1980

A three dimensional analysis of selected mechanics of the Arabian dive roll.

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A THREE DIMENSIONAL ANALYSIS OF SELECTED MECHANICS OF THE ARABIAN DIVE ROLL

By

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A Thesis
submitted to the Faculty of Graduate Studies
through the Faculty of
Human Kinetics in Partial Fulfillment
of the requirements for the Degree
of Master of Human Kinetics at
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1980

ABSTRACT

The dual purpose of the study was to establish a method of three-dimensional cinematographical angular determination and to use the method to investigate selected mechanics of the arabian dive roll. The experimental set up included two 16mm. high speed cameras positioned so that their optical axes were perpendicular. A structure, representing a standard orthogonal coordinate system, was filmed to provide a reference coordinate system. Seven subjects performed two arabian dive rolls and the best performance for each subject was selected for indepth analysis. The location of the body's center of gravity was determined from three dimensional spatial coordinates taken from film in conjunction with Dempster's (1955) and Clauser et al. (1969) segmental parameter data. Vertical force was determined by multiplying the subject's mass by the vertical acceleration of the subject's center of gravity. Segmental angular displacements were found using vector dot product identities. Angular displacements of the body around the principal axes of rotation were found using spherical polar coordinates along with coordinate transformations. The method's accuracy to measure spatial location, lens origin distance and absolute angles revealed measurement errors of 1.15cm., 5.2% and 4.3° respectively. Horizontal motion of the center of gravity demonstrated a constant displacement pattern throughout the arabian dive roll. Horizontal velocity decreased near take off and increased during the start of the roll phase. Vertical displacement of the center of gravity followed a parabolic path during the

airborne phase of the arabian dive roll. Vertical velocity was maximal just prior to take off, zero at the peak of the airborne phase and minimal at the start of the roll phase. Little lateral deviation of the body's center of gravity was observed during the execution of the arabian dive roll. Maximum vertical force occured at the start of the take off phase and remained constant through out the airborne phase. Vertical force showed a marked increase at the start of the roll phase and then leveled off during the completion of the skill. The subjects rotated a mean of 2.433 radians and .293 radians around the transverse and sagittal axes during the airborne phase respectively. Each subject exhibited rotations of less than 3.14 radians (180°) around the longitudinal axis. Segmental movements of the upper extremities did not reveal any apparent associations with relative angular velocities of the body around the principal axes of rotation in the airborne phase. Within the limitations of this study it can be concluded that the method used is a viable technique for the study of multi-axial rotational movements. Also, variations in segmental angular displacements do not totally explain the variance associated with relative angular velocities around the principal axes of rotation in the air borne phase of the arabian dive roll.

DEDICATION

This work is dedicated to Wendy Gervais, Paul and Giselle Gervais, and Carl and Pat Schell for their interest and encouragement throughout my studies.

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My sincerest appreciation is extended to Dr. G. Wayne Marino, my advisor and good friend for his continued help and guidance during my graduate studies. I am indebted to Drs. Jack L. Leavitt and Francis W. Lemire for their participation and contributions as my thesis committee members.

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CHAPTER I

INTRODUCTION

Cinematographic analysis has been the most commonly used technique to quantify human movement in biomechanical research. Traditionally this form of performance analysis has been done with a single camera set perpendicular to the plane of motion. Data is then collected from film using instruments that provide a two dimensional coordinate representation of the film image points. This information is used in conjunction with body segment parameter data to study kinematic and kinetic features of human movement.

The traditional filming technique can provide two dimensional data of linear displacement of the body as a whole. Absolute angular displacement of body segments, has been obtained from film or indirectly by mathematical calculations using coordinate data taken from film. Generally, two dimensional cinematography has dealt with quantification of general motion that occurs in a single plane. The axis of rotation, around which this motion occurs, is perpendicular to the film plane of the camera. Therefore, acquisition of relative angular displacement is obtained in the same fashion as absolute angular displacement. Even though two dimensional cinematography does provide a means of obtaining three forms of displacement data, it is restricted to the quantification of general motion that has rotational motion within one plane.

Man's linear displacement through space is accompanied by rotational motion that occurs in more than one plane, around more than one principal axes of rotation at a time. This fact has lead investigators (Bergeman 1974; Duquet et al. 1973; Miller and Petak 1973; Shapiro 1978; Dainis 1978; Van Gheluwe 1974) to develop three-dimensional filming techniques to more fully describe human movement. These investigators have extended the concepts of two dimensional spatial location of points to spatial location in a three dimensional coordinate system. This has provided a method of acquiring linear displacement-time data three dimensionally.

Most researchers of three dimensional analysis techniques have dealt exclusively with three dimensional spatial location determination and have only hypothesized that this would provide adequate information needed for angular determination. Since the principal axes of rotation are through the body's center of gravity, perpendicular to one another, a body rotation around one or more of the axes will also mean a concurrent rotation of the principal axes in relationship to the rotation of the body. Therefore, the concept of rotation around an axis perpendicular to the film plane will not describe relative angular displacement for a multi-axial rotational movement.

The main objective of this present study was the expansion of some of the existing methods of three dimensional cinematography to include acquisition of comparable displacement data as can be found with the traditional two dimensional filming technique. Specifically, this research dealt with the development of methods to obtain absolute and relative angular displacement.

As a consequence of the limitations associated with existing cinematographical analysis techniques, many movement patterns have not been adequately investigated. For example, the rotational complexity of many gymnastic skills has been a hindrance to quantitative biomechanical research in the sport of artistic gymnastics.

The arabian dive roll is a skill in which rotation around both the longitudinal and transverse axes occur simultaneously. This skill has been used as the preliminary skill in the learning sequence for many twisting backward somersaults. At present, this skill has not been investigated quantitatively. The second objective of this study was the investigation of the mechanical factors associated with the technical execution of the arabian dive roll.

Statement of the Problem

The purpose of this study was to establish a method of three-dimensional angular determination of both absolute angular displacement and angular displacement relative to the three principal axes of rotation of the human body. Secondly, it was the intent of the research to employ this method to investigate selected mechanical components of the arabian dive roll. Specifically the study dealt with quantification of the following mechanical aspects:

1) Time of execution of each of the three phases of the arabian dive roll.

2) The path of the body's center of gravity in three dimensions.

3) Segmental rotational displacements.

4) Angular displacement of the body around the principal axes of rotation.

5) Vertical force-time histories during the execution of the arabian dive roll.

6) The relationships between segmental displacements and angular velocities of the body around the principal axes of rotation.

Limitations

Cinematographical analysis, whether two dimensional or three dimensional, has some inherent errors associated with data collection. Errors due to the physical characteristics of film, lens optics, and the mechanical precision of cameras and analyzers can not be avoided completely. These errors along with the human factor in film data reduction were controlled as much as possible through periodic reliability checks. Preliminary tests were conducted to determine the specific mean error associated with data collection on the analysis system at the University of Windsor. This error estimate was used to weight the resulting data for film analysis.

The arabian dive roll can be considered an advanced tumbling skill. This fact precluded the use of a large sample size. A sample of seven gymnasts were used for this study.

Another unavoidable limitation within this study involved the use of body segment parameter data. Dempster (1955) conducted his original study on thirteen male cadavers. The data on segmental center of mass published by Clauser et al. (1969) was based largely on Dempster's data. The cadavers used in these studies do not totally resemble the living characteristics and anthropometric qualities of the athletes used in this study. However, the data developed by Clauser et al. and Dempster have been the most commonly used and are the most appropriate that are available.

Definition of Terms

The major terms used in this study were defined as follows:

Absolute Angle is the angle formed by two non-colinear vectors representing articulating body segments.

Relative Angle is the angle formed between a vector and an axis defined in space.

Longitudinal Axis is the rotation axis extending from the head to the feet passing through the body's center of gravity.

Transverse Axis is the rotation axis extending from right to left through the body's center of gravity at right angles to the other two axes.

Sagittal Axis is the rotation axis passing from front to rear through the body's center of gravity at right angles to the other two axes.

<u>Take off Phase</u> is that portion of the arabian dive roll from the time the center of gravity of the body starts moving in an upward direction to the instant the feet leave the ground.

<u>Take off</u> is that instant the feet leave the ground.

<u>Airborne Phase</u> is that portion of the arabian dive roll from the point of take off until the hands make contact with the mat.

<u>Roll Phase</u> is that portion of the arabian dive roll from the instant the hands made contact with the mat to the instant the feet make contact with the mat.

<u>Reference Coordinate System</u> is the orthogonal reference frame coordinate axes.

CHAPTER II

REVIEW OF LITERATURE

The arabian dive roll is a fundamental tumbling skill in gymnastics which includes rotation around both the longitudinal and transverse axis. In order to attempt a quantitative analysis of such a skill, a three dimensional cinematographical method was used.

A review of the literature pertaining to this study was conducted in three distinct areas: cinematography, angular determination, and sports skill analysis.

Cinematography

Researchers (Bergeman 1974; Duquet et al. 1973; Dainis 1978; Miller and Petak 1973; Shapiro 1978; Van Gheluwe 1974), in the field of three dimensional spatial determination have concluded that more than one camera is necessary in order to retrieve three dimensional spatial coordinate data from film. The characteristic similarities and differences in the researchers' methods stem from: camera positions, determination of camera positions (either through external measurement or from film measurements), and the method of combining two or more two dimensional views into three dimensional data.

Bergeman (1974) developed a method for three dimensional coordinate determination using two still cameras, positioned so that a common point of origin was visible in the field of view of both cameras. Measurements of actual camera parameters were taken with a transit prior to filming. Bergeman filmed a point of known spatial location, then using trigonometry he established a series of linear equations for each camera. Combining these equations and setting the partial derivatives equal to zero, he established a set of equations to determine the X,Y,Z, coordinates for any point in the field of view of the two cameras. Bergeman reported a mean absolute error of .25 inches in locating a point's three dimensional spatial location.

Dainis (1978) proposed a method for spatial coordinate determination from object field data. In order to calculate camera-object distances Dainis used three planar points and one non-coplanar point in the object field to make further calculations. Using the camera-object distance as a normal vector and using a least squares fit, he found the vector's length by using the image distances of six sides of the tetrahedron formed by the four points. The determination of a point's spatial orientation was achieved in a similar manner using vector identities. Dainis placed his main emphasis on the versatility of the method with respect to camera placements. He reported results for spatial determination in reference to different camera placements. Dainis' technique appears to be theoretically sound, yet he failed to report the actual reliability of the method in locating the true three dimensional spatial coordinates of a point.

In 1973, Miller and Petak proposed a tridimensional filming method using three cameras. The high speed camera positions were flexible except that all cameras were on the same horizontal plane. As in Bergeman's method, a transit was used to determine camera positions. The intersection of the optical axis of each camera at a single point was used as the origin of the rectangular system.

Miller and Petak used the following relationship to establish a series of two equations for each camera:

$$\frac{\text{image size}}{\text{lens-film plane distance}} = \frac{\text{object size}}{\text{lens-object distance}}$$

Substituting trigonometric transformations derived from the angular position of the camera's optical axes into the previous set of equations, they found it possible to determine the spatial coordinates of any point.

Duquet et al. (1973) positioned the optical axes of their cameras perpendicular to one another, with one camera at the side and the other overhead. Reference points were synchronized from the two filmed views and a distance conversion factor was found. If a point was visible in both views it was manipulated graphically by a series of rotations, to a common plane. Since the rotations were of the complete film plane, angles and lines retained their orientation to one another. This graphic manipulation to a common plane enabled Duquet to subsequently determine a point's spatial location tridimensionally.

Shapiro's method (1978), differed most from the previous ones described in that knowledge of the camera parameters or experimental set up prior to filming was not needed. Shapiro's method required that the cameras were set on the same horizontal plane and that their position remain fixed. The procedure also required that the experimental field be covered by an overlap of the two camera angles. A structure, having the shape of a pyramid, of known size and dimension, representing the X,Y,Z coordinates was filmed prior to the experimental filming. Standard film analysis was performed to find the X and Y coordinates from each film for each control point position on the structure. Shapiro established a series of twelve equations for each view derived from the coordinates of at least six non-coplanar control points. These equations were solved to find the direct linear transformation (DLT) parameters for each camera. These DLT parameters provided implicit information relating camera orientation and lens and film distortion. These equations with the DLT parameters enabled Shapiro to input the X,Y film coordinates for an unknown point to determine its tridimensional location. Shapiro's validation of the method revealed that the DLT method provided results which were as good for spatial location of points as conventional two dimensional cinematography.

Van Gheluwe (1974) proposed a method of three dimensional analysis based on the principle of orthogonal coordinate transformations. Two cameras were set so that their optical axes would intersect and all other camera parameters were calculated mathematically from image coordinates of points of known spatial location. Van Gheluwe assigned an orthogonal reference frame to each camera. Using the relationship between image size and object size described in Miller's method, Van Gheluwe applied the laws of orthogonal coordinate transformation to establish a set of equations for each camera. Using the image coordinates of known points, from each camera, the transformation functions were solved. Subsequent three dimensional location of an arbitrary point could be determined by inputting its X,Y film coordinates into these equations. Van Gheluwe reported that spatial location of a point was accurate to 1 cm. using this method.

Angular Determination

As has been previously mentioned the majority of cinematographic research using three dimensional techniques has dealt with spatial location determination. None of the previously mentioned authors dealt with angular determination in three dimensions.

Noss (1967) was the first to attempt a description of angular determination in a multi-camera filming technique. His method called "Tri-axial Analysis" had a camera configuration such that three cameras were set up perpendicular to the X,Y,Z coordinate axes of a standard right handed coordinate system. The optical axis of each camera intersected at the origin of the coordinate system. Noss theorized that the measurement of a static angle would equal the mean of the image angles measured from the film views of each camera.

In an evaluation of Noss' technique, Putman (1979) demonstrated mathematically that the angle formed by the intersection of two lines is not equal to the average of the angle formed by their projected images. Putman disproved Noss's method by citing one example where it fails. He represented the intersecting lines forming the angle as vectors. The angle formed was found using the dot product equation for two vectors:

$$\bar{A}\cdot\bar{B}=|\bar{A}|\,|\bar{B}|\cos\theta$$

$$\theta=\cos^{-1}\frac{\bar{A}\cdot\bar{B}}{|\bar{A}|\,|\bar{B}|}$$

where $\bar{A}$ and $\bar{B}$ are the vectors and $|\bar{A}|$; $|\bar{B}|$ are scalars representing their magnitudes.

Putman compared the average of the projected angles to that of the true angle as found by the dot product equation. There was no equality between the two solutions. His conclusion of Noss' method for measuring angles in three dimensions was that,

> the logical alternative method is to first obtain accurate three-dimensional coordinates of the end points of each line segment, and then to derive the magnitude of the angle between them by taking either the dot or the cross product of the vectors representing each segment.

Van Gheluwe and Duquet (1977) did a study of two twisting methods in the backwards somersault. Their filming method was based on the one proposed by Van Gheluwe in 1974. The angle of the hip bend was an important element in their investigation. Using the coordinates of the midpoint between the shoulders, hip and knees, they calculated the absolute angle of the hipbend using the dot product equation. Including the error associated with location of a point's coordinates and camera speed synchronization, they estimated an error of 6 degrees when calculating the hip angle.

In a preliminary investigation of angular determination, Gervais and Marino (1979) calculated the angular displacement of a vector from two coordinate axes of a X,Y,Z standard coordinate system. A filming technique similar to that of Van Gheluwe (1974) was used. End point data was found for two vectors and their angle relative to the X and Z axes was calculated using the end point data and spherical co-ordinate transformations. The mean deviation of the calculated measures from the true angles was found to be 4.86%.

Skill Analysis

The majority of the literature pertaining to tumbling was found to be of a descriptive nature. Through photographic sequences, coaches have described the performance of tumbling skills as performed by their elite gymnasts.

Some of the techniques important to the performance of the arabian dive roll were described by Criley (1970). He stated that the contact angle and body position following the round off were important factors related to take off. He felt that the position of the head and arms contributed significantly to the initiation of the twist. He also reported that a fully extended body must be maintained throughout the airborne phase and upon contact with the mat before the roll commences.

Kaneko (1977), using a similar sequential photo description, stated that upon take off a gymnast completes the first quarter twist due to rotation in his upper body. During the second quarter twist a gymnast arches his body to aid in the dive rotation.

George (1980), gave a non-quantitative mechanical account of the arabian dive roll. He related the description to desirable mechanical chracteristics within each phase of the movement.

> The initiation of maximum vertical lift, appropriate backwards rotation, and twist initiation with a fully extended body shape are desirable characteristics of the take off (George, 1980, p. 109).

Since the arabian dive roll requires only 180° of twist around the longitudinal axis, George stated that spreading the arms laterally prior to the peak of the airborne trajectory would check longitudinal rotation during the descent phase. The desirable characteristics of the roll phase were described as body control and dissipation of the downward momentum of the body. He stated that these objectives were enhanced by a fully extended body with arms stretched, reaching for the mat, prior to contact with the mat.

Quantitative studies of projectile type tumbling skills have substantiated many of the performance criteria important to the arabian dive roll. For example, Payne and Barker (1975) studied the take off forces in a flic flac and back somersault. They concluded that the moment of force at take off and the angle of take off are the main contributing factors in the performance of these airborne skills.

