AN ABSTRACT OF THE THESIS OF

EVELYN JEAN ZUMWALT for the degree of MASTER OF SCIENCE in Education presented on September 11, 1978.

Title: CINEMATOGRAPHIC ANALYSIS OF TECHNIQUE IN THE WOMEN'S 100 METER HURDLES Redacted for privacy

Abstract Approved: ______________________________
Dr. Donald E. Campbell

A cinematographic analysis of hurdling technique was completed using six high school women in the 100 meter hurdle event as subjects. The study was descriptive in design, intending to make objective comparisons of selected elements of the hurdling action. Sixteen hypotheses were developed and tested, in an effort to describe relationships between variables of the hurdling action.

Five correlation coefficients were significant at the .05 level, four of which confirmed relationships reported in the literature.

The data presented in this study confirmed two relationships which were not in agreement with relationships expressed in the literature. Lack of significance between leg length and take-off distance was contradictory to the relationship of those two variables as reported in the literature. The significant, negative correlation coefficient obtained between the smallest trunk to thigh angle of the subject, and the vertical distance which center of gravity was above the hurdle at clearance, was also in

disagreement with the literature.

Close examination of the data revealed that timing the execution of movements based upon mechanical principles is as critical as the employment of those principles.

The complex and interrelated nature of elements of the hurdling action, made evident through cinematographic techniques, points toward future study in the area of manipulation of variables, and the effects of those manipulations on the performance of the hurdler.

Cinematographic Analysis of Technique in the Women's 100 Meter Hurdles

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CHAPTER I

INTRODUCTION

Many conflicting theories and opinions appear in the literature related to techniques of hurdling. With the inefficient and primarily subjective methods of skill analysis that were available in the past, this is not surprising. However, with improved techniques in the area of cinematographic study, an objective method of identifying performance variables of sports skills through qualitative analysis now exists. Though cinematographic study in itself does not imply immediate answers for improvement of an athlete's performance, cinematography does allow for more objective comparisons of performances. These comparisons may perhaps lead to identification of those variables in technique, which characterize a successful performance of a particular skill.

Even with the improved methods of cinematographic study available, little research has been made of hurdlers. Research of hurdlers using female subjects is even more limited. The studies which have been carried out were descriptive in design. No studies attempting to assess the effects of manipulating variables of the hurdling action have been found.

Significance of the Study

Through the use of cinematographic techniques, objective information obtained on the subjects will be used for comparisons of various elements of the hurdling action. On the basis of the data collected, this study will attempt to verify relationships between elements of hurdling, as reported in the literature.

Methodology

Sixteen millimeter film was taken of six semi-finalists in the 100 meter hurdle event during the 1978 Oregon State AAA Girls Track and Field Championships. Tracings of each subject were made from the film at each specified event in the hurdling action. The tracings and film were then taken to the Data Analysis Laboratory at the University of Arizona. There, with the aid of an Image Motion Analyzer and Hewlett-Packard digitizer and computer, various measurements were taken from the tracings and the film. These measurements were the basis for comparison and computation of various correlations.

Delimitations

1. Filming was limited to the lateral view as filmed from the infield side of the track oval.

2. Filming was limited to six subjects who were clearly visible throughout clearance of the hurdle.

3. Filming was limited to the eighth hurdle.

4. Filming was limited to one trial for each subject.

Limitations

1. Not all subjects hurdled with their trail knee closest to the camera, therefore making it more difficult to determine when the trail knee reached the hurdle — identification of event e.

2. Because of the variation among subjects, there exist limitations in the generalizations that can be made beyond this group of subjects.

3. Limitations exist in the generalizations that can be made to other hurdles in the 100 meter hurdle event.

4. Limitations in the generalizations that can be made to additional trials of each subject exist.

5. Limitations to the techniques of cinematographic analysis exist.

Assumptions

1. It is assumed that for each subject, the trial filmed was representative of that subject's performance.

Statement of the Problem

The purpose of this study was to describe and compare selected elements of hurdling technique as ascertained through cinematographic procedures. Correlations were calculated in an effort to verify relationships between variables of the hurdling action, as reported in the literature.

This study will focus on the following aspects of the hurdling action: 1) take-off, 2) lead leg action during clearance, 3) trunk action during clearance, and 4) touchdown. The following events will be critical in analyzing the hurdling action: 1) touchdown of last stride before take-off, 2) mid-support of last stride before take-off, 3) take-off, 4) lead heel reaches the hurdle, 5) trail knee reaches the hurdle, 6) touchdown of lead foot, and 7) touchdown of trail foot.

Null hypotheses were developed and tested. Hypotheses appear in Table I. The level chosen for rejection of the hypotheses was .05.

Definition of Terms

Angle of Projection

Determined by the vertical and horizontal components, it is the angle at which the hurdler is projected into the air at take-off.

Angle of Touchdown (Touchdown Angle)

The angle formed by a line through the center of gravity and the supporting toe at tuchdown with a vertical axis through the supporting toe.

Angle of Trunk at Touchdown

The angle of the segment line of the trunk with the vertical axis at the moment of touchdown.

Clearance Stride

The total horizontal distance between take-off and touchdown.

Table I. Hypotheses Tested

$H_{o_{1-16}}$: No significant relationship exists between:

H_o	Variable	and	Variable
1	Clearance Time		Leg Length
2	Clearance Time		Height
3	Angle of Projection		Leg Length
4	Angle of Projection		Clearance Time
5	Vertical Velocity		Clearance Time
6	Take-off Angle		Horizontal Velocity
7	Horizontal Distance from Center of Gravity to Toe at Take-off		Horizontal Velocity
8	Initial Velocity		Take-off Distance
9	Leg Length		Take-off Distance
10	Lead Knee Angle at Take-off		Clearance Time
11	Smallest Trunk to Thigh Angle		Vertical Velocity
12	Smallest Trunk to Thigh Angle		Height of the Center of Gravity Above Hurdle
13	Angle of Trunk at Touchdown		Horizontal Distance from Center of Gravity to Point of Touchdown
14	Touchdown Angle		Take-off Angle
15	Angle of Projection		Clearance Stride
16	Initial Velocity		Clearance Stride

Clearance Time

The amount of time between take-off and touchdown.

Event

A designated point during the hurdling action that is defined by position of body parts relative to the track surface or hurdle.

High Point

This refers to the highest point of the trajectory of the center of gravity from take-off to touchdown.

Initial Velocity

The speed (feet/second) at which the hurdler is moving when projected into the air at take-off. It is made up of the vertical and horizontal velocity components.

Mid-support

During the support phase of a stride, mid-support is reached when the hip joint (greater trochanter of the femur) is directly over the heel of the supporting leg.

Smallest Trunk to Thigh Angle

The smallest angle formed by segment lines through the trunk and lead leg thigh during the hurdling action.

Take-off

Moment at which take-off leg breaks contact with the ground.

Take-off Angle

The angle formed by a line through the center of gravity and the supporting toe with a vertical axis through the supporting toe at take-off.

Take-off Distance

The horizontal distance between the supporting toe at take-off and the hurdle.

Touchdown

Moment at which lead foot contacts the ground.

Touchdown Distance

The horizontal distance between the supporting toe at touchdown and the hurdle.

CHAPTER II

REVIEW OF LITERATURE

Most information about hurdling technique appears in periodical articles or books on coaching track and field. Much less information appears in professional literature dealing with mechanics and the mechanical aspects of sport; and even less appears in research studies. Particularly in the categories of mechanics literature and research studies, the focus is on the men's high hurdle event. Very little research has been done with female subjects.

Many authors emphasize certain variables of the take-off, though not always including explanations or principles underlying the execution of those variables. The three variables of take-off most often emphasized are lead arm, lead leg and trunk action. Most authors advocate emphasizing lead knee or thigh lift at take-off (4, 8, 9, 11, 12, 16, 17, 27, 28, 30, 33, 34). Bowerman (4) and Singh (30) report the lead arm should be moved forward and upward at take-off; while Ross (28) contends that both arms should be lifted forward and upward. Ross (28) indicates that most hurdlers initially tend toward a double arm thrust. Most authors suggest a slight amount of trunk lean, body pitch or pike at take-off (9, 12, 28, 30). Van Patot (33) cautions against starting the forward lean too early, claiming that as a fault in hurdle technique. However, Foreman and Husted (12) emphasize that piking forward at take-off, when still in contact with the ground, facilitates lead leg lift and negates tendencies toward rearward rotation away from the hurdle. Riddle (27) disagrees by saying the trunk should be upright. Singh (30), Hay (16) and Dyson (9) report that the last stride before take-off is slightly shorter, reducing the duration of the supporting phase which results in forward rotation and consequently a more horizontally directed drive. Several authors comment on take-off distance (9, 16, 27). Hay (16) summarizes the factors affecting this distance. Those factors are height of the hurdler, leg length of the hurdler, velocity and technique, or the speed of the lead leg. All things being equal, the faster a hurdler's lead leg action, the closer the hurdler can afford to be to the hurdle at take-off (16). Similarly, the higher the approach velocity, the further away from the hurdle the take-off must be made (27).

Ross (28) has offered two checkpoints for assessing a hurdler's efficiency at take-off. The lead leg thigh and sole of the foot should be parallel to the ground. The head, lead knee and lead toe should all be in perfect vertical alignment.

Ecker (11) specifies the critical aspects of take-off. The angle of projection of the center of gravity is determined by the horizontal and vertical velocity components that must be combined to get the hurdler over the hurdle. The less vertical velocity required, the less reduction of horizontal velocity, the lower the take-off angle and the less time spent in the air. Therefore, the critical aspects are the ways in which the required vertical velocity can be reduced. Ecker (11) reports two ways to reduce the vertical velocity required at take-off. The first is to improve efficiency of hurdle clearance by lowering the center of gravity within the body. Secondly, raising the center of gravity at take-off will reduce the required vertical velocity.

Several theories prevail regarding lead leg action over the hurdle. All authors agree that the knee should lead the action when approaching the hurdle. However, disagreement exists as to when the lower leg should begin to come forward. Singh (30) reports that the lower leg should not cross the vertical plane until take-off is complete. Bowerman (4) advocates delaying the forward motion of the lower leg until the thigh has reached its peak angle. Dyson (9) points out that flexion at the knee and ankle of the lead leg early in the action reduces the moment of inertia facilitating a faster leg pick-up. Ross's (28) checkpoint indicates a 90° angle at the knee of the lead leg at take-off. Most authors agree that the lower leg should not come ahead of a vertical plane at the lead knee prior to take-off.

Most of the disagreement over the lead leg comes when discussing its position at clearance. Bowerman (4), Singh (30), Doherty (8) and Hay (16) agree that the lead leg should be slightly flexed.

Reasons for maintaining flexion of the lead knee include that a straight lead leg adds to clearance time because it cannot be brought back into sprinting position as quickly as a flexed lead leg; and that a locked knee checks body lean (4, 8, 16, 30). Foreman and Husted (12) contend that the knee should not be locked. Ross (28) claims the lead leg should be straight because it helps bring the athlete to the top of the hurdle sooner, thus allowing the hurdler to begin the descending action earlier. Wakefield, Harkins and Cooper (34) also claim the lead leg should be straight.

Van Patot (33) discusses the whip style lead leg action of Annelie Ehrhardt. The whip style lead leg action is a rapid whipping or kicking action which straightens the leg momentarily. Some believe that the sharp stretching of the muscles at the back of the thigh provokes a reflexive contraction of these same muscles which brings the lead leg more rapidly over the hurdle and down again.

Riddle (27) in her literature review section, reports that the question of straight versus flexed lead leg is decided by height of the hurdler. Shorter hurdlers must use a straight lead leg whereas taller hurdlers may use a flexed one. In the concluding section of her paper, Riddle (27) reports that a positive correlation exists between leg length and flexion or extension of the lead leg. Riddle (27) does not give a coefficient for the correlation, nor does she report whether or not the correlation is significant. The shorter legged subjects hurdled with a flexed lead leg and the longer legged subjects hurdled with the lead leg extended (27).

All authors agree that trunk lean during flight is essential. Van Patot (33) summarizes the positive and negative effects of trunk lean. While having little forward body lean causes less deviation from normal sprinting technique and prevents unnecessary movements, having a greater degree of forward trunk lean provides several advantages. Trunk lean helps bring the center of gravity to a lower position relative to body parts when in flight, meaning the drive can be more horizontal. Trunk lean aids the swing of the lead leg by either acting or reacting as an opposing force. A smaller angle of trunk rotation occurs when pulling the trail leg through as a result of trunk lean. Forward lean of the trunk allows for more resulting upper trunk motion during the landing phase, therefore aiding in downward action of the lead leg. Hay (16) contends that trunk lean reduces the amount of surface frontal area which can be acted upon by air resistance.

Most authors agree that the lead leg should be snapped down, although Ecker (11) reports that the concentration should be on snapping the trunk up to force the lead leg down quickly. Those who emphasize cutting down the lead leg note that the trunk rises in reaction and is erect at touchdown (13, 16, 27). Several key variables are related to touchdown. Action/reaction of the trunk and lead leg have an important function in getting the lead leg to the ground quickly. Position of the center of gravity relative to the point of touchdown is another critical variable of touchdown. The direction and magnitude of acceleration of the lower leg and foot are also of great importance at touchdown. Ecker (11) emphasizes action/reaction of the trunk and lead leg. Those authors who suggest having trunk lean at touchdown to improve the position of the center of gravity relative to the point of touchdown, seem to be placing most emphasis on touching down as nearly below the center of gravity as possible (9, 12, 30, 33). Foreman and Husted (12) also comment that the opening up or extending of the body as the lead leg is brought to the ground produces a breaking rather than a driving action and reduces the length of the first stride out of the hurdle. Maintaining some forward inclination is desirable. Considerable disagreement exists regarding the position of touchdown relative to the center of gravity. Hay (16), van Patot (33) and Ganslen (13) assert touchdown should be directly below the center of gravity. Singh (30), Sipes (31) and Riddle (27) claim it should be under or behind the center of gravity. Dyson (9) maintains touchdown is slightly ahead of the center of gravity.

The specific elements of hurdling technique this study is concerned with are the take-off, lead leg action during clearance, position of the trunk during clearance and touchdown of the lead leg. Considerable disagreement prevails in the literature relating to these various elements of hurdling. This disagreement is not unreasonable considering the methods by which much of the information was determined. Much of what is written has been subjectively concluded through viewing slow motion film or still pictures which have sometimes been taken at angles which distort the event. In some cases, even film has not been used to verify conclusions about performances.

Techniques of cinematography have emerged in an effort to increase understanding of performance in movement skills. Cinematographic techniques provide a medium through which performances may be precisely described and objectively compared. Minimizing error, as well as accounting for error, and improvement of analytic techniques have been of particular concern in the development of cinematographic study (5, 15, 18, 20, 21, 23, 32). Use of cinematographic techniques in understanding sports skills has usually involved qualitative analysis of one highly skilled performer. Very few studies have attempted to assess the effects of manipulation of variables within a sport skill.

The use of cinematographic techniques has been successful in analyzing various sport skills (1, 2, 3, 6, 7, 14, 19, 24, 25, 26, 29, 35). Cinematographic analysis aids in verifying technique faults and providing a basis for communication between investigator, coach and athlete (22). Cinematography may assist in identification of deficiencies in technique, as well as making possible the construction of profiles of successful performances in a specific skill (22).

CHAPTER III

METHODOLOGY

With the assistance of the Oregon State University Photo Service, 16 millimeter film was taken at the 1978 Oregon State AAA Girls Track and Field Championships. Six performers in the semifinal heats of the 100 meter hurdle event, were chosen as subjects for this study. Tracings of each subject were made from the film. Tracings and film were analyzed at the Data Analysis Laboratory on the University of Arizona campus in Tucson, Arizona. Data obtained were used for objective comparisons of specific elements of hurdle technique. As presented in the literature, considerable disagreement exists regarding the relationship of specific elements of hurdle technique. Coefficients of correlation were computed in an effort to test statistically, the described relationships between variables.

Pilot Study

A pilot study was conducted during the summer of 1977. Four trials of one subject were filmed from lateral and front views. The Oregon State University Photo Service assisted in the filming. Film was analyzed at the Data Analysis Laboratory on the University of Arizona campus. Resulting from this analysis, were the final methodology and aspects of the hurdling action to be studied.

Subjects

Six semi-finalists in the 100 meter hurdles at the 1978 Oregon State AAA Girls Track and Field Championships who were clearly visible throughout hurdle clearance were chosen as subjects for this study. The subjects were first, fourth and seventh place finishers in heat one, and first, third and sixth place finishers in heat two. The subjects will be referred to as S_1, S_2, S_3, S_4, S_5 and S_6 throughout the study.

Each subject was visited at her home where written permission of the subject and her parents was obtained. Permission form appears in Appendix A. Each subject's data were briefly discussed with her. Height and leg length of the subject were measured. An anthropometer was used to assess leg length. Leg length was measured from the greater trochanter of the femur to the floor as the subject stood in bare feet. The right leg only was measured. Years of hurdling experience were assessed.

Filming

Permission was obtained from the Oregon Scholastic Activities Association prior to the 1978 Oregon State AAA Girls Track and Field Championships, to film the semi-final heats of the 100 meter hurdles. Permission form appears in Appendix B. Semi-final heats rather than the final heat were filmed because a better spread between performers was expected. The meet director was notified in advance and field preparations for filming discussed.

Subjects were filmed from the lateral view only with the camera positioned perpendicular to the principal plane of motion at the eighth hurdle of the 100 meter hurdle event. The expected spread of the performers at that point in the event was the primary basis for choosing the eighth hurdle. Also considered was the desire to avoid interference with the finish line area. Hurdles were 33 inches in height. The camera was located to the inside of the track oval (infield), with lane one being closest to the camera and lane eight farthest from the camera. Horizontal distance of the camera lens from outside edge of lane one was 46 feet 3 3/4 inches. The vertical distance of point of focus above the hurdle was 15 inches or 48 inches above the surface of the track.

Instrumentation

A Red Lake Low Cam camera was used with a tripod and a level to insure that the camera was not setting at an angle. An angenoux lens with a 12 to 120 millimeter zoom ratio was used with the zoom set at 15 millimeters. The lens speed was f 2.8, which is the maximum aperture of the lens. Kodak 7241 color film was used, with an ASA of 160. Filming was done at f/.8. Filming speed was 64 frames per second with a reported error of ± .02 or one frame per second, whichever is greater.

Prior to filming the hurdle heats, a board with a known length of three feet was positioned perpendicular to the camera lens, in the center of the lane, and filmed in each lane of the track.

Conditions for filming were available light, overcast skies and rain.

Filming and processing of the film were done by the Oregon State University Photo Service, a section of the Oregon State University Physics Department. The investigator supervised the filming.

Film Analysis

Every fifth frame between frame numbers, appearing on the edge of the film, was penetrated with a pin so that a scratch line was left in the margin of that particular frame. These marks facilitated repeatedly locating events of the hurdling action for the various subjects.

A Bell and Howell 16 millimeter Film Projection Analyzer was used to project the film on a white wall. Clearprint technical paper with a ten squares to the inch grid was attached to the wall. Composite tracings of each subject were made at designated events: 1) touchdown of the last stride before take-off; 2) mid-support of last stride before take-off (i.e. when hip is directly over heel of support leg); 3) take-off; 4) lead heel reaches hurdle; 5) trail knee reaches hurdle; 6) touchdown of lead foot; 7) touchdown of trail foot. Tracings of all subjects appear in Appendix C.

The first subject traced was projected at a ratio of 85/50ths of an inch equal to three feet. Thereafter, the film analyzer was adjusted in distance from the wall so as to project all subjects at a similar ratio. The three foot yardstick in the film was used as a basis for adjustment.

Analysis of the film and tracings took place at the Data Analysis Laboratory on the University of Arizona campus in Tucson, Arizona. An Image Motion Analyzer with a magnetic platen and x and y coordinates, as well as Hewlett-Packard digitizer, calculator and computer were used in collecting data from the film and tracings.

