOVICH	65.52	0.217	1.43	1.53	117	39
LEAL	64.90	0.197	1.42	1.46	102	33
JUNG	57.96	0.202	1.45	1.29	128	17

Interpretation:

For men the preparation phase (single-support phase) lasts from 0.130 s to 0.305 s. The value of 0.305 s (MIZOGUSHI) seems to be an axtraordinary long duration of the preparation phase. For female throwers this phase lasts from 0.178 s to 0.256 s.
Concerning the length of the bracing stride, it was found that ZELESNY and WENNLUND have the shortest bracing strides of the male throwers (1.42 m, 1.43 m). The longest bracing stride was the 1.57 m of SHATILO.
For women the range of the bracing-stride length is between 1.33 m and 1.62 m. FELKE realised an extremly short (1.33 m) and LILLAK the longest (1.62 m) bracing stride. The values of the other female throwers are between 1.42 m to 1.52 m.

Only a few athletes achieved a relationship between the stride length of impulse step and bracing step near to 1.62 : 1, which is reported as optimal by TERAUDS (1985).
For most athletes this relationship is lower.

The values of the elbow angle of the throwing arm at the time of planting the bracing leg (ΨE_2) indicate that some athletes do not have their elbows stretched at the beginning of the delivery phase.

3.2.2 DELIVERY PHASE

Fundamentals

Beginning: Planting of the bracing leg
End : Moment of release (last contact between javelin and hand)
Objective: Maximal velocity of release v_0, optimum angles of release α_0 and of attitude β_0

The objective of the delivery phase is the achievement of a maximal velocity of release v_0 as well as an optimum angle of release α_0 and an optimum angle of attitude β_0. Velocity of release, angle of release and angle of attitude have different effects on the throwing distance depending on the wind conditions. Various investigations prove that the velocity of release is the most important variable determining the distance of flight. About 70 % of the velocity of release results from the delivery period. The optimum range of the angle of release in javelin throwing is characterized by lower values as compared to the aerodynamically large independent shot put. The optimum angle of release is the angle at which the thrower can achieve the maximal throwing distance. According to TERAUDS (1985) this individual different optimal angle is dependent on the javelin's optimum angle of release (mechanically optimal angle of release) and on the throwers maximum velocity angle (angle of release at which the thrower can generate the greatest velocity of release). For men usually the range of the optimal angle of release is between 30°-36°. Throwing into the wind the angle of release should be decreased by 1° for a velocity of the wind of 0.9 m/s. The angle of attack should be about 0°, so the angle of attitude should be in the same range as the angle of release.
Results of investigations (Tab. J-11) show that the aerodynamic prerequisites of a great throwing distance are more unfavourable for low-level than for top-level throwers.

Table J-11 Aerodynamic prerequisites of the throwing distance of different groups of throwers.

Perf.[m]	α	β	ɣ	N	Group of throwers	Author
56.32	36	40	4	7	Female specialists	MENZEL 1986
36.82	38	48	10	8	Pentathletes	MENZEL 1986
80.94	33	40	7	4	Male specialists	TERAUDS 1976
84.98	34	38	4	4	Male specialists	TERAUDS 1978
74.64	34	36	2	9	Male specialists	MENZEL 1986
53.60	38	47	9	9	Decathletes	MENZEL 1986

Perf. - Performance (Throwing distance)
α - Angle of release
β - Angle of attitude
ɣ - Angle of attack
N - Number of athletes

The angle or release and the velocity are established at the path of acceleration. According to BAUERSFELD/SCHRÖTER (1986) the path of acceleration should have an optimal length and a smooth course.

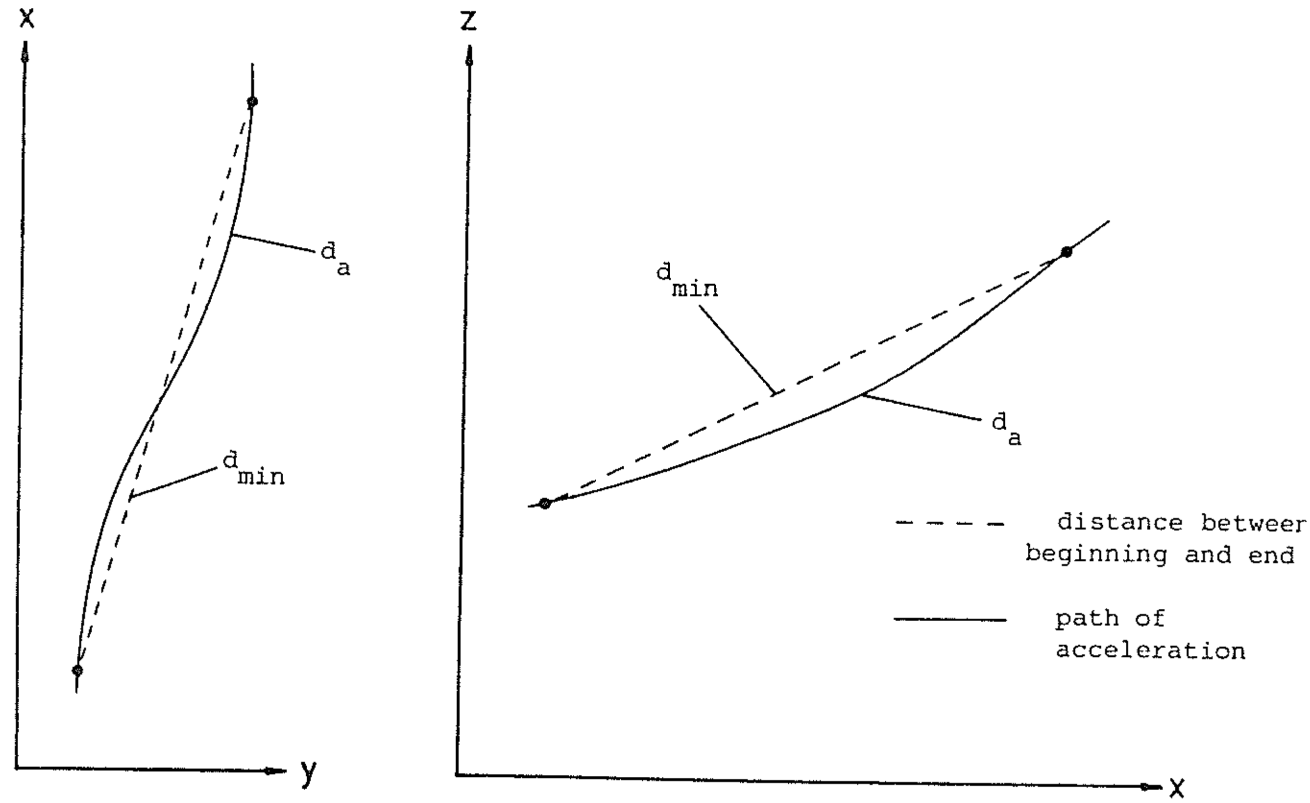


Figure J-4 Path of acceleration in the delivery phase

Variables for quantifying the length and the smooth path of acceleration are the acceleration distance of the javelin d_a, the relation d_r between the acceleration distance d_a and the shortest distance between the beginning and the end of the path of acceleration d_{min} ($d_r = d_a/d_{min}$) and the lateral deviation of the path of acceleration from the throwing direction.

For the identification of biomechanical factors determining the velocity of release a deterministic model was applied. In order to determine the velocities of the joints (hip, shoulder, elbow) and the velocity of release, a 6-segment model was constructed (see 2.1). The segments represent the shank and thigh of the bracing leg, the hip axis, the longitudinal trunk axis on the throwing arm side, the upper arm and the forearm of the throwing arm. Mechanical factors which define the velocities of the joint points and the velocity of release are the three-dimensional angles between the segments and the angular velocities of the joints.

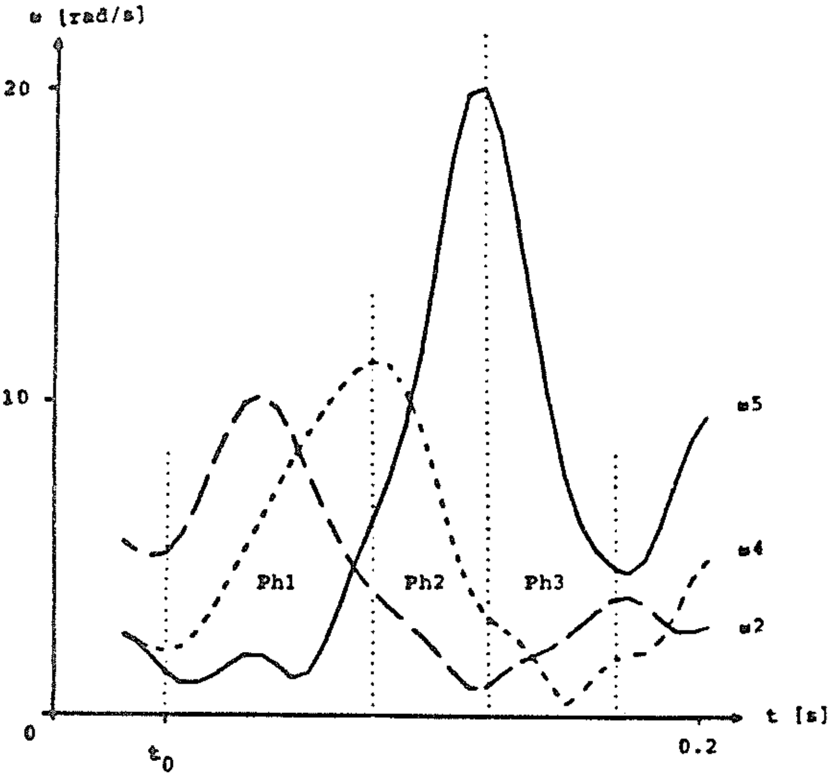


Figure J-5 Angular-velocity-time characteristics of the rotation of the thigh (ω2), longitudinal trunk axis (ω4) and upper arm (ω 5)

It was found that first the angular velocity of the knee angle of the bracing leg reaches its maximum (effort of the bracing leg), followed by the angular velocity of the rotation of the longitudinal trunk axis and finally the angular velocity of the rotation of the upper arm (Fig. J-5).

Research findings (MENZEL 1987 b) prove that the angular velocities (at the beginning of the delivery phase) of the hip axis, longitudinal trunk axis, upper arm and forearm and the maximum angular velocity of the upper arm (elbow joint) and the knee joint of the bracing leg are the most important biomechanical factors of influence for the velocity of release. In addition to these variables the velocity of release is dependent on the minimal knee-angle of the bracing leg, the three-dimensional angle of the shoulder joint at the time of release and the increase of angular velocity of the elbow joint in the last subphase of the delivery phase.

Results

At the moment of release the following variables were analysed (Fig. J-6)

v_0 - Velocity of release [m/s]
α - Angle of release [°]
β - Angle of attitude [°]
β_{xz} - Angle of attitude in the xz-plane (view from the side) [°]
β_{yz} - Angle of attitude in the yz-plane (view from behind) [°]
γ - Angle of attack (β - α) [°]
h - Height of release [m]

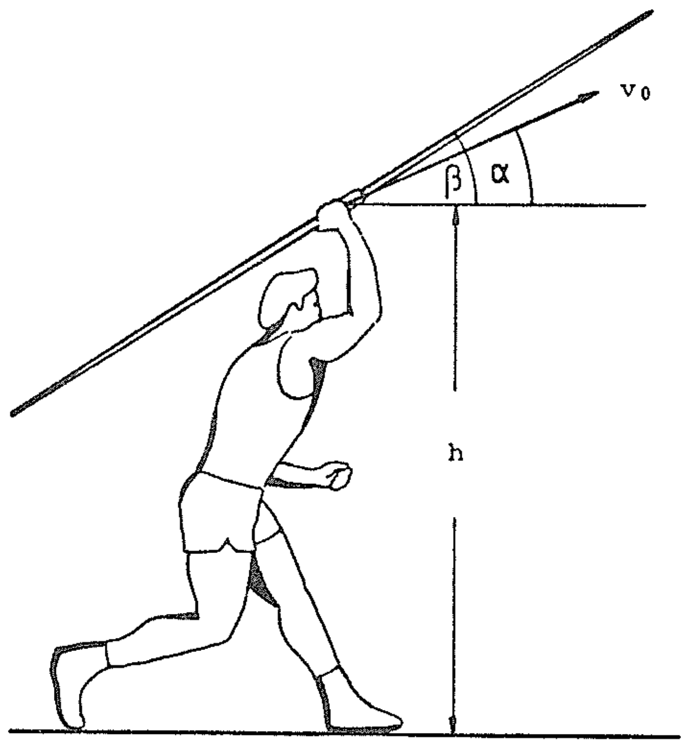


Figure J-6 Variables of the moment of release.