According to the analogue to Newton's first law of motion, once a gymnast is in the air his angular momentum is constant. Since angular momentum is composed of moments of inertia and angular velocity, a gymnast can manipulate the moments of inertia thus directly influencing angular velocity. Borms et al. (1973) and Van Gheluwe et al. (1977), in their investigations of a full twisting backwards somersault, evaluated the trunk, hip, leg angle. Since rotation around the longitudinal axis is common to both the arabian dive roll and the full twisting back somersault, the size of the hip angle is an important mechanical consideration of both skills. These investigators found that the greater the hip angle, the greater the athlete's moment of inertia thus reducing his angular velocity and the degree of success in performing the skill.

The performance of the arabian dive roll, which is a projectile activity, is influenced by a gymnast's take off angle and the vertical force at take off. Quantification of technical factors and the path of the center of gravity, can provide information on a gymnast's ability to meet the technique requirements of the skill as described by Kaneko (1977), Criley (1970), and George (1980). Other factors which have an influence on execution of the arabian dive roll are segmental angles and their displacements over time. The arabian dive roll has been described as a 180 degree twist around the longitudinal axis as well as rotation around the transverse axis. Since the skill has rotation around more than one axis at a time, it would appear that in order to study the rotational chracteristics of the arabian dive roll more precisely, a three dimensional analysis technique must be employed.

Summary of the Literature

A review of the research pertaining to cinematography has revealed that the use of a multi-camera technique is essential for the acquisition of three dimensional data. The majority of the techniques reported in the literature have dealt primarily with three dimensional spatial coordinate determination. It appears that few attempts have been made to extend three dimensional analysis to rotational mechanics. However, the literature related to theories of angular determination has demonstrated that through the use of vector dot product and spherical polar coordinates, absolute and relative angular displacement can be found.

The literature on the arabian dive roll revealed some of the execution parameters of importance to a successful performance. The execution parameters included vertical lift, proper body extension and form. Related to these parameters are the mechanical components of vertical velocity, segmental displacement and body rotation.

CHAPTER III

METHODS

The dual purpose of this study was the establishment of a cinematographical technique designed to acquire three dimensional spatial and angular data and the employment of this technique to investigate selected mechanical components of the arabian dive roll.

Subjects

Seven male gymnasts between the ages of 17 and 22 were used for this study. They ranged in gymnastic expertise from excellent club gymnasts to one who is a national team member. The physical chracteristics of the subjects are described in Appendix A.

Preliminary Measures

Prior to the actual experimental filming, anthropometric measurements were taken for each subject. Steps were undertaken to familiarize the subjects with the filming procedure and to aid film data reduction.

Each subject wore a swim suit during the filming of each trial. Several body landmarks were identified and marked by white tape patches with a black cross hatch over the landmark's center. Landmarks identified and marked included: lateral and medial malleoli of both ankles; lateral and medial condyles of each knee; right and left greater trochanters; suprasternal notch and its positional equivalent on the back; the acromioclavicular joints of each shoulder; and the medial and lateral epicondyles of the elbows. Also, a strip was placed around the carpals, touching the styloid processes of each wrist.

Using a body caliper the segmental lengths of the upper arm, lower arm, upper leg, and lower leg for the right side of the body were measured on each subject. Each subject's body weight was also determined.

Task

Each subject was asked to perform an arabian dive roll from a round-off. Each subject was allowed as many warm-up trials as he felt were necessary in order to establish a take off position which would allow the skill to be performed in the approximate center of the filming area. The task was repeated until the subject performed two satisfactory arabian dive rolls.

Filming Area

The experimental filming was conducted within a gymnasium. The subjects performed the arabian dive roll on a Speith Anderson Floor Exercise mat of approximately 3 inches in thickness. The mat was 12 meters long and 2 meters wide. The skill was performed within the half of the mat closest to the front camera.

Five photographic lights were placed around the filming area to provide sufficient illumination for the filming. The gymnasium's physical make up provided for numerous reference marks which were used to ensure proper film carriage during the film analysis procedure.

Cinematography

A 16 mm. Locam camera with a 10mm. lens and a 16mm. Hycam camera with a 25mm. lens were used in this study. The Locam was placed at the side of the filming area and the Hycam was positioned at the front of the filming area. Figure 1 provides a schematic representation of the camera set up.

The cameras were set to operate at 100 frames per second. True film speed was determined later from timing marks on the films. These timing marks were produced from the light emitting diodes within each camera, which operated at 100 impulses per second.

The first step in the camera placement procedure consisted of marking a center for the filming area on the mat. From this point, using elementary geometry, two surveying chains were used to measure the camera distances from the film area center. The front view camera was positioned at 15.24 meters from the center and the side view camera was positioned at 9.15 meters from the center. Final leveling and positioning of the cameras was done with carpenter levels and plumb bobs.

A general reference frame was placed at the center of the filming area such that its X coordinate axis was parallel to the film plane of the front view camera. The structure's Y coordinate axis was parallel to the film plane of the side view camera (figure 2). This structure was filmed using both cameras, prior to the filming of the subjects' performances. The reference frame defined the reference

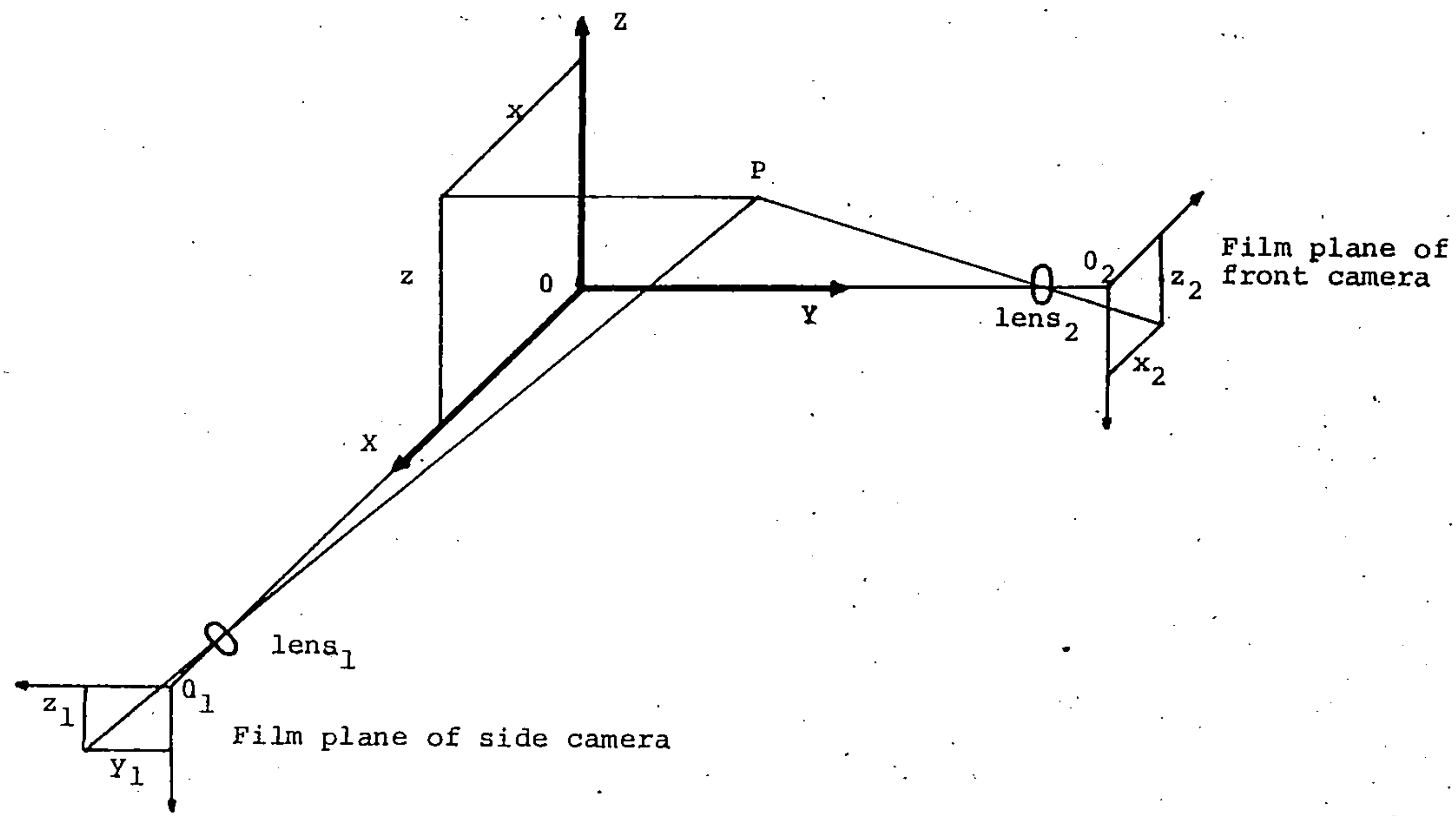


Figure 1. CAMERA SET UP

coordinate system which was used in all subsequent data analysis. Positioned, at various places around the structure, was a set of twelve points of known spatial location. These twelve points were used as spatial point references.

During the filming of each trial, the cameras were turned on as the performer's front foot touched down in the hurdle step prior to the round-off. An incandescent light was placed within the film view of each camera. This light was turned on shortly after the cameras were started. The purpose of this procedure was to provide a common time reference for subsequent synchronization of the frame rates of the two cameras.

Film Analysis

Film analysis was conducted on the film analysis system at the University of Windsor. A Numonics Digitizer was used to obtain coordinate data of film image points. The horizontal coordinates for the front view film image corresponded to the X coordinate axis of the reference coordinate system. The horizontal and vertical coordinates for the side view film image corresponded to the Y and Z coordinate axes of the reference coordinate system. All cartesian coordinates found this way were translated by the structure's origin image coordinates. This procedure, accomplished through a computer program, ensured that the positions of all points were defined relative to the reference coordinate system's origin.

All mathematical computations were completed by a fortran computer program on the computer system at the University of Windsor.

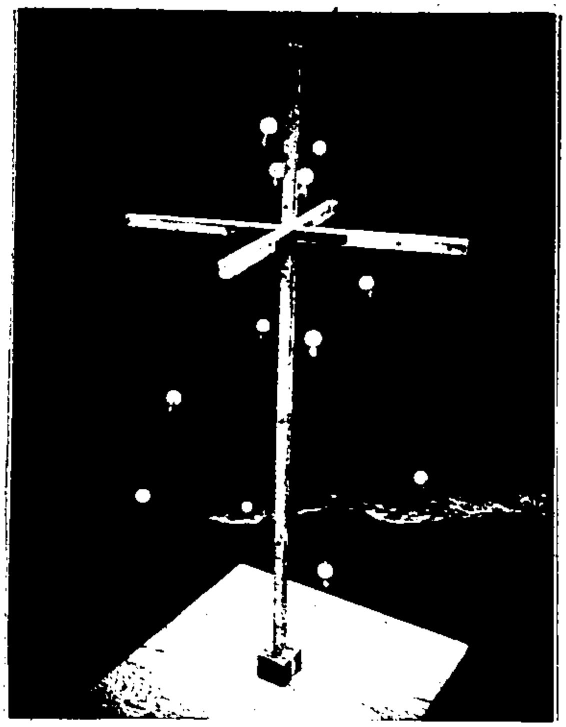


Figure 2. REFERENCE COORDINATE SYSTEM STRUCTURE

Time Parameters

Film speed was determined for each trial for both film views. The film speed was calculated by using the timing marks placed on the film at a rate of 100 per second by the internal light emitting diodes. For each trial the number of frames and timing marks were counted. The frame rate was then found using the following calculation:

$$\text{Frame Rate} = \frac{\text{number of frames}}{\text{number of timing marks X .01 sec.}}$$

Film data was taken from every fourth frame of film. The time interval between frames was calculated by the following:

$$\text{Time Between Frames} = \frac{4}{\text{frame rate}}$$

The time interval for each phase of the arabian dive roll was found by counting the number of frames for the phase and dividing that number by the film rate for that trial.

Time Synchronization

The two cameras used in this study were set to operate at 100 frames per second. Since running speeds were dependent on mechanical efficiency, the camera rates were not identical. In order to facilitate the synchronization of rate and time, a common time reference was provided by an incandescent light.

The X image coordinates taken from the front view were synchronized to the time base of the Y and Z coordinates taken from the side view for each trial. Using the previously calculated film rates for each view of a trial, the time interval from the light's illumination to an entity common to both views was calculated. The distinguishable movement entity, which was common to both views and which had a common time interval from the time reference, was selected as the time synchronizing frame. Spline interpolation, (McLaughlin et al. 1977), was used to estimate the X coordinates taken from the front view at an equivalent time between frames found on the side view film. Figure 3 provides a schematic representation of the time synchronization procedure used. These synchronized coordinates were used in conjunction with the Y and Z image coordinates in subsequent analysis.

Tridimensional Spatial Location

A point's three dimensional location was defined relative to the reference coordinate system. The image coordinates (x,y,z) taken from the films were translated in terms of the origin's image coordinates. These new coordinates, were used as input into the following equations for the direct calculation of a point's spatial coordinates:

$$X = \frac{f_1 D_2 x_2 - D_1 y_1 x_2}{f_1 f_2 - y_1 x_2} \tag{1}$$

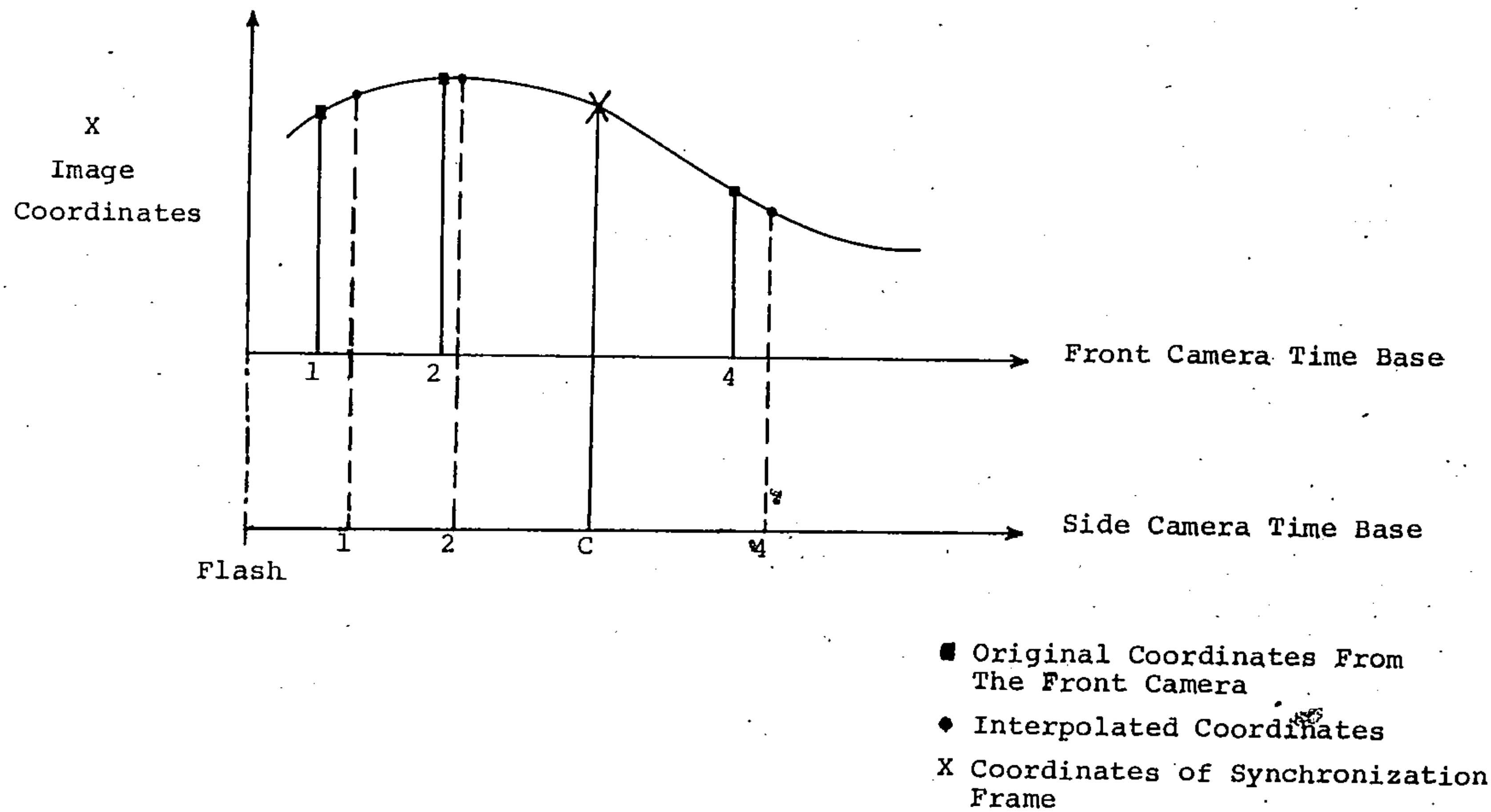


Figure 3. SCHEMATIC REPRESENTATION OF TIME SYNCHRONIZATION

(1)

$$Y = \frac{D_1 y_1 - X y_1}{f_1}$$

$$Z = \frac{D_1 z_1 - X z_1}{f_1}$$

where f_1 and f_2 are the focal lengths for each camera and D_1 and D_2 are the lens center to origin distances for each camera respectively. (subscript 1 refers to the side camera, subscript 2 refers to the front camera)

Preliminary Analysis

Preliminary analysis using the twelve reference points around the structure was conducted. The image (x,y,z) and the real coordinates (X,Y,Z) of one of the twelve points were used to calculate the distance from the structure origin to each lens center with the following algorithms:

(2)

$$D_1 = \frac{f_1 Y}{y_1} + X \qquad \text{(side camera distance)}$$

$$D_2 = \frac{f_2 X}{x_2} + Y \qquad \text{(front camera distance)}$$

Utilizing these distances and equations (1), the spatial location of the remaining eleven points were found. The mean value of the deviation between the calculated coordinates and the measured coordinates of those eleven points was determined. This procedure was repeated using each point as the reference, calculating the coordinates for the remaining eleven points and finding the mean deviation. The reference point that produced the least mean deviation was selected as the reference point for the remaining computations for this study. The origin to lens distances found using this point were the parameters used for equations (1). The mean deviation between calculated and measured location was used as the error estimate in the cubic spline interpolation function.