In order to assure that standardization of distances was consistent when both the yardstick was filmed and the hurdlers were filmed, the distance conversion factor used in later calculations was figured as follows. A ratio was set up between the yardstick and a railing visible in the background of filming both the yardstick and the hurdlers.

a = yardstick (in inches) as originally filmed in lane ____

b = what yardstick would have been (in inches) if it had been filmed in lane ____ during hurdling

c = distance (in inches) between railings in original yardstick filming

d = distance (in inches) between railings during filming of hurdling

$$\frac{a}{b} = \frac{c}{d}$$

Each distance was digitized a minimum of three times with no variation occurring greater than 0.02. The calculations for lane two, heat one are shown here. The same calculations were done for all lanes and repeated for heat two. Measures between heats were found to be identical.

$$\frac{2.55}{b} = \frac{4.10}{1.68}$$

$$\frac{2.55}{b} = 2.43$$

$$b = \frac{2.55}{2.43}$$

$$b = 1.05$$

The distance conversion factor is equal to the known length (three feet) divided by the distance of that length as it appears in film (1.05 inches). Therefore, one inch on film is equal to 2.86 feet, real distance.

$$\text{conversion factor (lane two)} = \frac{3}{1.05} = 2.86$$

Conversion factors for all lanes used in this study appear in Appendix D.

During the interval of flight over the hurdle, center of gravity coordinates were collected at the first frame following take-off plus every second frame for the next ten consecutive frames. These measures were made directly from film and the coordinates used in the projection program. Each center of gravity measure was repeated three times with no variation greater than 0.02. Documentation of the center of gravity program is in

Appendix E.

Using the x coordinate for the center of gravity of the hurdler at take-off, and the distance conversion factor for the lane of each subject, real values were figured for take-off distance and horizontal distance between the center of gravity and the supporting toe at take-off. These values appear in Table II.

The projection program was used to obtain the horizontal, vertical and initial velocities of the subjects at take-off, as well as the angle of projection. Those values appear in Table II. Calculation of information prior to operation of projection program, including calculation of h factor and the center of gravity coordinates used in the projection program, appear in Appendix F. Print-outs of projection program for all subjects appear in Appendix G. Documentation for the projection program appears in Appendix H.

The center of gravity program was used in locating the centers of gravity on the tracings. The following measures were then made from the tracings: 1) take-off angle; 2) touchdown angle; 3) horizontal distance of center of gravity from supporting toe at touchdown; 4) distance of touchdown from hurdle; 5) height of center of gravity above hurdle at crossing. Examples of the measurement of take-off angle, touchdown angle and height of center of gravity above hurdle are shown in Figures 1, 2 and 3. Values for take-off angle, touchdown angle and height of center of gravity above hurdle, for all subjects appear in Table II.

Table II. Physical Characteristics of Subjects and Elements of the Hurdling Action

Subject	Height (in.)	Leg Length (in.)	Experience (yr.)	100 Meter Hurdle Time[a] (sec.)	Angle of Projection (°)	Horizontal Velocity (ft./sec.)	Vertical Velocity (ft./sec.)	Initial Velocity (ft./sec.)	Clearance Time (sec.)	Take-off Distance (ft.)	Horiz. Dist. C. G. to Toe at Take-off (ft.)	Take-off Angle (°)
1	64.5	32.4	4.0	14.9	16.33	22.28	6.53	23.22	.34	5.97	1.00	17
2	66.5	33.2	4.0	15.0	16.01	21.67	6.22	22.55	.37	6.47	1.33	18
3	66.0	33.7	1.5	15.7	15.05	20.68	5.56	21.41	.37	6.48	1.77	25
4	65.8	32.6	4.0	15.8	17.42	21.14	6.63	22.16	.39	6.98	1.20	20
5	65.5	33.2	5.0	16.1	15.57	18.74	5.22	19.46	.37	5.38	1.12	17
6	63.0	32.3	4.0	16.3	22.23	17.04	6.96	18.41	.41	5.32	.82	15

[a] Unofficial times are given for S_5 and S_6

Table II. (continued)

Subject	Touchdown Angle (°)	Touchdown Distance (ft.)	Horiz. Dist. C. G. to Toe at Touchdown (in.)	Clearance Stride (ft.)	Lead Knee Angle at Take-off (°)	Smallest Trunk to Thigh Angle (°)	Time to High Point (sec.)	Horiz. Dist. to High Point (ft.)	Horiz. Dist. High Point to Hurdle (ft.)	Height of C. G. Above Hurdle (in.)	Angle of Trunk at Touchdown (°)
1	14	3.42	9.44	9.39	57	38	.20	4.52	1.45	13.36	29
2	9	3.82	6.55	10.29	84	36	.19	4.19	2.28	16.01	40
3	14	3.55	9.64	10.03	72	38	.17	3.57	2.91	16.58	38
4	12	3.15	8.93	10.13	80	51	.21	4.36	2.62	11.48	33
5	13	3.50	8.95	8.88	91	37	.16	3.04	2.34	12.36	38
6	10	3.29	6.84	8.61	48	31	.22	3.69	1.63	19.25	35

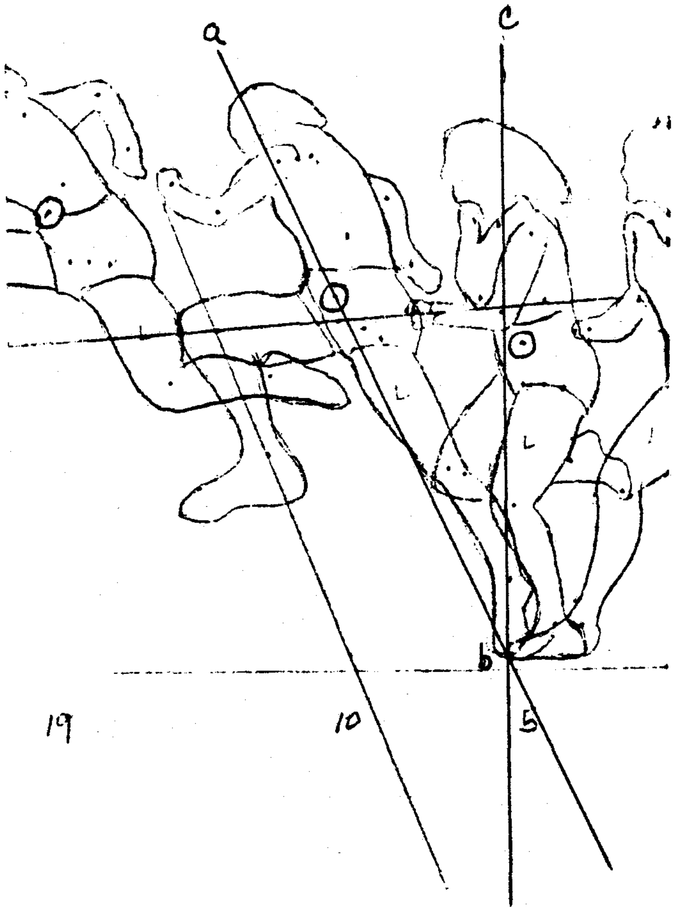


Figure 1. Take-off Angle — ∠ abc

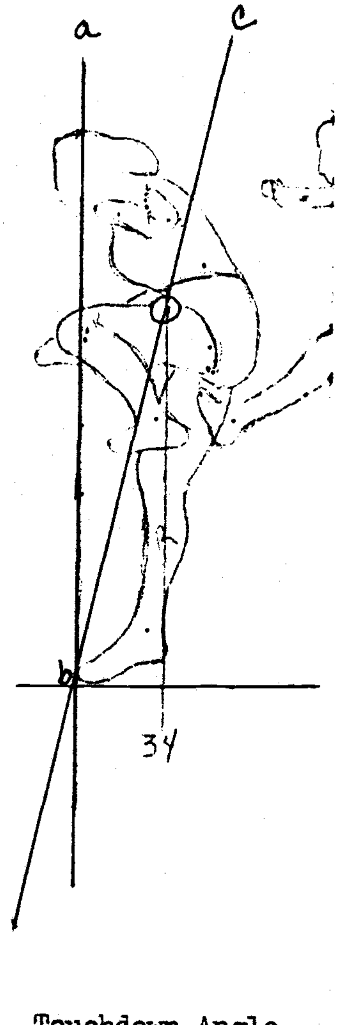


Figure 2. Touchdown Angle — ∠ abc

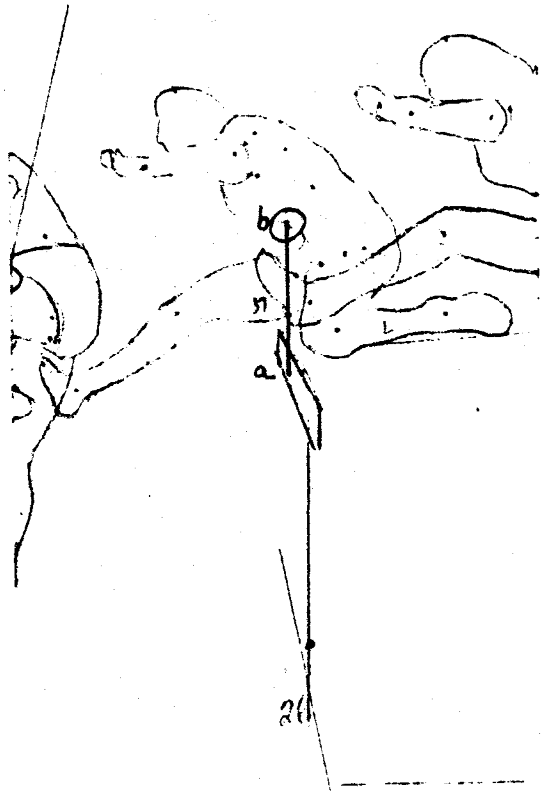


Figure 3. Height of Center of Gravity Above Hurdle — $\overline{ab}$

A ratio was set up to determine the distance conversion factors for the tracings.

a = touchdown distance as measured on tracing (____/50ths inch)

b = real touchdown distance (feet)

c = take-off distance as measured on tracing (____/50ths inch)

d = real take-off distance (feet)

$\frac{a}{b} = \frac{c}{d}$ Solve for $b = \frac{ad}{c}$

The same procedure was followed to assess horizontal distance of touchdown from hurdle, horizontal distance of center of gravity from supporting toe at touchdown and height of center of gravity above hurdle. Calculations appear in Appendix I. Values for all subjects appear in Table II.

A large image Recordak in the laboratory at Tucson was used to obtain segmental line drawings. Clearprint technical paper with a ten squares to the inch gid was attached to the projection surface of the Recordak. Horizontal and vertical lines on the paper were aligned with horizontal and vertical references in the film. Segment lines were drawn in for the trunk and lead leg thigh of each subject at take-off and in each frame following, until performer's trail knee reached the hurdle. Segment lines were also drawn in at the frame of touchdown. These segment line drawings appear in Appendix J. It was not deemed necessary to measure the magnitude of error in placing the segment lines because of the way in which the data were used.

The Hewlett-Packard computer and digitizer, utilizing the angle-finding program, were used to measure the trunk to horizontal and thigh to horizontal angles. The values for the trunk to horizontal and thigh to horizontal angles were combined to determine the trunk to thigh angle. This angle was graphed for each subject and five points noted on the graph: 1) high point of center of gravity; 2) trail knee at hurdle — subject considered above hurdle; 3) point at which smallest trunk to horizontal angle occurred; 4) point at which smallest thigh to horizontal angle occurred; 5) point at which smallest trunk to thigh angle occurred. Figure 4 depicts an example of a trunk to thigh angle graph. The smallest trunk to thigh angle for each subject appears in Table II. All trunk and thigh angular measures for all subjects appear in Appendix K.

Segment lines for the lead leg thigh and lower leg were drawn in, and the angle at the lead knee measured with a protractor. An example of the knee angle measure appears in Figure 5. Values for the knee angles of all subjects appear in Table II.

Means, standard deviations and ranges for all variables in Table II appear in Table III.

Clearance time was calculated for all subjects by multiplying the number of frames between take-off and touchdown by the frame interval of .0156 seconds.

Real and relative times for the occurrence of each specified

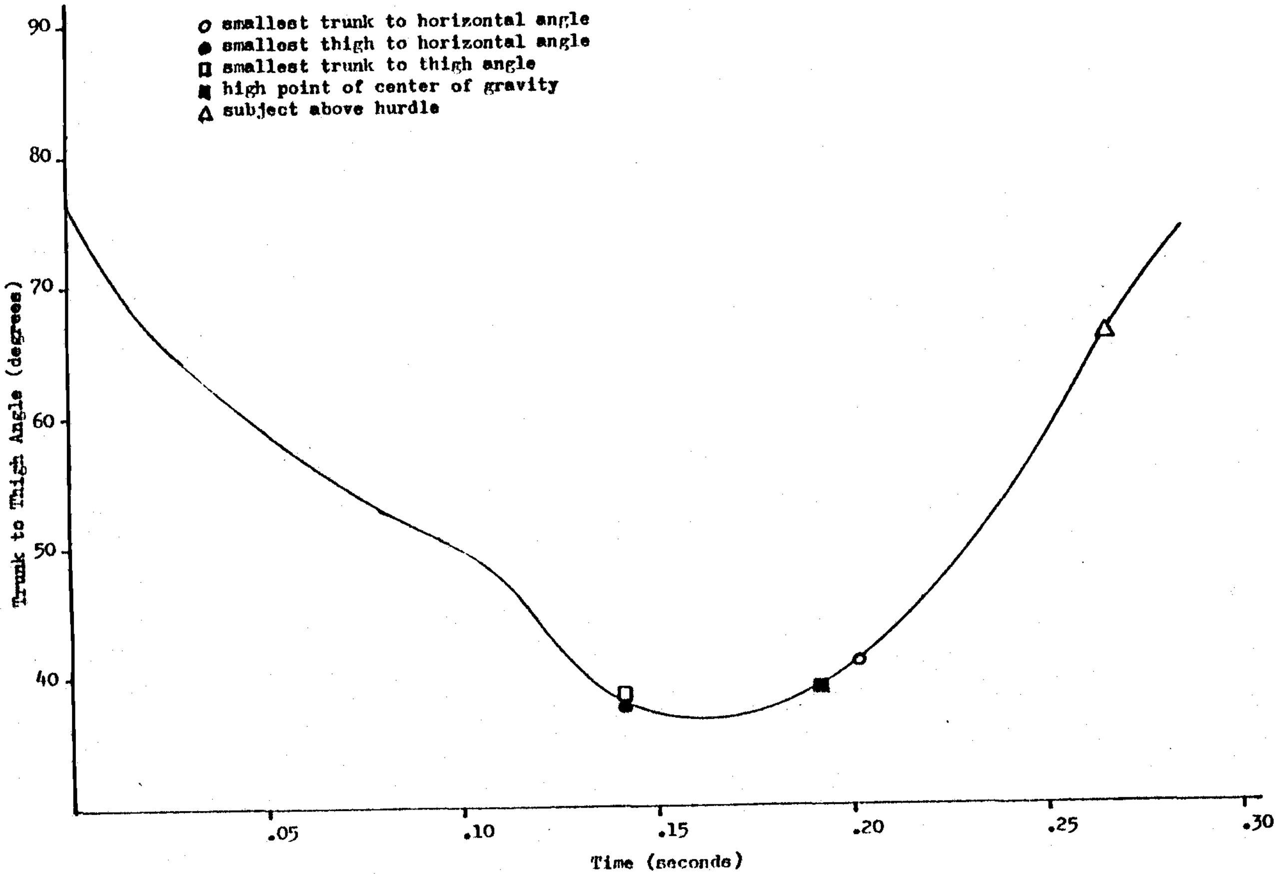


Figure 4. Trunk to Thigh Angle Graph

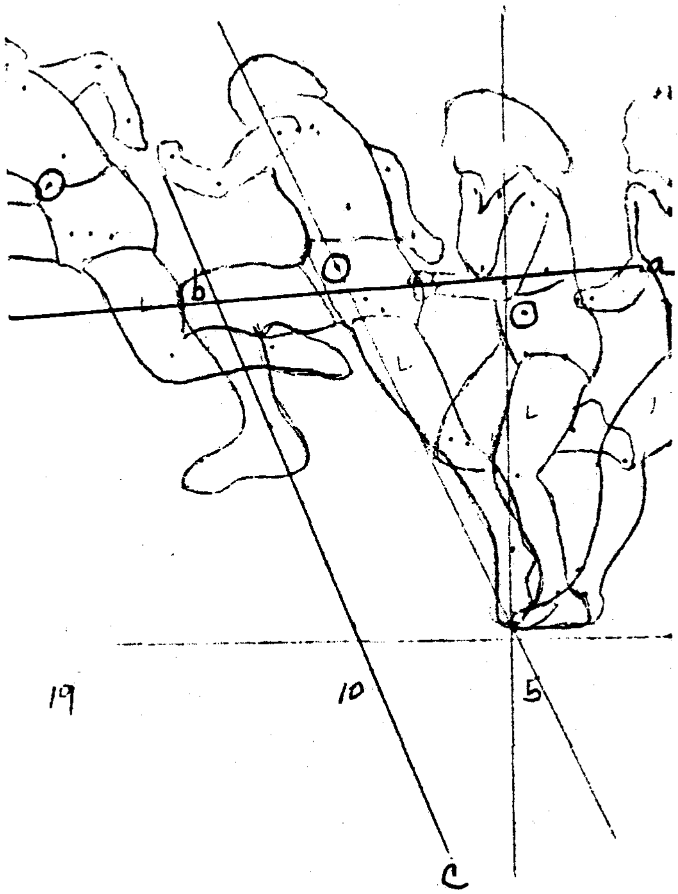


Figure 5. Lead Knee Angle — ∠ abc

Table III. Mean, Standard Deviation and Range for Physical Characteristics of Subjects and Elements of the Hurdling Action

Variable	$\bar{X}$	S	Range
Height (in.)	65.20	1.27	63.0 to 66.5
Leg Length (in.)	32.93	.56	32.3 to 33.74
Experience (yr.)	3.75	1.17	1.5 to 5
100 Meter Hurdle Time (sec.)	15.63	.57	14.9 to 16.3
Angle of Projection (°)	17.10	2.64	15.05 to 22.23
Horizontal Velocity (ft./sec.)	20.26	1.99	17.04 to 22.28
Vertical Velocity (ft./sec.)	6.19	.67	5.22 to 6.96
Initial Velocity (ft./sec.)	21.20	1.88	18.41 to 23.22
Clearance Time (sec.)	.38	.02	.34 to .41
Take-off Distance (ft.)	6.10	.66	5.32 to 6.98
Horizontal Distance from Center of Gravity to Toe at Take-off (ft.)	1.21	.32	.82 to 1.77
Take-off Angle (°)	18.75	3.49	15 to 25
Touchdown Angle (°)	12.10	1.93	9 to 14
Angle of Trunk at Touchdown (°)	35.50	4.00	29 to 40
Touchdown Distance (ft.)	3.46	.23	3.15 to 3.82
Horizontal Distance from Center of Gravity to Toe at Touchdown (in.)	8.39	1.35	6.55 to 9.64
Clearance Stride (ft.)	9.56	.70	8.61 to 10.29
Lead Knee Angle at Take-off (°)	72.00	16.60	48 to 91
Smallest Trunk to Thigh Angle (°)	38.60	6.65	32 to 51
Time to High Point (sec.)	.19	.02	.16 to .22
Horizontal Distance to High Point of Center of Gravity	3.90	.56	3.04 to 4.52
Horizontal Distance from High Point to Hurdle (ft.)	2.20	.56	1.45 to 2.91
Distance Center of Gravity Above Hurdle (in.)	14.84	2.95	11.48 to 19.25

event in the hurdling action were located for all subjects. The temporal analysis graphs appear in Figure 6 and Figure 7.

Treatment of Data

The Pearson product-moment correlation (r) was used to test the hypotheses.

Trunk to lead leg thigh angles were graphed.

A temporal analysis was done with real and relative time values for specified events of the hurdling action depicted in graph form.