Table J-12 Results of the release (men).

Name	Perf.[m]	v_o	α	β	β_{xz}	β_{yz}	γ	h
RATY	82.32	29.6	37	33	34	82	17	1.81
ZELESNY	82.20	30.0	37	40	41	69	10	1.64
PETRANOFF	80.46	29.1	33	40	42	66	11	1.72
YEVSYUKOV	80.34	28.2	38	33	33	75	12	1.71
HILL	78.14	29.2	35	38	39	71	12	1.69
MIZOGUSHI	77.78	27.4	36	37	38	66	12	1.57
WENNLUND	76.76	27.1	37	30	32	64	12	1.69
SHATILO	71.42	27.9	31	35	36	68	19	1.81

Table J-13 Results of the release (women).

Name	Perf.[m]	v_o	α	β	β_{xz}	β_{yz}	γ	h
WHITBREAD	76.64	27.3	39	40	40	84	7	1.49
FELKE	71.76	27.1	35	38	40	67	19	1.47
PETERS	68.82	26.4	32	39	40	72	10	1.64
SANDERSON	67.54	25.5	34	37	37	77	10	1.47
LILLAK	66.82	26.0	36	37	37	90	9	1.69
ERMOLOVICH	65.52	25.4	33	41	41	85	16	1.59
LEAL	64.90	24.9	41	48	48	80	14	1.52
JUNG	57.96	24.4	35	33	34	65	11	1.55

The following variables of the acceleration phase have been analysed (Fig. J-8 and Fig. J-4):

d_a - Acceleration distance of the javelin [m]
d_{min} - Shortest distance between the beginning and the end of the acceleration path [m]
d_r - Relation between the acceleration distance d_a and the shortest distance between the beginning and the end of the acceleration path d_{min} ($d_r = d_a / d_{min}$)
Δy - Absolute lateral deviation of the path of acceleration from the throwing direction [m]
ϕ - Maximal relative lateral deviation of the path of acceleration from the throwing direction [°]

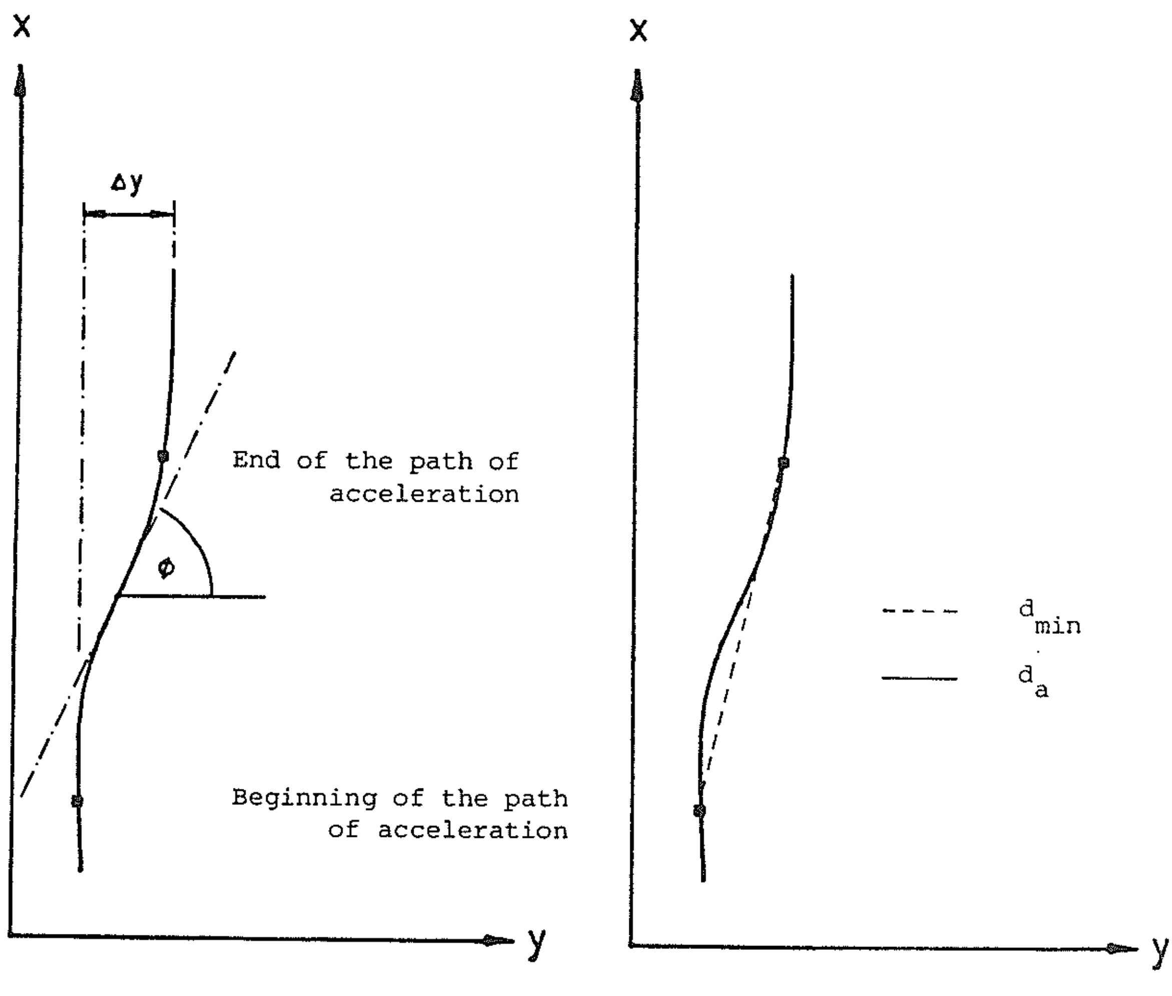


Figure J-7 Variables of the acceleration path in the x,y-phase.

Table J-14 Results of the acceleration path (men).

Name	Perf.[m]	d_a	d_{min}	d_r	Δy	∅
RATY	82.32	1.94	1.87	1.04	0.19	73
ZELESNY	82.20	1.59	1.52	1.05	0.49	57
PETRANOFF	80.46	1.83	1.78	1.03	0.77	48
YEVSYUKOV	80.34	1.38	1.34	1.04	0.18	75
HILL	78.14	1.93	1.86	1.04	0.41	66
MIZOGUSHI	77.78	1.54	1.51	1.02	0.41	66
WENNLUND	76.76	1.69	1.60	1.05	0.60	51
SHATILO	71.42	1.66	1.61	1.03	0.27	72

Table J-15 Results of the acceleration path (women).

Name	Perf.[m]	d_a	d_{min}	d_r	Δy	∅
WHITBREAD	76.64	1.54	1.46	1.05	0.14	77
FELKE	71.76	1.28	1.24	1.03	0.40	62
PETERS	68.82	1.38	1.34	1.03	0.42	65
SANDERSON	67.54	1.41	1.39	1.02	0.23	71
LILLAK	66.82	1.41	1.37	1.03	0.13	76
ERMOLOVICH	65.52	1.44	1.41	1.02	0.09	80
LEAL	64.90	1.33	1.27	1.05	0.29	68
JUNG	57.96	1.55	1.49	1.09	0.40	62

The following variables of the delivery phase have been analysed:

t - Period of delivery phase [s]

Bracing leg:

t_{KF} - Flexion period of the knee joint angle [s]

w_{KF} - Maximum flexion angular velocity [rad/s]

φ_K - Minimum knee angle [°]

Trunk:

ωH_{to} - Angular velocity of the rotation of the hip axis at the beginning of the delivery phase [rad/s]

ωT_{to} - Angular velocity of the rotation of the longitudinal trunk axis on the throwing arm side at the beginning of the delivery phase [rad/s]

t_T - Period until the rotation of the longitudinal trunk axis on the throwing arm side has reached its maximum [s]

φ_{BT} - Minimum angle between the hip axis and the trunk axis on the throwing arm side [°]

δ - Deviation of the longitudinal trunk axis from the vertical line at the time of release [°]

Throwing arm:

ωuA_{to} - Angular velocity of the rotation of the upper arm at the beginning of the delivery phase [rad/s]

ωFA_{to} - Angular velocity of the rotation of the forearm at the beginning of the delivery phase [rad/s]

ωFA_F - Maximum of flexion - angular velocity of the forearm [rad/s]

ωFA_S - Maximum of stretch - angular velocity of the forearm [rad/s]

t_{EF} - Flexion period of the elbow joint angle [s]

t_{ES} - Stretching period of the elbow joint angle [s]

φS_{tr} - Angle of the shoulder joint at the time of release [°]

φ_E - Minimum of the elbow angle [°]

Table J-16 Results of the delivery phase (men).

Name	Perf. [m]	t_{KF}	ω_{KF}	φ_K	ωH_{to}	ωT_{to}	t_T	φ_{HT}	δ	ωUA_{to}	ωFA_{to}	ωFA_F	ωFA_S	t_{EF}	t_{ES}	φS_{tr}	φ_E	t
RATY	82.32	0.08	10.9	153	2.2	6.0	0.06	46	57	4.6	9.3	12.5	38.2	0.11	0.04	110	79	0.15
ZELESNY	82.20	0.07	5.0	166	3.9	5.4	0.07	49	50	5.4	7.5	14.9	29.3	0.05	0.07	102	86	0.12
PETRANOFF	80.46	0.07	6.0	164	8.5	1.3	0.06	60	17	0.8	9.3	19.9	29.9	0.06	0.06	118	89	0.12
YEVSYUKOV	80.34	0.09	10.0	145	5.0	3.5	0.06	72	53	7.0	8.7	9.1	35.2	0.08	0.03	99	90	0.11
HILL	78.14	0.09	5.9	160	5.9	6.4	0.07	56	26	7.4	15.3	16.2	39.1	0.07	0.07	108	99	0.14
MIZOGUSHI	77.78	0.07	5.9	165	2.5	1.2	0.05	53	52	11.3	8.5	9.8	25.7	0.03	0.08	131	113	0.11
WENNLUND	76.76	0.11	4.1	156	4.1	1.6	0.09	68	54	5.3	5.1	5.3	28.6	0.06	0.08	111	108	0.14
SHATILO	71.42	0.12	11.0	147	2.2	1.3	0.05	54	42	5.1	4.5	10.9	30.9	0.09	0.03	141	111	0.12

Table J-17 Results of the delivery phase (women).

Name	Perf. [m]	t_{KF}	ω_{KF}	φ_K	ωH_{to}	ωT_{to}	t_T	ψ_{HT}	δ	ωUA_{to}	ωFA_{to}	ωFA_F	ωFA_S	t_{EF}	t_{ES}	φS_{tr}	φ_E	t
WHITBREAD	76.64	-	-	167	6.1	3.9	0.05	71	63	2.8	4.6	11.4	48.1	0.09	0.03	116	86	0.12
FELKE	71.76	0.04	3.4	160	5.6	0.9	0.04	75	40	5.4	6.2	5.3	29.0	0.07	0.03	110	91	0.10
PETERS	68.82	0.06	5.1	161	5.5	3.6	0.05	75	50	4.7	9.6	9.6	31.6	0.07	0.03	102	86	0.105
SANDERSON	67.54	0.06	5.7	146	8.6	4.7	0.04	74	70	3.7	11.6	12.8	40.7	0.08	0.04	111	89	0.12
LILLAK	66.82	0.04	1.1	163	6.4	7.8	0.05	60	15	4.4	7.0	8.0	27.8	0.06	0.04	123	92	0.11
ERMOLOVICH	65.52	0.08	9.3	160	9.0	8.7	0.04	60	69	5.5	11.8	11.9	22.4	0.07	0.04	130	90	0.12
LEAL	64.90	0.07	8.8	151	2.4	4.8	0.04	98	60	9.6	7.2	7.7	29.0	0.08	0.03	103	84	0.11
JUNG	57.96	0.08	9.7	137	7.3	3.9	0.05	68	67	4.5	7.5	10.0	32.5	0.10	0.03	112	78	0.13

In three-dimensional analysis the angle of attack usually is not the difference between the values of angle of release and angle of attitude, because these angles are located in different planes. Therefore the (three-dimensional) angle of attack is defined as the angle between the attitude of the javelin and the direction of its velocity.
The results of these investigations prove that for three-dimensional analysis the angles of attack are greater than for two-dimensional analysis (x-z plane). The angle of attack is between 7 - 19°. The lowest angle of attack was realised by WHITBREAD (7°). The angles of release are between 31° - 38° for men and between 32° - 41° for women.
According to the body height the height of release is higher for men (1.57 m - 1.81 m) than for women (1.47 m - 1.69 m).
Therefore longer acceleration distances could be found for men than for women (men: 1.38 m - 1.94 m, women: 1.28 m - 1.55 m).
The results also prove that high release velocities can also be realised by rather short acceleration distances (e.g.: FELKE: d_a = 1.28, YEVSYUKOV: d_a = 1.38 m). The lateral deviation and the relative distance d_r of the acceleration path do not seem to have a great influence on the velocity of release or the angle of attack. Further investigations into this problem are necessary.