Segmental End Point Coordinates

The fourteen segment model of the body, proposed by Clauser et al. (1969), was used for this study. Three dimensional spatial locations of twenty one segmental end points were determined in order to provide data required for subsequent analysis. The locations of the segmental end points were found for every frame of film analyzed. Spatial location was determined from the (x,y,z) image coordinates for each point using equations (1). The segmental end points are listed in Table 1.

Center of Gravity

Following time synchronization of the X coordinates and the spatial location of the twenty one segmental end points, the position of the body's center of gravity was determined for each frame analyzed.

TABLE 1

SEGMENTAL END POINTS USED TO CALCULATE CENTER OF GRAVITY

SEGMENT	POINT*	END POINT
1. Right foot	(1)	Tip of longest toe
	(2)	Heel
2. Right calf	(3)	Ankle axis
	(4)	Knee axis
3. Right thigh	(5)	Right greater trochanter
4. Trunk	(6)	Suprasternal notch
5. Head	(7)	Chin neck intersection
	(8)	Head vertex
6. Right upper arm	(9)	Right shoulder axis
	(10)	Right elbow axis
7. Right lower arm	(11)	Right wrist axis
8. Right hand	(12)	Right knuckle III
9. Left foot	(13)	Tip of longest toe
	(14)	Heel
10. Left calf	(15)	Ankle axis
	(16)	Knee axis
11. Left thigh	(17)	Left greater trochanter
12. Left upper arm	(18)	Left shoulder axis
	(19)	Left elbow axis
13. Left lower arm	(20)	Left wrist axis
14. Left hand	(21)	Left knuckle III

*The point numbers refer to the segmental end point input order for the computer program to calculate the three dimensional location of the body's center of gravity using the segmental method.

The segmental method was used to determine the three dimensional location of the body's center of gravity. Dempster's (1955) segmental weights and the center of segmental mass percentages found by Clauser et al. (1969) were used to calculate the moments about the X,Y,Z coordinate axes. The spatial coordinates for the segmental end points of the segmental model were used in the fortran program to compute the center of gravity.

In an attempt to gain greater insight into the mechanics of the arabian dive roll, the first and second time derivatives were calculated for center of gravity displacement. The center of gravity displacement-time data was smoothed using the cubic spline smoothing technique described by McLaughlin et al. (1977). The Finite Differences method, described by Miller and Nelson (1973), was used to calculate instantaneous velocity and acceleration for the center of gravity.

Vertical Force

The vertical force-time curve for each subject was calculated by multiplying the gymnast's mass times the instantaneous accelerations of his body's center of gravity in the vertical direction during the execution of the arabian dive roll.

Absolute Angular Determination

Absolute angular determination was achieved through vector identities. Segments were described in terms of vectors in three dimensional space. The angle formed by two segments was found by applying the dot product between the segments' vector representations. The angle was found by the following algorithms:

$$\text{Absolute Angle} = \delta = \cos^{-1} \frac{A \cdot B}{|A|\,|B|}$$

(3)

$$|A| = \sqrt{x_1^2 + y_1^2 + z_1^2}$$

$$|B| = \sqrt{x_2^2 + y_2^2 + z_2^2}$$

$$A \cdot B = x_1 \cdot x_2 + y_1 \cdot y_2 + z_1 \cdot z_2$$

where A,B are the distal end points of the segments having been translated so that the joint center has the value (0,0,0); and x,y, z are the coordinates for the segmental end points after translation.

A list of the segmental angles calculated is found in Table 2.

During the preliminary analysis of this study, the dot product was used to calculate the angles formed by the reference frame structure's axes. The average deviation of these angles from 90 degrees was used as the error estimate parameter in the cubic spline subroutine. This was used to smooth angular displacement data. Following smoothing of data, finite differences was used to calculate instantaneous velocity for segmental rotation.

TABLE 2

ABSOLUTE SEGMENTAL ANGLES

ANGLE	ORIGIN	END POINTS*
Trunk Thigh Angle	Hip Center	i. center between center of mass for both thighs ii. suprasternal notch
Head Trunk Angle	Chin Neck Intersection	i. head vertex ii. hip center
Arm Across Angle (right and left)	Shoulder Axis	i. elbow axis ii. opposite side greater trochanter
Arm Side Angle (right and left)	Shoulder Axis	i. elbow axis ii. same side greater trochanter
Arm Flexion (right and left)	Elbow Axis	i. shoulder axis ii. wrist axis

*Segmental end points representing the terminal points of the vector representations of side i. and ii. of the angle

Relative Angular Displacement

The center of mass for the upper and lower body was used to describe rotation around the transverse and sagittal axes of the body. The right greater trochanter was used to calculate body displacement around its longitudinal axis during the execution of the arabian dive roll. Rotation around the transverse and sagittal axes was found for the airborne phase only. This was done because only during the airborne phase does rotation around these axes occur relative to the body's center of gravity.

Rotation of the body is also accompanied by a concurrent reorientation of its rotational axes relative to the body's position. In order to calculate the body's angular displacement around the principal axes, a measure of the body's displacement from the reference coordinate system had to be found. These values were subsequently used as input into identities for conformal coordinate transformation. This provided the proper orientation of the reference coordinate system to that of the body's rotational axes for the determination of relative angular displacement.

Angular position relative to the axes of the reference system was found using spherical polar coordinates as follows:

a) Position around Z axis, ψ_i

$$\theta_1 = \cos^{-1} \frac{z_i}{r}$$

$$\psi_i = \cos^{-1} \frac{x_i}{r \sin \theta_1}$$

b) Position around Y axis, λ_i

$$\Theta_2 = \cos^{-1} \frac{Y_i}{r}$$

$$\lambda_i = \cos^{-1} \frac{z_i}{r \sin \Theta_2}$$

(4]

c) Position around X axis, β_i

$$\Theta_3 = \cos^{-1} \frac{x_i}{r}$$

$$\beta_i = \cos^{-1} \frac{Y_i}{r \sin \Theta_3}$$

where i=1,2,3   1 = position of upper body center of mass

2 = position of lower body center of mass

3 = position of right greater trochanter

r is the radius between the body's center of gravity and the coordinates for the i vector end points.

x,y,z are the translated spatial coordinates of the i vector end points when the center of gravity has been translated to (0,0,0)

(figure 4 provides a graphical representation of these angles)

Three dimensional conformal coordinate transformations have been well documented in the area of photogrammetry, (Wolf, 1974; and Hallert 1960). These coordinate transformations rotate the desired center of mass and segmental end point to their position relative to the principle axes.

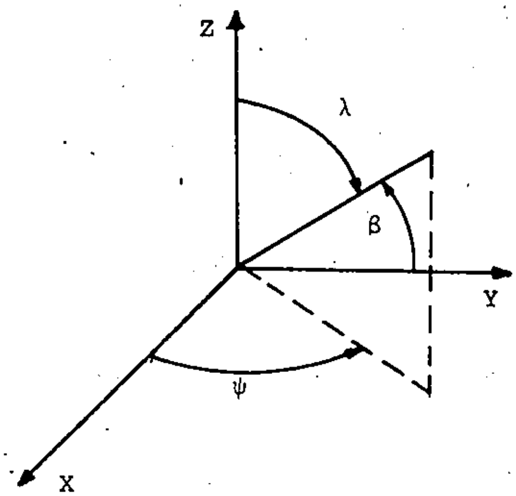


Figure 4. Angles Relative To The Axes

Following is a description of the coordinate transformations used:

a) For ψ rotation (rotation around the Z axis)

$$x' = x\cos\psi_i + y\sin\psi_i$$
$$y' = -x\sin\psi_i + y\cos\psi_i$$
$$z' = z$$

(5)

b) For β rotation (rotation around the X axis)

$$x'' = x$$
$$y'' = y\cos\beta_i + z\sin\beta_i$$
$$z'' = -y\sin\beta_i + z\cos\beta_i$$

c) For λ rotation (rotation around the Y axis)

$$x''' = x \cos\lambda_i - z \sin\lambda_i$$

$$y''' = y$$

$$z''' = x \sin\lambda_i + z \cos\lambda_i$$

where x^j, y^j, z^j are coordinates.

To describe the rotation of the center of mass of the upper and lower body around the transverse axis the following procedure was utilized. The x',y',z' transformed values were found using equation (5)a. and ψ_3. Secondly, these transformed values were used in equations (4)c.

Rotation around the sagittal axis for the upper body center of mass was calculated in three stages. First, the upper body center of mass coordinates were transformed using equations (5)c. and λ_1. Secondly, these transformed coordinates were used in equation (5)a. with ψ_3. Finally, the relative angular position of the upper body's center of mass around the sagittal axis was found using x',y'z' from (5)a. in equations (4)b. A similar method was used for the lower body around the sagittal axis using λ_2 in the first stage of the procedure.

Rotation of the body around the longitudinal axis was represented by the relative displacement of the right trochanter around that axis. Equation (5)b. with β_1 transformed the right trochanter's coordinates. x",y",z" were substituted in equation (4)a. to calculate longitudinal displacement.

This computational procedure was repeated within the computer program for each frame of film analyzed. Final analysis of relative angular displacement consisted of smoothing the data with the cubic spline and calculating velocity using finite differences.

Accuracy and Consistency of Measurement

Measurement consistency and accuracy were desired throughout this study. During actual film analysis periodic checks were made to ensure proper analysis procedures were being followed. Periodic verification of the film transport mechanism on the projector was made by verifying the coordinates of reference marks in the image. All data collection from the film was completed by the author. Periodically, a frame's analysis was repeated as a means of testing the consistency of the point's positional selection. Identification and verification of the data deck was performed before the final computer analysis was completed.

To check the accuracy of spatial location determination, the mean deviation between measured and computed coordinates for the reference structure points was determined. Using the pythagorean theorem the segmental lengths for the right upper arm, right forearm, right thigh, and right calf were found for each frame analyzed. A dependent samples t test was carried out to see if there was a significant difference between the measured and computed segmental lengths.

Data Analysis

Once airborne the total angular momentum the gymnast possesses remains constant. Angular momentum is composed of angular velocity and moments of inertia. Moment of inertia is proportional to the mass distribution around the axis of rotation. This relationship between mass distribution and angular velocity was investigated. Since rotational velocity is affected by several factors, the common variance between segmental rotational positions and relative angular velocities was found. The following steps were used to find common variance between an absolute angular position and a relative angular velocity:

1. A correlation coefficient was found between the two parameters for the best performance of the arabian dive roll for each subject.

2. The seven correlation coefficients were converted to z scores using the following formula:

   $$z = \frac{1}{2} \ln \frac{1 + r}{1 - r}$$

3. A weighted average of these z scores was taken

   $$z_{av} = \frac{(N_i - 7) z_i}{(N_i - 7)}$$

   where N_i = the number of data points per subject for the airborne phase.

4. This z_{av} was converted back to a correlation coefficient and squared to provide a measure of common variance.

   $$r = \frac{e^{2 z_{av}} - 1}{e^{2 z_{av}} + 1}$$

   common variance = r^2

Common variance was found between relative angular velocities of the upper and lower body around the transverse and sagittal axes, and absolute angular displacement of the segmental angles. Common variance was also calculated between relative angular velocities of the body around the longitudinal axis, and absolute angular displacement of the segmental angles. Absolute angular displacements correlated were right and left arm flexion, right and left arm across angles, right and left arm side angles, trunk thigh angle, head trunk angle, and the straddle leg angle.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to develop and implement a three dimensional cinematographical technique to investigate selected mechanics of the arabian dive roll. From film analysis, linear and angular displacement-time data for the arabian dive roll were acquired. Angular displacement consisted of absolute and relative displacement time data.

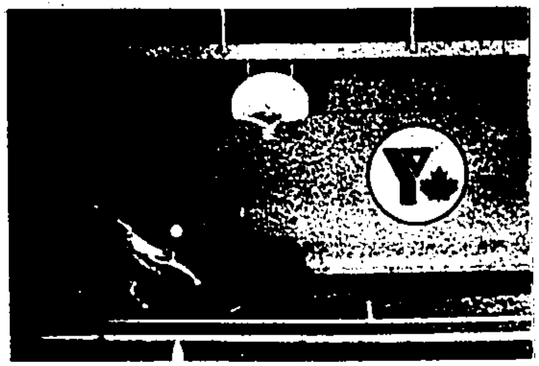
Figure 5 shows sequences of a subject performing the arabian dive roll. These sequences were taken from the side view film.

Within the contents of this chapter, due to the large quantity of data found in this study, the majority of kinematic and kinetic time histories will be reported for one subject only. The data presented on this subject will be discussed in view of its characterization of the trends found for all subjects. Data for the other subjects are presented in Appendices C,D, and E.

Error Assessment

The method employed in this study was designed to retrieve three dimensional spatial data. This consisted of determining spatial location of points, lens origin distances, and angular determination (both absolute and relative).

The first test consisted of using each structure point as the reference point and determining the three dimensional spatial locations of the remaining eleven points. The



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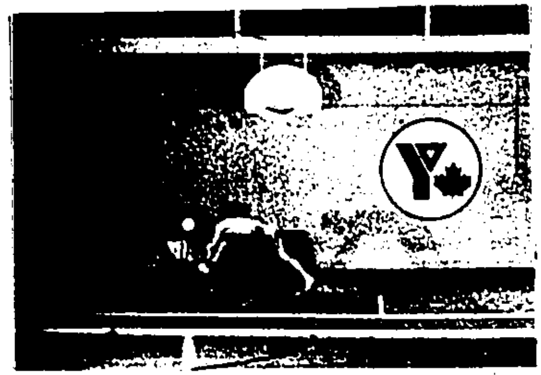

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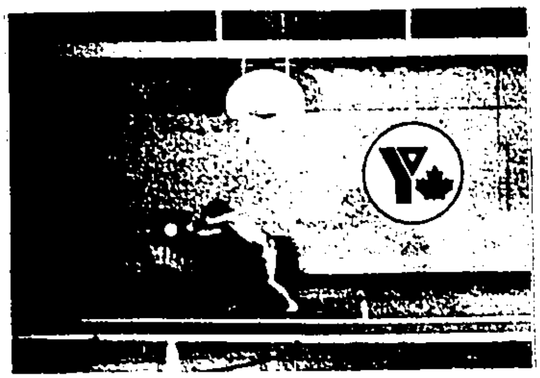

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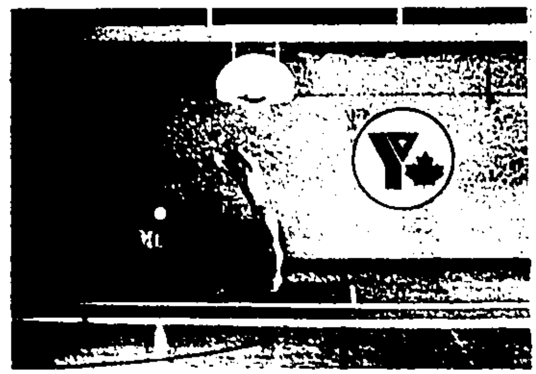

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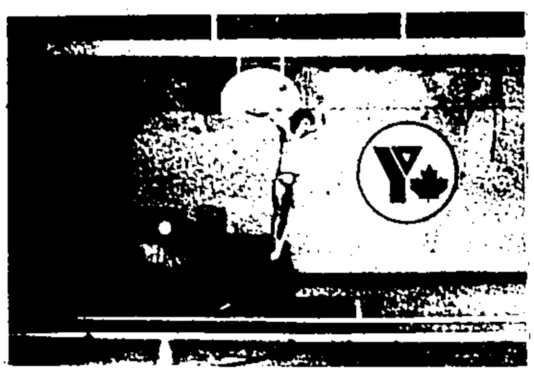

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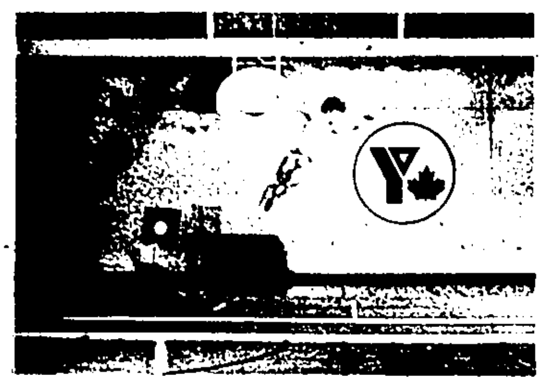