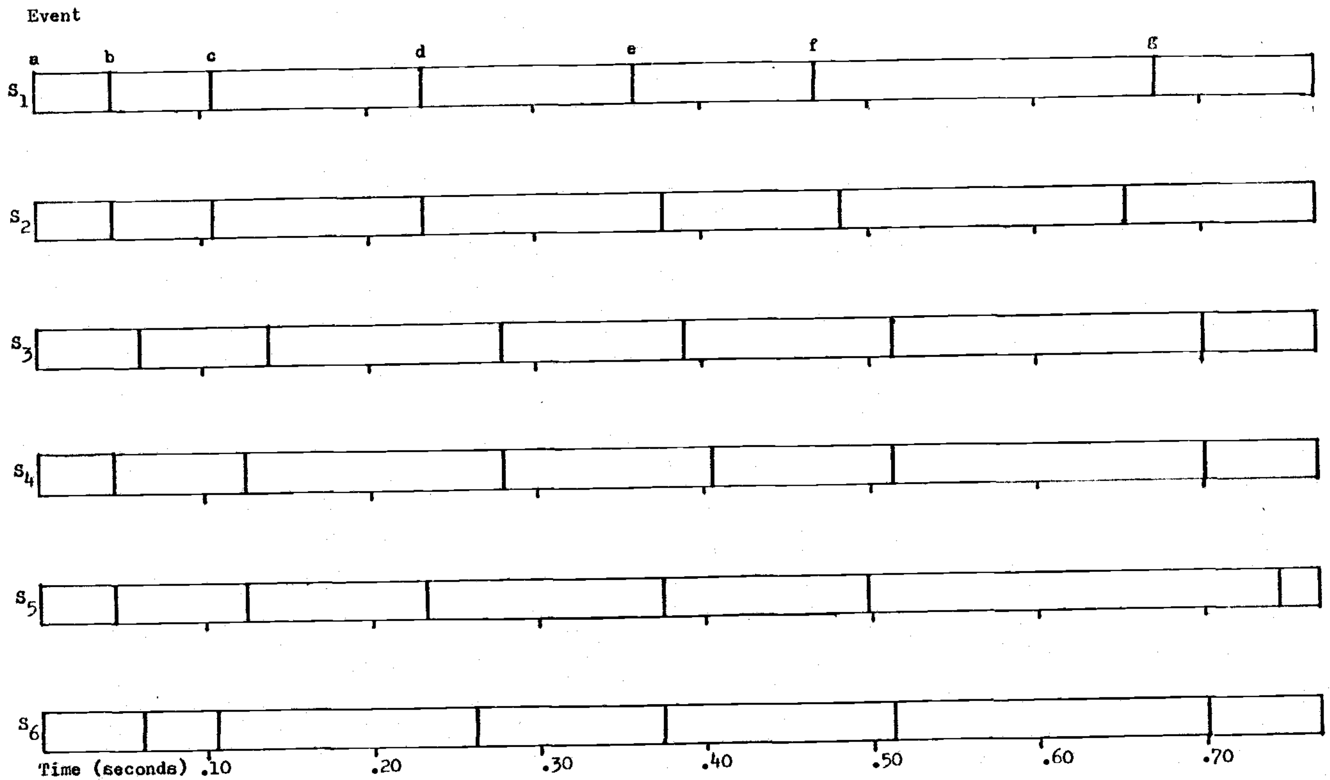


Figure 6. Temporal Analysis. Real Time Graphs for all subjects. Event: a. touchdown of last stride before take-off; b. mid-support of last stride; c. take-off; d. lead heel at hurdle; e. trail knee at hurdle; f. touchdown of lead foot; g. touchdown of trail foot.

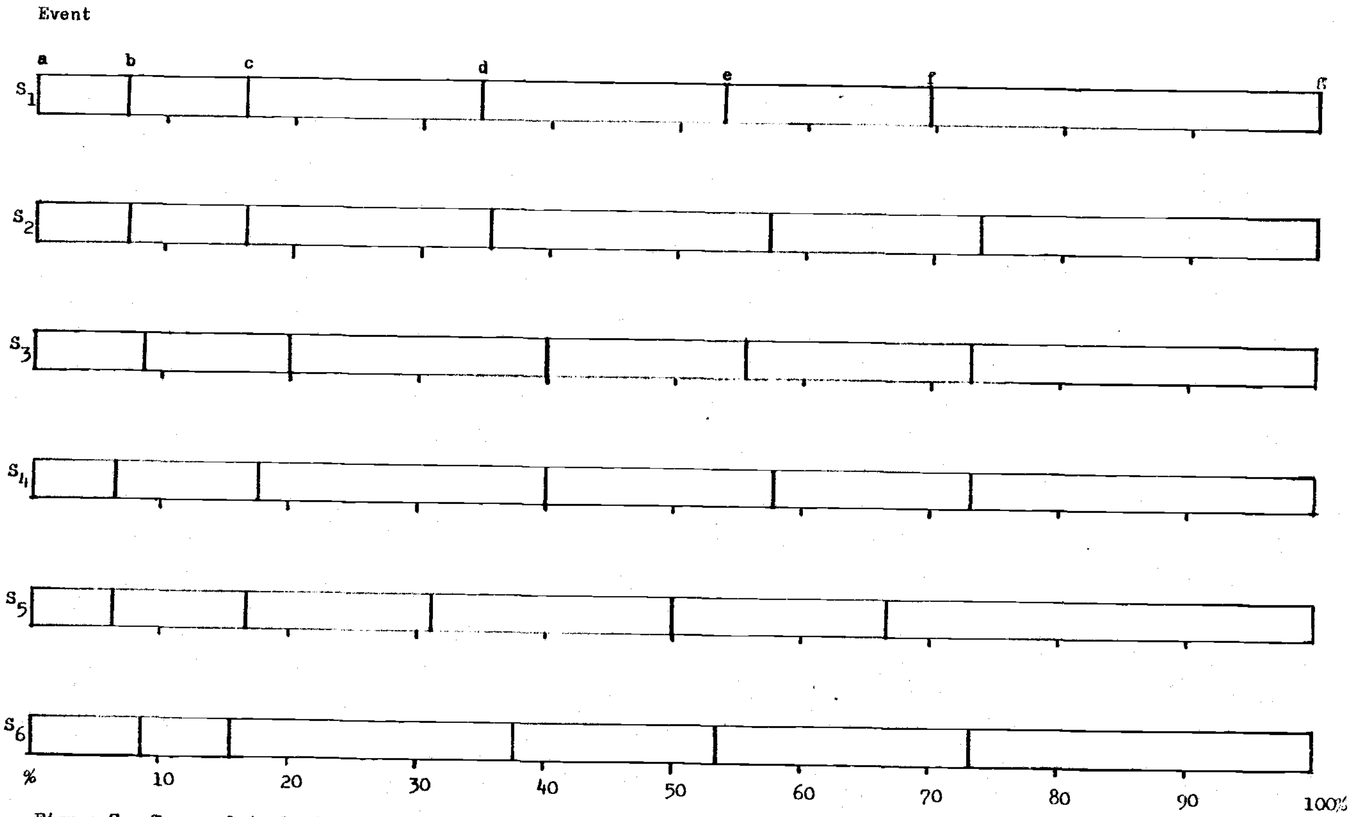


Figure 7. Temporal Analysis. Relative Time Graphs for all subjects. Event: a. touchdown of last stride before take-off; b. mid-support of last stride; c. take-off; d. lead heel at hurdle; e. trail knee at hurdle; f. touch-down of lead foot; g. touchdown of trail foot.

CHAPTER IV

RESULTS AND DISCUSSION

Sixteen millimeter film was taken of women hurdlers at a film speed of 64 frames per second. An Image Motion Analyzer and Hewlett-Packard digitizer, calculator and computer facilitated analysis of the film. Data obtained made possible objective comparisons of various elements of hurdling technique.

Subjects

Six high school aged female athletes participating in the semi-final heats of the 100 meter hurdles at the 1978 Oregon State AAA Girls Track and Field Championships were subjects in this study. They ranged in height from 63 inches to 66.5 inches, with the subject having the fastest time for the event being 64.5 inches tall and the subject having the slowest time for the event being 63 inches tall. Four of the six subjects were taller than the subject having the fastest 100 meter hurdle time. They ranged in leg length from 32.3 inches to 33.7 inches, with the shortest subject having the smallest leg length, but the tallest subject not having the greatest leg length. The fastest hurdler possessed a leg length 50 per cent of her height and the slowest hurdler possessed a leg length 51 per cent of her height. No significant relationship was found for either clearance time and leg length or clearance time and height. Correlations are reported in Table IV.

Table IV. Paired Variables and Correlation Coefficients[a]

Variable	Correlation Coefficient[b]	Variable
Leg Length	-.23	Clearance Time
Height	-.45	Clearance Time
Angle of Projection	-.74	Leg Length
Angle of Projection	.72	Clearance Time
Vertical Velocity	.35	Clearance Time
Take-off Angle	.42	Horizontal Velocity
Horizontal Distance from Center of Gravity to Toe at Take-off	.42	Horizontal Velocity
Initial Velocity	.74	Take-off Distance
Take-off Distance	.28	Leg Length
Lead Knee Angle at Take-off	-.18	Clearance Time
Vertical Velocity	.08	Smallest Trunk to Thigh Angle
Height of the Center of Gravity Above Hurdle	-.75	Smallest Trunk to Thigh Angle
Angle of Trunk at Touchdown	-.37	Horizontal Distance from Center of Gravity to Point of Touchdown
Touchdown Angle	.35	Take-off Angle
Angle of Projection	-.57	Clearance Stride
Initial Velocity	.78	Clearance Stride

[a] $N=6$

[b] $p \leq .05$ for $r \geq .71$

The subjects ranged in years of hurdling experience from one and one-half to five years. The fastest and slowest subjects both had four years experience. Values for height, leg length, experience and 100 meter hurdle time appear in Table II. The mean, standard deviation and range for each variable appears in Table III.

Take-off

The mean, standard deviation and range for all take-off variables appear in Table III.

As reported in the review of literature, many authors discuss certain aspects of the take-off, most frequently commenting on the lead arm, lead leg and trunk action. While all authors advocate lifting the thigh or knee of the lead leg, only some advocate lifting the lead arm (4, 28, 30), while Ross (28) advocates lifting both arms forward and upward. Though the technique is being expressed by many authors, the underlying principle is pointed out by Ecker (11) when he emphasizes raising the center of gravity at take-off as a method of reducing the vertical velocity component needed to clear the hurdle. Elevation of body parts at take-off would seem to be desirable, as well as complete extension of the take-off leg in affecting the height of the center of gravity at take-off. Also contributing to this factor in hurdling is the hurdler's height, or more precisely, leg length. Angle of projection and leg length values were correlated and a significant negative value was obtained. A significant positive correlation was found to exist between the angle of projection and clearance time. However, as already reported, there was no significant relationship between leg length and clearance time, indicating that there are other variables involved, and leg length was not found to be relative to clearance time. No significant relationship existed between the vertical velocity component and clearance time. This points to the importance of the horizontal velocity component of the projection angle at take-off. Values for correlations appear in Table IV.

The concern for trunk positioning (lean or pike) at take-off and its influence on positioning of the center of gravity for a horizontal drive does not receive support from the data in this study. The take-off angle formed by the center of gravity and a vertical axis drawn through the supporting toe, was correlated with horizontal velocity. No significant relationship was found. Nor was a significant relationship found between horizontal velocity and the horizontal distance of the center of gravity ahead of the supporting toe at take-off. Values for the correlations appear in Table IV.

The factors affecting take-off distance were summarized by Hay (16) in the review of literature as the height and leg length of the hurdler, velocity, and technique, or the speed of the lead leg. Take-off distances and initial velocities for all subjects appear in Table II. A significant relationship was found between the initial velocity and the take-off distance, confirming the literature. However, the correlation coefficient for leg length and take-off distance was not found to be significant. No significance between leg length and take-off distance conflicts with the literature, and again points to velocity as the overwhelmingly dominant factor at take-off. Correlation values may be found in Table IV.

Lead Leg

The mean, standard deviation and range for the lead leg variables appear in Table III.

As indicated in the literature, two primary concerns prevail regarding the lead leg action. One is whether the lead leg should be flexed (4, 8, 16, 30) or extended (28, 33, 34) during clearance. The other concern is the position of the lower leg of the lead leg at take-off. Most authors agree that the lower leg should not come ahead of a vertical plane at the lead knee prior to take-off. The lead leg knee angles at take-off for all subjects appear in Table II. Only S_5 exhibited an angle greater than 90°, Ross's (28) checkpoint. However, since her thigh was below the horizontal, she still had not broken the vertical plane at the knee of her lead leg. In an effort to see if this angle was related to clearance time (any indication of speed of the lead leg), a correlation was computed. A very small value was obtained.

Trunk

The mean, standard deviation and range values for variables of the trunk appear in Table III.

Much attention has been placed on the action of the trunk, as well as the lead leg, in contributing to lowering the center of gravity within the body during flight (11, 16, 33). Ecker (11) emphasizes that the closer the trunk and lead leg can be brought together, the more the center of gravity will be lowered with respect to body parts, and the less vertical velocity component the hurdler will require to clear the hurdle. The smallest trunk to thigh angle of each subject was correlated with her vertical velocity component. No significant relationship was found. Since lowering the center of gravity within the body would allow the center of gravity to pass closer to the hurdle (fewer body parts below the center of gravity), the smallest trunk to thigh angle was also correlated with the height of the center of gravity above the hurdle during clearance — point at which trail knee reached the hurdle. A negative, significant correlation was found! Perhaps this negative correlation can be explained when considering the subjects involved. The subjects involved might be considered moderately good hurdlers. Of the six, two of the subjects had extreme differences on these specific parameters. S_6 showed the smallest trunk to thigh angle of 32 degrees, yet the largest value for distance of center of gravity above hurdle during clearance.

Due to her extremely high projection angle, 22 degrees, her center of gravity was over 19 inches above the hurdle during clearance. In contrast, the greatest trunk to thigh angle, was shown by S_4 as 51 degrees, and her center of gravity passed closest to the hurdle, being only 11.48 inches above. She had a much lower projection angle of 17 degrees combined with a larger initial velocity of 22.16 feet per second and the longest take-off distance (almost seven feet) of all subjects. Timing or efficiency of movements is very important in taking advantage of mechanical principles. S_6 with her small trunk to thigh angle passed very high above the hurdle. She attained her smallest trunk to thigh angle only .09 seconds after take-off and had already opened up or extended at the hip joint a considerable degree as she reached the hurdle. S_4 was more efficient. Although she did not bring her trunk and thigh as close together, her smallest trunk to thigh angle occurred .17 seconds after take-off when she was beginning to cross the hurdle. See Figures 8 through 13.

As depicted in the graphs of trunk to thigh angle for all subjects, some interesting relationships can be noted. For all subjects except S_2 and S_5, the smallest thigh to horizontal angle occurred first. For all subjects except S_5, the smallest thigh to horizontal angle occurred before high point of center of gravity was reached. For all subjects except S_3 and S_5, the smallest trunk to horizontal angle occurred latest of the three angles. For all subjects, the smallest trunk to thigh angle occurred before high

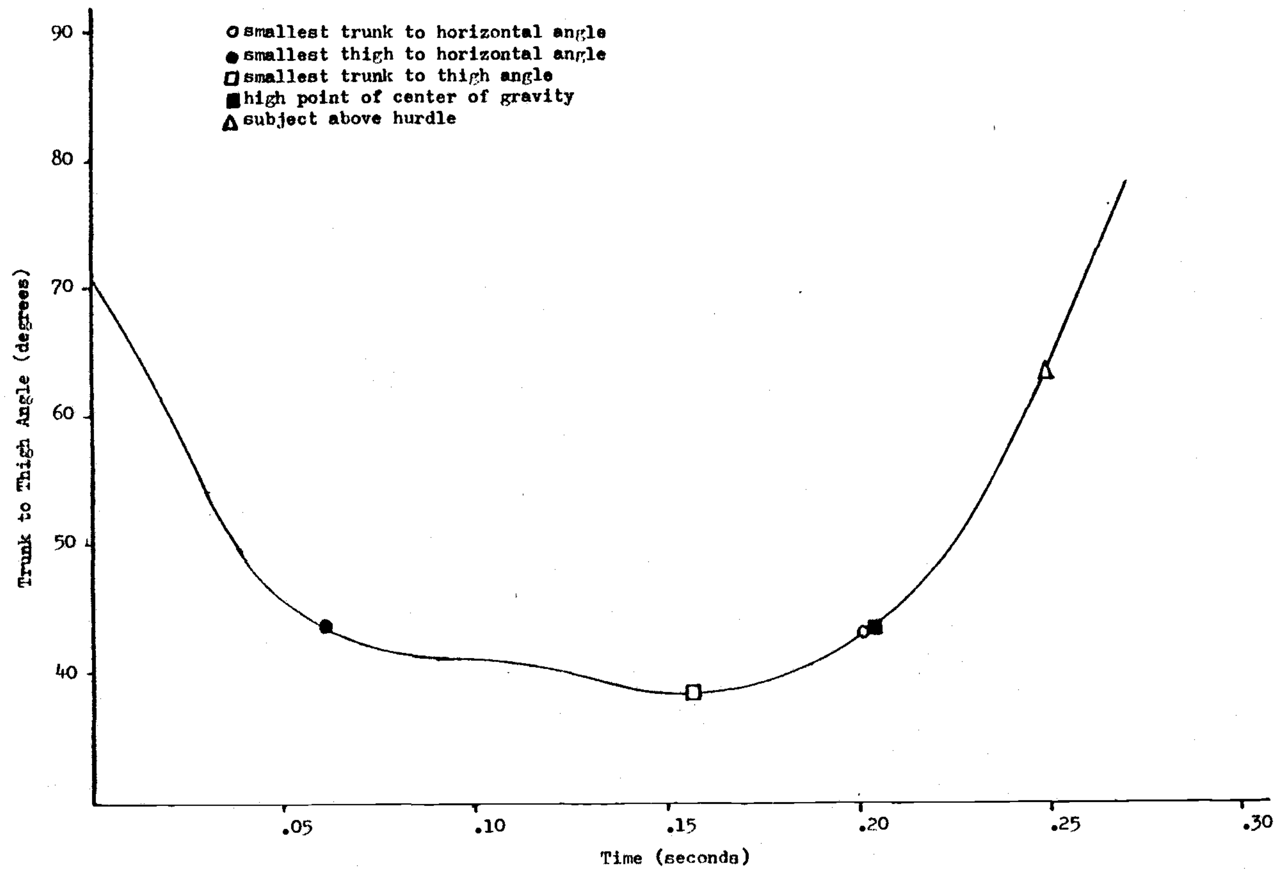


Figure 8. Trunk to Thigh Angles for S_1.

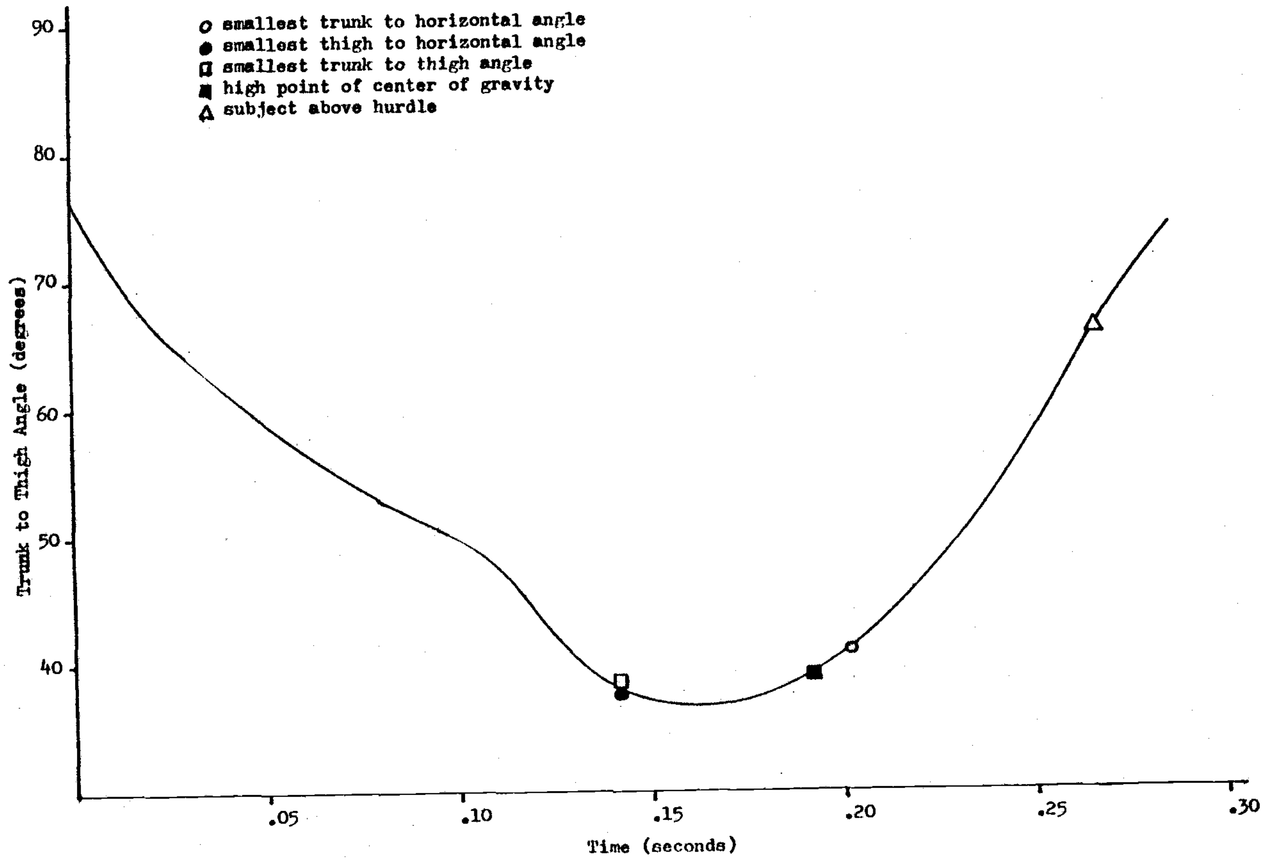


Figure 9. Trunk to Thigh Angles for S_2.