Concerning the movements of the bracing leg, trunk and throwing arm, the data prove that the flexion period of the bracing leg should be as short as possible. Women have realised shorter flexion periods than men.
The most intensive application of the bracing leg was performed by WHITBREAD (no flexion period) and ZELESNY (flexion period: 0.07 s).
Indicator of an intensive application is the minimal knee angle of the bracing leg. This knee angle should be greater than 155°.
The variables H_{to} and T_{to} describe the movement of the trunk at the beginning of the delivery phase. Results of former investigations (MENZEL 1987) prove that high velocities of the trunk axis (ωT_{to}) have negative influence on the release velocity.
Concerning the movement of the throwing arm the maximal stretching angular velocity of the elbow joint is the most important indicator of the throwing arm action. The highest values for men are 39.1 rad/s (HILL) and 38.2 rad/s (RATY), for women 48.1 rad/s (WHITBREAD) and 40.7 rad/s (SANDERSON).
An indicator for the upper arm movement is the angle of the shoulder joint at the moment of release. This angle should be as small as possible. Values of 130° and more, as are found for ERMOLOVICH, MIZOGUSHI and SHATILO, are unfavourable conditions.

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BIOMECHANICAL ANALYSIS OF THE HAMMER THROW

Otto, R.M.

H A M M E R T H R O W

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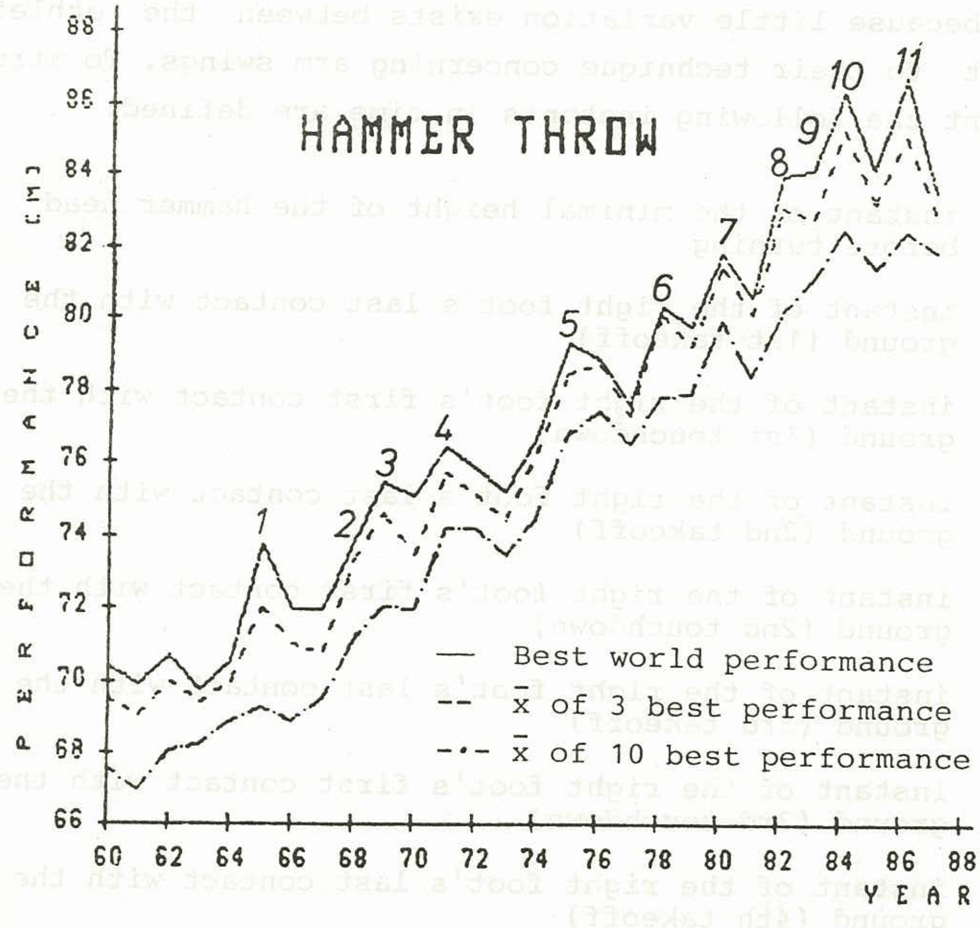
1. INTRODUCTION

During the last 30 years world-class athletes in the hammer throw have shown a consistent tendency towards improved performances. This has been true for top ranked athletes as well as for those having lower rankings. The modification of the rules in 1981, in which the diameter of the hammer head was enlarged, did not impede this progress. Figure 1 shows the hammer throw's development since 1960:



1	Zsivotzky	(73.74)	5	Schmidt	(79.30)	9	Litvinov	(84.14)
2	Zsivotzky	(73.76)	6	Riehm	(80.32)	10	Sedykh	(86.34)
3	Bondarchuk	(75.48)	7	Sedykh	(81.80)	11	Sedykh	(86.74)
4	Schmidt	(76.40)	8	Litvinov	(83.98)			

Figure 1: Progression of performance in the hammer throw

2. BIOMECHANICS OF THE HAMMER THROW

2.1. Division of the Event

The hammer throw may be divided into the following three phases:

- introductory arm swings
- turns (usually 3 or 4)
- delivery phase.

The evaluation begins with the hammer's motion, when it reaches its deepest point, and ends about 0.2 s after the release, which is the moment the hammer grip leaves the hand. The reason for this is because little variation exists between the athletes with respect to their technique concerning arm swings. To structure the event the following instants in time are defined:

t_0	instant of the minimal height of the hammer head before turning
t_1	instant of the right foot's last contact with the ground (1st takeoff)
t_2	instant of the right foot's first contact with the ground (1st touchdown)
t_3	instant of the right foot's last contact with the ground (2nd takeoff)
t_4	instant of the right foot's first contact with the ground (2nd touchdown)
t_5	instant of the right foot's last contact with the ground (3rd takeoff)
t_6	instant of the right foot's first contact with the ground (3rd touchdown)
t_7	instant of the right foot's last contact with the ground (4th takeoff)
t_8	instant of the right foot's first contact with the ground (4th touchdown)
t_9	instant of the last contact between the hammer grip and the hand.

t_7 and t_8 are dropped when only 3 turns are made. The instants of time listed above are needed to define the phases of movement:

t_0	-	t_2	1st turn (T 1)
t_2	-	t_4	2nd turn (T 2)
t_4	-	t_6	3rd turn (T 3)
t_6	-	t_8	4th turn (T 4) (if performed)
$t_{8(6)}$	-	t_9	release phase (R).

Furthermore, every turn has been divided into a double-support phase, t_{DS}, (both feet are in contact with the ground) and a single-support phase, t_{SS}, (only the left foot touches the ground). The following figure provides a survey of the division of the phases of movement.

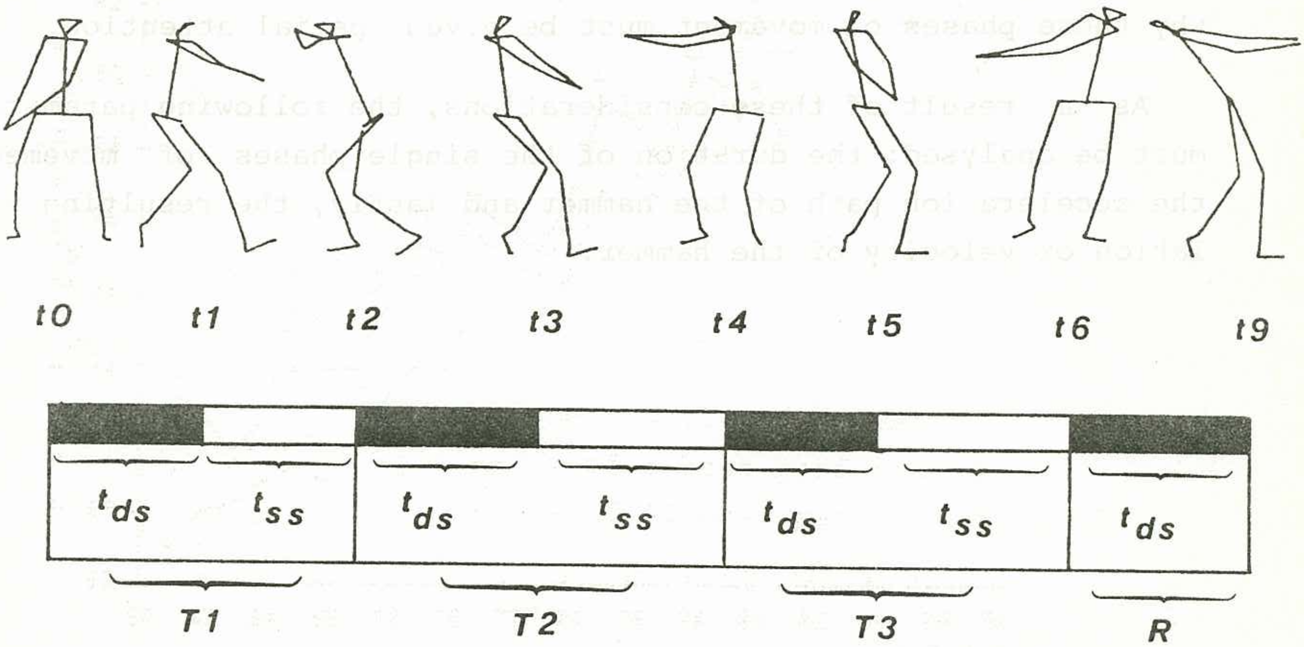


Figure 2: Phases of movement for the hammer throw with three turns

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All descriptions of movement refer to athletes who turn to their left. At the present time there are no world class athletes who turn to their right.

2.2. Limiting Factors of the Hammer Throw

The technique of the hammer throw during the delivery aims at giving the hammer a maximum velocity of release with an optimal angle of release. The angle of release is defined as the angle between the hammer path and the horizontal plane.

The velocity of release is determined by the acceleration affecting the hammer during the turns. Therefore, the final velocity depends on the duration as well as on the quantity of acceleration during the single phases of movement. The maximum of final velocity can also be achieved by the process of acceleration throughout the path of movement.

An efficient acceleration of the hammer is only possible when there is a counterforce between the feet and the ground. That is why these phases of movement must be given special attention.

As a result of these considerations, the following parameters must be analysed: the duration of the single phases of movement, the acceleration path of the hammer and lastly, the resulting variation of velocity of the hammer.

Time parameters

The total duration of the hammer throw, which begins with the lowest point of the hammer's movement (t_0) and ends with the release (t_9), varies from 1.60 - 2.60 s for all the throws investigated. Distances thrown depended on technical proficiency and the number of turns made (3 or 4). Just as the total duration differs, the duration of a single turn varies greatly among the athletes. Investigations by FRACCIA (1976) and ARIEL (1980) found the following durations for a single turn among the top athletes of the 1970's:

Sachse	(RDA)	76.04 m	0.58 - 0.54 - 0.46
Riehm	(FRG)	77.50 m	0.46 - 0.50 - 0.47
Dmitrenko	(URS)	77.22 m	0.60 - 0.66 - 0.51 - 0.45
Schmidt	(FRG)	74.72 m	0.48 - 0.58 - 0.49
Bondarchuk	(URS)	75.48 m	0.48 - 0.54 - 0.51
Spiridonov	(URS)	76.08 m	0.54 - 0.70 - 0.53 - 0.48

Recent investigations of throws performed during the 1986 World Junior Championships (Athens), and the European Championships (Stuttgart) have shown that there is an increase in speed compared to athletes of the 1970's, especially in the last turn of those athletes having good technical skills:

Alisevitch**	(URS)	71.12 m	? - 0.54 - 0.44
Sedykh*	(URS)	86.74 m	0.45 - 0.47 - 0.43
Litvinov*	(URS)	85.74 m	0.44 - 0.60 - 0.44 - 0.43
Nikulin*	(URS)	82.00 m	0.53 - 0.65 - 0.46 - 0.45
Rodehau*	(RDA)	79.84 m	0.58 - 0.66 - 0.48 - 0.48
Schäfer*	(FRG)	79.68 m	0.45 - 0.60 - 0.51
Haber*	(RDA)	78.74 m	0.47 - 0.51 - 0.50
Moder*	(RDA)	78.70 m	0.62 - 0.67 - 0.54 - 0.50
Sahner*	(FRG)	77.12 m	0.45 - 0.64 - 0.51 - 0.45
Ploghaus*	(FRG)	76.36 m	0.48 - 0.48 - 0.47 - 0.45

** Junior World Championships, Athens (SUSANKA 1986)
* European Championships, Stuttgart (OTTO 1986)

The duration of the release phase (Rt_{DS}) varies from 0.22 - 0.28 s among top athletes. Among American 1st team athletes, durations of up to 0.34 s were measured for the release phase (ARIEL 1980).