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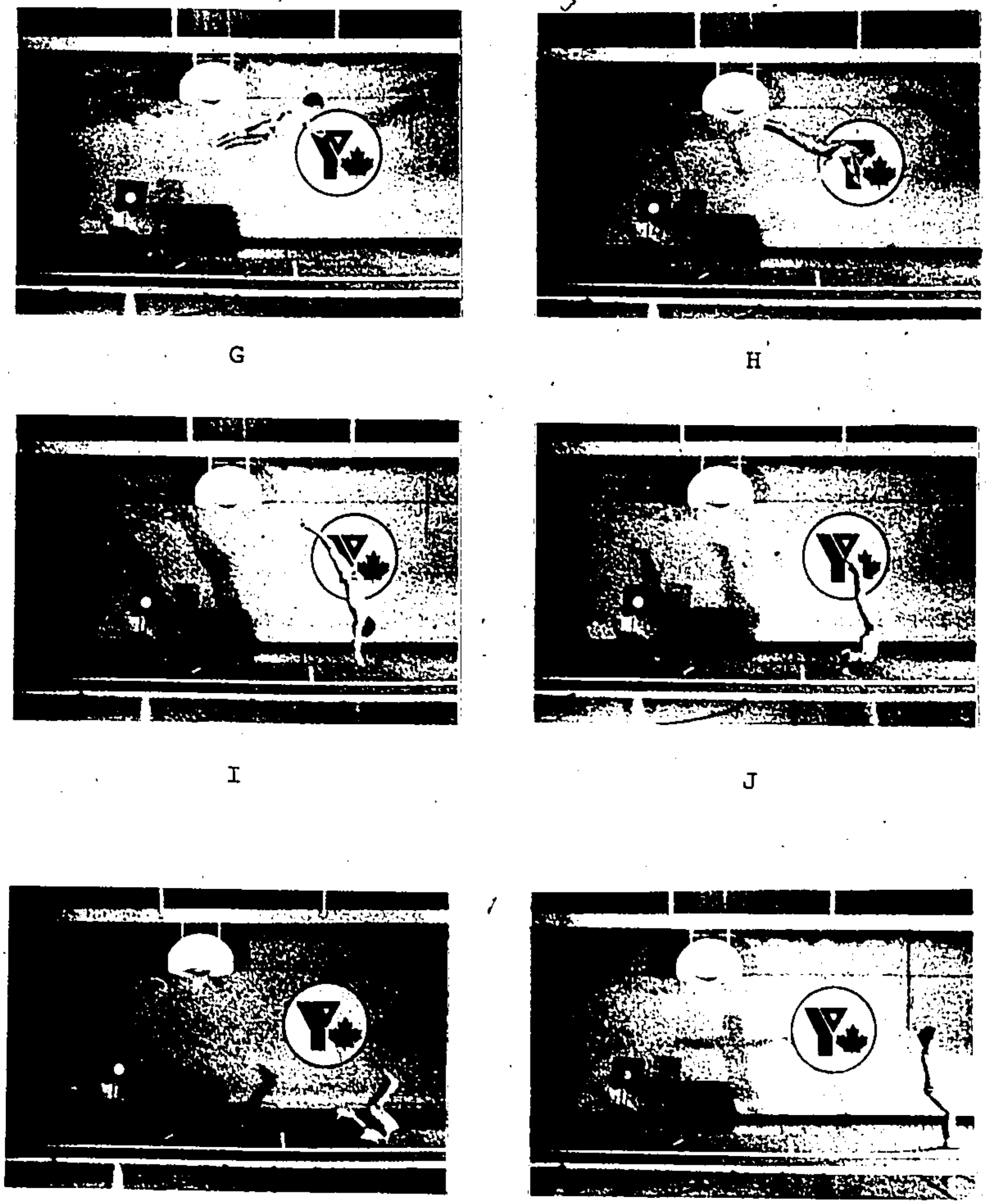
Figure 5a. Side view of a subject during an actual performance of the arabian dive roll.



G H

I J

K L

Figure 5b. Side view of a subject during the actual performance of the arabian dive roll.

nature of the equations was such that a reference point containing a zero coordinate did not produce meaningful results. This test was also performed using the measured lens-center to origin distances for each camera. Table 3 lists the mean difference found between measured and computed spatial location for the structure points.

TABLE 3

SPATIAL LOCATION DETERMINATION

Parameter	X	Y	Z	n
D_1, D_2	.041	.013	.018	12
points				
2	.009	.015	.013	11
3	.021	.016	.013	11
4	.013	.036	.058	11
5	.009	.017	.023	11
6	.007	.022	.033	11
8	.020	.034	.063	11
9	.007	.014	.014	11
10	.016	.014	.016	11
11	.008	.027	.032	11
12	.007	.023	.032	11
$\overline{X}$	.014	.021	.030	
s	.010	.008	.018	

(measurements reported in meters)

Point number nine produced the smallest mean deviation (X = 1.15cm., s = 0.01) in calculating the spatial location of the remaining eleven points. The measured and computed coordinates of the eleven points using point nine as the reference are listed in Appendix B.

Among the objectives of this filming technique were versatility in terms of camera set up, and minimization of required measurements during set up. A measure which may not be easily acquired during the filming of a competitive event is lens center to origin distance. The percent error between calculated and measured distances for this parameter was 5.2%.

Use of the dot product to calculate the angles formed by the structure's axes produced a mean deviation from the measured values of 4.3 degrees. The results for spatial location, lens origin distances and absolute angle determination are consistent with those reported by Gervais and Marino (1979).

From traced drawings taken from film of various performances of the arabian dive roll a subjective evaluation was made of relative angular positional data. Although this was of a subjective nature it was evident that the computed measurements of relative angular positions were compatible with the event occuring in the performance.

The last evaluation for accuracy of measurement consisted of a comparison between the computed segmental lengths for each trial and those measured on the subjects. A paired t test was performed to determine if there was a statistically significant difference between computed and measured distances at the $p < .01$ level of significance. None of the differences per trial were found to be significant (Table 4).

TABLE 4

t RATIOS FOR PAIRED t TEST BETWEEN COMPUTED

AND MEASURED SEGMENTAL LENGTHS

Subject	Trial	n	Right Calf	Right Thigh	Right Forearm	Right Arm
1.	1.	44	.24	.21	.28	.23
	2.	48	.24	.21	.24	.23
2.	1.	41	.32	.25	.24	.25
	2.	40	.25	.25	.25	.29
3.	1.	41	.25	.21	.25	.25
	2.	40	.27	.23	.25	.29
4.	1.	38	.28	.24	.26	.28
	2.	37	.25	.24	.25	.27
5.	1.	42	.23	.22	.25	.23
	2.	40	.27	.26	.25	.26
6.	1.	37	.25	.22	.25	.25
	2.	38	.23	.28	.27	.29
7.	1.	38	.33	.28	.25	.28
	2.	38	.31	.28	.27	.29

(all t ratios are not statistically significant at $p < .01$)

The results indicated that there was some error associated with the method but that it is within the limits reported in the literature on biomechanical research techniques. In an effort to minimize some of these errors, the errors associated with spatial location and absolute angular determination were used as error estimates in the data smoothing method employed. The cubic spline employed these estimates to weigh the data prior to smoothing.

Temporal Data

For the purpose of analysis the arabian dive roll was partitioned into three phases, take off, airborne and roll. Table 5 lists the execution times for each subject. The average time taken to complete the skill was 1.21 sec. The take off, airborne, and roll phases comprised, on the average, 6.9%, 57.5%, and 35.6% of the total performance time.

The vertical displacement of the center of gravity in the airborne phase is proportional to vertical velocity at take off. From the Impulse-Momentum Relationship it is known that vertical velocity at take off is related to the vertical impulse generated during the take off phase. Vertical impulse, by definition, depends on the magnitude of the force and the time of its application. The time, that the force was applied by the gymnasts, during the take off phase, was relatively short (range from .06 to .11 sec). It would appear that the impulsiveness of the vertical force was sufficient to produce the needed change in momentum to project the gymnast into the airborne phase. An average

TABLE 5

EXECUTION TIME FOR EACH PHASE OF THE ARABIAN DIVE ROLL

Subject/trial		Total Time	Take off Phase	% of Total	Airborne Phase	% of Total	Roll Phase	% of Total
1)	1.	1.31	.09	6.9	.82	62.6	.40	30.5
	2.	1.34	.06	4.5	.81	60.4	.47	35.1
2)	1.	1.14	.10	8.8	.59	51.7	.45	39.5
	2.	1.19	.11	9.2	.62	52.1	.46	38.7
3)	1.	1.25	.09	7.2	.75	60.0	.41	32.8
	2.	1.18	.10	8.5	.72	61.0	.36	30.5
4)	1.	1.09	.10	9.2	.52	47.7	.47	43.1
	2.	1.08	.08	7.4	.54	50.0	.46	42.6
5)	1.	1.32	.08	6.1	.83	62.9	.41	31.0
	2.	1.30	.07	5.4	.83	63.8	.40	30.8
6)	1.	1.19	.06	5.0	.62	52.1	.51	42.9
	2.	1.15	.07	6.1	.69	60.0	.39	33.9
7)	1.	1.21	.08	6.6	.73	60.3	.40	33.1
	2.	1.25	.07	5.6	.76	60.8	.42	33.6
	$\overline{X}$	1.21	.08	6.9	.70	57.5	.43	35.6
	s	.08	.02	1.6	.11	5.5	.04	4.8

take off time of .07 seconds was associated with a mean take off velocity of 3.159 meters per second.

Center of Gravity, Displacement and Velocity

All results and discussion, for the remainder of this chapter, will refer to the best performance of the task for each subject. A qualitative assessment, using the standard execution deductions as described in the FIG (1975) Code of Points, was performed for each trial. On this basis, one trial for each subject was selected for subsequent indepth analysis.

The three dimensional location of the gymnast's center of gravity was determined for each frame of film analyzed. This was found to provide insight into the kinematic patterns associated with the displacement and velocity of the body's center of gravity during the execution of the arabian dive roll.

The segmental method was used to calculate the position of the center of gravity relative to the reference coordinate system. This data was smoothed using the cubic spline. Instantaneous velocities were then computed using finite differences.

Figures 6, 7, and 8 show the displacement and velocity curves for the center of gravity for subject five. The horizontal displacement curve (Y direction), which is similar to that of all subjects, shows a linear trend with a fairly constant slope. The horizontal velocity decreased during the round off and take off phase. During this time