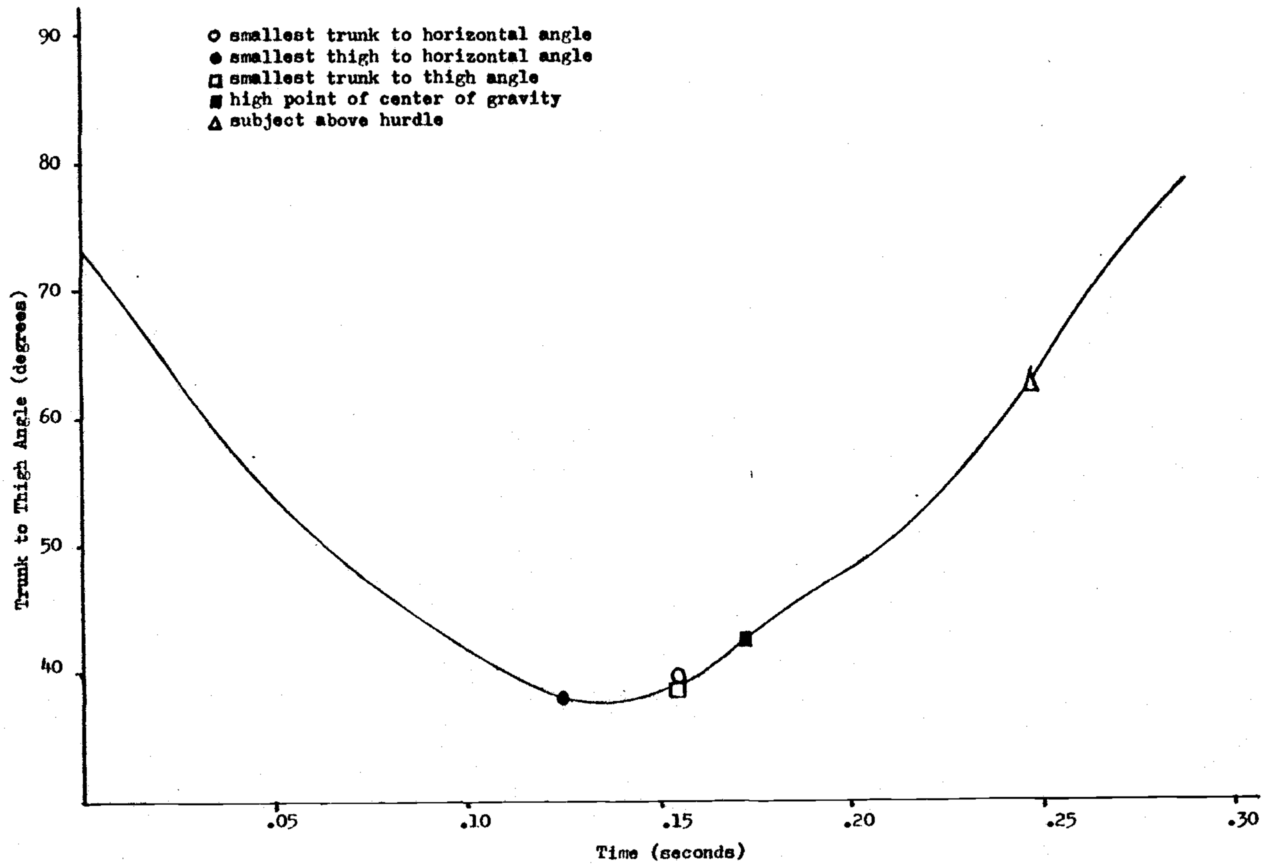


Figure 10. Trunk to Thigh Angles for S_3.

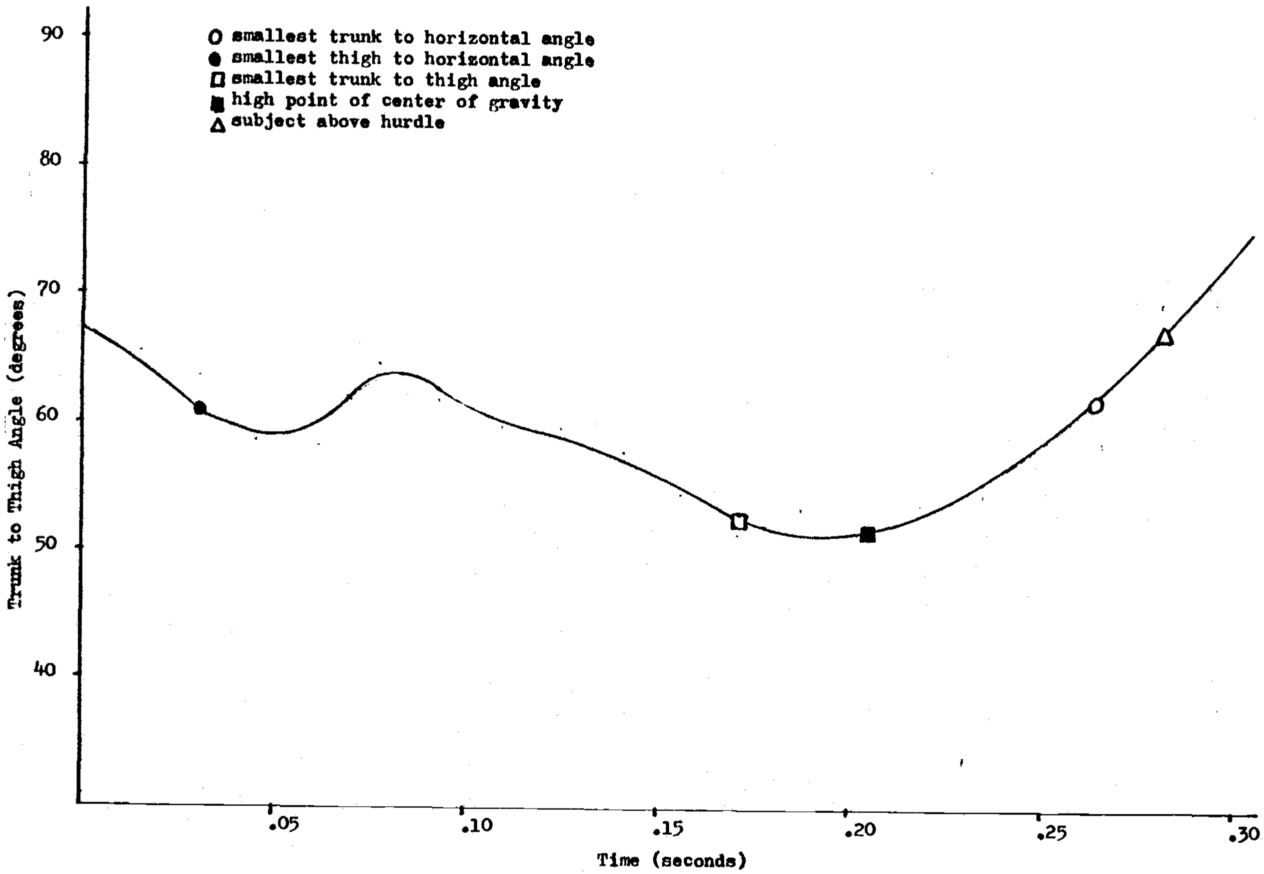


Figure 11. Trunk to Thigh Angles for S_4.

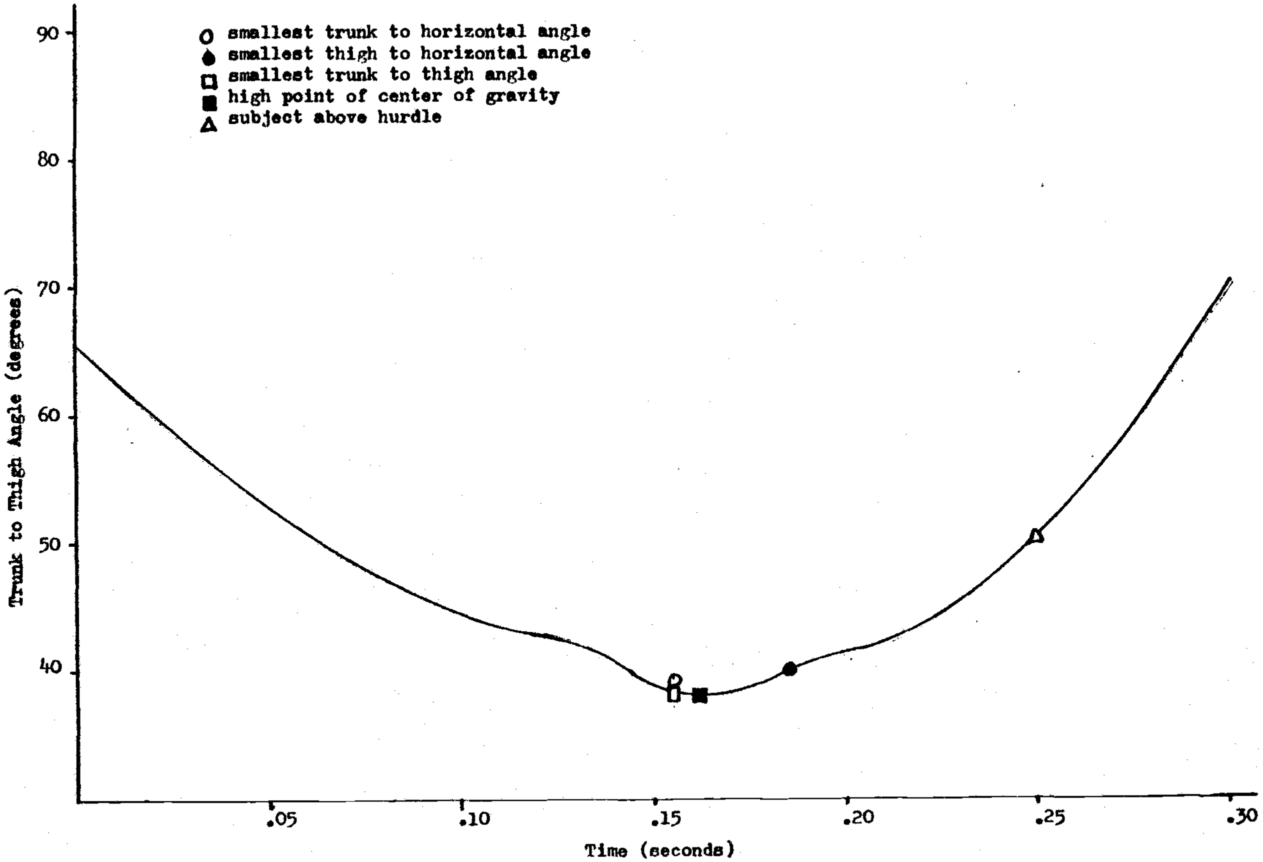


Figure 12. Trunk to Thigh Angles for S_5.

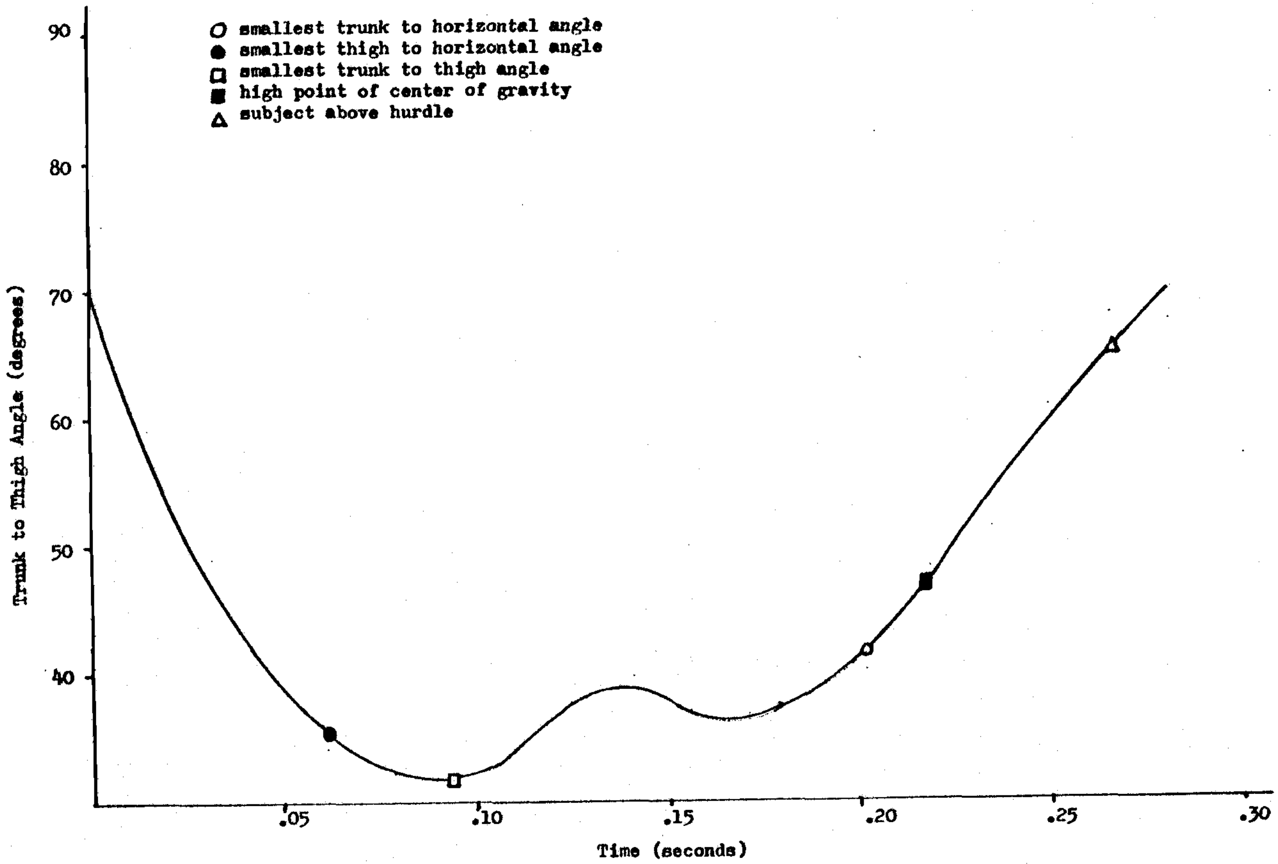


Figure 13. Trunk to Thigh Angles for S_6.

point of center of gravity was reached. Since all subjects reached high point before crossing the hurdle, then for every subject, their smallest trunk to thigh angle occurred before crossing the hurdle. Values for smallest trunk to thigh angle, height of center of gravity above hurdle at clearance, time to high point of center of gravity, horizontal distance to high point and horizontal distance high point occurs before hurdle, appear in Table II. All values for the three angular measures taken appear in Appendix K.

Touchdown

Mean, standard deviation and range values for touchdown variables appear in Table III.

Several concerns exist regarding touchdown from the hurdle. They were summarized in the literature review as: 1) the action/reaction of the trunk and lead leg to get the lead leg to the ground quickly; 2) position of the center of gravity relative to the point of touchdown; 3) the direction and magnitude of acceleration of the lower leg and foot at touchdown. Most theories relative to action/reaction of the trunk and lead leg differ only as to where the emphasis should be placed — on snapping the lead leg down (4, 27, 28, 31) or on snapping the trunk up (11). Considerable disagreement exists surrounding the position of touchdown relative to the center of gravity. Those who emphasize action/reaction of trunk do not advocate maintaining a forward lean at touchdown (11, 13, 16), yet those who emphasize positioning the center of gravity closer to the point of touchdown to reduce breaking action feel that trunk inclination is vital (9, 12, 30, 33). The angle of the trunk at touchdown (away from the vertical) was correlated with the horizontal distance between point of touchdown and center of gravity. No significant correlation was found. All subjects exhibited trunk inclination at touchdown. The values for trunk angle at touchdown and distance of center of gravity from point of touchdown appear in Table II.

Considerable disagreement as to the exact positioning of touchdown relative to the center of gravity, is evident in the literature. Some authors report touchdown should be directly below center of gravity (13, 16, 33); and others report below or behind center of gravity (27, 30, 31). The results of this study are in agreement with Dyson (9), who reports touchdown will be slightly ahead of the gravity. All subjects in this study had touchdown points ahead of the center of gravity, ranging from 6.55 inches to 9.44 inches. Values appear in Table II.

Clearance Stride

Means, standard deviation and ranges for variables relating to clearance stride can be found in Table III.

Touchdown angle was measured for all subjects and ranged from nine to fourteen degrees. No significant relationship was found between touchdown angle and the take-off angle.

The distance of touchdown from the hurdle was measured for each subject and used in computing the total clearance stride. Touchdown distances ranged from 3.15 feet to 3.82 feet. Total clearance stride distances ranged from 8.61 feet to 10.29 feet. S_4 had the shortest touchdown distance and the longest take-off distance. S_6 with the slowest 100 meter hurdle time showed the shortest clearance stride of 8.61 feet. S_2, with the second fastest 100 meter hurdle time, exhibited the longest clearance stride of 10.29 feet. A significant correlation was not found between the angle of projection and the clearance stride. However, initial velocity and clearance stride are significantly related. Touchdown angle, touchdown distance and distance of clearance stride appear in Table II.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The literature relating to hurdling technique includes many conflicting viewpoints. Little of the literature could be considered research; and very little is concerned specifically with the technique of female hurdlers.

The purpose of this study was to objectively describe and compare specific elements of hurdling techique. It was also intended to test relationships between variables of hurdling, as reported in the literature. Sixteen hypotheses were developed and tested. They were that no significant relationships would exist between the paired variables. Those variables and their correlation coefficients have been presented in Table IV.

Equipment

A sixteen millimeter Red Lake Low Cam camera was used for filming. Tracings of the film were obtained with a Bell and Howell Film Projection Analyzer and a large image Recordak. Data were collected with an Image Motion Analyzer and Hewlett-Packard digitizer, calculator and computer.

Procedures

Subjects were filmed during competition at the 1978 Oregon State AAA Girls Track and Field Championships. Tracings were made from the film. Tracings and film were taken to the Data Analysis Laboratory at the University of Arizona where the data were collected. Physical measures were taken of each subject. Comparisons and correlations of the data were made.

Treatment of the Data

The Pearson correlation coefficient was used to test the hypotheses. A temporal analysis was completed; and trunk to thigh angle values were graphed.

Results

Hypotheses 1, 2, 5, 6, 7, 9, 10, 11, 13, 14, and 15, that no significant relationships would exist between the paired variables were not rejected on the basis of Pearson coefficients of correlation which were not statistically significant.

Hypothesis 3, that no significant relationship would exist between the angle of projection and leg length, was rejected on the basis of $r = -.73$ which was statistically significant at the .05 level. This finding supports the literature.

Hypothesis 4, that no significant relationship exists between the angle of projection and clearance time, was rejected on the basis of r = .72 which was statistically significant at the .05 level. The relationship therefore shown to exist, supports the literature.

Hypothesis 8, that no significant relationship would exist between initial velocity and take-off distance, was rejected on the basis of r = .74 which was statistically significant at the .05 level. The relationship shown is in agreement with the literature. The acceptance of Hypothesis 9 as already indicated, and with no significant relationship between leg length and take-off distance, contradicts the literature.