Apart from the duration of the turns, the ratio between the double-support and the single-support phases is of great importance. The hammer's velocity can only be increased in the double-support phase (SAMOZWETOW 1980, BONDARCHUK 1977, BLACK 1980, SIMONYI 1980, WOICIK 1980). Thus it is necessary to lengthen this phase and reduce the single-support phase. This means that athletes should strive to maintain the double-support phase longer, or it should last at least as long as the single-support phase. In earlier investigations this was noticed only for Sedykh, Litvinov, Haber, Sahner, Ploghaus and Weis. All other athletes showed an inverse ratio (longer single-support phases). This disadvantageous proportion is obvious among athletes with performances below 70 m. In such cases, the durations of the single-support were found to be up to 50% longer than the durations of the double-support phase. The complete turn (refering to the last turn) lasts 0.50 s.

Location

The following parameters are chosen to describe the technique of the hammer throw (measured in m):

- diameter of the hammer path
- height of the hammer
- height of the centre of the hip
- height of the right foot (swinging leg).

With the aid of this choice of parameters it is possible to analyse the technique of a hammer thrower.

The diameter of the hammer path during the turns, that is the maximum span of the hammer path in the turns from a frontal view at ground projection was between 3.60 and 4.20 m for Alisevitch (URS, Junior World Champion, Athens 1986). Our own investigations during the European Championships at Stuttgart in 1986 showed somewhat lower values; for example, between 3.20 and 3.50 m for Sedykh.

The maximum height of the hammer varies from 2.00 m in the beginning of the turns to 2.50 m at the end. The height of the delivery was measured at 1.65 m.

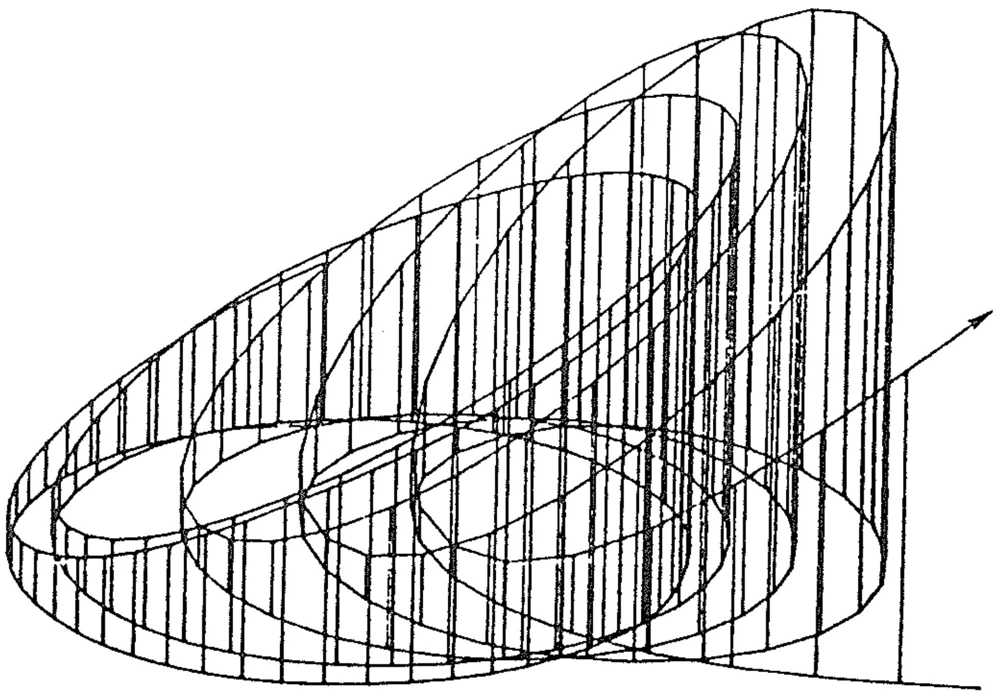

Figure 3: Hammer path during periods of 0.02 s (DAPENA 1984)

All values of the hammer given are in reference to the centre of the hammer head.

The results of the minimum and maximum values of an athlete's centre of the hip provide information about the starting point of the hip, depending on body height, and the lowering of the hip. The height of the centre of the hip varies during the turns from an average of 0.70 m to 1.00 m. The lowest values, as well as the maximum lowering of the hip, were measured for Sedykh during his world record throw (86.74 m) with a minimum of 0.63 m and a lowering of the hip of 0.23 m in the last turn. For all athletes, the lowering of the hip opposes the height of the hammer. That is, the moment the hammer reaches its maximum height the hip reaches its minimum. For athletes with poorer performances, this tendency is less pronounced. For performances below 70 m it is not pronounced at all. For example, Alisevitch lifted his hip on his 71.12-m-throw at the Junior World Championships, which he eventually won.

Another parameter which is used to describe the technique is the height of the swinging foot during the turns, because lifting the foot too high causes a longer lasting single-support-phase. When observing the maximum height of the foot, it must be remembered that the determination and the evaluation refers to the height of the ankle in order to eliminate the factor of foot position during the analysis. To get the absolute height, 8 cm must be subtracted (anthropometric mean of the ankle's height measured among West German 1st team athletes).

Investigations among West German team athletes showed feet heights from 0.35 - 0.60 cm. For athletes with poor technical skills, an increase in foot height from turn to turn was pronounced.

Acceleration Path

Two characteristics which describe the technique of hammer throwing are the length of the acceleration path of the hammer (measured in degrees) while turning and the position of the hammer in spatial relation to the thrower. SAMOZWETOW (1974) defines the hammer acceleration path as that part which corresponds to the double-supporting position of the rotation. It is during this phase of the movement that the thrower is able to accelerate the hammer. It is important to cover a path as long as possible without reducing the radius of the hammer.

The starting point and the finishing point are determined by the planting of the right swinging leg on the ground (t_2, t_4, t_6, t_8) by the lifting of the leg from the ground (t_1, t_3, t_5, t_7), and by the release of the hammer (t_9). The position of the hammer is associated with these times by the azimuth of the hammer. As defined, the angle sums up to 0° or 360° in the front of the thrower, 90° to the left, 180° in the back, and 270° to the right. The zero-point of the system of coordinates is located in the centre of that line which combines the feet with the respective instant of analysis (see figure 4).

At the moment of lifting the right leg from the ground the angle of rotation of the hammer is in the region of 20° to 115°. The moment the foot is set on the ground this angle is in the region of 180° to 330° (SAMOZWETOW 1974). The length of the acceleration path (measured in degrees) is equal to the sum of the average of planting and the average of lifting the swinging leg.

Based on filmshots of more than 100 throwers, SAMOZWETOW classified the hammer throw technique according to the following scheme:

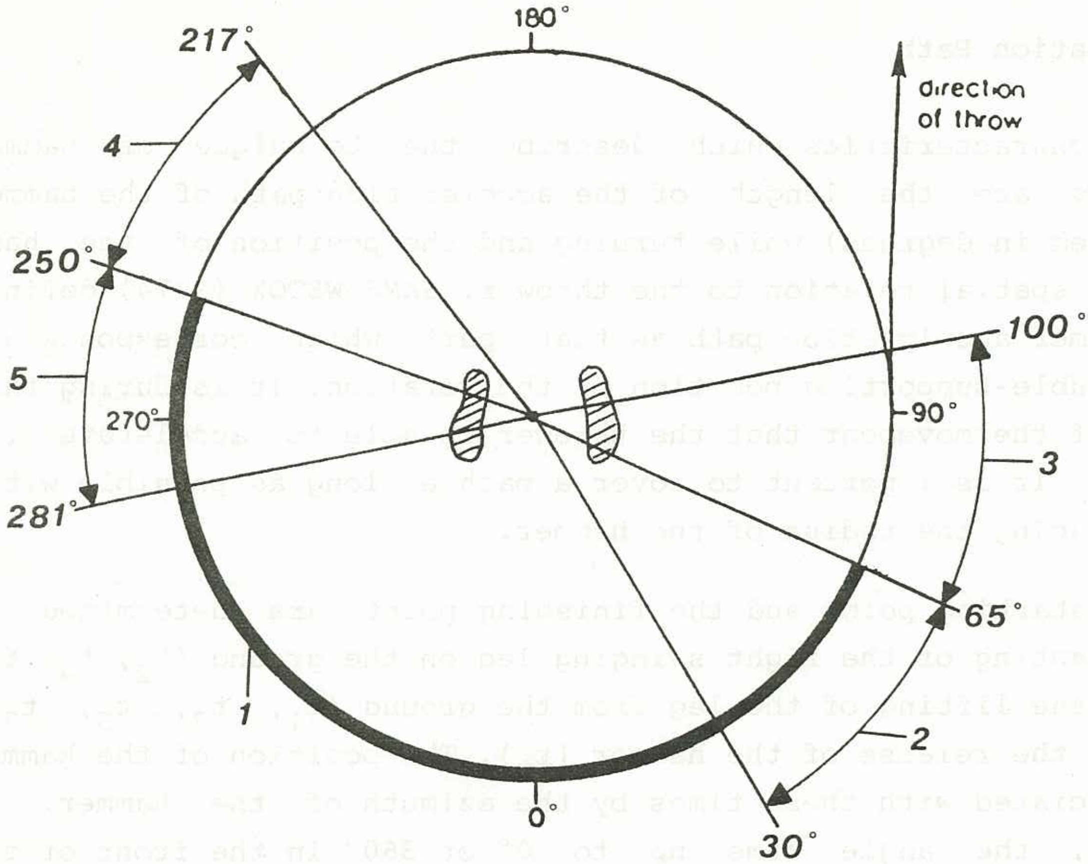

Figure 4: Acceleration path and categories of classification

1 Acceleration path
2 Lifting the right foot early
3 Lifting the right foot late
4 Planting the right foot early
5 Planting the right foot late

In the literature several authors have published the length of acceleration path and the azimuth at defined times. SAMOZWETOW (1974) suggests, for the best hammer throw technique an early lifting (30°) and an early planting (230°) of the foot is necessary with an acceleration path of 160°. This technique is shown for example, by Bondarchuk (45° - 215°).

A differing claim, made by TSCHIENE and BONDARCHUK (BOSEN 1984), is that the technique of late lifting and early planting of the foot is more favourable. One example of this is a throw by Sedykh at the 1980 Olympic Games (BOSEN 1984). He lifted at 65° and set down at 212° (acceleration path = 213°).

MCGILL (1984) calculated, using a different throw from Sedykh, a lift up of 53° and a set down of 220°. GOLDHAMMER (1984) also finds a late lift and an early set favourable and recommends 80/85° and 250/270°. These values, however, do not fit in the classification system of SAMOZWETOW (1974) (see figure 4).

Some measurements in the 1986 European Championships led to the following results:

name (distance)	takeoff (degrees)	touchdown (degrees)	acceleration path (degrees)
Sedykh (86.74 m)	46	222	184
Litvinov (86.12 m)	54	234	180
Schäfer (79.36 m)	39	251	148

These results indicate a trend confirmed by DAPENA (1986). He analysed 16 throws and obtained an average of 54° (std = 17) for the lifting of the right foot and 241° (std = 13) for the planting of the right foot.

Velocity

The distance of the hammer throw is influenced by three factors:

- height of the hammer at release,
- angle of release,
- velocity of release.

The velocity of release has the greatest influence on the distance of the throw. A decrease in velocity of 1 m/s results in approximately a 5 m loss in distance. The optimal angle of release, which is dependent on the distance, is about 44°. In comparison to this optimum, a deviation in this angle of about 5° results in a loss of distance of approximately 1 m. A difference in respect to the height of the hammer at release causes an approximately equivalent variation of distance which is dependent on the angle of release. Thus, a release which is located 0.20 m higher would have the effect in which the hammer achieves a longer distance of only 0.18 m with the angle of release being 44° (TUTJOWITSCH 1976).

The air friction and wind conditions represent other factors which influence the performance of the hammer throw. The athletes themselves are not able to control these factors, which influence the estimation of the theoretically calculated velocity of release and the analysed one. A wind velocity of 2 m/s for instance, is responsible for a difference of distance of ±0.5 m (TUTJOWITSCH 1976). The hammer's air resistance, which is not considered in the theoretical calculation, diminishes the distance by 3.0 m.

The measured velocities at the instant of release (about 30 m/s) appear to be entirely realistic for a throw of 80 m. TUTJOWITSCH's theoretically defined values for a throw of 80 m came to approximately 28 m/s without considering air friction and wind conditions.