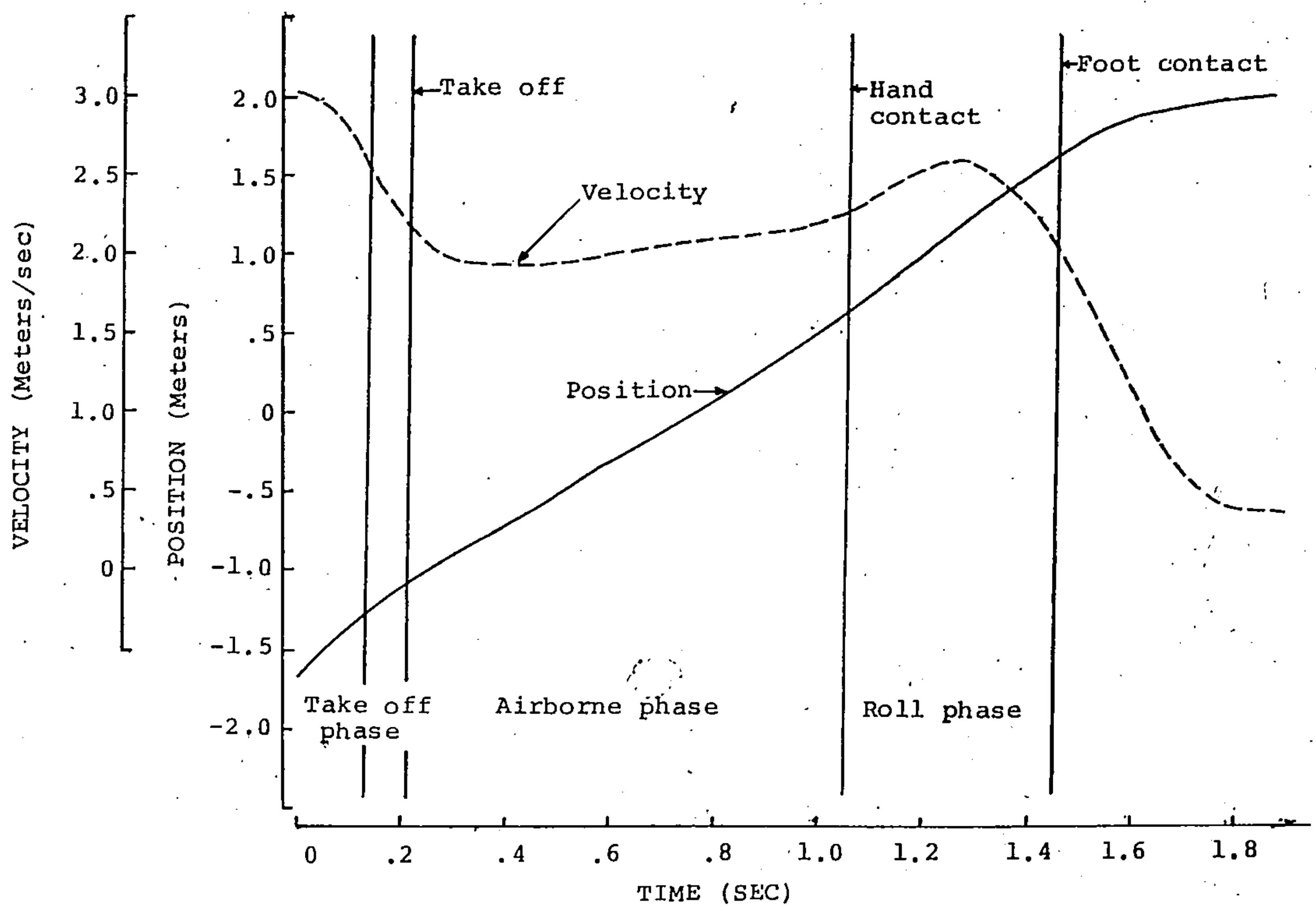


Figure 6. CENTER OF GRAVITY HORIZONTAL DIRECTION SUBJECT 5

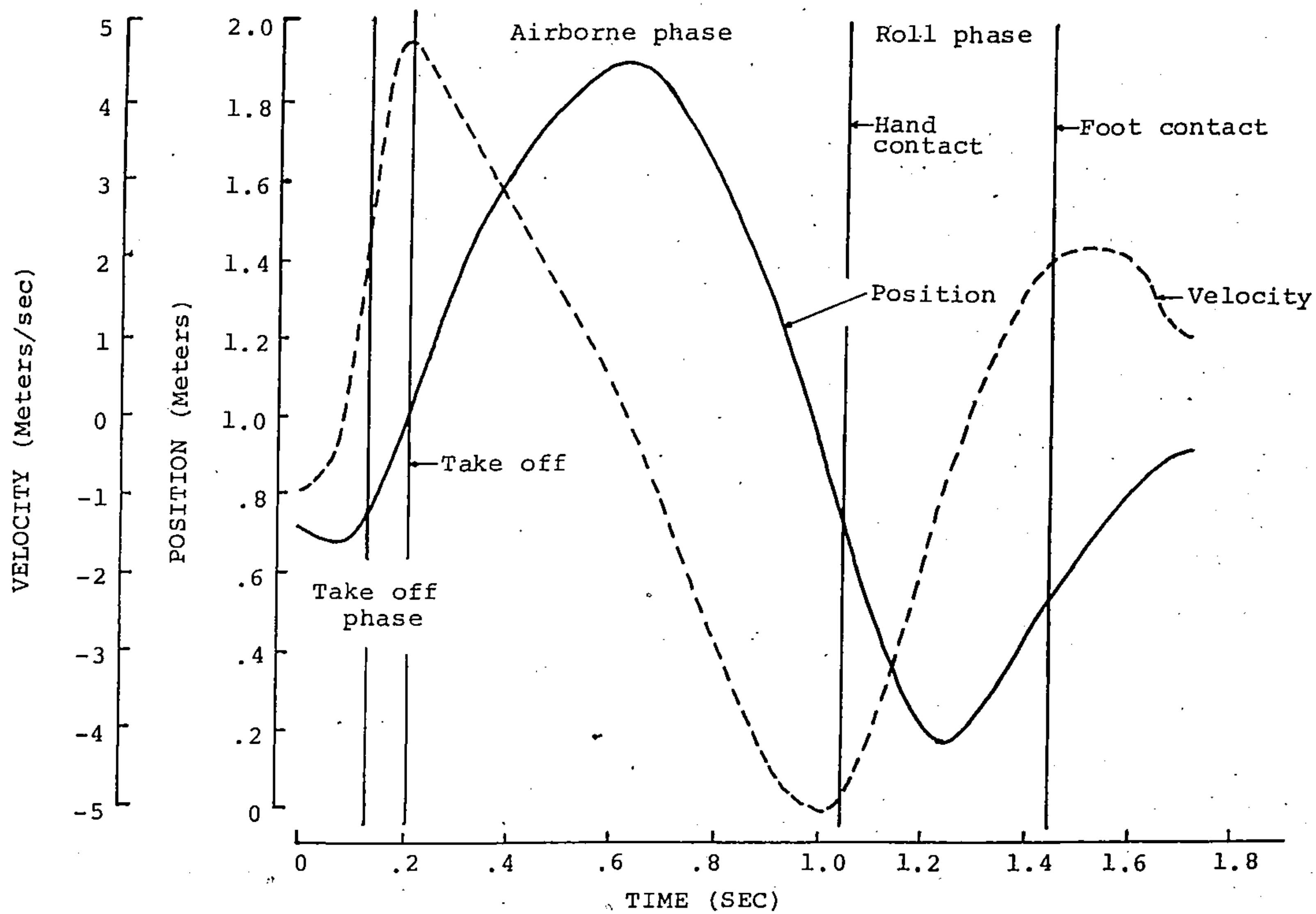


Figure 7. CENTER OF GRAVITY VERTICAL DIRECTION SUBJECT 5

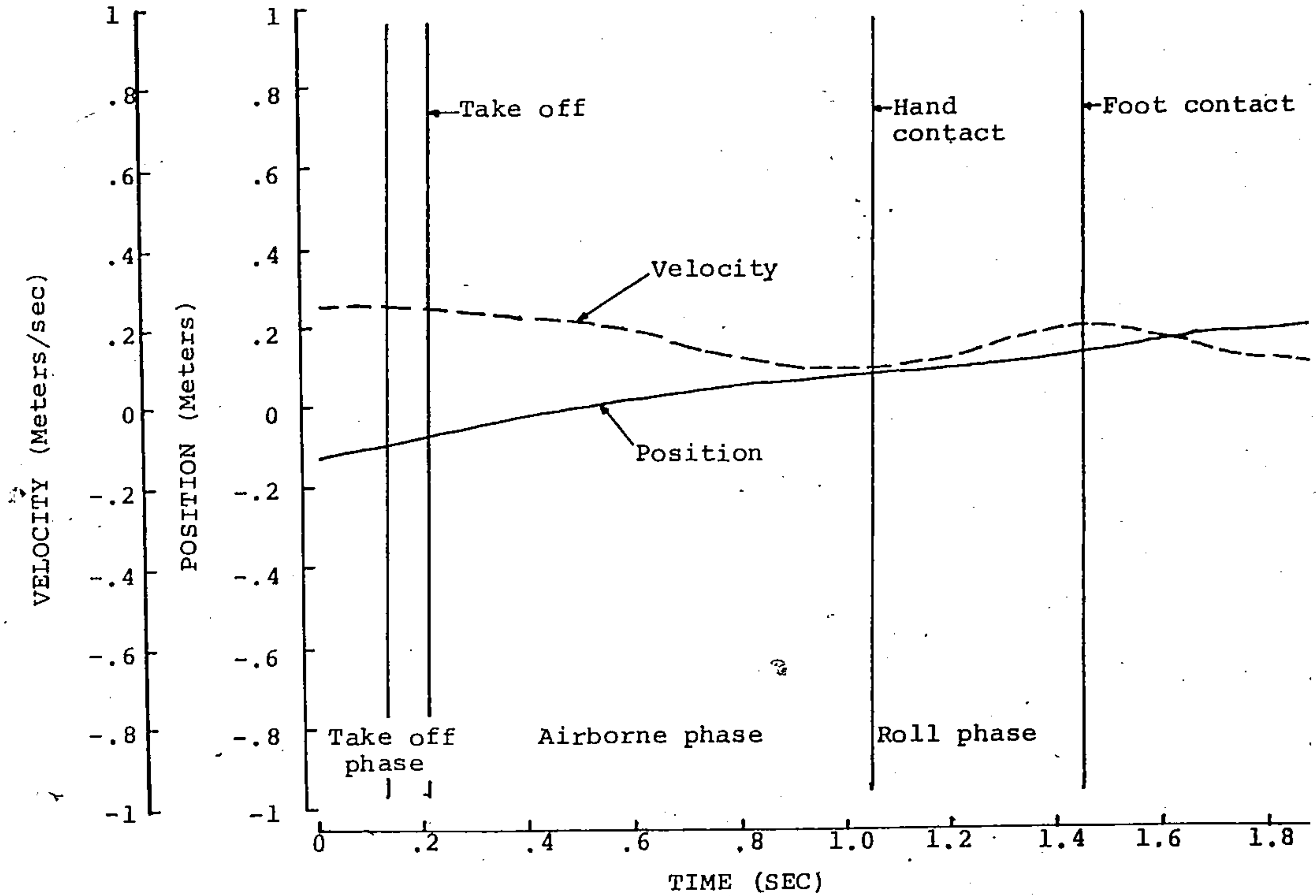


Figure 8. CENTER OF GRAVITY LATERAL DIRECTION SUBJECT 5

interval the gymnast was redirecting his horizontal movement to a vertical direction in preparation for take off. Since the only force acting on the body during the airborne phase to impede horizontal velocity is air resistance, velocity showed little deviation. At the start of the roll phase the gymnast began to assume a tuck position thus reducing his moments of inertia, and increasing his velocity. Once the gymnast began to extend from the tucked position, his velocity underwent a downward trend towards a horizontal velocity of zero.

The displacement curve in the vertical direction (Z direction, figure 7) provides a representation of the parabolic flight path commonly associated with projectiles. The center of gravity was travelling in a negative direction until the commencement of the take off phase. From this point to the peak of the airborne phase the vertical displacement followed a smooth curved path. The body's center of gravity descended from this height to its lowest point in the roll phase. This point coincided with the tucked position when the gymnast's back was in contact with the mat. The subject then began to extend from the tuck and started to stand up at the completion of the roll phase. The vertical velocity-time curve shows that the gymnast was constantly speeding up in the positive direction during the start of the arabian dive roll. Maximum vertical velocity was reached just prior to take off. From that instant until maximum vertical displacement was reached, the body was slowing down in the positive direction. Velocity was zero as the gymnast reached the peak of his flight path and then velocity started to increase in the downward direction. The body slowed in the downward direction during the start of the roll phase until the gymnast assumed a full tucked position (ie. minimum vertical position). From this position the subject speeded up in the upward direction then velocity decreased during the completion of the skill.

Preliminary analysis of lateral displacement and velocity curves did not reveal any apparent trends. No quantitative evaluation was performed in an attempt to arrive at a possible cause for this lack of similarity. A possible avenue of inquiry for this lack of similarity could be in the take off position of the body relative to the horizontal direction of movement. Also, the resultant direction of the eccentric forces at take off may be an influential factor.

Except for subject two, and subject four, all other subjects did demonstrate similar displacement patterns during the last half of the arabian dive roll. There was little or no lateral deviation apparent during the descent portion of the airborne phase. Upon contact with the hands and continuing throughout the roll phase there was an increase in lateral displacement. A slope of near zero during the descent was consistent with the objective of checking displacement around the longitudinal axis by creating a larger moment of inertia. Since the body still possessed a certain amount of angular momentum at hand contact, there was the potential for lateral displacement during the roll phase. The velocity curve for the X direction showed no trend except for an increase in velocity during the latter part of the roll phase. The lateral deviations described, however, were not of a greater magnitude. This is consistent with the technique requirement of the arabian dive roll. The magnitudes for lateral displacement are listed in Table 6.

TABLE 6

LATERAL DISPLACEMENT OF THE BODY'S CENTER OF GRAVITY

SUBJECT	TOTAL	TAKE OFF PHASE	AIRBORNE PHASE	ROLL PHASE
1.	.107	.012	.081	.014
2.	.152	.014	.096	.042
3.	.123	.011	.085	.027
4.	.437	.069	.342	.026
5.	.200	.019	.127	.054
6.	.178	.019	.082	.006
7.	.058	.003	.002	.053
$\overline{X}$	.179	.021	.116	.032
s	.123	.022	.106	.019
$\tilde{X}$	.152	.014	.085	.027

(Measurements reported in meters)

Various kinematic values for vertical displacement for each subject are listed in Table 7. One of the performance criteria for the arabian dive roll is vertical amplitude during the airborne phase. The average vertical displacement of the center of gravity from take off to the peak of the

TABLE 7

KINEMATIC DATA FOR VERTICAL DISPLACEMENT

OF THE BODY'S CENTER OF GRAVITY

Subjects	Vertical Velocity at Take Off (meters/sec)	Vertical Displacement to Peak of Airborne Phase (meters)	Vertical Displacement from Hand Contact to Lowest Point in Roll Phase (meters)
1.	3.778	.897	.998
2.	2.699	.415	.784
3.	3.214	.688	.899
4.	2.682	.267	.681
5.	3.796	.885	.778
6.	2.965	.563	.681
7.	2.980	.565	.614
$\bar{X}$	3.159	.611	.776
s	0.466	.232	.135

airborne phase was 61.1 cm. The height attained by each gymnast was directly proportional to vertical velocity at take off. The mean vertical velocity at take off was found to be 3.159 meters per second. Subject five had the largest take off velocity and had the greatest vertical displacement of his center of gravity during the airborne phase. Product-moment correlation between vertical velocity at take off and vertical displacement in the airborne phase resulted in a coefficient of $r = .96$ which is significant at $p < .01$ level. Although a direct relationship between vertical velocity and height is expected in projectile mechanics, this result does lend credance to the accuracy of the cinematographical technique used in this study.

The gymnast should attempt to make contact with the mat, after the airborne phase, in a fully extended body position. The average vertical distance from hand contact to the lowest point in the roll phase was found to be 77.6 cm. This distance allows for the dissipation of the downward force in order to prevent injury and in order to maintain body control through the roll phase.

Body control is another evaluation criteria of the arabian dive roll. The magnitude of the lateral deviation from the intended line of movement can have a significant bearing on how a performance is judged. It was found that the average deviation in the X direction was 17.9 cm., with a median value of 15.2 cm. Subject four was the only gymnast that moved laterally more than 20 cm. Although no quantitative evaluation was performed to assess this relationship, it would appear that subject four alone would have been penalized for this perfomance aspect.

In summary, the body's center of gravity followed a parabolic path during the airborne phase. The height attained by each gymnast was proportional to the vertical velocity at take off. Finally, most of the gymnasts demonstrated little lateral deviation in performing the arabian dive roll.

Vertical Force

Calculation of vertical force was achieved in two steps. Using finite differences the vertical acceleration of the body's center of gravity was determined. Newton's second law of motion, force equals mass times acceleration, was used to calculate force in the vertical direction. The vertical force calculated in this manner is representative of the vertical component of the ground reaction force. Figure 9 shows the vertical force time curve for subject five. The maximum ground reaction force occured at the commencement of the take off phase at which time the gymnast began to extend maximally. During the airborne phase the weight of the gymnast is the influential force. In the airborne phase the vertical force had a negative value and was constant. At hand contact, vertical force showed a steady increase through to the point where the gymnast's center of gravity was lowest in the tucked position. Vertical force continued to decrease from this point on as vertical acceleration approached zero in the completion of the skill. From this force time curve two events are apparent. First, the gymnast applied a vertical

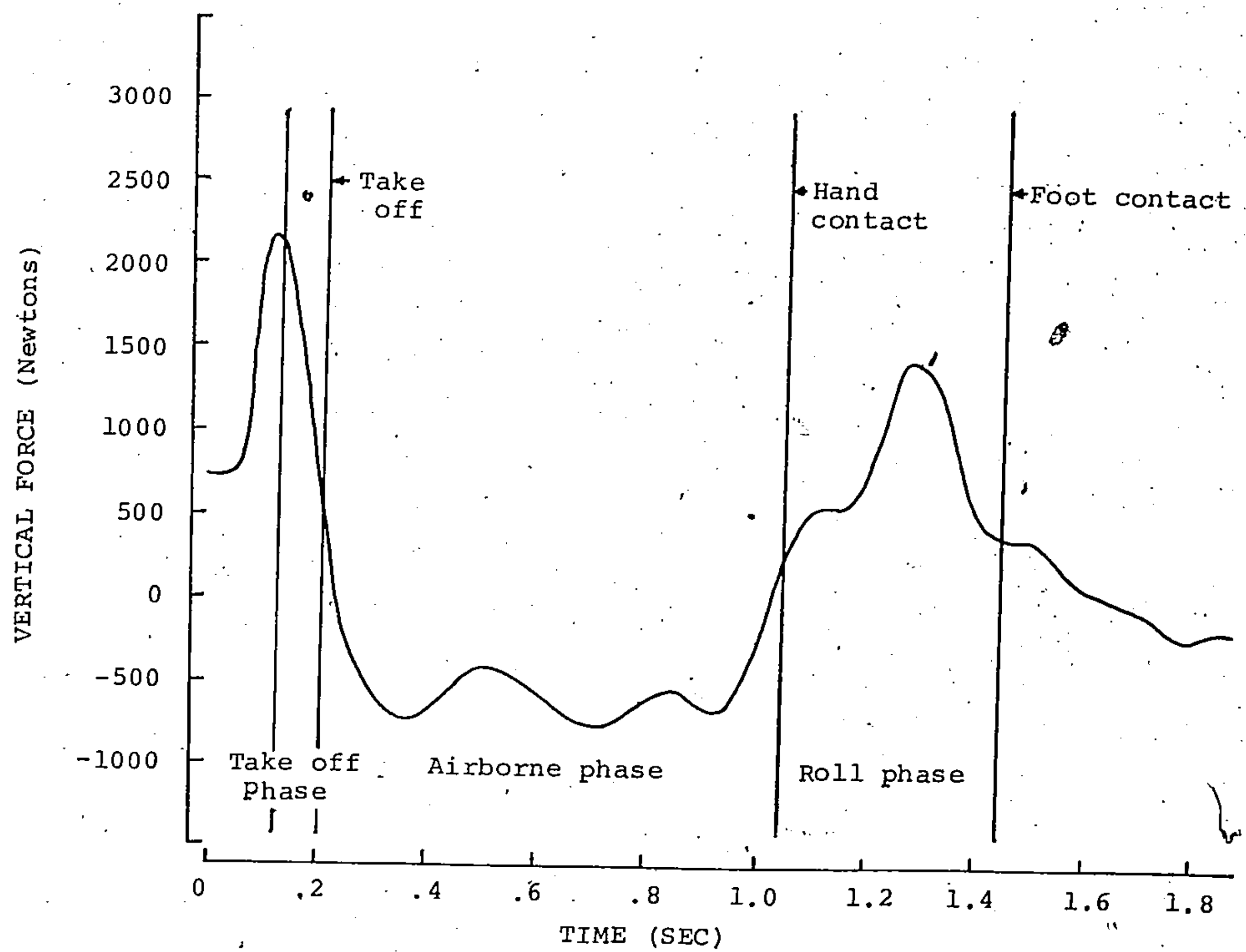


Figure 9. VERTICAL FORCE SUBJECT 5

force during the take off phase to aid him in acquiring lift for the airborne phase. Secondly, during the roll phase the gymnast used the forces produced by the muscles in his upper extremities to reduce the vertical force to the equivalent body weight.

Angular Kinematics

Angular displacement-time data included both absolute and relative angular displacement. The mechanics of twisting are complex and dependent on many factors. Prior to the airborne phase the gymnast must acquire certain kinematic and kinetic quantities that will determine much of his success in performing the technical requirements of the skill. He must produce sufficient vertical velocity to get the needed height and time to complete the required rotations around the longitudinal and transverse axes. Since the gymnast, once airborne, cannot create additional angular momentum, he must generate a sufficient amount prior to take off.

The gymnast's body position relative to the axis of rotation, through his feet, and the forces he is applying will determine his resultant moment of force at take off. Although this resultant moment of force was not quantified in this study, some insight into the longitudinal component can be arrived at from observing the body's relative position at take off. The positions are listed in Table 8 and relative angular displacements for the longitudinal axis are listed in Table 9. Product moment correlation between relative position at take off and the longitudinal displacement in the airborne phase was found to be significant ($r = .99$, $p < .01$). From these results it can be concluded that there is a direct relationship between the eccentric forces produced at take off, due to the relative position of the body, and the total displacement of the body around the longitudinal axis during the airborne phase.