Hypothesis 12, that no significant relationship would exist between the smallest trunk to thigh angle and the height of the center of gravity above the hurdle during clearance, was rejected on the basis of r = -.75 which was significant at the .05 level. The negative nature of this relationship contradicts the literature. Seeming to contradict mechanical laws as well, a careful examination of the data indicates that it is not enough to say that bringing body parts close together during the hurdling action is important. The relative timing of this technique in the hurdling action must be considered. If occurring too early in the action, the small trunk to thigh angle may produce a negative rather than a positive result.

Hypothesis 16, that no significant relationship would exist between initial velocity and clearance stride, was rejected on the basis of r = .78 which was significant at the .05 level. This finding supports the literature.

Results pointed on several occasions to the critical effect of the horizontal velocity component at take-off, relative to clearance time and clearance stride.

Results also establish that all subjects exhibit a touch-down point in front of their centers of gravity, which conflicts with much of the literature.

The complicated nature of the hurdling action and the inter-relatedness of the many variables indicate a need for further research of descriptive design.

Conclusions

The data presented in this study confirmed two relationships which contradict those expressed in the literature. The lack of a significant relationship between leg length and take-off distance disagreed with the literature which indicated a significant relationship exists between leg length and take-off distance. The significant, negative correlation coefficient obtained between the smallest trunk to thigh angle of the subject, and the vertical distance which center of gravity was above the hurdle at clearance disagrees with the literature as well. The negative value of this coefficient is contradictory to the nature of the relationship as it appears in the literature. The literature reports that the smaller the angle formed by the trunk and lead leg thigh, or the closer body parts can be brought together, the closer the center of gravity is allowed to pass over the hurdle. The opposite was true for subjects in this study. Examination of the data indicated the dual nature of this principle. Not only should body parts be brought close together during the flight interval of the hurdling action, but the timing of the hip flexion/extension action is of utmost importance in assuring efficiency of technique.

Even though it is felt cinematographic techniques may reveal performance characteristics associated with successful performance of a particular skill, it is also of extreme importance to consider the individual characteristics of the performer.

The interrelatedness of variables in hurdling seems to imply that more emphasis need be placed on certain variables as opposed to others, specific to each individual performer. Determining the effects of manipulating different variables or combinations of variables for a given performer, seems to be necessary in order to determine specifically the technique adjustments required for that performer.

The results of this study merit replication in several ways. Similar studies of correlative nature need be carried out with high school males and with male and female subjects of world class ability.

REFERENCES

1. Ayoub, M. M., R. E. Dryden, and J. W. McDaniel. 1974. Models for lifting activities. IN: R. C. Nelson and C. A. Morehouse (Editors) Biomechanics IV, pp. 30-36. University Park Press, Baltimore.

2. Baumann, W. 1973. The influence of mechanical factors on speed at tobogganing. IN: S. Cerquiglini, A. Venerando, and J. Wartenweiler (Editors) Biomechanics III, pp. 453-459. S. Karger, Basel.

3. Blievernicht, J. G. 1968. Accuracy in the tennis forehand drive: Cinematographic analysis. Research Quarterly, 39: 776-779.

4. Bowerman, W. J. 1974. Coaching Track and Field. Houghton-Mifflin Company, Boston.

5. Chaffin, D. B. 1969. A computerized biomechanical model — development of and use in studying gross body actions. J. Biomechanics 2:429-441.

6. Chaffin, D. B. and W. H. Baker. 1970. A biomechanical model for analysis of symmetric sagittal plane lifting. AIIE Tras. Industrial Engineering Research and Development 2: 16-27.

7. Clemence, W. J. 1968. A Cinematographical Study of the Variation in Momentum when Swinging Varying Club Head Weights. Doctoral Dissertation. University of Arkansas, Fayetteville.

8. Doherty, K. 1967. Track and Field Movies on Paper, 2nd Edition. Doherty, Swarthmore.

9. Dyson, G. H. G. 1968. The Mechanics of Athletics. University of London Press, London.

10. Ecker, T. 1974. Track and Field Dynamics, 2nd Edition. Tafnews Press, Los Altos.

11. Ecker, T. 1976. Track and Field Technique Through Dynamics. Tafnews Press, Los Altos.

12. Foreman, K. and V. Husted. 1971. Track and Field Techniques for Girls and Women. Wm. C. Brown Co., Dubuque.

13. Ganslen, R. V. 1949. High Hurdling. Scholastic Coach 18: February.

14. Grieve, D. W. 1974. Dynamic characteristics of man during crouch and stoop-lifting. IN: R. C. Nelson and C. A. Morehouse (Editors) Biomechanics IV, pp. 19-29. University Park Press, Baltimore.

15. Grieve, D. W., D. I. Miller, D. L. Mitchell, J. P. Paul and A. J. Smith. 1976. Techniques for the Analysis of Human Movement. Princeton Book Company, Princeton.

16. Hay, J. G. 1973. The Biomechanics of Sports Techniques. Prentice-Hall, Inc., Englewood Cliffs.

17. Justin, G. 1970. Art of Hurdling. Track Technique. March Issue.

18. Miller, D. I. and R. C. Nelson. 1973. Biomechanics of Sports. Lea & Fiebiger, Philadelphia.

19. Nelson, R. C., C. I. Dillman, P. Lagasse and P. Bickell. 1972. Biomechanics of overground versus treadmill running. Medicine and Science in Sports 4:233-240.

20. Northrip, J. W., G. A. Logan and W. C. McKinney. 1974. Kinesiology. Wm. C. Brown, Dubuque.

21. O'Connell, A. L. 1968. A simple method of synchronizing cinematographic-electromyographic data. IN: J. Wartenweiler (Editor) Biomechanics I, pp. 128-131. S. Karger, Basel.

22. Pauling, L. 1975. Linus Pauling Before Congress. Healthline. December, p. 2.

23. Plagenhoef, S. C. 1971. Patterns of Human Motion. Prentice Hall, Englewood Cliffs.

24. Quigley, B. M. and D. B. Chaffin. 1971. A computerized biomechanical model applied to the analysis of skiing. Medicine and Science in Sports 3:39-96.

25. Race, D. E. 1960. A Cinematographical and Mechanical Analysis of the External Movements Involved in Hitting a Baseball Effectively. Master's Thesis, Springfield College, Springfield.

26. Ramey, M. R. 1970. Force relationship in the running long jump. Medicine and Science in Sports. pp. 146-151.

27. Riddle, P. E. 1971. Cinematographic Analysis of Women Hurdlers. Master's Thesis, University of Illinois.

28. Ross, W. L. 1969. The Hurdler's Bible, 2nd Edition. Yates Printing Company, Arlington.

29. Roozbazar, A. 1974. Biomechanics of lifting. IN: R. C. Nelson and C. A. Morehouse (Editors) Biomechanics IV, pp. 37-43. University Park Press, Baltimore.

30. Singh, J. 1974. The High Hurdles. IN: F. Wilt, J. Hay and T. Ecker. Olympic Track and Field Techniques, An Illustrated Guide to Developing Champions. Parker Publishing Company, West Nyack.

31. Sipes, M. 1976. Hurdling Mechanics for the Female Athlete. Track Technique. September.

32. Smith, A. J. 1975. Photographic analysis of movement. IN: D. W. Grieve, D. I. Miller, D. L. Mitchelson, J. P. Paul and A. J. Smith. Techniques of Human Movement, pp. 3-29. Princeton Book Co., Princeton.

33. van Patot, P. T. 1974. The Women's Hurdles. IN: F. Wilt, J. Hay and T. Ecker. Olympic Track and Field Techniques, An Illustrated Guide to Developing Champions. Parker Publishing Company, West Nyack.

34. Wakefield, F., D. Harkins and J. M. Cooper. 1970. Track and Field Fundamentals for Girls and Women. C. V. Mosby, St. Louis.

35. Williams, D. 1967. The dynamics of the golf swing. Quart J Mech Appl Math. 20:247-264.

APPENDICES

APPENDIX A

SUBJECT PERMISSION FORM

ACKNOWLEDGEMENT OF WILLINGNESS TO PARTICIPATE

The undersigned acknowledges that she will volunteer to be a subject in a cinematographical analysis of hurdling being conducted through Oregon State University.

Signed ______________________

Date ______________ Age _____

CONSENT AND RELEASE FOR PERSONS UNDER TWENTY-ONE YEARS OF AGE

My daughter, __________________, who is under the age of twenty-one (21) has my permission to be a subject in a cinematographical analysis of hurdling being conducted through Oregon State University.

Signature
of Parent ____________________

Address ______________________

____

Date ________________________

APPENDIX B

OSAA PERMISSION FORM

ACKNOWLEDGEMENT OF PERMISSION TO FILM

The undersigned acknowledges that permission has been granted to film the semi-final heats of the girls 100 meter hurdle event at the 1978 Oregon Scholastic Activities Association State AAA Girls Track and Field Championships. The film will be used in a cinematographical analysis of hurdling being conducted through Oregon State University.

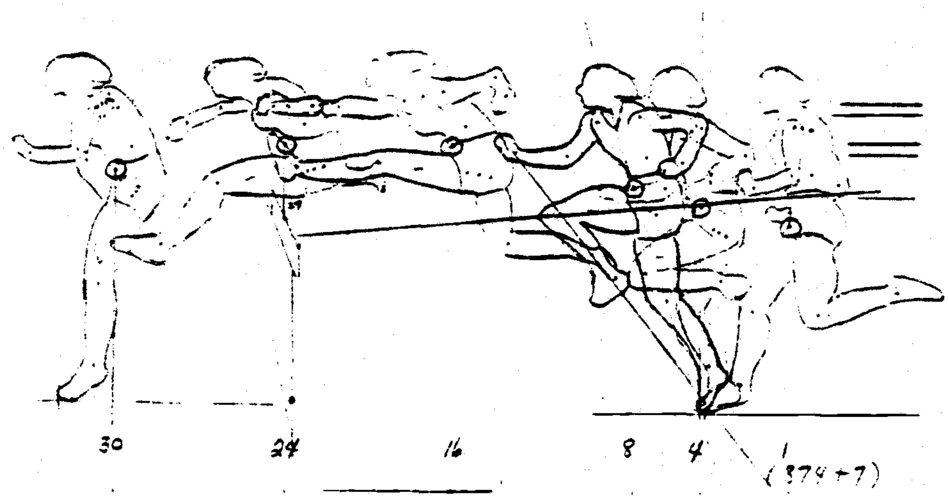
Signed

Title

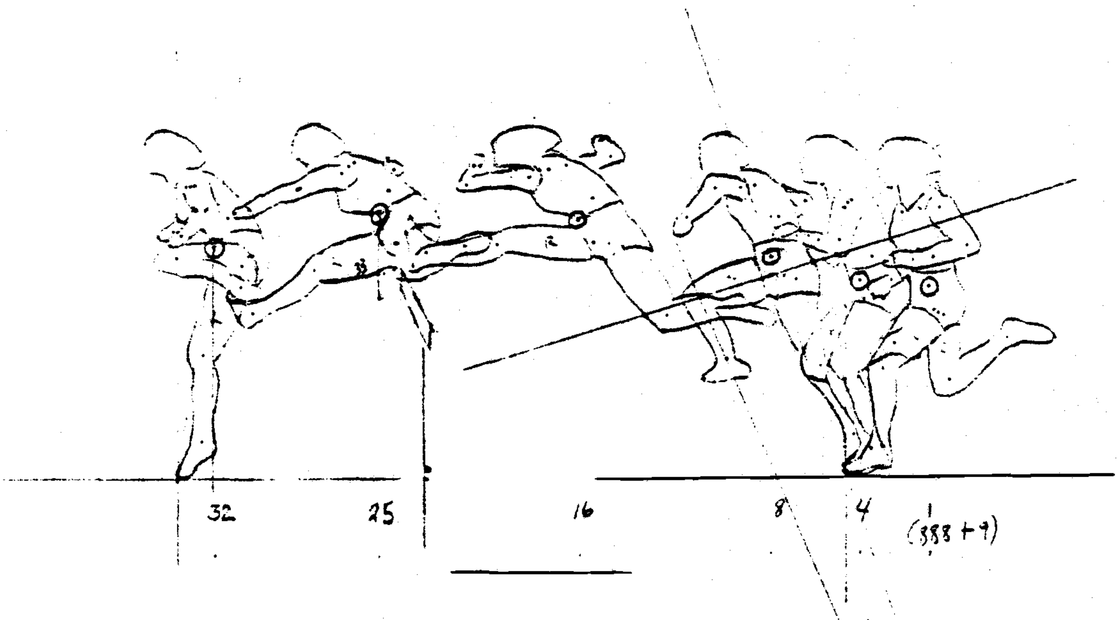
OSAA
#1 Plaza
6900 S. W. Haines Rd.
Tigard, Oregon 97223

APPENDIX C

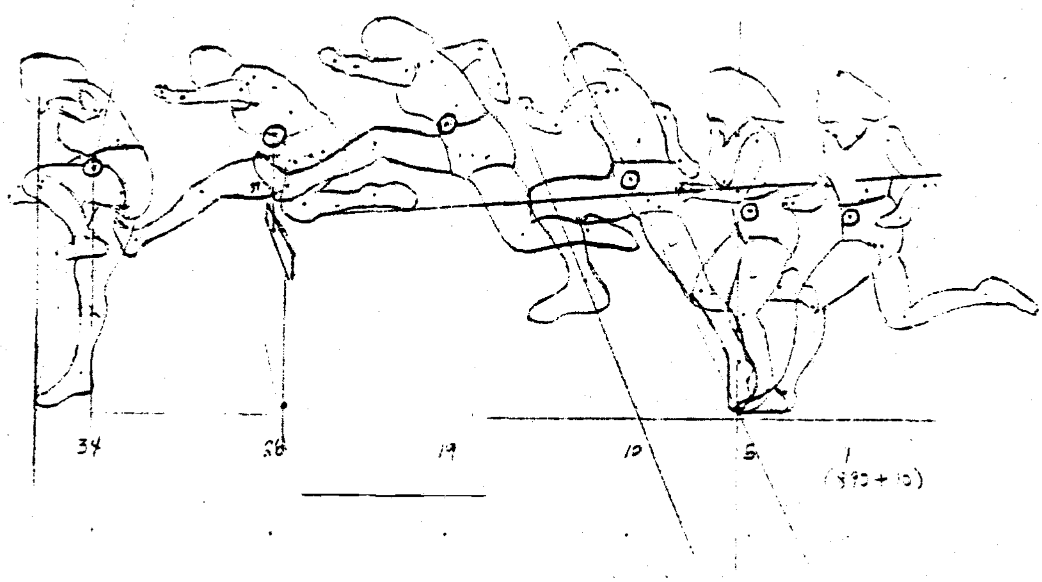
COMPOSITE TRACINGS



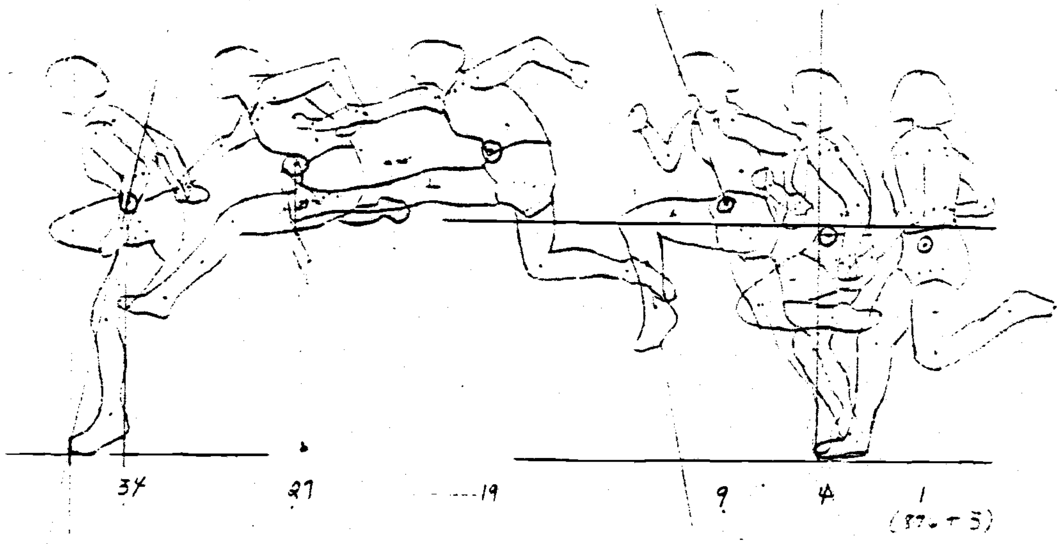
Composite Tracing — S_1



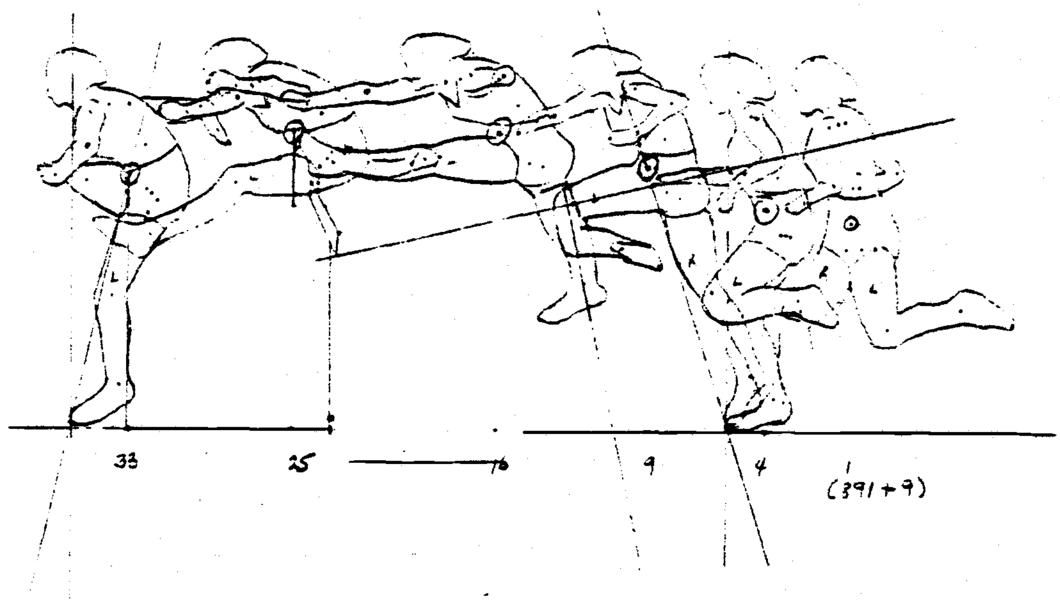
Composite Tracing — S_2



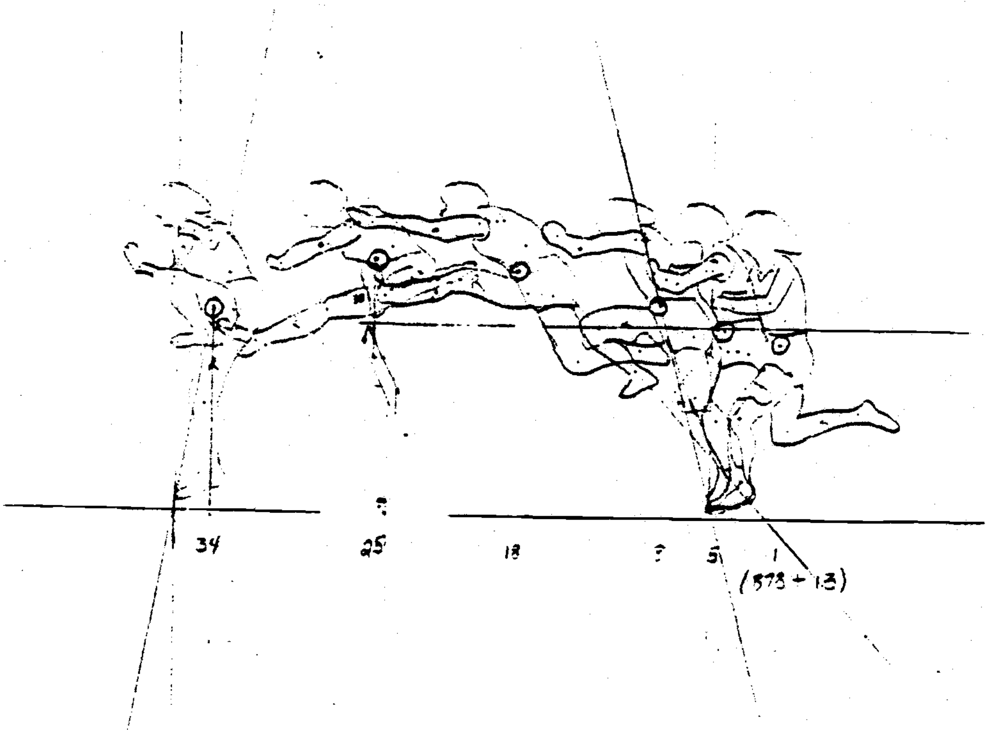
Composite Tracing — S_3



Composite Tracing — S_4



Composite Tracing — S_5



Composite Tracing — S_6

APPENDIX D

DISTANCE CONVERSION FACTORS FOR FILM

Calculation of distance conversion factors for film:

a = yardstick (in inches) as originally filmed in lane:

2 — 2.55
3 — 2.43
4 — 2.31
5 — 2.19
6 — 2.07
7 — 1.95
8 — 1.83

b = what yardstick would have been (in inches) if it had been filmed in lane ____ during hurdling

c = distance (in inches) between railings in original yardstick filming — 4.10

d = distance (in inches) between railings during hurdling

$$\frac{a}{b} = \frac{c}{d}$$

conversion factor for each lane = three feet (known length) ÷ b

Heat 1

lane 2	$\frac{2.55}{b} = \frac{4.10}{1.685}$	b = 1.048	$\frac{3}{b} = 2.86$
lane 4	$\frac{2.31}{b} = \frac{4.10}{1.685}$	b = .9494	$\frac{3}{b} = 3.16$
lane 7	$\frac{1.95}{b} = \frac{4.10}{1.685}$	b = .8014	$\frac{3}{b} = 3.74$

Heat 2

lane 2	same as for heat 1		
lane 4	same as for heat 1		
lane 5	$\frac{2.19}{b} = \frac{4.10}{1.685}$	b = .9000	$\frac{3}{b} = 3.33$

APPENDIX E

CENTER OF GRAVITY PROGRAM DOCUMENTATION

"NEW" CENTER OF GRAVITY WITH DIGITIZER FOR 20 POINTS

This program finds the coordinates of the body's center of gravity in inches, from either a tracing or a direct film projection onto the digitizer platen. Input consists of the coordinates of the 20 points, as pictured in the diagram.