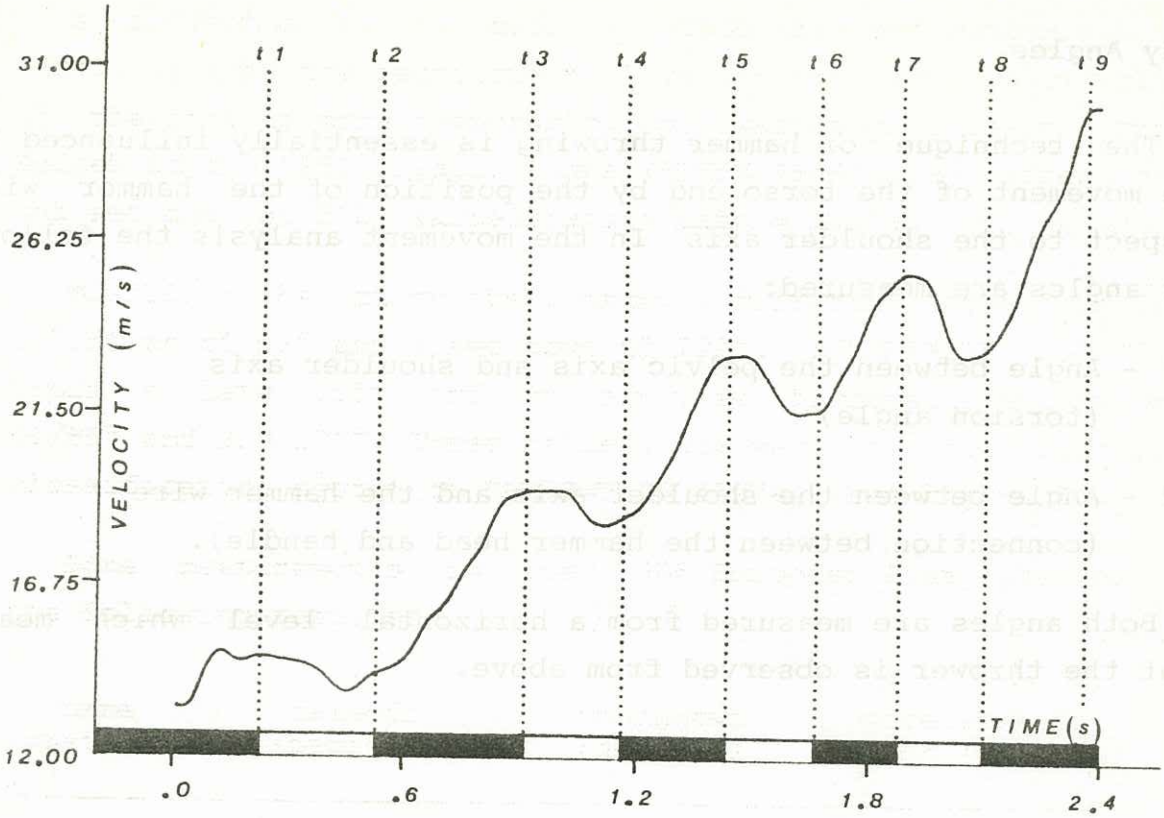

Figure 5: Change in velocity of the hammer during turning and release

Figure 5 illustrates a typical velocity curve of an 80-m-throw. The release velocity is about 30 m/s. The loss in total velocity between single turns is given by SUSANKA (1986) as approximately 4-7 m/s. The gain in velocity at the release is about 3-5 m/s (TUTJOWITSCH 1976). With these calculations a comparison between the maximum velocity of the last turn and the velocity of release can be made.

The release angle is calculated from the horizontal and vertical velocity of release parameters and is, therefore, given along with the velocity characteristics. In the literature an optimum angle of release of approximately 44° is usually given. In practice the angles of release are mostly found to vary between 38° and 44°. Sedykh, for instance, achieved his world record throw of 86.74 m with an angle of 41.1°.

Body Angles

The technique of hammer throwing is essentially influenced by the movement of the torso and by the position of the hammer with respect to the shoulder axis. In the movement analysis the following angles are measured:

A 1 - Angle between the pelvic axis and shoulder axis (torsion angle)

A 2 - Angle between the shoulder axis and the hammer wire (connection between the hammer head and handle).

Both angles are measured from a horizontal level which means that the thrower is observed from above.

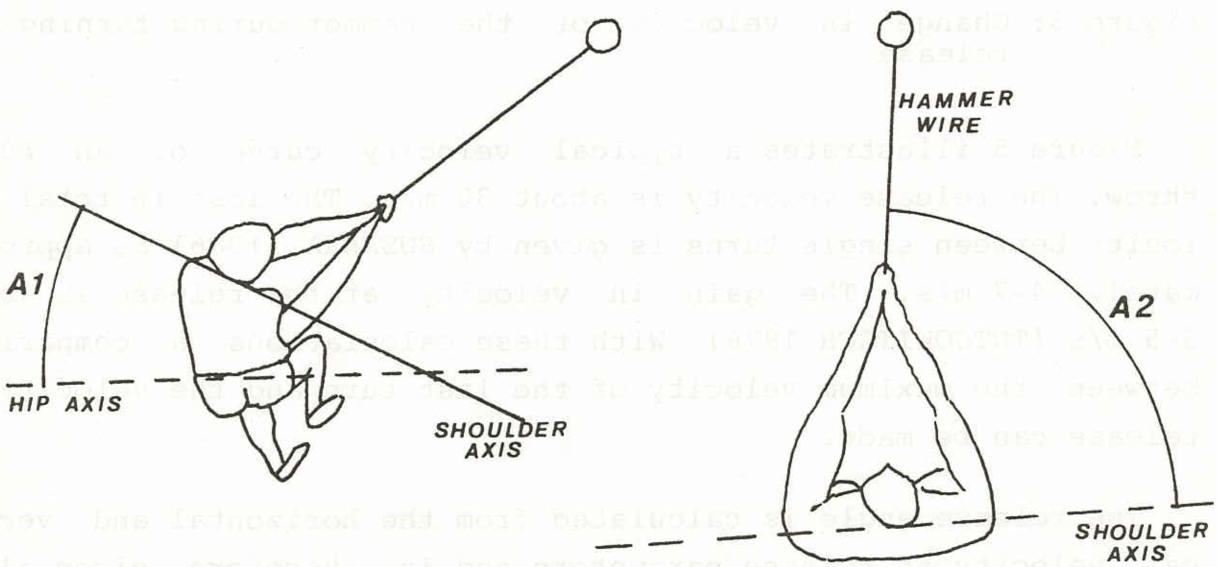

Figure 6: Illustration of angles A 1 and A 2

The calculation is carried out by projecting the determined points on to the floor and then measuring them. The twisting angle is defined as 0° when the pelvic and shoulder axes are parallel. A turning of the shoulder to the right in relation to the pelvis axis is measured as an increase of the angle A 1, while a turning to the left is measured as a negative value.

The angle A 2 equals 90° when the hammer is located directly in front of the thrower. A "trailing" of the hammer increases the angle (A 1 > 90°) and a "leading" causes a decrease (A 1 < 90°).

The literature states that an angle of torsion of more than 90° is not anatomically possible. An increase in the velocity of the hammer is only possible when the thrower unwinds from his twisted position (SAMOZWETOW 1972). When the axes are parallel (A 1 = 0°) it is no longer possible to accelerate. SAMOZWETOW, through his investigations, maintains that a twisting to the left gives poorer results. Furthermore, he supposes that a maximum value of A 1 between 60° and 70° is favourable. These values are also confirmed by different authors (for example, BLACK 1980).

Little useful information on the angle between the shoulder axis and the hammer wire is available. Recent investigations of CSSR throwers found values between 90° and 160°, or 90° and 130°. Investigations of West German athletes give values of 90° and 120°, and in extreme cases 90° and 150°. The analysis of Sedykh's world record throw gave values between 75° and 105°. This clearly contradicts the trend of all other throwers examined.

3. FINDINGS OF THE ROME COMPETITION

3.1. Method and Procedure

Eight athletes reached the hammer throw finals on September 1, 1987. With 29°C and a relative humidity of 64%, the exterior conditions were optimal.

Four LOCAM highspeed cameras were used to analyse the competition. Two cameras worked from a lateral view and two others were in a frontal position for an oblique view. The cameras were used alternately in order to avoid missing important attempts during film reloading. Approximately 20 frames of the hammer's flight were photographed. In each example the frame rate was 200 fps. This frequency is necessary for a precise analysis of timing. All cameras were controlled from a central point and externally synchronized.

The 3-D-analysis was made with the help of DLT-technique. For further processing and description within this report, special software was developed. Based upon the preceding biomechanical discussion, the best final throws of the eight highest placed athletes were analysed using the following parameters:

	unit
- duration of the turns (T1-T4)	s
- duration of the delivery phase	s
- duration of the single-support phases	s
- duration of the double-support phases	s
- total duration of the throw	s
- diameter of the hammer path	m
- minimal and maximal height of the hammer during the turns	m
- height of the hammer at release	m
- minimal and maximal height of the centre of the hip during the turns and the delivery	m
- average lowering of the centre of the hip during each turn and during the complete throw	m
- maximal height of the foot of the swinging leg (height of the ankle) during the turns	m
- azimuth of the hammer during defined instants of time	°
- azimuth and acceleration distance of the hammer in the mean	°
- minimal and maximal velocity of the hammer during the turns	m/s
- velocity of release	m/s
- angle of release (α)	°
- percentage of increase in velocity as a result of the delivery	%
- minimal and maximal torso torsion (A1) during the turns and variation	°
- minimal and maximal angle between the shoulder axis and the hammer wire and variation	°

3.2. Event Scorecard

name	nation	1	2	3	4	5	6	rank
		results (m)						
Litvinov, Sergey	URS	74.76	<u>83.06</u>	80.58	81.50	x	80.64	1
Tamm, Juri	URS	78.38	77.94	x	76.88	78.18	<u>80.84</u>	2
Haber, Ralf	GDR	x	77.92	78.94	79.18	<u>80.76</u>	78.78	3
Sahner, Christoph	FRG	72.38	75.80	76.88	77.32	79.50	<u>80.58</u>	4
Nikulin, Igor	URS	76.62	78.74	79.48	78.18	<u>80.18</u>	80.00	5
Weis, Heinz	FRG	77.70	79.02	78.32	79.26	<u>80.18</u>	78.76	6
Gecsek, Tibor	HUN	76.54	75.80	<u>77.34</u>	77.56	74.94	76.94	7
Minev, Plamen	BUL	75.16	<u>77.06</u>	x	x	x	x	8

Time: 16:35 - Temp.: 29°C - Rel. Hum.: 64%

Note: The analysis is based on the underlined results.

3.3. Biomechanical Results

3.3.1. Time Parameters

name	T 1		T 2		T 3		T 4		R	Σ
(distance)	t_{DS}	t_{SS}	t_{DS}	t_{SS}	t_{DS}	t_{SS}	t_{DS}	t_{SS}	t_{DS}	
Litvinov	0.49		0.56		0.46		0.41			
(83.06 m)	0.19	0.30	0.30	0.26	0.23	0.23	0.20	0.21	0.22	2.14
Tamm	0.50		0.58		0.50					
(80.84 m)	0.18	0.32	0.24	0.34	0.18	0.32	/		0.22	1.80
Haber	0.43		0.52		0.50					
(80.76 m)	0.16	0.27	0.29	0.23	0.25	0.25	/		0.24	1.69
Sahner	0.49		0.63		0.50		0.43			
(80.58 m)	0.19	0.30	0.38	0.25	0.27	0.23	0.21	0.22	0.26	2.31
Nikulin	0.52		0.62		0.45		0.42			
(80.18 m)	0.20	0.32	0.35	0.27	0.20	0.25	0.17	0.25	0.26	2.27
Weis	0.53		0.58		0.49		0.45			
(80.18 m)	0.20	0.33	0.31	0.27	0.25	0.24	0.22	0.23	0.25	2.30
Gecsek	0.46		0.60		0.49		0.44			
(77.34 m)	0.19	0.27	0.35	0.25	0.27	0.22	0.23	0.21	0.28	2.27
Minev	0.47		0.56		0.49					
(77.06 m)	0.20	0.27	0.32	0.24	0.22	0.27	/		0.23	1.75

Table 1: Duration of the turns with single-support and double-support positions during defined periods (definition see 2.1.)

Among the analysed throws Tamm, Haber and Minev demonstrated a technique with three turns while Litvinov, Sahner, Nikulin, Weis and Gecsek preferred four turns.
The total duration of the throws varies among the throwers with three turns between 1.69 and 1.80 s. Among athletes with four turns it varies between 2.14 and about 2.30 s. Litvinov's time was 2.14 s whereas all the other athletes were closer to 2.30 s.