TABLE 8

RELATIVE ANGULAR POSITIONS

AROUND THE LONGITUDINAL AXIS

Subject	Foot Contact After Round off	Take Off	Hand Contact
Theoretical Ideal	3.142	3.142	.0
1.	2.398	1.736	.475
2.	2.889	2.374	.513
3.	2.934	2.200	.508
4.	1.838	.696	.805
5.	2.933	2.124	.501
6.	2.808	1.424	.327
7.	2.686	2.410	.444
$\overline{X}$	2.641	1.852	.510
s	0.401	0.621	.145

(Values in radians)

Table 10 lists the displacements around the transverse and sagittal axes. A mean displacement around the transverse axis of 2.433 radians in the airborne phase is consistent with the technique range of the arabian dive roll. An evaluation criterion of the arabian dive roll is that there

TABLE 9

RELATIVE ANGULAR DISPLACEMENT

AROUND THE LONGITUDINAL AXIS

Subject	Foot Contact To Start of Take Off Phase (Rad)	Foot Contact To Start of Take Off Phase % of Total	Take Off Phase (Rad)	Take Off Phase % of Total	Airborne Phase (Rad)	Airborne Phase % of Total	Total Angular Displacement
1.	.161	8.4	.501	26.0	1.261	65.6	1.923
2.	.225	9.5	.290	12.2	1.861	78.3	2.376
3.	.547	22.5	.187	7.7	1.692	69.8	2.426
4.	.191	15.3	.951	76.0	0.109	8.7	1.251
5.	.302	12.4	.507	20.9	1.623	66.7	2.432
6.	.476	19.2	.908	36.6	1.097	44.2	2.481
7.	.181	8.1	.095	4.2	1.966	87.7	2.242
$\overline{X}$	.298	13.6	.491	26.2	1.373	60.2	2.162
s	.154	5.6	.336	24.6	0.638	26.3	0.444

TABLE 10

RELATIVE ANGULAR DISPLACEMENT AROUND
THE TRANSVERSE AXIS AND SAGITTAL AXIS
FOR THE AIRBORNE PHASE

	Transverse Axis		Sagittal Axis		Sagittal Axis Maximum Deviation	
Subject	Upper Body	Lower Body	Upper Body	Lower Body	Upper Body	Lower Body
1.	2.390	2.391	.337	.337	1.129	1.129
2.	2.517	2.517	.395	.394	1.586	1.585
3.	2.696	2.696	.289	.289	1.590	1.590
4.	2.288	2.288	.496	.496	1.201	1.201
5.	2.566	2.566	.022	.022	0.998	0.998
6.	2.366	2.363	.191	.192	1.619	1.619
7.	2.211	2.210	.320	.320	1.957	1.957
$\overline{X}$	2.433	2.433	.293	.293	1.440	1.440
s	0.169	0.169	.152	.152	0.340	0.340

(values in radians)

should be little sagittal displacement. A mean displacement from take off to landing of .293 radians complies with this criterion. Identical values for both the upper and lower body for these displacements is in agreement with the definition of rotational motion.

The data presented in Table 10, specifically rotation around the sagittal axis, provide numerical evidence to support various observations reported in the literature on twisting. Gluck (1979) and George (1980) stated that when a twist is initiated from the floor there is a tendency for the body to assume a side arched position rather than a straight line body shape. This was found to have occured in all the subjects. From Table 9 it can be seen that all gymnasts initiated the twist while in contact with the mat. Both Gluck and George, also reported that when there is a concurrent rotation around the transverse and longitudinal axes the straight line body shape tends to somersault slightly off of "top dead center". Specifically, rotation around the transverse axis does not occur through a plane of motion directly perpendicular to the ground. The tendency to rotate off center was evident from the data presented on the lateral path of the center of gravity in Table 6 and Figure 8. Related to these findings are the maximum deviations found around the sagittal axis. An average maximum deviation of 1.440 radians, demonstrates that there was a fairly substantial amount of rotation around the sagittal axis possibly due to simultaneous rotation around the transverse and longitudinal axes.

An execution requirement of the arabian dive roll is a 180 degree twist around the longitudinal axis. A judge can not view precisely where this may be initiated but is concerned that the majority of the twist is completed during the airborne phase prior to hand contact. The round off should position the gymnast so that his feet and hips are perpendicular to the horizontal line of motion. From the time the feet make contact with the mats after the round off until his hands touch at the start of the roll phase, a 180 degree rotation around the longitudinal axis should have occured. Theoretically if this requirement is met the gymnast will have a greater potential to receive complete marks for technical execution. From the position of the right hip at foot contact upon completion of the round off (Table 8) it can be seen that no gymnast was ideally positioned prior to the commencement of the skill. Each gymnast rotated in the round off to position himself so that he would not need a 180 degree twist. Subject four, the least skilled gymnast, positioned himself so that he needed to rotate only 105° (1.838 radians), to meet the 180° requirement. Excluding subject four the remaining gymnasts positioned themselves at a mean of 2.775 radians ($s = .207$) upon completion of the round off. Therefore, on the average they required an additional 159° of rotation. In terms of total rotation performed from the round off to hand contact each gymnast showed various percentages of twist in the various time intervals reported in Table 9. During the take off phase subject four demonstrated the greatest percentage of twist completed in this phase even though it was not the greatest actual angular displacement. Subject four had little rotation during the airborne phase while the others performed between 44% and 87% of their twists during this phase. Due to the positions in which the gymnasts placed themselves upon completion of the round off, not one actually rotated through 180° around the longitudinal axis. Borms et al. (1973) and Van Gheluwe et al. (1977) in their investigations of a full twisting backwards somersault found similar results. They reported that their subjects rotated less than the required 360°.

In summary, it was found that the amount of twist performed during the arabian dive roll was influenced by the relative position resulting from the round off. All twists were initiated to some degree while in contact with the ground and all subjects twisted less than 180° in the arabian dive roll itself.

Segmental angular displacements and velocities during the take off phase aid in the projection of the gymnast into the air. In order to arrive at the most advantageous position for take off, the body segments should be near full extension and continuing to extend at a constant positive velocity. In Table 11 the absolute angles for various segments at take off are listed. The trunk-thigh angle had a mean value of 2.849 radians which indicates good body extension at take off. In Figures 10 and 11 it can be seen that

TABLE 11

ABSOLUTE ANGULAR SEGMENTAL POSITION AT TAKE OFF

Subject	Trunk Thigh	Segmental Angles*					
		Arm Flexion		Arm Across		Arm Side	
		Right	Left	Right	Left	Right	Left
1.	2.892	2.374	2.313	1.835	1.877	2.578	2.828
2.	2.942	2.907	2.861	1.809	1.894	2.656	2.622
3.	2.995	2.842	2.745	1.720	1.771	2.632	2.743
4.	2.775	2.263	2.975	1.973	2.101	2.102	2.505
5.	2.730	2.294	2.154	1.845	1.889	2.475	2.351
6.	2.740	2.728	2.141	2.043	1.853	2.690	2.757
7.	2.867	2.974	2.906	2.034	1.860	2.419	2.258
$\overline{X}$	2.849	2.626	2.585	1.894	1.892	2.507	2.581
s	0.103	0.306	0.368	0.123	0.101	0.204	0.217

*values in radians

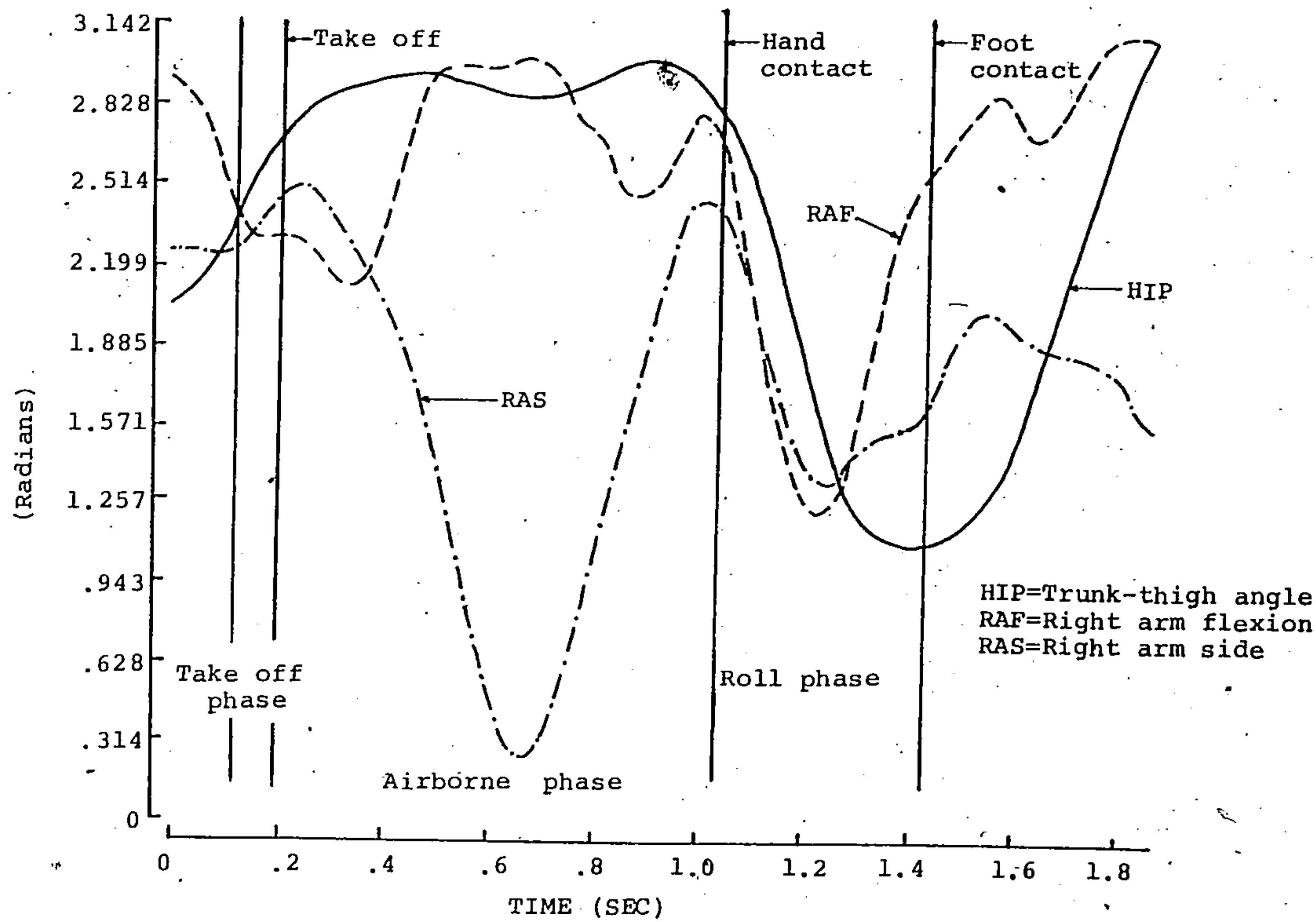


Figure 10. SEGMENTAL ANGLES SUBJECT 5

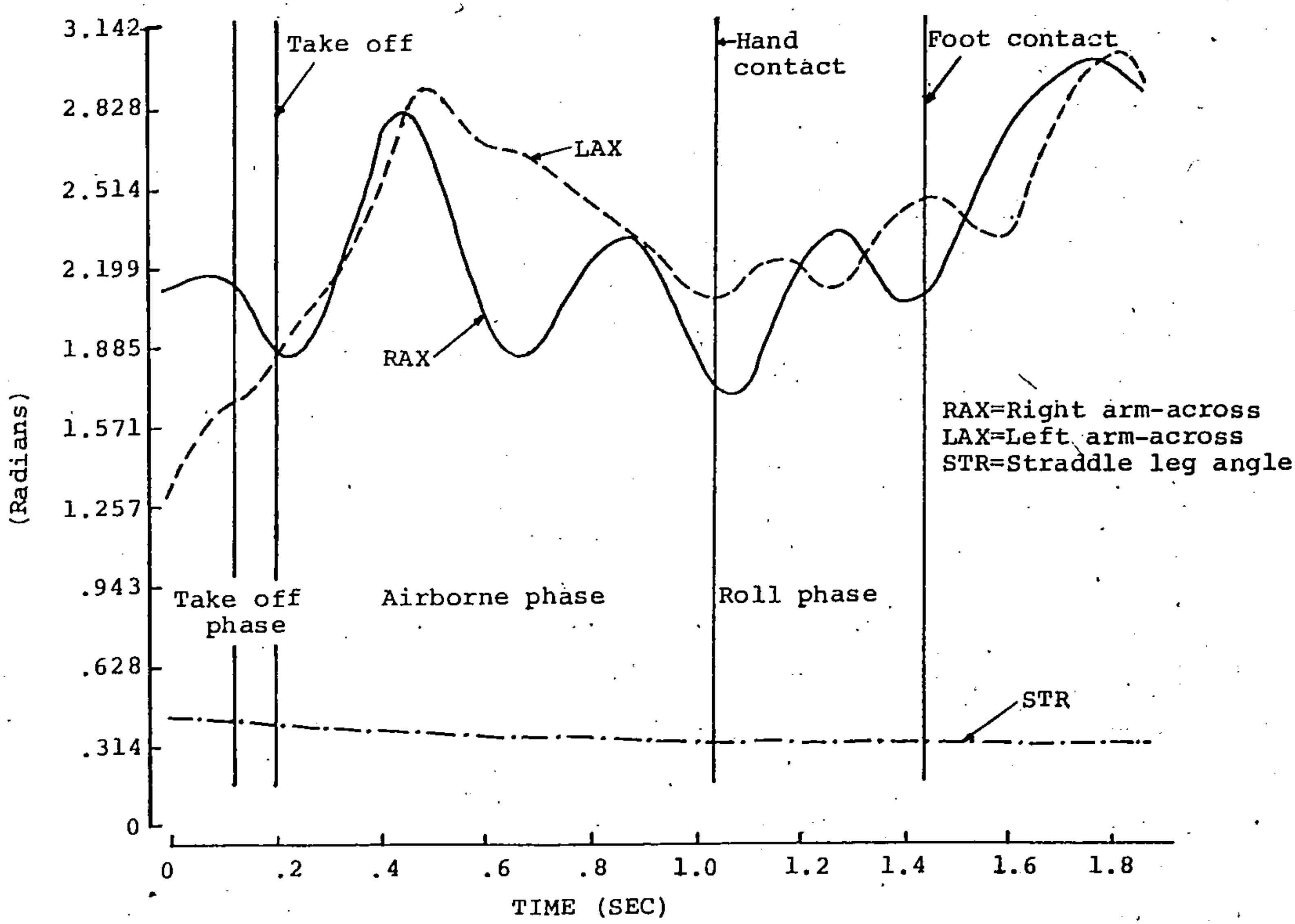


Figure 11. SEGMENTAL ANGLES SUBJECT 5

the gymnast's trunk-thigh and right and left arm across angles[1] continued to extend pass take off. This occurrence was observed in all subjects. The right and left arm across angular velocities were still increasing in the positive direction during take off. This was not the case for the trunk-thigh angle. A possible explanation for this observation may lie with the results obtained for vertical velocity of the center of gravity at take off. It was seen that the maximum vertical velocity of the body's center of gravity occurred prior to take off. In the airborne phase the gymnasts had angular displacements of 2.433, .293, and 1.373 radians around the transverse, sagittal and longitudinal axes respectively. The gymnast, once in the air, can not change the rotational quality his body possesses, yet he can effectively manipulate his rotational velocities around the principal axes. The gymnast can accomplish this by segmental movement which has the effect of changing the moments of inertia around the principal axes of rotation. These segmental movements must comply with the general lines of the body in order for the movement to be aesthetic in nature. From Figures 10 and 11 it can be seen that the body did not unduly bend at the waist and that the legs remained close together throughout the airborne phase. It was observed in all subjects that the head trunk angle deviated only during the time there was a large amount of rotation around the longitudinal axis. An

[1]the arm across angle provides a measure of horizontal flexion between the arm and the trunk. The origin is the shoulder axis with the elbow axis and opposite side hip axis as end points.

example of this can be seen for subject five in Figure 12. The only other distinguishable pattern observed in the subject was the arm across angular displacements. In both the right and left across angles there was a parabolic type path displayed. An increase was seen when the arms spread laterally around the peak of the airborne phase. A subjective evaluation of the results obtained for the seven gymnasts for absolute segmental angular displacements during the airborne phase indicated that segmental movement patterns are subject specific. This would indicate that no one general pattern describes segmental movement in the arabian dive roll.

The final analysis was based on the relationship between segmental movements and relative angular velocities. As has been previously stated this relationship is derived from Newton's Law of Conservation of Angular Momentum and the definition of angular momentum. The common variance between absolute angular displacements and relative angular velocities were found. Listed in Table 12 are the values for the relationships that were evaluated.

It was found that 30.5 percent of the variance in relative angular velocity of the upper and lower body around the sagittal axis is in common with variance in the right arm across angle. Theoretically a reduction in the moments of inertia around the longitudinal axis will produce a concurrent increase in angular velocity. Percents of 25.1, 38.7, and 30.7 for variance in angular velocity of the body around the longitudinal axis can be linked to variations in segmental displacements in the left arm-side, right arm flexion and straddle leg angles respectively.