I. GIVEN

$(X_1, Y_1), (X_2 Y_2), \ldots, (X_{20}, Y_{20})$

II. CALCULATE center of gravity (center of mass) of each segment, CX_i $(i = 1, \ldots, 15)$ and CY_i $(i = 1, \ldots, 15)$.

$$CX_1 = (.571(X_2 - X_1) + X_1) \qquad CY_1 = (.571(Y_2 - Y_1) + Y_1)$$
$$CX_2 = (.567(X_3 - X_2) + X_2) \qquad CY_2 = (.567(Y_3 - Y_2) + Y_2)$$
$$CX_3 = (.567(X_4 - X_3) + X_3) \qquad CY_3 = (.567(Y_4 - Y_3) + Y_3)$$
$$CX_4 = (.401(X_6 - X_5) + X_5) \qquad CY_4 = (.401(Y_6 - Y_5) + Y_5)$$
$$CX_5 = (.373(X_7 - X_6) + X_6) \qquad CY_5 = (.373(Y_7 - Y_6) + Y_6)$$
$$CX_6 = (.567(X_8 - X_7) + X_7) \qquad CY_6 = (.567(Y_8 - Y_7) + Y_7)$$
$$CX_7 = (.436(X_{10} - X_9) + X_9) \qquad CY_7 = (.436(Y_{10} - Y_9) + Y_9)$$
$$CX_8 = (.430(X_{11} - X_{10}) + X_{10}) \qquad CY_8 = (.430(Y_{11} - Y_{10}) + Y_{10})$$
$$CX_9 = (.506(X_{12} - X_{11}) + X_{11}) \qquad CY_9 = (.506(Y_{12} - Y_{11}) + Y_{11})$$
$$CX_{10} = (.571(X_{14} - X_{13}) + X_{13}) \qquad CY_{10} = (.571(Y_{14} - Y_{13}) + Y_{13})$$
$$CX_{11} = (.567(X_{15} - X_{14}) + X_{14}) \qquad CY_{11} = (.567(Y_{15} - Y_{14}) + Y_{14})$$
$$CX_{12} = (.567(X_{16} - X_{15}) + X_{15}) \qquad CY_{12} = (.567(Y_{16} - Y_{15}) + Y_{15})$$
$$CX_{13} = (.436(X_{18} - X_{17}) + X_{17}) \qquad CY_{13} = (.436(Y_{18} - Y_{17}) + Y_{17})$$
$$CX_{14} = (.430(X_{19} - X_{18}) + X_{18}) \qquad CY_{14} = (.430(Y_{19} - Y_{18}) + Y_{18})$$
$$CX_{15} = (.506(X_{20} - X_{19}) + X_{19}) \qquad CY_{15} = (.506(Y_{20} - Y_{19}) + Y_{19})$$

C.G. % of Segment — Dempster - Hay (Kines. Review) 1973, p. 29

III. GIVEN constant weight percentages: (Dempster 1955, modified a bit from Miller - Nelson, p. 97)

$W_1 = .0145$ | $W_9 = .0060$
$W_2 = .0470$ | $W_{10} = .0145$
$W_3 = .0995$ | $W_{11} = .0470$
$W_4 = .2320$ | $W_{12} = .0995$
$W_5 = .2170$ | $W_{13} = .0280$
$W_6 = .0790$ | $W_{14} = .0160$
$W_7 = .0280$ | $W_{15} = .0060$
$W_8 = .0160$

IV. CALCULATE "X" and "Y" moments, where

$XM_1 = CX_1 * W_1$ $\qquad$ $YM_1 = CY_1 * W_1$

$XM_2 = CX_2 * W_2$ $\qquad$ $YM_2 = CY_2 * W_2$

•

•

•

$XM_{15} = CX_{15} * W_{15}$ $\qquad$ $YM_{15} = CY_{15} * W_{15}$

V. SUM the "X" and "Y" moments:

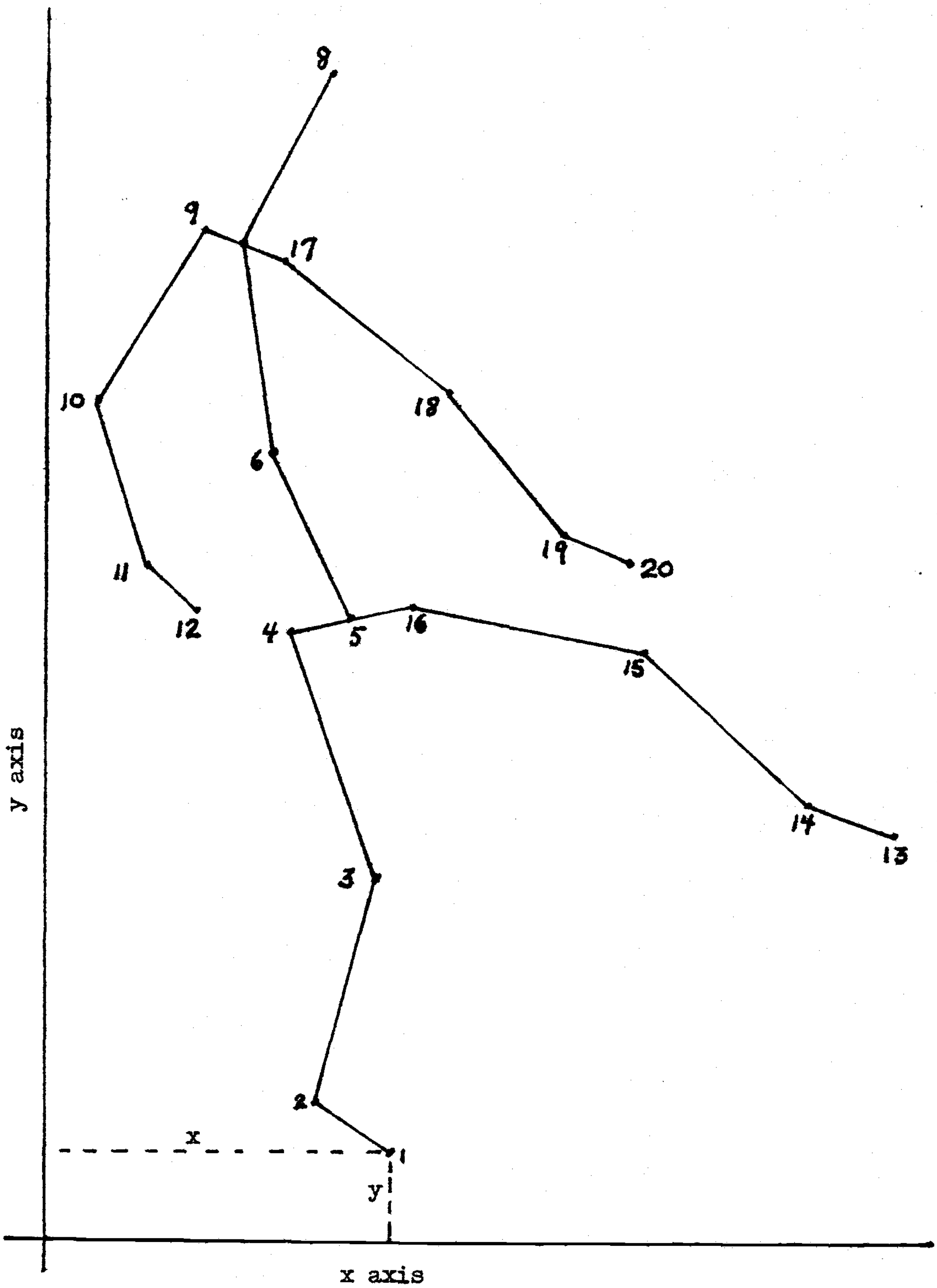
$XM = \sum_{1}^{15} (CX_i * W_i)$ $\qquad$ $YM = \sum_{1}^{15} (CY_i * W_i)$

VI. The center of gravity of the body is, therefore (XM,YM).

Center of Gravity Location — Segmental Method

Identification of 20 points to be digitized:

1. right toe
2. right ankle
3. right knee
4. right hip joint
5. mid-hip joints
6. first lumbar vertebra
7. mid-shoulder joints (level of seventh cervical vertebra)
8. top of head
9. right shoulder joint
10. right elbow
11. right wrist
12. right fingertips
13. left toe
14. left ankle
15. left knee
16. left hip joint
17. left shoulder joint
18. left elbow
19. left wrist
20. left fingertips


8
9
17
10
18
6
19
20
11
12
4
5
16
15
y axis
14
13
3
2
x
1
y
x axis

APPENDIX F

CALCULATION OF INFORMATION FOR PROJECTION PROGRAM

Calculation of information for projection program:

S_1

conversion factor = 3.16

x,y coordinates for:

origin to toe (.98, .40)

origin to base of hurdle (-.92, .36)

frame 1 (.66, 1.38)

3 (.44, 1.44)

5 (.22, 1.49)

7 (.00, 1.53)

9 (-.22, 1.56)

11 (-.44, 1.57)

hurdle to origin = .92 or 2.89 feet

toe to origin = .98 or 3.08 feet

toe to hurdle = 1.89 or 5.97 feet

c. g. to origin = .66 or 2.09 feet

c. g. to toe = .32 or 1.00 feet

c. g. to hurdle = 1.58 or 4.98 feet

height of c. g. above origin at take-off = 1.38

height of toe above origin at take-off = .40

height of c. g. above toe at take-off = .98

toe is .04 inches above ground

h = 1.02

S_2

conversion factor = 3.33

x,y coordinates for:

origin to toe (1.0, .47)

origin to base of hurdle (-.94, .44)

frame 1 (.60, 1.45)

3 (.40, 1.50)

5 (.20, 1.55)

7 (-.01, 1.59)

9 (-.22, 1.61)

11 (-.43, 1.62)

hurdle to origin = .94 or 3.13 feet

toe to origin = 1.0 or 3.33 feet

toe to hurdle = 1.94 or 6.47 feet

c. g. to origin = .60 or 2.0 feet

c. g. to toe = .40 or 1.33 feet

c. g. to hurdle = 1.54 or 5.13 feet

height of c. g. above origin at take-off = 1.45

height of toe above origin at take-off = .47

height of c. g. above toe at take-off = .98

toe is .03 above ground

h = 1.01

S_3

conversion factor = 3.16

x,y coordinates for:

origin to toe (1.13, .42)

origin to base of hurdle (-.92, .35)

frame 1 (.57, 1.49)

3 (.37, 1.54)

5 (.17, 1.58)

7 (-.05, 1.61)

9 (-.27, 1.63)

11 (-.47, 1.61)

hurdle to origin = .92 or 2.91 feet

toe to origin = 1.13 or 3.57 feet

toe to hurdle = 2.05 or 6.48 feet

c. g. to origin = .57 or 1.80 feet

c. g. to toe = .56 or 1.77 feet

c. g. to hurdle = 1.49 or 4.71 feet

height of c. g. above origin at take-off = 1.49

height of toe above origin at take-off = .42

height of c. g. above toe at take-off = 1.06

toe is .08 above ground

h = 1.14

S_4

conversion factor = 2.86

x,y coordinates for:

origin to toe (1.55, .18)

origin to base of hurdle (-.89, .17)

frame 1 (1.13, 1.37)

3 (.90, 1.44)

5 (.67, 1.49)

7 (.44, 1.53)

9 (.21, 1.57)

11 (- .03, 1.60)

hurdle to origin = .89 or 2.55 feet

toe to origin = 1.55 or 4.44 feet

toe to hurdle = 2.44 or 6.98 feet

c. g. to origin = 1.13 or 3.23 feet

c. g. to toe = .42 or 1.20 feet

c. g. to hurdle = 2.02 or 5.78 feet

height of c. g. above origin at take-off = 1.37

height of toe above origin at take-off = .18

height of c. g. above toe at take-off = 1.19

toe is .01 above ground

h = 1.20

S_5

conversion factor = 2.86

x,y coordinates for:

origin to toe (.99, .20)

origin to base of hurdle (-.89, .17)

frame 1 (.60, 1.41)

3 (.40, 1.46)

5 (.19, 1.50)

7 (-.01, 1.53)

9 (-.22, 1.56)

11 (-.44, 1.56)

hurdle to origin = .89 or 2.55 feet

toe to origin = .99 or 2.83 feet

toe to hurdle = 1.88 or 5.38 feet

c. g. to origin = .60 or 1.72 feet

c. g. to toe = .39 or 1.12 feet

c. g. to hurdle = 1.49 or 4.26 feet

height of c. g. above origin at take-off = 1.41

height of toe above origin at take-off = .20

height of c. g. above toe at take-off = 1.21

toe is .03 above ground

h = 1.24

S_6

conversion factor = 3.74

x,y coordinates for:

origin to toe (.43, .61)

origin to base of hurdle (-.99, .58)

frame 1 (.21, 1.45)

3 (.07, 1.51)

5 (-.07, 1.55)

6 (-.22, 1.58)

7 (-.36, 1.61)

8 (-.51, 1.62)

hurdle to origin = .99 or 3.71 feet

toe to origin = .43 or 1.61 feet

toe to hurdle = 1.42 or 5.32 feet

c. g. to origin = .21 or .79 feet

c. g. to toe = .22 or .82 feet

c. g. to hurdle = 1.20 or 4.49 feet

height of c. g. above origin at take-off = 1.45

height of toe above origin at take-off = .61

height of c. g. above toe at take-off = .84

toe is .03 above ground

h = .87

APPENDIX G

PRINT-OUTS OF PROJECTION PROGRAM

```
INITIAL V(Y)
        6.5291
      (FT/SEC)

INITIAL V(X) =
      -22.2815
      (FT/SEC)

INITIAL V(0) =
      -23.2184
      (FT/SEC)

ANGLE OF
PROJECTION =
      -16.3320
      (DEGREES)

TIME TO HP =
        0.2029
         (SEC)

HT. ABOVE START.
LEVEL AT HP =
        0.6625
          (FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
        3.8856
          (FT)

HORIZONTAL DIS-
TANCE TO HP =
       -4.5218
          (FT)
```

S_1

```
INITIAL V(Y)
        6.2207
      (FT/SEC)

INITIAL V(X) =
      -21.6746
      (FT/SEC)

INITIAL V(0) =
      -22.5496
      (FT/SEC)

ANGLE OF
PROJECTION =
      -16.0136
      (DEGREES)

TIME TO HP =
        0.1934
         (SEC)

HT. ABOVE START.
LEVEL AT HP =
        0.6014
          (FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
        3.9680
          (FT)

HORIZONTAL DIS-
TANCE TO HP =
       -4.1908
          (FT)
```

S_2

[illegible]
5.5614
(FT/SEC)

INITIAL V(X) =
-20.6775
(FT/SEC)

INITIAL V(0) =
-21.4123
(FT/SEC)

ANGLE OF
PROJECTION =
-15.0540
(DEGREES)

TIME TO HP =
0.1729
(SEC)

HT. ABOVE START.
LEVEL AT HP =
0.4807
(FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
4.0830
(FT)

HORIZONTAL DIS-
TANCE TO HP =
[illegible]

S_3

[illegible]
6.6312
(FT/SEC)

INITIAL V(X) =
-21.1400
(FT/SEC)

INITIAL V(0) =
-22.1556
(FT/SEC)

ANGLE OF
PROJECTION =
-17.4155
(DEGREES)

TIME TO HP =
0.2061
(SEC)

HT. ABOVE START.
LEVEL AT HP =
0.6834
(FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
4.1185
(FT)

HORIZONTAL DIS-
TANCE TO HP =
[illegible].3572
(FT)

S_4

INITIAL V(Y)
5.2215
(FT/SEC)

INITIAL V(X) =
-18.7418
(FT/SEC)

INITIAL V(0) =
-19.4555
(FT/SEC)

ANGLE OF
PROJECTION =
-15.5679
(DEGREES)

TIME TO HP =
0.1623
(SEC)

HT. ABOVE START.
LEVEL AT HP =
0.4237
(FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
3.9733
(FT)

HORIZONTAL DIS-
TANCE TO HP =
-3.0417
(FT)

S_5

INITIAL V(Y)
6.9031
(FT/SEC)

INITIAL V(X) =
-17.0382
(FT/SEC)

INITIAL V(0) =
-18.4062
(FT/SEC)

ANGLE OF
PROJECTION =
-22.2286
(DEGREES)

TIME TO HP =
0.2164
(SEC)

HT. ABOVE START.
LEVEL AT HP =
0.7535
(FT)

HT. ABOVE FLOOR
(GROUND) AT HP =
4.0104
(FT)

HORIZONTAL DIS-
TANCE TO HP =
-3.[illegible]876
(FT)

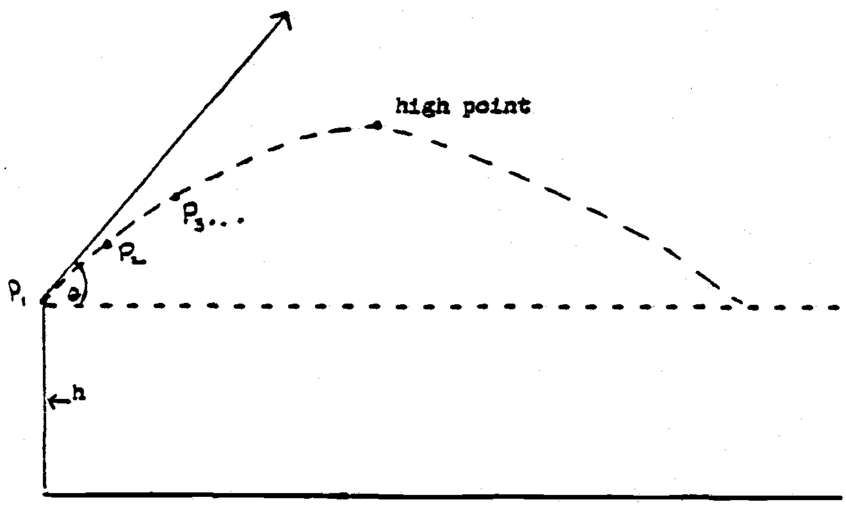
S_6

APPENDIX H

DOCUMENTATION OF PROJECTION PROGRAM

PROJECTION

This program calculates the initial velocity and angle of projection of a point (x,y). These values are obtained from "n" independent measurements at equal time intervals, and an average value for initial velocity and angle of projection are calculated. Using these values, the flight characteristics of the projected object (or point) are obtained. A plot of the trajectory is optional. The mathematical basis for the program follows:



Total Range

A. Definitions

1. Measured Points (P_i): ($i = 1,2,3,\ldots,n$)

   $P_1 = (x_1,y_1)$: take off, or initial point.