Compared to the preceding year (EM 1986) Litvinov and Haber show nearly the same results. Sahner performs his turns markedly faster which helps to explain his improvement of 3.5 m.
A change for the worse is noticed for Nikulin; he loses nearly 2.0 m compared to the preceding year.

Furthermore, the relationship between the single-support and the double-support position is remarkable for Nikulin, Tamm and Minev. Especially for the last two athletes, the extremely long single-support phase of the final turn causes a shortening of the duration of the delivery phase. Also, Litvinov demonstrates a short duration of the delivery phase (in comparison to his EM-throw in 1986 with 85.74 m). Gecsek's throws, analysed for the first time, and Weis's throws show very good timing. In earlier investigations (1985-1987), Weis especially demonstrated markedly slower turns.

3.3.2. Kinematic Parameters

Location

name (distance)	body-height (m)	T 1	T 2	T 3	T 4
Litvinov (83.06 m)	1.80	3.24	3.18	3.13	3.02
Tamm (80.84 m)	1.93	3.45	3.40	3.31	/
Haber (80.76 m)	1.89	3.42	3.34	3.27	
Sahner (80.58 m)	1.79	3.42	3.33	3.29	3.29
Nikulin (80.18 m)	1.92	3.51	3.38	3.26	3.25
Weis (80.18 m)	1.93	3.60	3.49	3.44	3.43
Gecsek (77.34 m)	?	3.48	3.39	3.29	3.24
Minev (77.06 m)	?	3.40	3.30	3.23	/

Table 2: Dimension of the diameter of the hammer path during the turns (T1-T4)

The values of the diameter of the hammer path showed the same tendency when analysed during the European Championships in 1986, with values between 3.00 and 3.60 m. The steeper angle between the hammer and the plane causes the decrease of the values (on an average of 20 cm) with an increasing number of turns. These facts lead to a decrease in the diameter of the path.

There seems to be no influence from body-height and arm length on the diameter. This was expected. The smallest thrower in the competition, with a deficit in body-height up to 14 cm, reached the same values as the other athletes. So it appears that technique, body position and the counter movement of the body in relation to the hammer influence the dimension of the diameter of the hammer path. Figure 7 graphically describes two hammer path courses for athletes Weis (maximal diameter of the hammer path) and Litvinov (minimal diameter of the hammer path) from above. Apart from the differing diameters of the path, an incorrect turning to the left by Weis can be recognized.

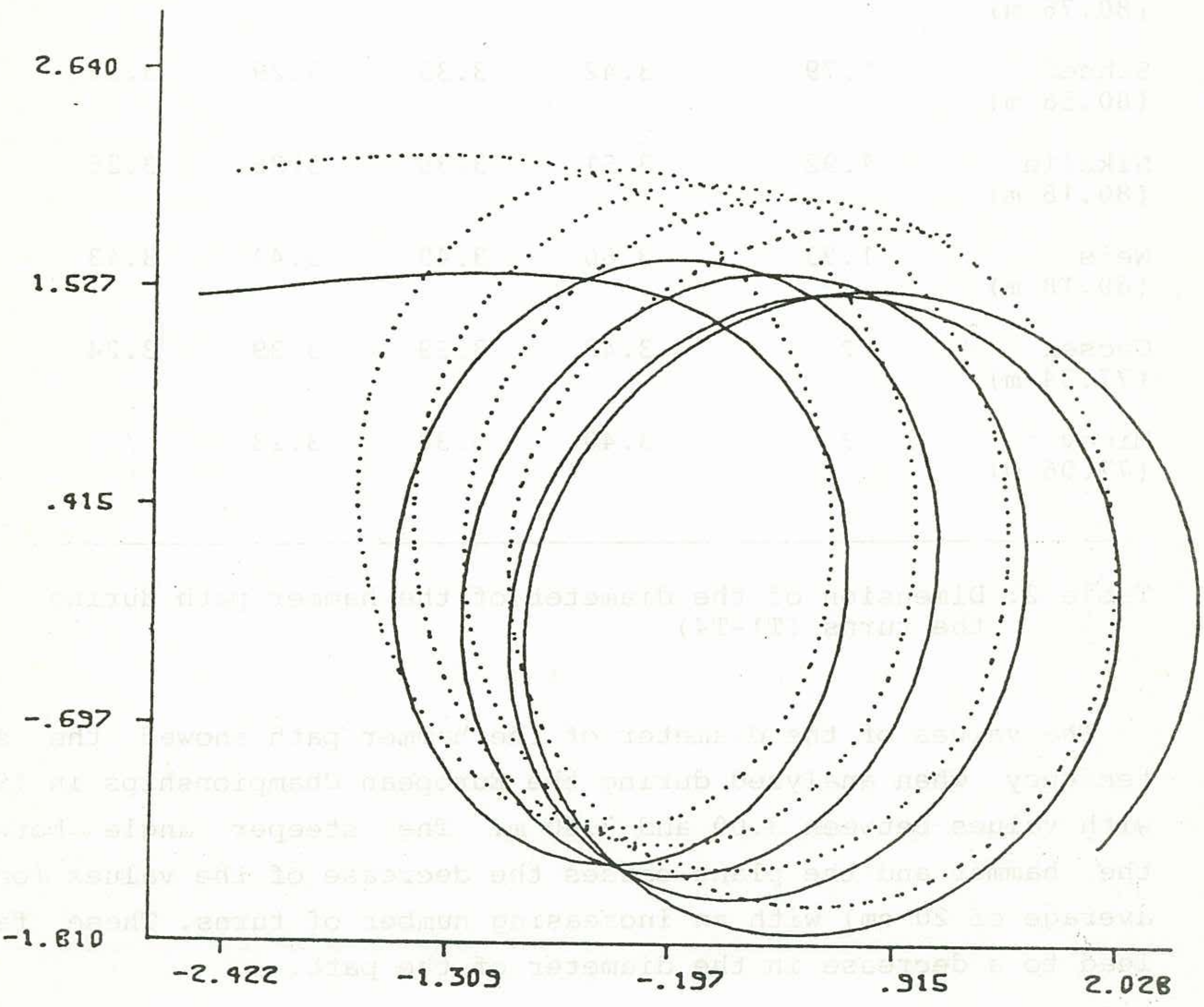

Figure 7: Hammer path of Litvinov (——) compared to Weis (...)

name	body-height	T 1		T 2		T 3		T 4		R	
(distance)	(m)	t_0	max	min	max	min	max	min	max	min	t_9
Litvinov (83.06 m)	1.80	/	1.79	0.23	2.13	0.14	2.25	0.09	2.30	0.07	1.7
Tamm (80.84 m)	1.93	0.25	2.01	0.24	2.46	0.12	2.64	/		0.07	1.9
Haber (80.76 m)	1.89	0.23	1.95	0.17	2.33	0.09	2.48	/		0.08	1.7
Sahner (80.58 m)	1.79	0.34	1.63	0.25	1.89	0.16	2.11	0.12	2.26	0.07	1.6
Nikulin (80.18 m)	1.92	0.36	1.91	0.40	2.17	0.34	2.45	0.25	2.52	0.11	1.8
Weis (80.18 m)	1.93	/	1.78	0.36	2.07	0.26	2.29	0.17	2.39	0.11	1.6
Gecsek (77.34 m)	?	0.25	1.85	0.14	2.03	0.16	2.18	0.19	2.28	0.14	1.7
Minev (77.06 m)	?	/	1.91	0.20	2.18	0.16	2.35	/		0.13	1.6

Table 3: Minimum and maximum values of the height of the hammer (m) during the turns (T1-T4) and in the instant of release

The height extremes of the hammer during the turns and release influence the dimension of the angle of release, and point out the consistency in turning technique.

A consistent development (a symmetric increase of the maximum of the hammer path and at the same time a decrease of the minimum) can be noticed for Litvinov, Sahner, Weis and Minev, while Tamm and Haber suddenly change the course of the path only at the end of the first turn. Nikulin and Gecsek however, show quite an irregular development (lowering of the hammer).
The greatest differences between minimal and maximal heights which influence the angles of delivery positively are shown by Tamm, Haber and Nikulin (see 3.3.3.).

The values of the delivery phase are also interesting. Referring to the lowering of the hammer, the four best placed athletes reach an optimal low height of 7 or 8 cm. Considering the measuring technique, scanning in the centre of the hammer head, the result is a tolerance distance of barely 2 cm to the ground! In this regard the remaining throwers, especially Gecsek, are able to improve their technique which will positively affect the angle of release.

Regarding the height of delivery, body-height must be particularly considered. Maximal heights of delivery are shown by Litvinov and Tamm, while Sahner (compared to Litvinov), Nikulin and Haber (compared to Tamm) lose about 10 cm of height.
The lowest height of delivery is shown by Weis with a loss of 24 cm compared to Tamm. A comparative analysis of the athletes from Hungary and Bulgaria is omitted because there was no information concerning body-height.

name (distance)	T 1 max	T 1 min	T 2 max	T 2 min	T 3 max	T 3 min	T 4 max	T 4 min	R max	average lowering
	difference									
Litvinov	0.83	0.72	0.81	0.69	0.83	0.68	0.85	0.68	0.88	
(83.06 m)	0.11		0.12		0.15		0.17			0.14
Tamm	0.82	0.81	0.92	0.81	0.95	0.82			1.00	
(80.84 m)	0.01		0.11		0.13		/			0.08
Haber	0.85	0.72	0.91	0.74	0.93	0.76			0.94	
(80.76 m)	0.13		0.17		0.17		/			0.16
Sahner	0.79	0.73	0.80	0.71	0.84	0.72	0.91	0.71	0.93	
(80.58 m)	0.06		0.09		0.12		0.20			0.12
Nikulin	0.93	0.87	0.95	0.89	1.02	0.83	1.04	0.81	1.03	
(80.18 m)	0.06		0.06		0.19		0.23			0.14
Weis	0.83	0.79	0.91	0.77	0.96	0.78	0.97	0.77	1.03	
(80.18 m)	0.04		0.14		0.18		0.20			0.14
Gecsek	0.81	0.73	0.78	0.69	0.84	0.70	0.90	0.69	1.00	
(77.34 m)	0.08		0.09		0.14		0.21			0.13
Minev	0.85	0.76	0.89	0.78	0.95	0.79			1.00	
(77.06 m)	0.09		0.11		0.16		/			0.12

Table 4: Height of the centre of the hip (m) and average lowering during all turns (definition see 2.1.)

A fundamental characteristic of the world's best hammer throwers is a distinct lowering of the hip. A turn as fast as possible (less than 0.45 s) seems to be possible only by a maximized lowering of the hip (with minimal values of about 0.70 m). In the present analysis, Litvinov, Sahner and Gecsek especially show this tendency. They have the best analysed timed results.

Furthermore, one can notice that especially Haber and Nikulin reach this great difference between the highest and the lowest point rather by an almost maximal extension than by an active lowering. For Tamm this extension is not noticable, and it effects a rather small difference between the highest and the lowest point of the hip. However, the extension of delivery for

Haber with only 0.94 m is very small. One can assume that this is not a proper delivery. His body height is comparable to that of Tamm, Nikulin and Weis.

Compared to the investigation during the European Championships (Stuttgart 1986), Litvinov shows an almost identical path of the hip (± 1 cm) in all turns. The values of Sedykh's world record of 86.74 m, analysed at that time, could not be reached by any athlete during the present investigation (see Figure 8).