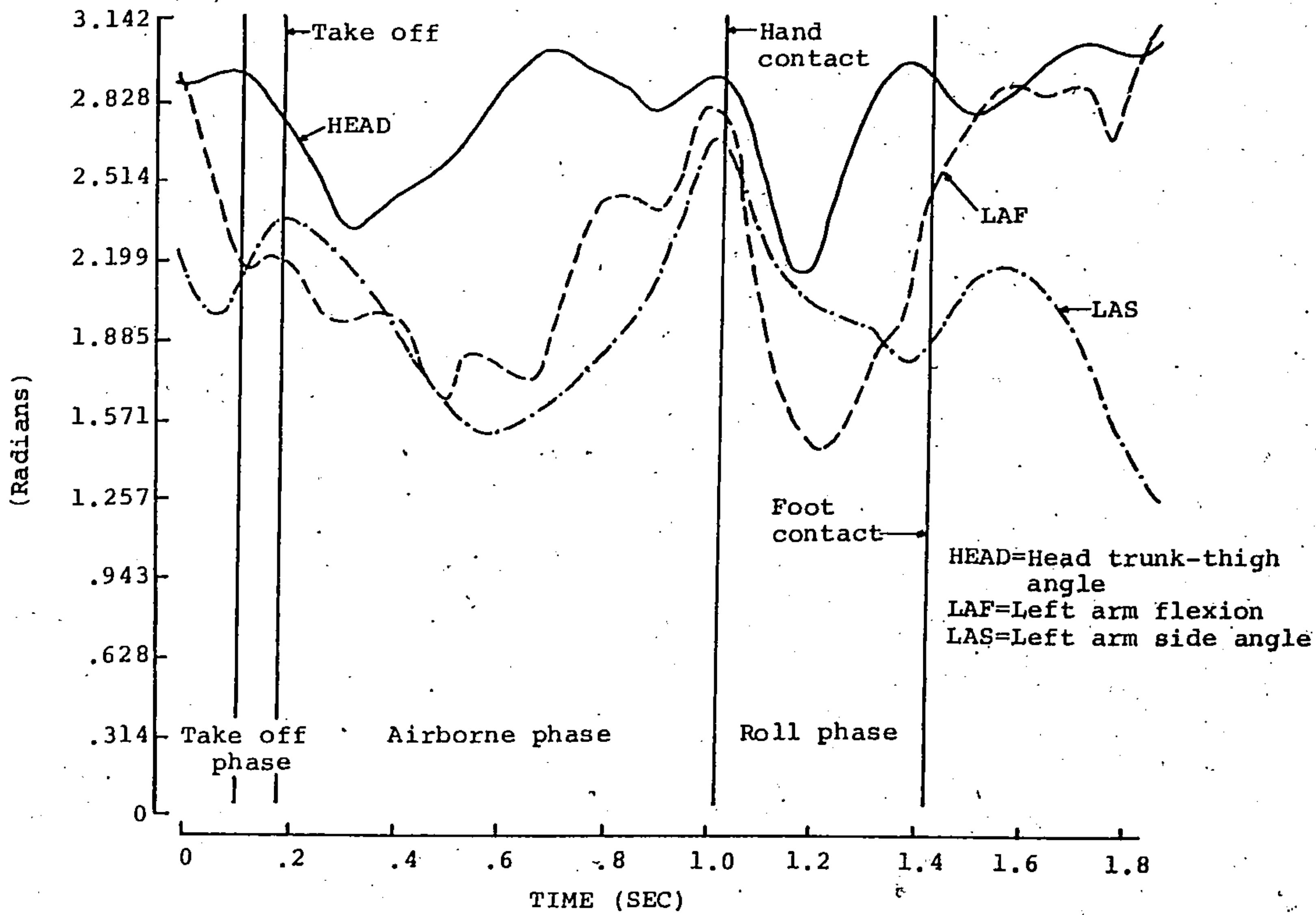


Figure 12. SEGMENTAL ANGLES SUBJECT 5

TABLE 12

COMMON VARIANCE* BETWEEN ABSOLUTE ANGULAR DISPLACEMENTS AND RELATIVE ANGULAR VELOCITIES

Absolute Segmental Angular Displacements	Relative Angular Velocities				
	Upper Body Center of Mass		Lower Body Center of Mass		Right Greater Trochanter
	Transverse Axis (%)	Sagittal Axis (%)	Transverse Axis (%)	Sagittal Axis (%)	Longitudinal Axis (%)
Trunk Thigh Angle	0.7	15.1	4.5	15.1	15.3
Head Trunk Angle	1.1	6.5	0.3	6.5	12.8
Right Arm Across	3.4	30.5	5.2	30.5	5.7
Left Arm Across	20.2	16.2	32.7	16.2	0.1
Right Arm Side	19.0	0.5	38.9	0.5	17.1
Left Arm Side	27.5	0.0	51.7	0.0	25.1
Right arm Flexion	14.4	2.7	35.3	2.7	38.7
Left Arm Flexion	0.3	12.7	0.7	12.7	5.1
Straddle Leg Angle	18.1	10.7	39.6	10.7	30.7

*Common Variance = $r^2 \times 100$

Since more than one segment moves during the course of the airborne phase, relative angular velocities cannot be predicted totally from one variable alone. However, the variance in relative angular velocity around the transverse axis can be explained by the variance in the angular displacement of the straddle leg angle. Common variances of 18.1 and 39.6 percents for the upper and lower body respectively were found between these variables. Common variance of 35.3% was found between relative velocity of the lower body around the transverse axis and absolute angular displacement in the right arm flexion angle.

When an object is in free flight and a part of the body experiences a reduction in angular momentum another part of the body must experience an increase in angular momentum. The concept of transfer of momentum can be used to explain various results obtained for the relationships listed in Table 12. The correlations between relative angular velocity for the lower body around the transverse axis and the segmental angular displacements of the left arm across angle and the right and left arm-side angles represented 32.7, 38.9, and 51.7 percent associations respectively. It was also found that 27.5 and 20.2 percent of the variance for the upper body's rotational velocities around the transverse axis are associated with the variance in the absolute angular displacements for the left arm side angle and left arm across angle respectively.

The above results do not imply any causal relationships but do point to the fact that the variance in relative angular velocities is associated with changes which occur in other variables investigated.

CHAPTER V

SUMMARY AND CONCLUSIONS

The investigation of existing three dimensional cinematographical techniques has revealed that no previous research in the field of biomechanics has provided a suitable means to investigate relative angular kinematics. Through use of mathematical theory on three dimensional euclidean geometry, the main purpose of this research was to develop a method to assess angular kinematics for three dimensional movement analysis. More specifically, a technique was developed to measure angular kinematic properties relative to the principal axes of rotation. Secondly it was the intent of the research to employ this method to investigate various biomechanical features of the arabian dive roll.

Seven subjects were used in this study. Each subject performed two arabian dive rolls. Filming was accomplished through the use of two high speed 16mm. cameras set perpendicular to one another. Prior to the actual filming, body segment parameters were taken for each subject and a general orthogonal reference frame was filmed by both cameras.

Film rates for each camera were synchronized using a common time reference and a cubic spline interpolation procedure. Twenty one segmental end points were located from film and used to calculate displacement and instantaneous velocities for the center of gravity. Vertical force was determined for each subject during the execution of the task. Absolute angular determination consisted of computing various segmental displacements. Relative angular displacement-time data for the body around the three principal axes was found for the airborne phase of the arabian dive roll.

Preliminary analysis of the method's accuracy to measure spatial location, lens origin distance and absolute angles revealed measurement errors of 1.15 cm, 5.2%, and 4.3 degrees respectively. The method's accuracy of measuring data taken from the body moving in space revealed no statistically significant difference between measured and computed segmental data.

The kinematic patterns associated with the displacement and instantaneous velocity of the body's center of gravity were investigated. The horizontal displacement curve demonstrated a constant displacement pattern throughout the execution of the skill. The velocity curves showed a negative trend near take off and an increase in the positive direction during the start of the roll phase. No distinctive pattern was observed for the lateral path of the center of gravity. However each gymnast did demonstrate some lateral deviation. The vertical displacement of the center of gravity followed a parabolic path during the airborne phase. A significant correlation was found between the vertical velocity at take off and the subsequent vertical displacement of the center of gravity in the airborne phase. Vertical velocity was near maximum at take off, zero at the peak of the airborne phase and had its minimum value at the completion of the airborne phase.

The vertical force time curve displayed a similar pattern for all seven subjects. Vertical force was maximal at the start of the take off phase. It was demonstrated that gravity is the only external force affecting the body during the airborne phase. Vertical force exhibited a substantial increase from hand contact to near the end of the roll phase when acceleration began to decrease.

In general it was found that all gymnasts rotated through sufficient amounts around the transverse axis but exhibited less than 180 degrees around the longitudinal axis. Rotation around the sagittal axis showed a parabolic pattern with a mean displacement of .293 radians during the airborne phase.

Absolute angular displacements demonstrated that the gymnasts, with the possible exception of subject four, complied with the aesthetic nature of the arabian dive roll. Segmental movements of the upper extremities did not reveal any apparent patterns associated with the relative rotational features of the arabian dive roll. Common variance between absolute angular displacements and relative angular velocities did not yield high percentage associations.

Future modifications to the methods used in this study, could be in the area of data smoothing. Possibly an alternative or more substantial smoothing technique could be found to aid in reducing the error associated with film data reduction. Additions to the data analysis techniques, within the computer program, could be facilitated in order to provide more kinetic data. This could provide a means to more fully investigate the causal factors in the arabian dive roll. An investigation of kinetic factors such as moments of force at take off and angular momentum during the airborne phase would provide further insight into the mechanical features of the arabian dive roll.

Based on the results obtained in this study, within the limitations of this research, the following conclusions are warranted.

1. The method employed in this study does provide a valid and accurate technique which can be used in the determination of movement features in three dimensions, in the context of biomechanical research.

2. The method used in this study does provide a means of investigation for multi-axial rotational movements, through assessment of absolute and relative angular kinematic variables.

3. Vertical velocity at take off is significantly related to vertical displacement in the airborne phase of the arabian dive roll.

4. The amount of angular displacement around the longitudinal axis, in the airborne phase, is proportional to the finishing position of the round off in the arabian dive roll.

5. Twist initiation occurs while in contact with the ground during the execution of the arabian dive roll.

6. Variations in segmental angular displacements do not totally explain the variance associated with relative angular velocities around the principle axes of rotation in the airborne phase of the arabian dive roll.

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APPENDIX A

PHYSICAL CHARACTERISTICS

TABLE 13

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

			Segmental Lengths			
Subject	Age	Weight (lb)	Right Calf (cm)	Right Thigh (cm)	Right Arm (cm)	Right Forearm (cm)
1.	17	156	40.8	39.9	29.8	25.3
2.	17	141	40.6	41.4	28.7	27.6
3.	18	143	39.9	40.1	31.1	27.1
4.	17	126	38.5	39.3	27.7	23.6
5.	22	132	37.9	39.9	25.6	24.9
6.	16	120	39.8	39.8	28.3	23.2
7.	17	128	32.6	38.7	26.8	22.3

APPENDIX B

MEASURED AND COMPUTED SPATIAL COORDINATES

TABLE 14

MEASURED AND COMPUTED SPATIAL COORDINATES

USING POINT 9 AS REFERENCE

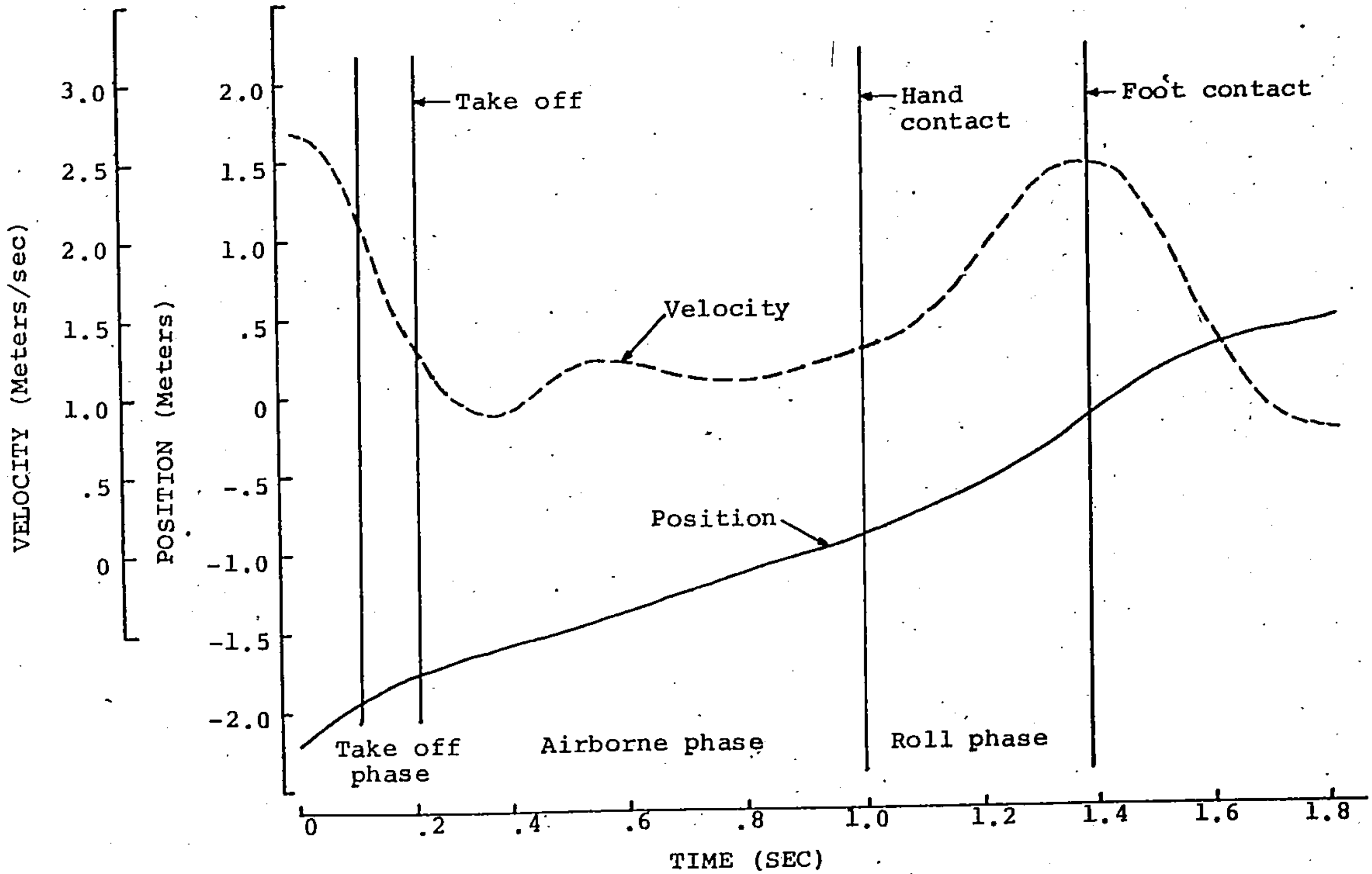
Measured Spatial Coordinates			Computed spatial Coordinates		
X	Y	Z	X	Y	Z
0.0	20.9	30.3	0.0	22.1	30.4
-6.8	11.2	17.4	-6.7	11.1	16.5
-13.7	21.4	-20.7	-12.6	21.0	-22.8
-15.7	30.4	-44.7	-16.8	27.4	-46.3
-20.7	-12.5	-15.5	-21.5	-13.1	-17.2
-41.5	-22.8	-80.9	-41.6	-24.5	-84.9
0.0	-46.8	5.1	0.0	-47.3	6.1
16.9	-26.4	-49.5	18.8	-30.7	-48.5
27.8	-44.1	-93.9	26.3	-45.1	-92.7
28.1	17.1	-42.0	28.9	15.8	-41.5
39.3	23.8	-76.8	39.4	22.4	-76.2

The mean deviation = 1.15 cm (s=.01)

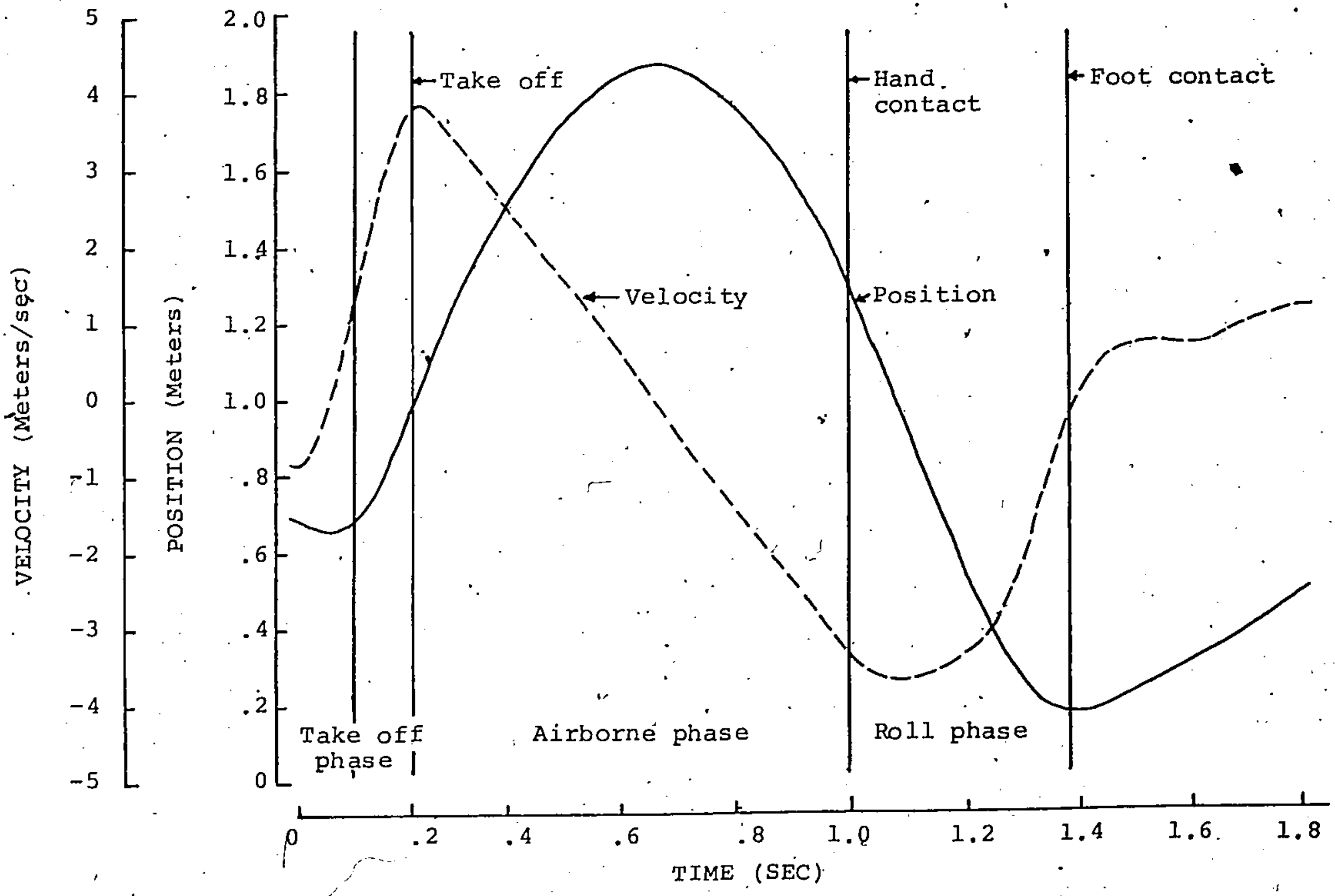
(measurements in cm. in relationship to reference frame origin)