   $P_2 = (x_2,y_2)$

   .
   .
   .

   $P_n = (x_n,y_n)$

2. Time interval (t_i): ($i = 1,2,3,\ldots,n-1$)

   If there are "n" measurements, then there are "n-1" time intervals. If Δt = the time (in seconds) of each interval, then:

   $t_1 = (1)*\Delta t$ seconds

   $t_2 = (2)*\Delta t$ seconds

   .
   .
   .

   $t_{n-1} = (n-1)*\Delta t$ seconds

3. Displacement.

   If P_1 (x_1,y_1) = initial (take off) point) then:

   $(x_2 - x_1)$ = <u>horizontal</u> <u>displacement</u> in time interval, t_1.

   $(x_3 - x_1)$ = " " " " " , t_2.

   .
   .
   .

   $(x_n - x_1)$ = " " " " " , t_{n-1}.

   Likewise:

   $(y_2 - y_1)$ = <u>vertical</u> <u>displacement</u> in time interval, t_1.

   $(y_3 - y_1)$ = " " " " " , t_2.

   .
   .
   .

   $(y_n - y_1)$ = " " " " " , t_{n-1}.

4. Conversion Factor.

Confac = film conversion factor.

Measured point coordinates (x_1,y_1), (x_2,y_2),....,(x_n,y_n)

and

"h" (height above ground or flcor at P_1)

are given in graph units by the user as data input. In order for the output to be given in feet and in feet/sec, a film conversion factor must be given. If the user enters the above data in "feet" units, this conversion factor (Confac) = 1.

B. Calculations

1. Horizontal Velocity: (initial, but constant).

$\overrightarrow{V_x(t_i)}$ at any point $(x_i, y_i) = \dfrac{d(x_i - x_1)}{dt_i}$

In this program the horizontal velocity is used to calculate the initial velocity. Vertical velocity is not used to find the initial velocity, but could be found using the following formula:

Vertical Velocity (initial):

$$\overrightarrow{V_y(t_i)} = \frac{d\left[(y_i - y_1) + \frac{1}{2}g(t_i)^2\right]}{dt_i} \quad \text{and} \quad \overrightarrow{V_o(t_i)} = \sqrt{V_x(t_i)^2 + V_y(t_i)^2}$$

$$= \frac{d(y_i - y_1)}{dt_i} + gt_i \quad \text{where } g = 32.1725 \text{ ft/sec}^2$$

2. Angle of Projection.

$$\theta_i = \tan^{-1}\left[\frac{(y_i - y_1) + \frac{1}{2}g(t_i)^2}{(x_i - x_1)}\right]$$

3. Initial Velocity.

$$\overrightarrow{V_o(t_i)} = \overrightarrow{V_x(t_i)}\cos\theta$$

(This program calculates initial velocity using this formula)

C. Averaging.

Theoretically, $\overrightarrow{V_o(t_1)} = \overrightarrow{V_o(t_2)} = \ldots = \overrightarrow{V_o(t_{n-1})}$ and, likewise, $\theta_1 = \theta_2 = \theta_3 = \ldots = \theta_{n-1}$.

However, due to error, this will not be the case. Therefore, to find a good approximation of both values ($\overrightarrow{V_o}$ and θ), calculate the average θ and $\overrightarrow{V_o}$ values.

1. Average Velocity (Initial):

$$\overline{\overrightarrow{V_o(t)}} = \frac{\sum_{i=1}^{n-1} (\overrightarrow{V_o(t_i)})}{n-1}$$

2. Average Angle of Projection:

$$\bar{\theta} = \frac{\sum_{i=1}^{n-1} (\theta_i)}{n-1}$$

D. Flight Characteristics

1. Initial Vertical Velocity.

$$\overrightarrow{V_y(t)} = \overrightarrow{V_o} \sin \theta - gt$$

where $\begin{cases} t = 0 \\ \theta = \bar{\theta} \text{ (calculated)} \\ \overrightarrow{V_o} = \overrightarrow{\bar{V}_o} \text{ (calculated)} \end{cases}$

2. Initial (Constant) Horizontal Velocity.

$$\overrightarrow{V_x(t)} = \overrightarrow{V_o} \cos \theta$$

where $\begin{cases} \theta = \bar{\theta} \text{ (calculated)} \\ \overrightarrow{V_o} = \overrightarrow{\bar{V}_o} \text{ (calculated)} \end{cases}$

3. Initial Velocity.

$$\overrightarrow{V_o} = \overrightarrow{\bar{V}_o}$$

4. Angle of Projection.

$$\theta = \bar{\theta}$$

5. Time to High Point (HP).

$$= \frac{\overrightarrow{V_y(t)}}{g}$$

where $g = 32.1725 \text{ ft/sec}^2$

6. Height Above Starting Level at High Point (HP).

$$= \frac{\overrightarrow{V_y(t)} * \overrightarrow{V_y(t)}}{g} - \tfrac{1}{2} g (t_{hp})^2$$

where $\{ t_{hp}$ = time to HP

7. Height Above Floor (ground) at High Point.

= (Ht. above start at HP) + h

where { h = height above ground (floor) at P_1.

h = given input data

8. Horizontal Distance to HP.

$= \vec{V}_x * t_{hp}$

9. RANGE OF FLIGHT:

A) Total Time.

$= t_{hp} + t_j$ where { t_j = the time to drop from the height calculated in #7, above: if this height = s, then

$$t_j = \sqrt{\frac{2s}{g}}$$

B) Distance.

$= \vec{V}_x * (t_{hp} + t_j)$

10. PLOT OPTION.

Plot obtained from:

$$y = x\tan\theta - \frac{gx^2}{2\vec{V}_o^{\,2}\cos^2\theta}$$

where {
$\theta = \bar{\theta}$
$\vec{V}_o = \bar{\vec{V}}_o$
x = independent variable (given input data as "tic mark interval")
y = dependent variable

This equation derived from the following parametric relationships:

$$x = (\vec{V}_o \cos\theta)t$$
$$y = (\vec{V}_o \sin\theta)t - \tfrac{1}{2}gt^2$$

Program PROJECTION

PLOT Labels:

The user must supply own labels for the trajectory plot.

Suggested labels include:

1. Tic - mark intervals.
2. Maximum height of the non-gravity line, or hand drawn non-gravity line.
3. Height point of the trajectory.
4. Original data points.
5. "h" value on the y-axis.
6. Total horizontal distance.

USERS NOTES:

A) Disregard the section of the plotted trajectory which sometimes falls below ground line level. This is necessary for ending the plot calculations within the program.

B) If the plot is not smooth enough, decrease the size of the x-interval entered in step #16.

Data Analysis Submittal Form for Program

PROJECTION

Part One of program PROJECTION calculates the average angle of projection and average initial velocity and is based on "n" number of data points.

Part Two of program PROJECTION calculates the flight characteristics of the projected object and incorporates a plot option.

Please give the following data (as defined below) on the data sheet (attached).

P_1 = initial (or take-off, for body projection) point.

P_2 =
P_3 =
P_4 =
.
.
.
P_n =

Equal-interval data points sampled. The user may include as many points as desired (the minimum = two: P_1 and any other value, P_i).

Δt = time interval between each point (must be an equal interval between each set of points: i.e. 1 frame, 2 frames, etc.).

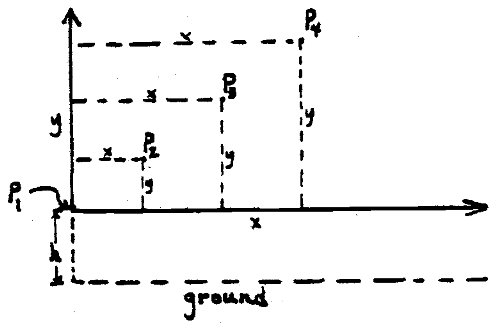
Confac = film conversion factor.

h = height above the ground (or floor) of the object, or point at the initial (or take-off) point.

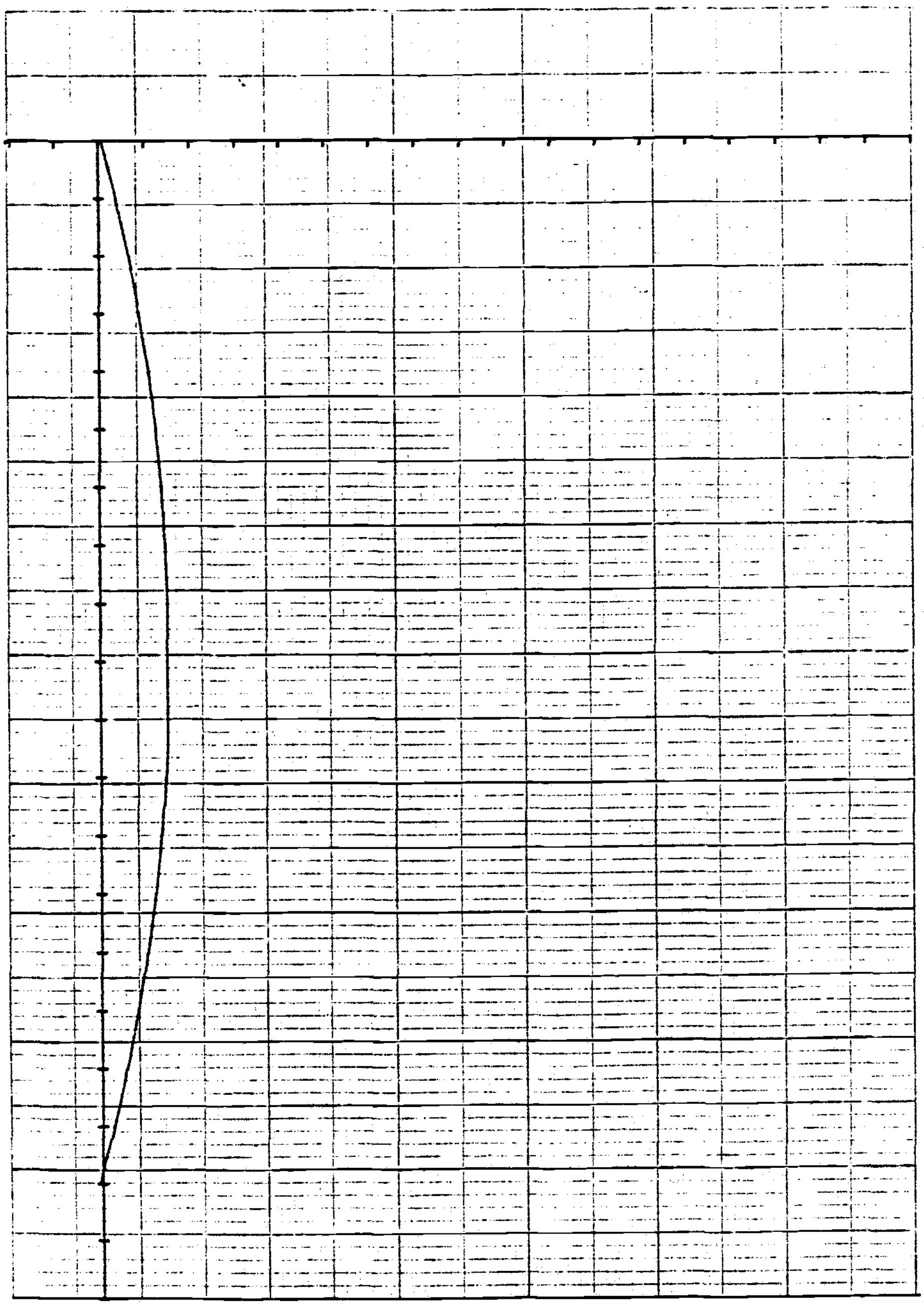
PLOT option: [X] = plot

[0] = no plot

UNITS: All data points P_i and the value h are to be given in film measurement units (e.g. 50ths of an inch). Δt is a time measurement in seconds. Confac is the film conversion factor.



P4
x
P3
x
y
y
P2
x
y
y
P1
y
x
h
ground



APPENDIX I

CALCULATIONS OF DISTANCES ON TRACINGS

S_1 take-off distance 5.97 feet = 155.5 50ths inch

distance touchdown to hurdle $\frac{155.5}{5.97} = \frac{89}{x}$ 3.42 feet

distance touchdown to c.g. $\frac{155.5}{5.97} = \frac{20.5}{x}$ x = 9.44 inches

height c. g. above hurdle $\frac{155.5}{5.97} = \frac{29}{x}$ x = 13.36 inches

S_2 take-off distance 6.47 feet = 160 50ths inch

distance touchdown to hurdle $\frac{160}{6.47} = \frac{94.5}{x}$ x = 3.82 feet

distance touchdown to c.g. $\frac{160}{6.47} = \frac{13.5}{x}$ x = 6.55 inches

height c. g. above hurdle $\frac{160}{6.47} = \frac{33}{x}$ x = 16.01 inches

S_3 take-off distance 6.48 feet = 173.5 50ths inch

distance touchdown to hurdle $\frac{173.5}{6.48} = \frac{95}{x}$ x = 3.55 feet

distance touchdown to c. g. $\frac{173.5}{6.48} = \frac{21.5}{x}$ x = 9.64 inches

height c. g. above hurdle $\frac{173.5}{6.48} = \frac{37}{x}$ x = 16.58 inches

S_4 take-off distance 6.98 feet = 197 50ths inch

distance touchdown to hurdle $\frac{197}{6.98} = \frac{89}{x}$ x = 3.15 feet

distance touchdown to c. g. $\frac{197}{6.98} = \frac{21}{x}$ x = 8.93 inches

height c. g. above hurdle $\frac{197}{6.98} = \frac{27}{x}$ x = 11.48 inches

S_5 take-off distance 5.38 feet = 151.5 50ths inch

distance touchdown to hurdle $\frac{151.5}{5.38} = \frac{98.5}{x}$ x = 3.5 feet distance touchdown to c. g. $\frac{151.5}{5.38} = \frac{21}{x}$ x = 8.95 inches

height c. g. above hurdle $\frac{151.5}{5.38} = \frac{29}{x}$ x = 12.36 inches

S_6 take-off distance 5.32 feet = 126 50ths inch

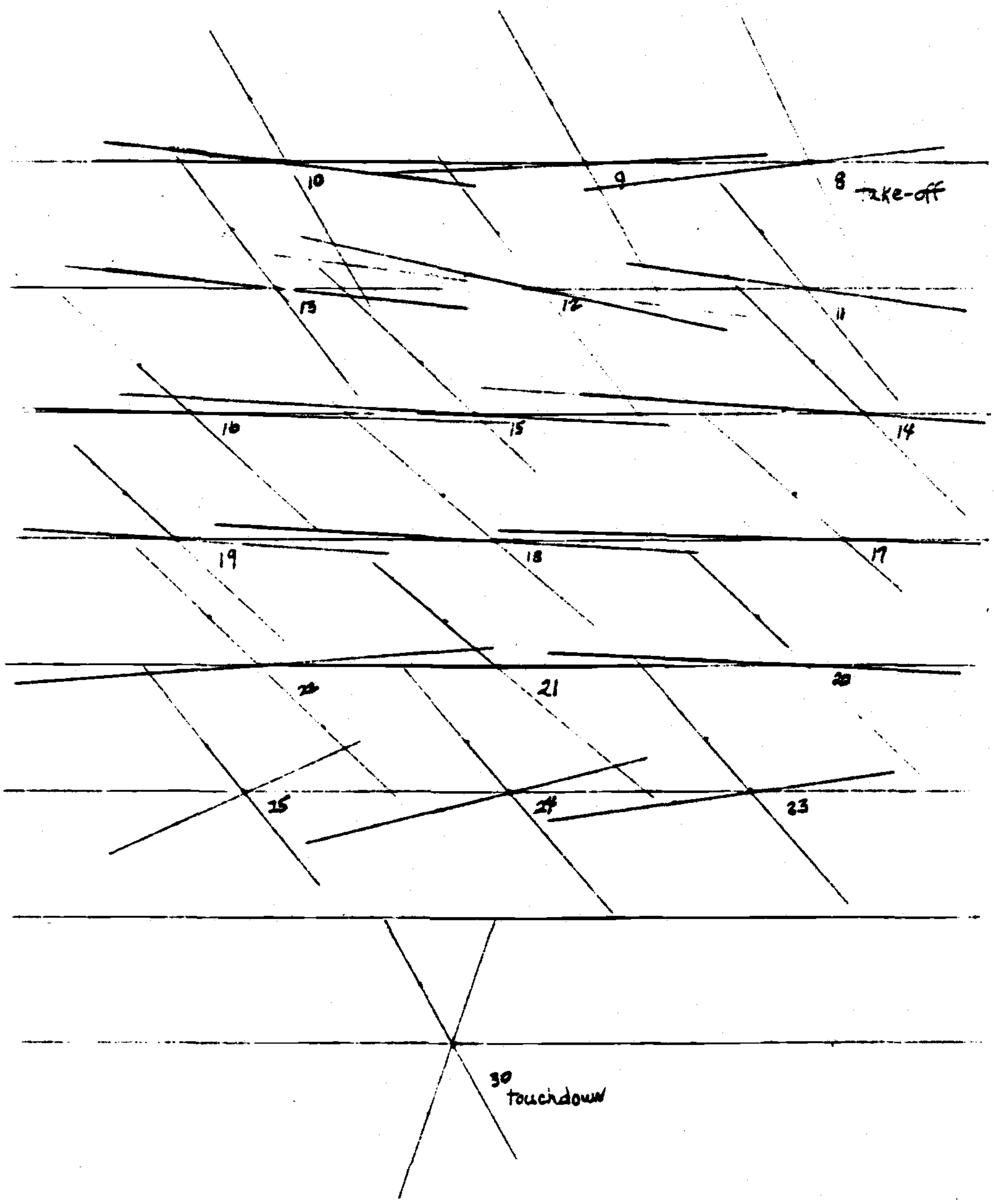
distance touchdown to hurdle $\frac{126}{5.32} = \frac{78}{x}$ x = 3.29 feet

distance touchdown to c. g. $\frac{126}{5.32} = \frac{13.5}{x}$ x = 6.84 inches

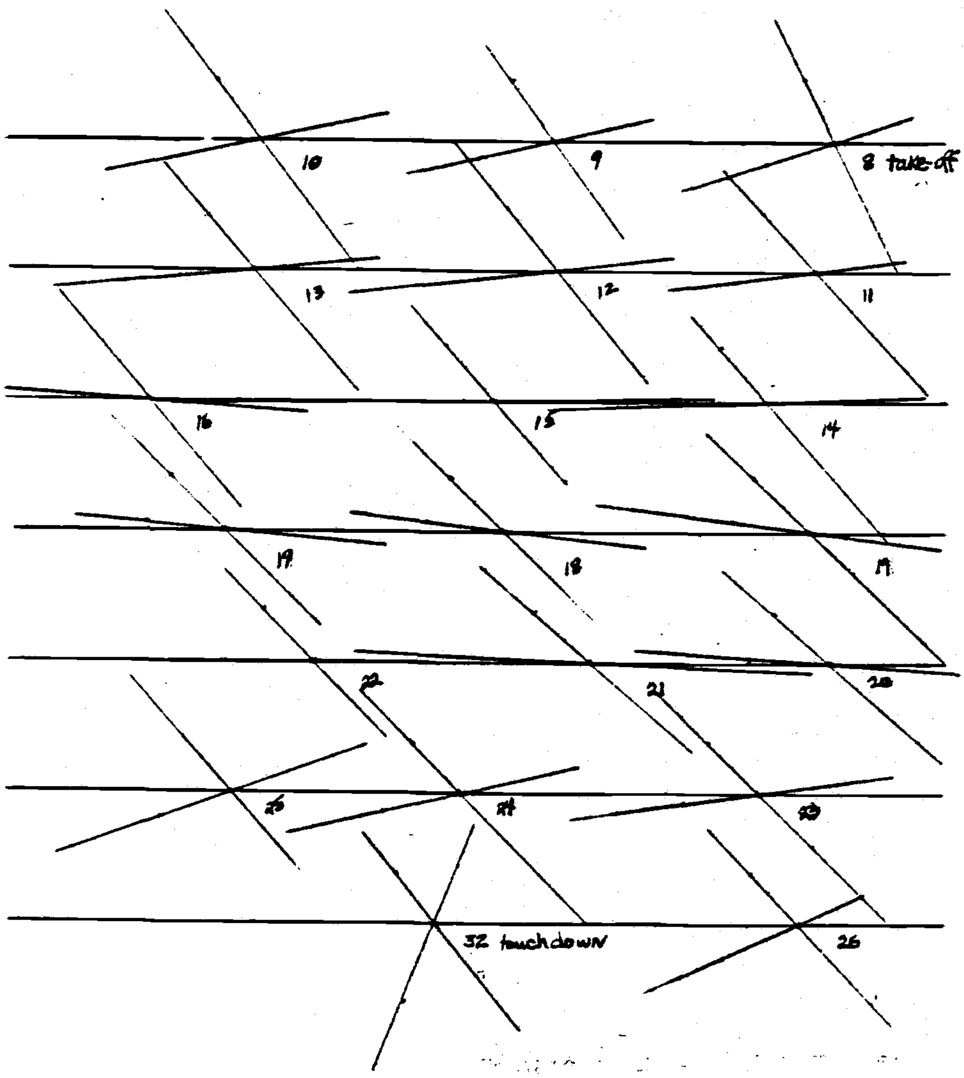
height c. g. above hurdle $\frac{126}{5.32} = \frac{38}{x}$ x = 19.25 inches