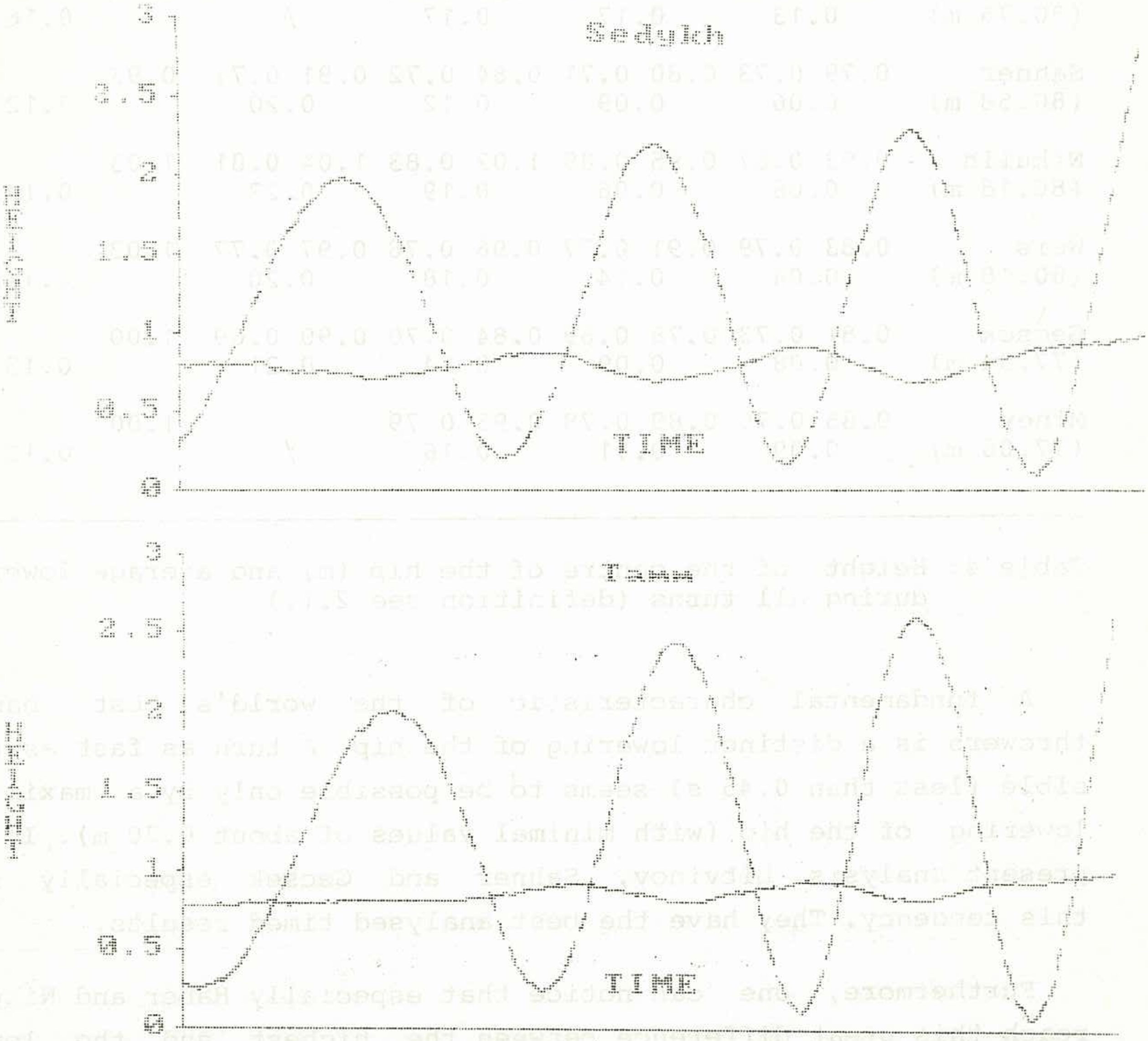

Figure 8: Description of Sedykh's lowering of the hip compared to Tamm's with the course of the height of the hammer (m)

name (distance)	T 1 max	T 2 max	T 3 max	T 4 max
Litvinov (83.06 m)	.30	.30	.28	.31
Tamm (80.34 m)	.28	.30	.30	-
Haber (80.76 m)	.28	.31	.32	-
Sahner (80.58 m)	.28	.34	.36	.36
Nikulin (80.18 m)	.28	.35	.40	.44
Weis (80.18 m)	.33	.36	.41	.40
Gecsek (77.34 m)	.27	.25	.27	.33
Minev (77.06 m)	.37	.42	.50	-

Table 5: Maximum height of feet (m) during the turns (T1-T4)

When measuring the maximum height of the feet, or more precisely the height of the ankles, the three best placed athletes show a nearly identical course of height during all turns with the lowest values (approximately 0.30 M). The other throwers achieve clearly poorer performances (with the exception of Gecsek) and at each throw they show the tendency of higher foot lifting with increasing turns. This tendency was already established in earlier investigations, and it seems to be one characteristic of the hammer throw technique which determines performance.

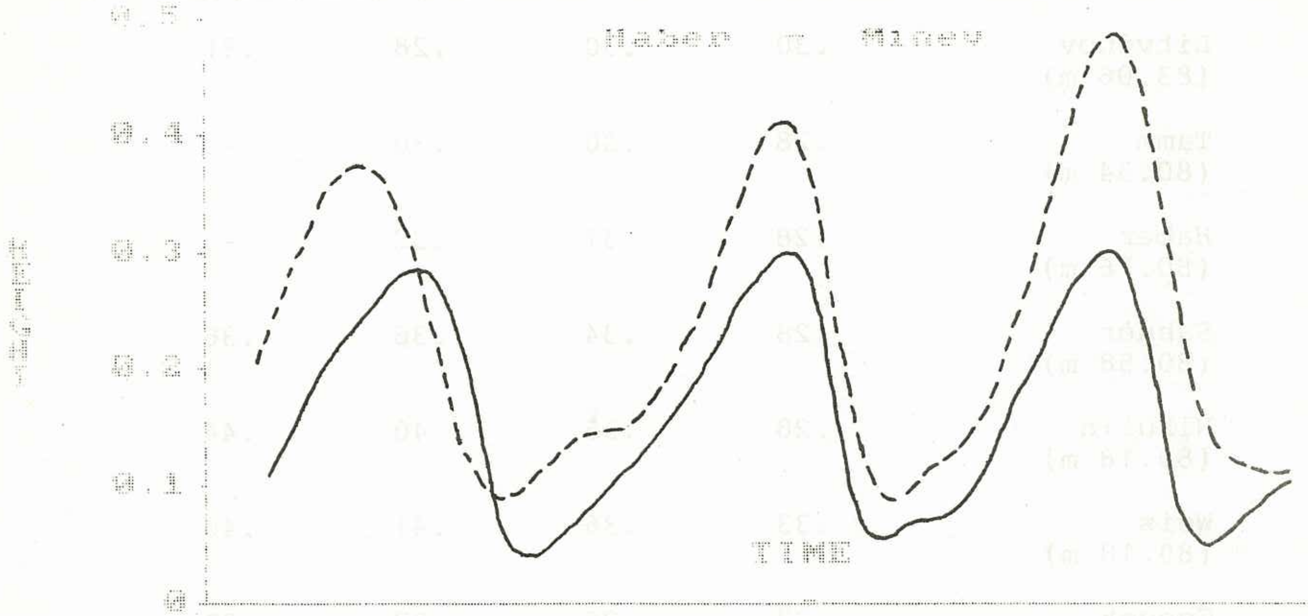

Figure 9: Comparison of maximum height of feet between Haber (——) and Minev (---)

name (distance)	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9
Litvinov (83.06 m)	46	213	52	243	75	268	86	263	116
Tamm (80.84 m)	66	224	17	255	36	281	-	-	113
Haber (80.76 m)	83	223	64	230	78	282	-	-	119
Sahner (80.58 m)	77	203	67	216	64	234	61	240	111
Nikulin (80.18 m)	65	214	69	241	44	236	37	243	106
Weis (80.18 m)	63	212	52	219	62	233	70	254	105
Gecsek (77.34 m)	79	242	92	251	82	244	68	239	114
Minev (77.06 m)	78	213	66	225	51	258	-	-	101

Table 6: Azimuth (degrees) at defined instants of time (definition see 2.1.)

The mean variation of the azimuths extends, for the takeoff of the right foot, from 17° as a minimum (Tamm) to 92° as a maximum value (Gecsek). For the touchdown a range is reached between 203° (Sahner) and up to 282° (Haber). The azimuth of release varies between 101° (Minev) and 119° (Haber).

When touching down the foot, it is striking to note the tendency of the throwers to make increasingly later contact with the ground (average about 50°) as the number of turns increase. Only Minev touches down with a constant value. During the takeoff no tendency of this kind can be observed. Litvinov and Weis demonstrate the tendency of losing contact with the ground always a little later. Sahner, Nikulin and Minev lift their foot off the ground during each turn a little earlier, whereas Tamm demonstrates extreme deviations in his three turns. Especially in his second turn with only 17°, he performs a technique which contradicts all the teaching templates.

name (distance)	mean azimuth of hammer (°) takeoff	touchdown	mean length of acceleration path (°)	(%)	azimuth of mean acceleration path (°)
Litvinov (83.06 m)	65	247	178	49	336
Tamm (80.84 m)	40	253	147	41	327
Haber (80.76 m)	75	245	190	53	340
Sahner (80.58 m)	67	223	204	57	325
Nikulin (80.18 m)	54	234	180	50	324
Weis (80.18 m)	62	230	192	53	326
Gecsek (77.34 m)	80	244	196	54	342
Minev (77.06 m)	65	232	193	54	329

Table 7: Comparison between mean azimuth and mean length of the acceleration path (see SAMOZWETOW 1974)

The mean azimuth of a hammer throw, determined by the single azimuths of four or five turns, provides information about the tendency of early or late takeoff/touchdown of the right foot on the ground. As classified by SAMOZWETOW's scheme (1974) the techniques of Litvinov, Haber, Sahner, Gecsek and Minev correspond to the group of late takeoff and early touchdown by the swinging leg. An early takeoff and an early touchdown can be noticed for Weis and Nikulin. Tamm's technique is characterized by an early takeoff and late touchdown.

In comparison to investigations during the European Championships, Litvinov differs a great deal. The two phases of motion concerning this analysis take place approximately 20° later. The length of the acceleration path has been diminished by 6°. There are no comparative results of other finalists.

The length of the acceleration path is approximately 180° or more. Sahner achieves the longest path with 204°. The technique used by Tamm presents an exception. For him only 41% of the hammer path is available. This technique was also applied by Schäfer at the European Championships in 1986. The other top athletes were always located close to the 50% level or above it. The present analysis confirms this general tendency (see figure 9).
With a mean value of 64° for the takeoff and 239° for the touchdown of the right foot, the result is an average acceleration path of 185° (51%). These findings support the current techniques used in the hammer throw shown by DAPENA in 1986.

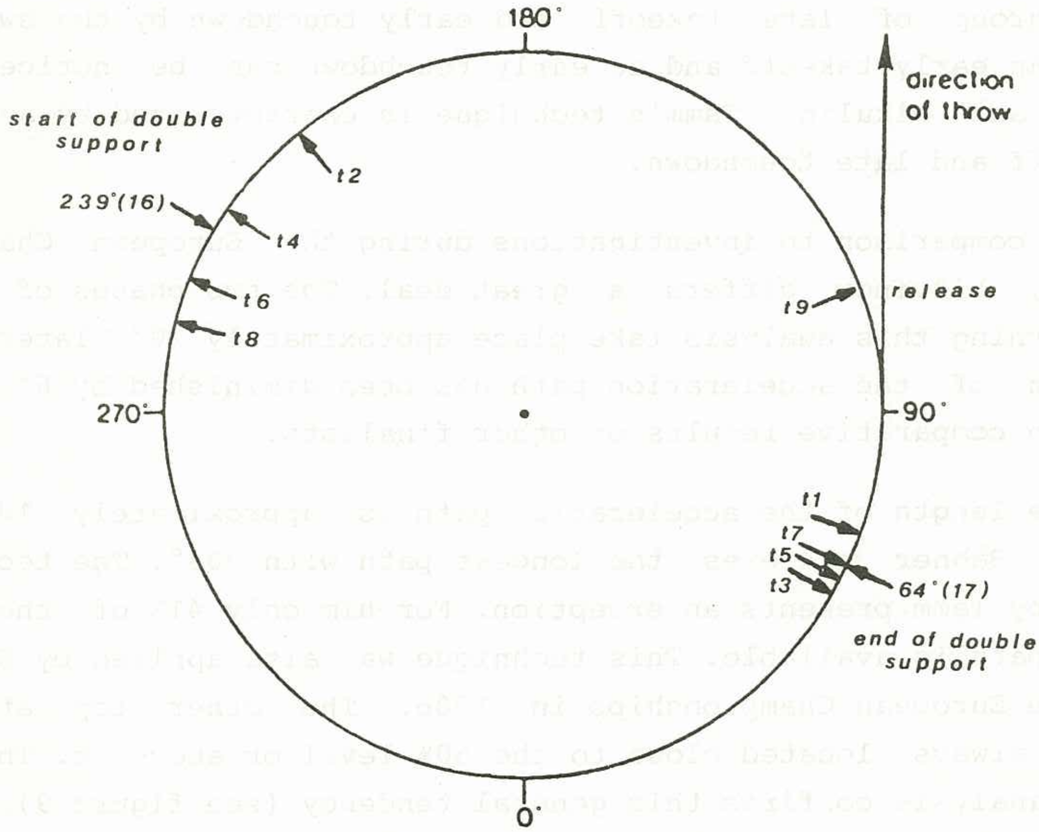

Figure 10: Mean azimuth of the total sample (8 athletes) with the listing of the standard deviation (in brackets)

Velocity

name (distance)	t_0	T 1 max	T 1 min	T 2 max	T 2 min	T 3 max	T 3 min	T 4 max	T 4 min	R t_9
Litvinov (83.06 m)	15.8	17.1	15.5	22.1	19.9	25.3	21.8	26.8	22.5	30.4
Tamm (80.84 m)	13.7	17.3	15.7	22.6	20.1	24.6	22.5	-	-	29.9
Haber (80.76 m)	15.6	18.0	16.4	23.0	20.6	26.2	22.1	-	-	30.0
Sahner (80.58 m)	13.4	14.9	13.7	19.4	18.4	23.2	21.5	25.5	23.1	30.1
Nikulin (80.18 m)	15.1	16.1	14.3	21.7	19.1	24.8	22.0	26.0	23.1	29.7
Weis (80.18 m)	15.4	16.1	15.6	21.4	20.0	24.4	22.5	26.2	23.8	29.9
Gecsek (77.34 m)	15.1	16.4	14.9	20.4	18.1	22.7	20.6	24.8	22.2	28.9
Minev (77.06 m)	15.3	17.0	16.3	21.5	20.2	24.6	22.2	-	-	29.0

Table 8: Change in velocity of the hammer (m/s) during turning (T1-T4) and at the moment of release (R)

The record of the velocity of the hammer, related to the centre of the hammer head, shows similar results for all the finalists. It is striking that Tamm and Sahner start with a rather low level (see t_0). There are also differences between athletes who perform three turns to those who prefer four turns. The first group increases the velocity from the beginning, whereas the second group (four turns) does not gain any more velocity during the first turn. To some extent the level of velocity is even lower than the values before beginning the turning phase.

Information about the total value as well as the specific components of velocity (horizontal velocity V_{xy} and vertical velocity V_z), and the resulting angle of release (α) is needed to interprete the values of velocity during the phase of delivery. The values of velocity established in this investigation are located approximately 5% above the theoretically obtained values (calculated by distance, height and angle of release).
These discrepancies are traceable to the influence of air friction and wind conditions (see 2.2.).

name	velocity of release (m/s)	V_{xy} (m/s)	V_z (m/s)	α (°)	increase of velocity as result of release (%)
Litvinov (83.06 m)	30.4	23.8	18.9	38.4	11.8
Tamm (80.84 m)	29.9	21.8	20.5	43.2	17.7
Haber (80.76 m)	30.0	22.8	19.5	40.5	12.7
Sahner (80.58 m)	30.1	23.0	19.3	40.0	15.3
Nikulin (80.18 m)	29.7	21.4	20.7	44.0	12.5
Weis (80.18 m)	29.9	22.8	19.3	40.2	12.4
Gecsek (77.34 m)	28.9	22.1	18.6	40.1	14.2
Minev (77.06 m)	29.0	22.7	18.0	38.4	15.2

Table 9: Parameters of release in the instant t_9

The information concerning the increase of velocity during the delivery is based on the maximum velocity of the turns compared to the velocity of the delivery. Inspection of these data shows Tamm's excellent delivery technique; with this he compensates for his poor turning technique. Good results are also achieved by Sahner, Gecsek and Minev, whereas the other athletes' increase in velocity as result of the delivery proves to be small.

Tamm and Nikulin compensate for the low values of velocity during the turns and the delivery phase by means of a physically favourable angle of release. Litvinov's release, which is more than 2° lower compared to his throw at the European Championships in 1986, is surprisingly flat.

Body Angles

The following table illustrates the specific maximum and minimum of twisting during the turns and the delivery. The highest amount of torsion is measured just before, or at the moment of planting the right foot. The mimimum amount of torsion was obtained between the azimuth of zero and the right foot's takeoff.

No athlete in this investigation achieved the maximum torsion values of 60-70° as they are described in the literature. The highest torsion values are earned by Minev (more than 50°) and for the West German throwers Weis and Sahner (approximately 40°). The other throwers achieve lower values. Haber and Nikulin exibit little perceptible torsion with values of about 20°.

In comparison to 1986, it is striking that Litvinov diminishes his angle of torsion by about 10°, and that he has a tendency to unwind excessively i.e. beyond the parallel of the axis.

name (distance)	T 1 max	T 1 min	T 1 difference	T 2 max	T 2 min	T 2 difference	T 3 max	T 3 min	T 3 difference	T 4 max	T 4 min	T 4 difference	R max	R min	R difference
Litvinov (83.06 m)	0	-24	24	50	-5	55	30	-6	36	30	-6	36	29	-11	40
Tamm (80.84 m)	-	2	-	36	9	25	34	7	27				34	-25	59
Haber (80.76 m)	25	-1	26	28	11	17	23	7	16				22	-17	39
Sahner (80.58 m)	17	-12	29	31	0	31	43	10	33	38	9	29	42	-16	58
Nikulin (80.18 m)	20	-4	24	36	0	36	19	9	10	23	3	20	17	-26	43
Weis (80.18 m)	-	-	-	49	3	46	56	6	50	42	7	35	40	-18	58
Gecsek (77.34 m)	5	-16	21	47	-5	52	45	2	43	34	0	34	28	-23	51
Minev (77.06 m)	-	18	-	63	15	48	51	15	36				51	3	48

Table 10: Minimum and maximum angle of torsion (in degrees) during the turns (T1-T4) and in the delivery phase (R)

The tendency of all analysed throws is thus far uniform; that is, with an increasing number of turns the amount of torsion is reduced or remains constant regarding the three best placed athletes. A striking technique of delivery is performed by Minev who cannot manage to unwind till the instant t_9.

name		T 1			T 2			T 3			T 4		R
(distance)	max		min	max		min	max		min	max		min	t_9
						difference							
Litvinov (83.06 m)	87	35	122	72	45	117	70	44	114	70	46	116	74
Tamm (80.84 m)	92	35	127	81	35	116	78	46	124				92
Haber (80.76 m)	86	32	118	91	26	117	87	38	125				82
Sahner (80.58 m)	87	33	120	91	23	114	92	23	115	95	28	123	89
Nikulin (80.18 m)	90	30	120	88	33	121	80	30	110	70	42	112	89
Weis (80.18 m)	96	23	119	97	21	118	96	25	121	92	34	126	94
Gecsek (77.34 m)	97	20	117	95	20	115	96	25	121	96	24	120	103
Minev (77.06 m)	84	40	124	89	30	119	94	25	119				97

Table 11: Minimum and maximum angle between shoulder axis and hammer wire (A2 - in degrees) during the turns (T1-T4) and at the moment of release (R)

There are significant differences between the Soviet throwers and the other athletes concerning the angle between the shoulder axis and the hammer wire (A2). Regarding the athletes from the USSR, one can recognize a clear 'leading' of the hammer (A2<90°) with values of 70°. This tendency was also analysed for Sedykh in 1986. All of the other throwers vary between 90° and 120°. The extreme values of up to 180°, which were observed in earlier investigations, do not appear in these studies of top athletes. The apparent variations of the Soviet throwers of nearly 40° are also clearly above those of the remaining throwers who obtain values of less than 30°.

In the instant of release Haber and especially Litvinov achieve the lowest values, whereas Gecsek and Minev, who both throw 77 m, 'trail' the hammer clearly. As a result they do not perform a favourable delivery technique.

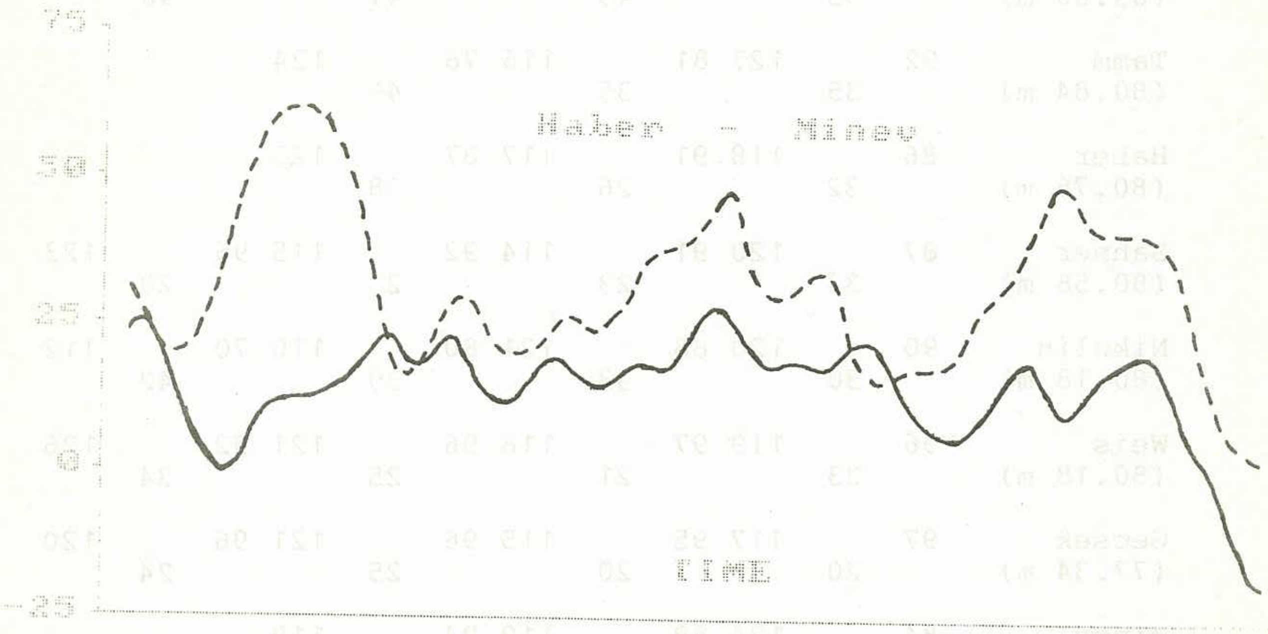

Figure 11: Comparison between Haber (——) and Minev (---)

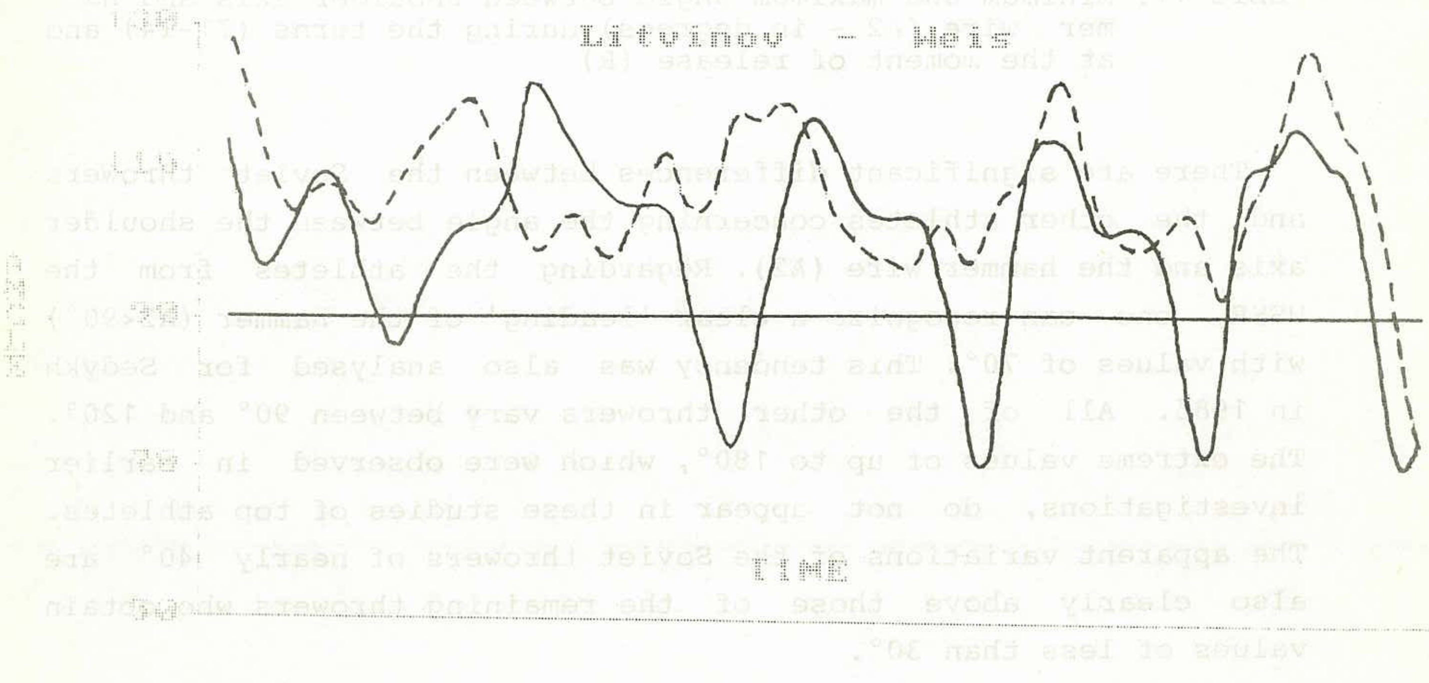

Figure 12: Comparison between Litvinov (——) and Weis (---)

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