APPENDIX J

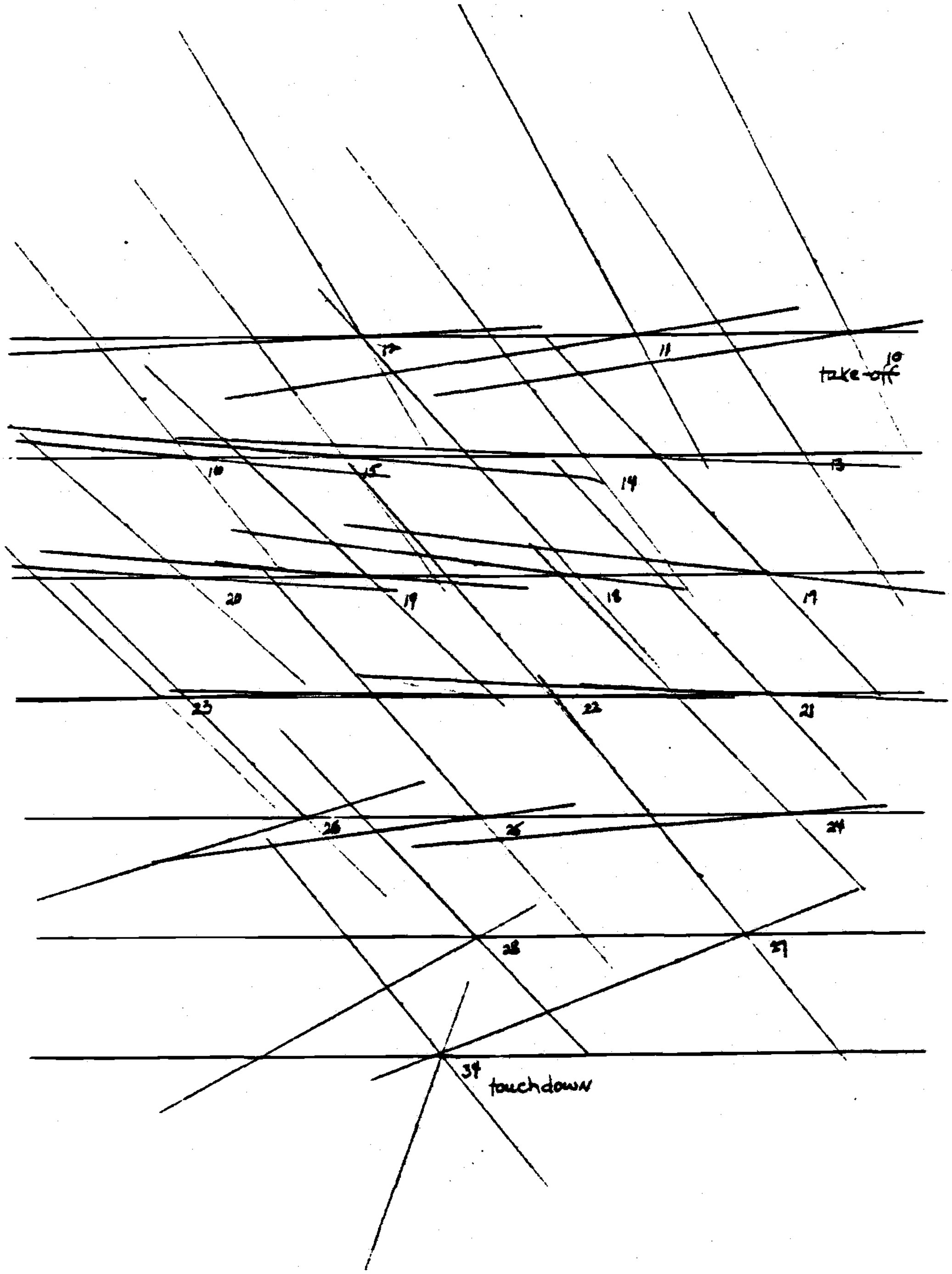
SEGMENT LINE DRAWINGS TRUNK AND LEAD LEG THIGH



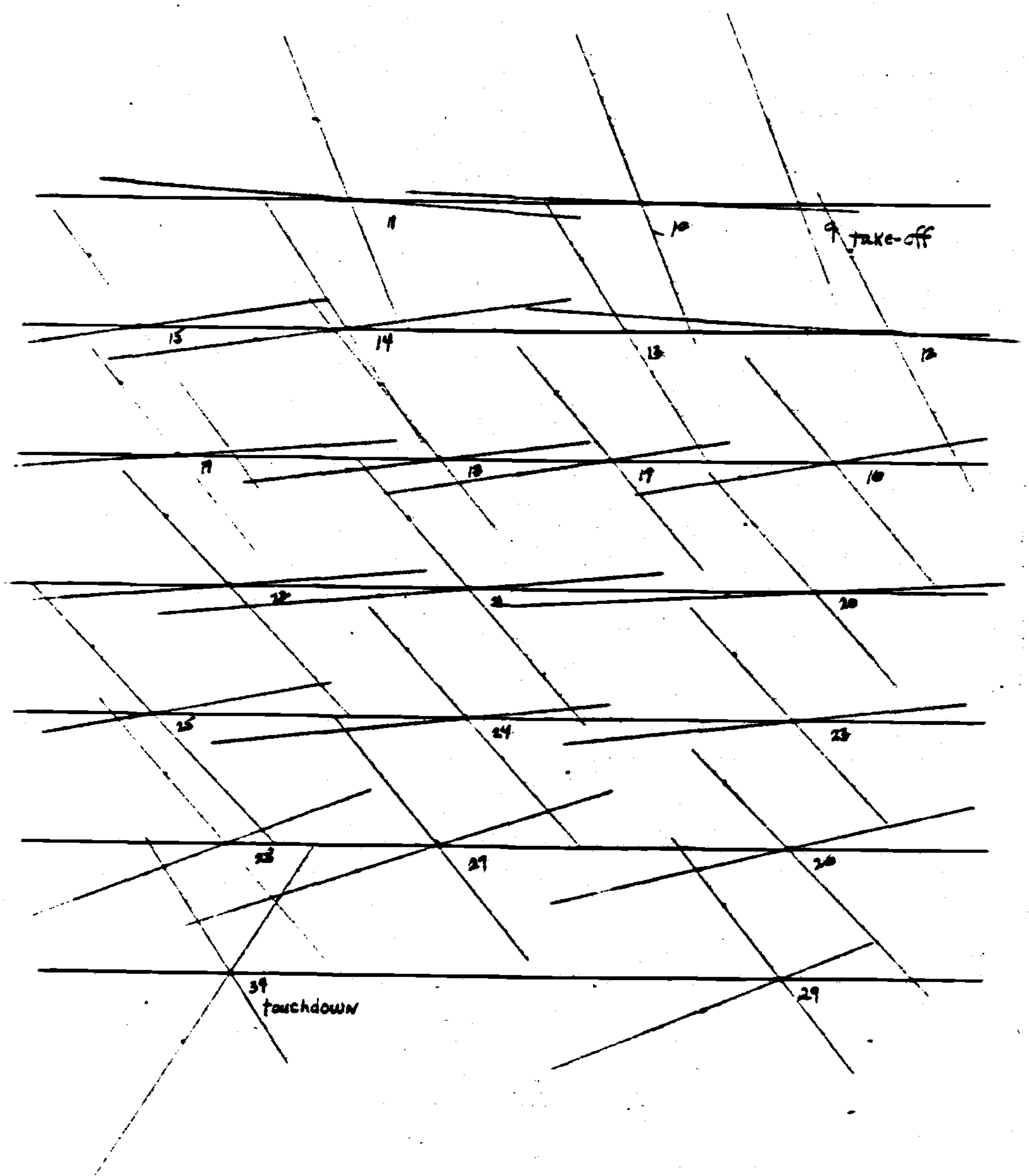
S_1



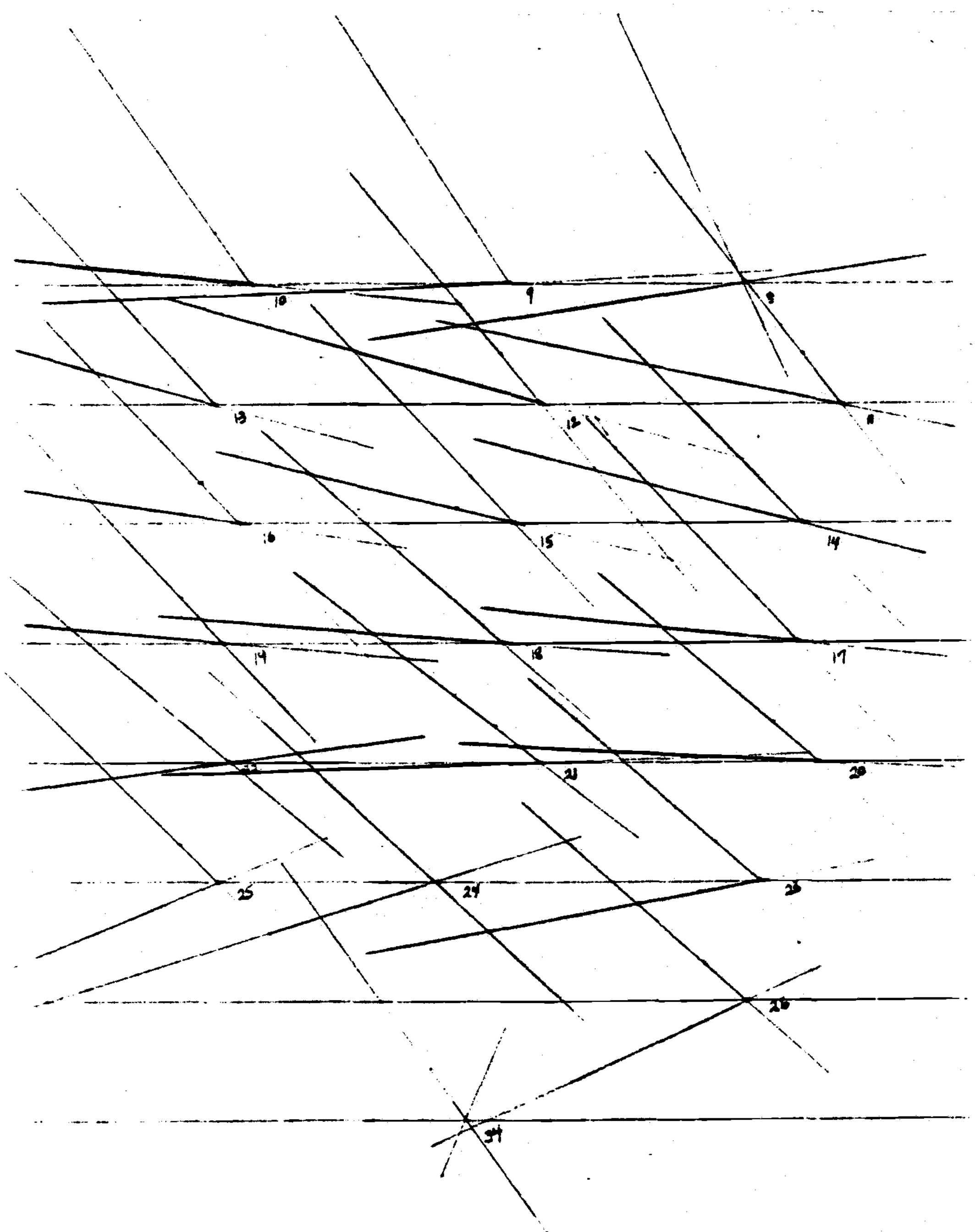
S_2



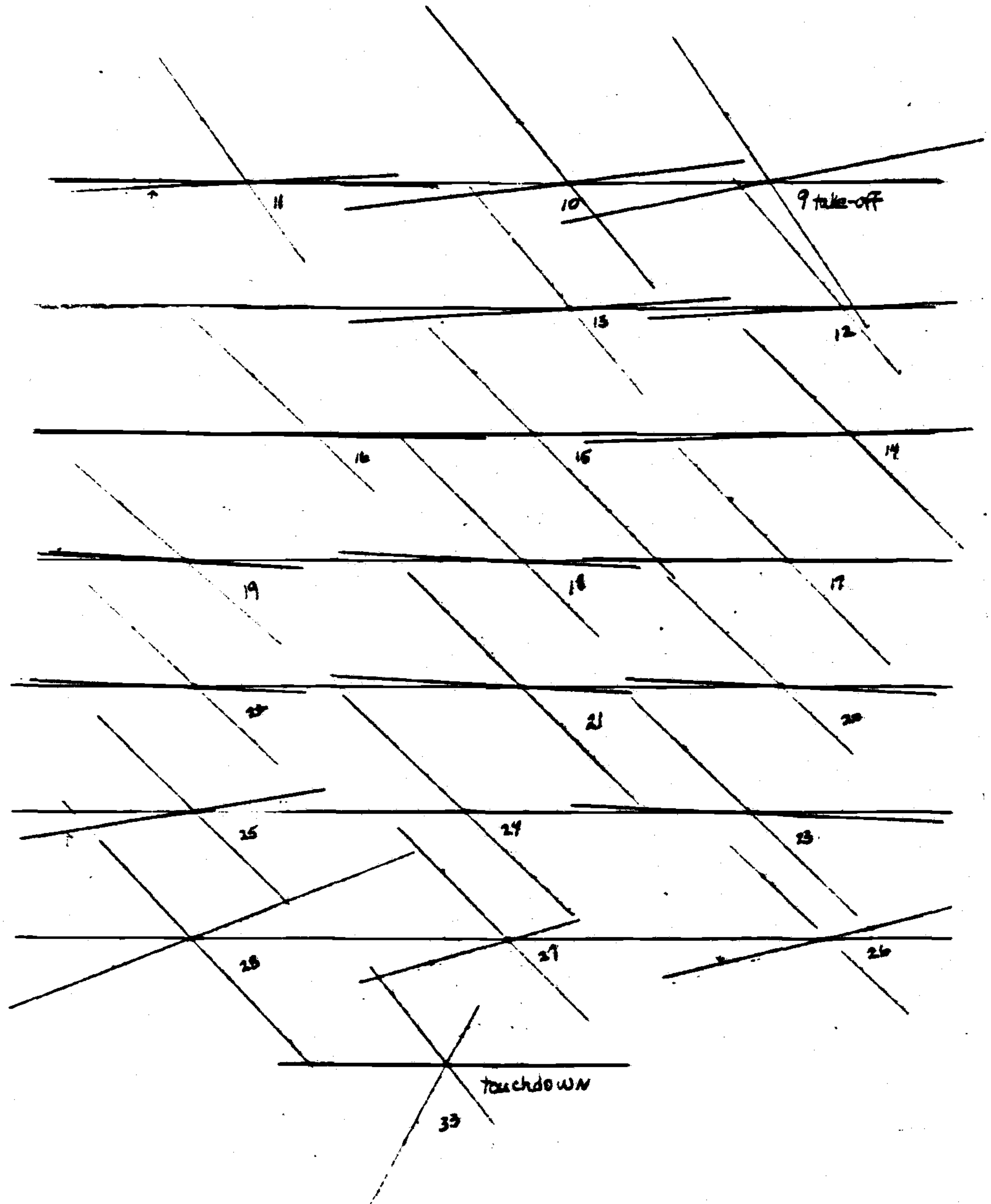
S_3



S_4



S_5


11
10
9 take-off
13
12
16
15
14
19
18
17
21
25
24
23
28
27
26
touchdown
33

S$_6$

APPENDIX K

TRUNK AND THIGH ANGLE MEASUREMENTS

S_1

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
8	65	- 7	72
9	61	- 3	64
10	59	7	53
11	51	8	43
12	52	12	40
13	53	6	46
14	45	4	41
15	43	3	40
16	42	1	41
17	42	2	40
18	41	3	38
19	43	4	40
20	44	3	41
21	40	0	40
22	44	- 5	48
23	49	- 8	57
24	50	-14	64
25	52	-25	76
30	61	-71	132

[a] - denotes below horizontal; all positive values denote above horizontal

S_2

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
8	63	-18	81
9	54	-13	66
10	53	-12	65
11	48	- 7	54
12	51	- 7	57
13	49	- 5	55
14	48	- 2	50
15	49	- 1	49
16	50	3	46
17	44	7	36
18	44	7	38
19	44	5	39
20	41	4	37
21	41	2	39
22	46	0	46
23	45	- 8	53
24	46	-13	59
25	49	-20	69
26	47	-25	71
32	51	-68	118

[a] - denotes below horizontal; all positive values denote above horizontal

S_3

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
10	64	- 8	72
11	62	- 9	71
12	60	- 3	63
13	57	0	57
14	53	3	50
15	53	6	47
16	52	6	46
17	47	7	40
18	48	8	40
19	44	5	39
20	42	4	38
21	48	3	44
22	50	1	48
23	44	- 2	46
24	46	- 5	51
25	49	- 8	57
26	46	-17	62
27	52	-21	72
28	47	-29	76
34	52	-70	122

[a] - denotes below horizontal; all positive values denote above horizontal

S_4

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
9	69	1	68
10	68	2	65
11	67	4	63
12	62	4	58
13	57	- 1	58
14	56	- 8	64
15	53	- 9	62
16	50	-10	60
17	50	- 9	60
18	50	- 7	58
19	50	- 5	54
20	48	- 3	51
21	49	- 5	54
22	47	- 5	52
23	47	- 6	54
24	48	- 6	54
25	46	-11	57
26	46	-13	58
27	51	-18	69
28	48	-21	70
29	51	-22	73
34	57	-57	114

[a] - denotes below horizontal; all positive values denote above horizontal

S_5

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
9	57	-11	67
10	51	- 7	58
11	55	- 4	58
12	50	- 3	53
13	50	- 4	54
14	45	- 2	47
15	45	0	45
16	43	1	43
17	46	1	45
18	45	3	42
19	41	4	37
20	44	3	40
21	45	4	42
22	43	2	41
23	44	2	42
24	44	0	44
25	44	- 9	53
26	43	-13	56
27	45	-17	62
28	47	-21	68
33	52	-61	113

[a] - denotes below horizontal; all positive values denote above horizontal

S_6

Frame	Trunk to Horizontal (°)	Thigh to Horizontal[a] (°)	Trunk to Thigh (°)
8	65	- 9	74
9	57	- 2	59
10	55	6	49
11	52	12	40
12	50	16	34
13	48	15	32
14	46	14	32
15	47	14	33
16	46	9	38
17	46	6	40
18	42	5	37
19	42	6	36
20	41	3	38
21	38	- 2	40
22	40	- 8	48
23	41	-10	51
24	43	-18	60
25	45	-22	68
26	42	-25	67
34	55	-67	122

[a] - denotes below horizontal; all positive values denote above horizontal