APPENDIX C

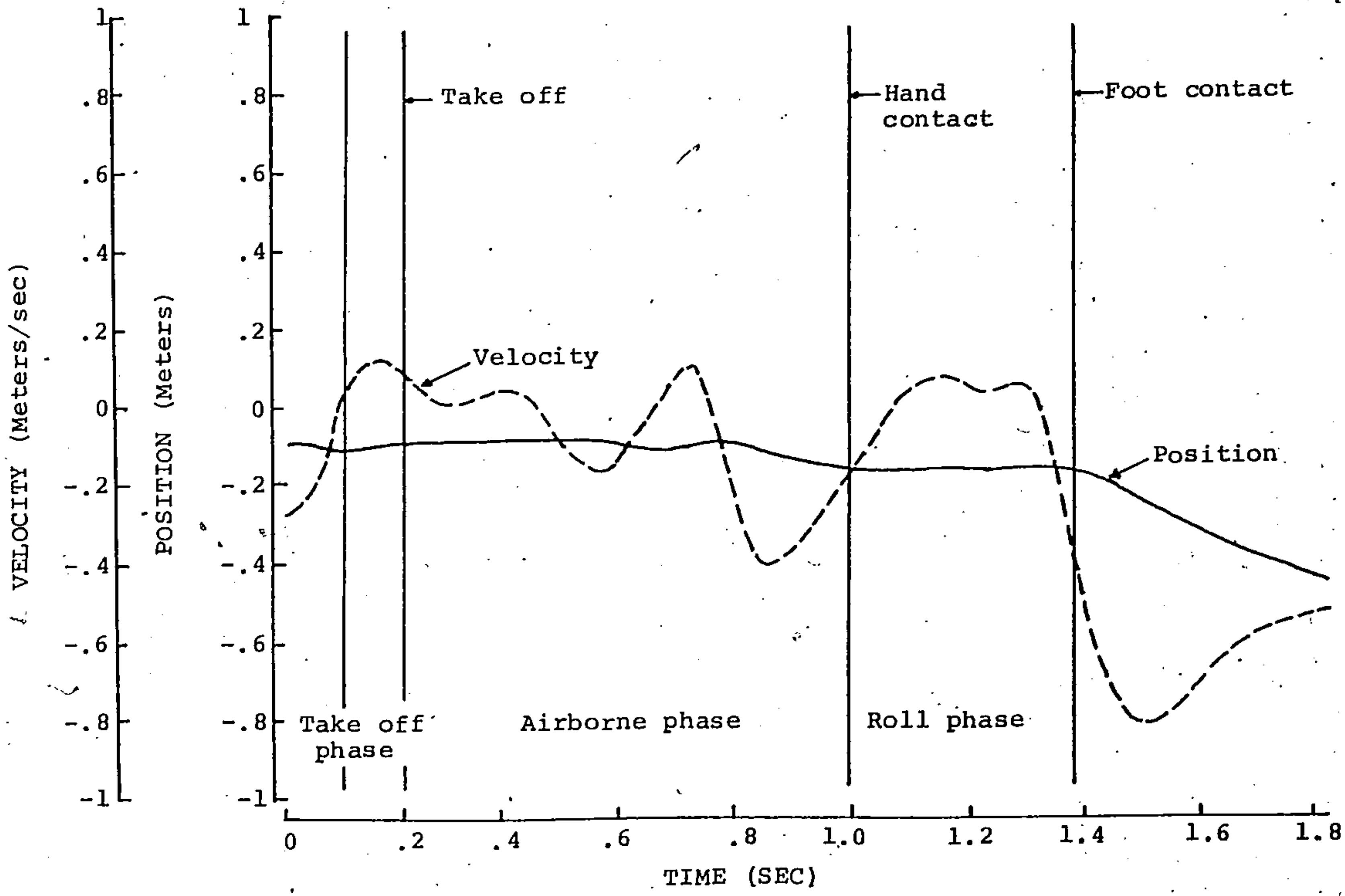
CENTER OF GRAVITY CURVES



CENTER OF GRAVITY HORIZONTAL DIRECTION SUBJECT 1



CENTER OF GRAVITY VERTICAL DIRECTION SUBJECT 1



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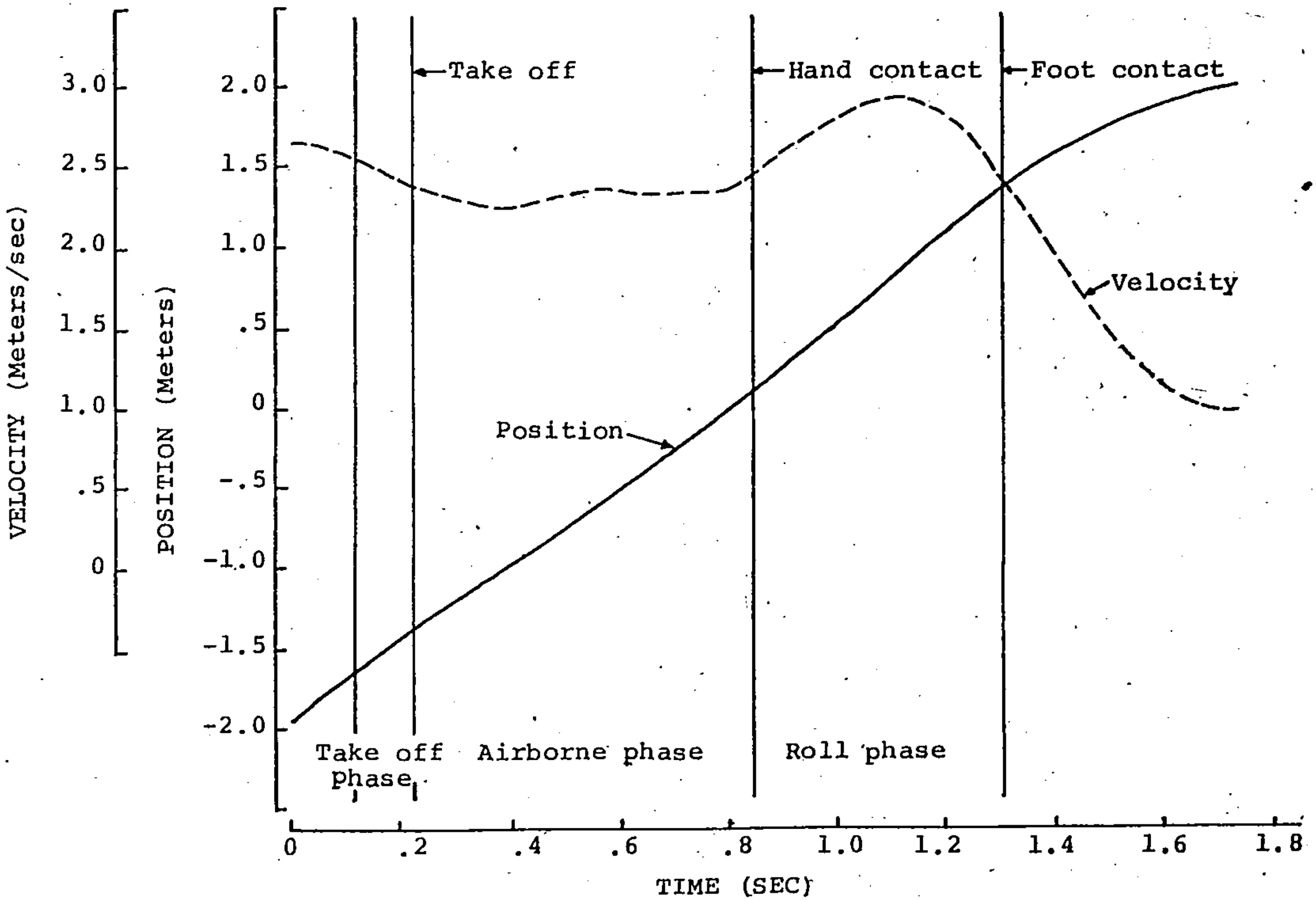

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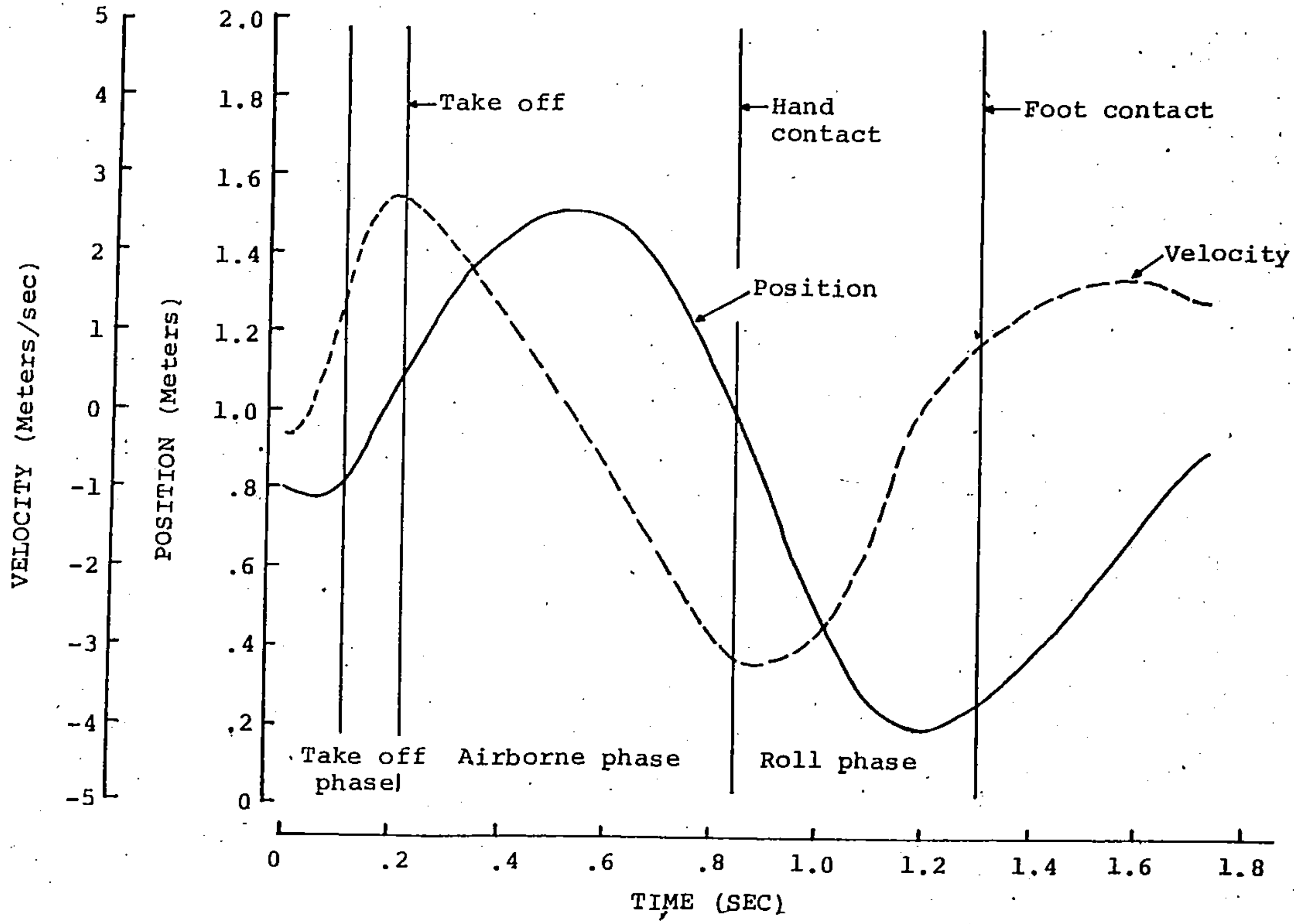

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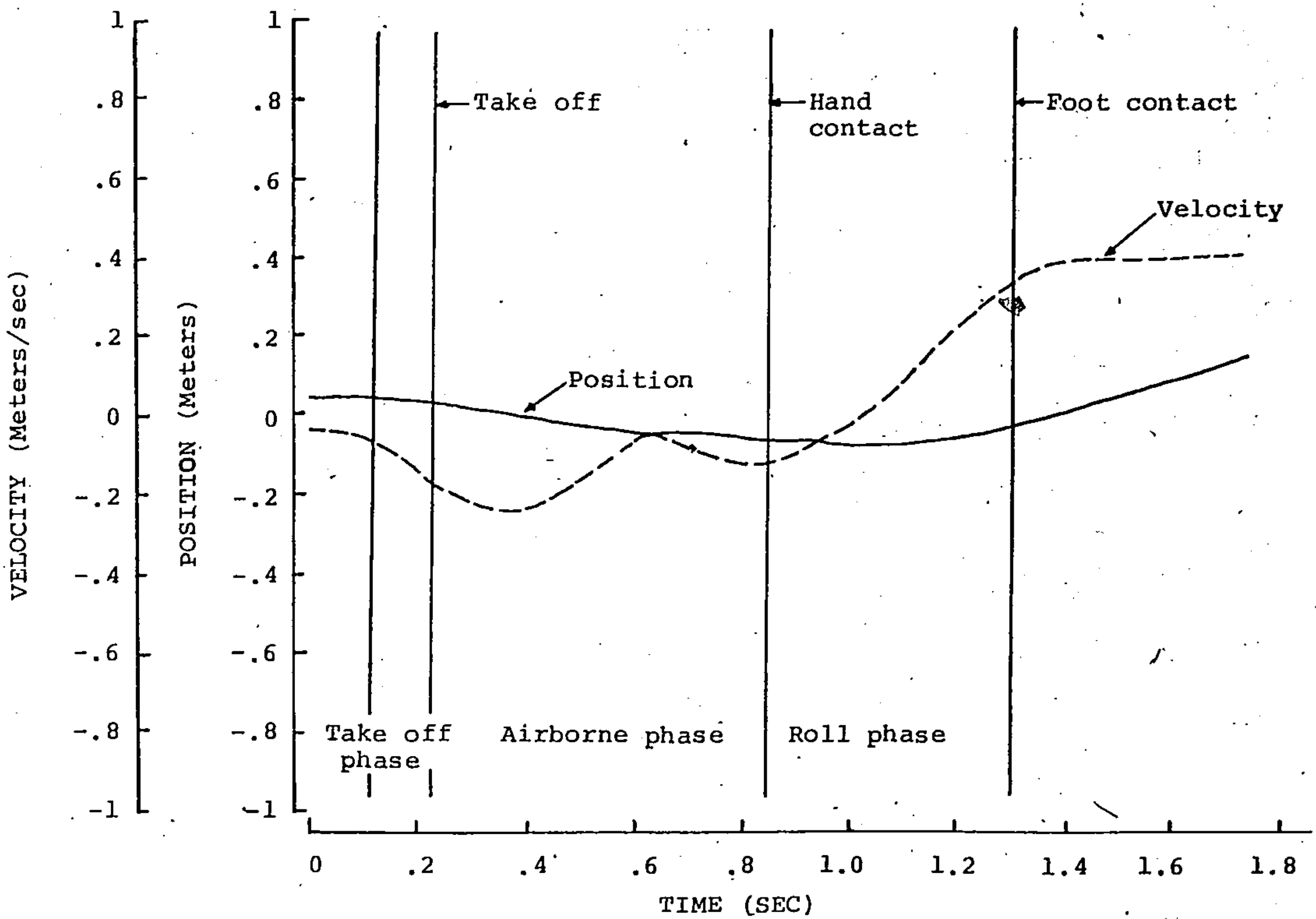

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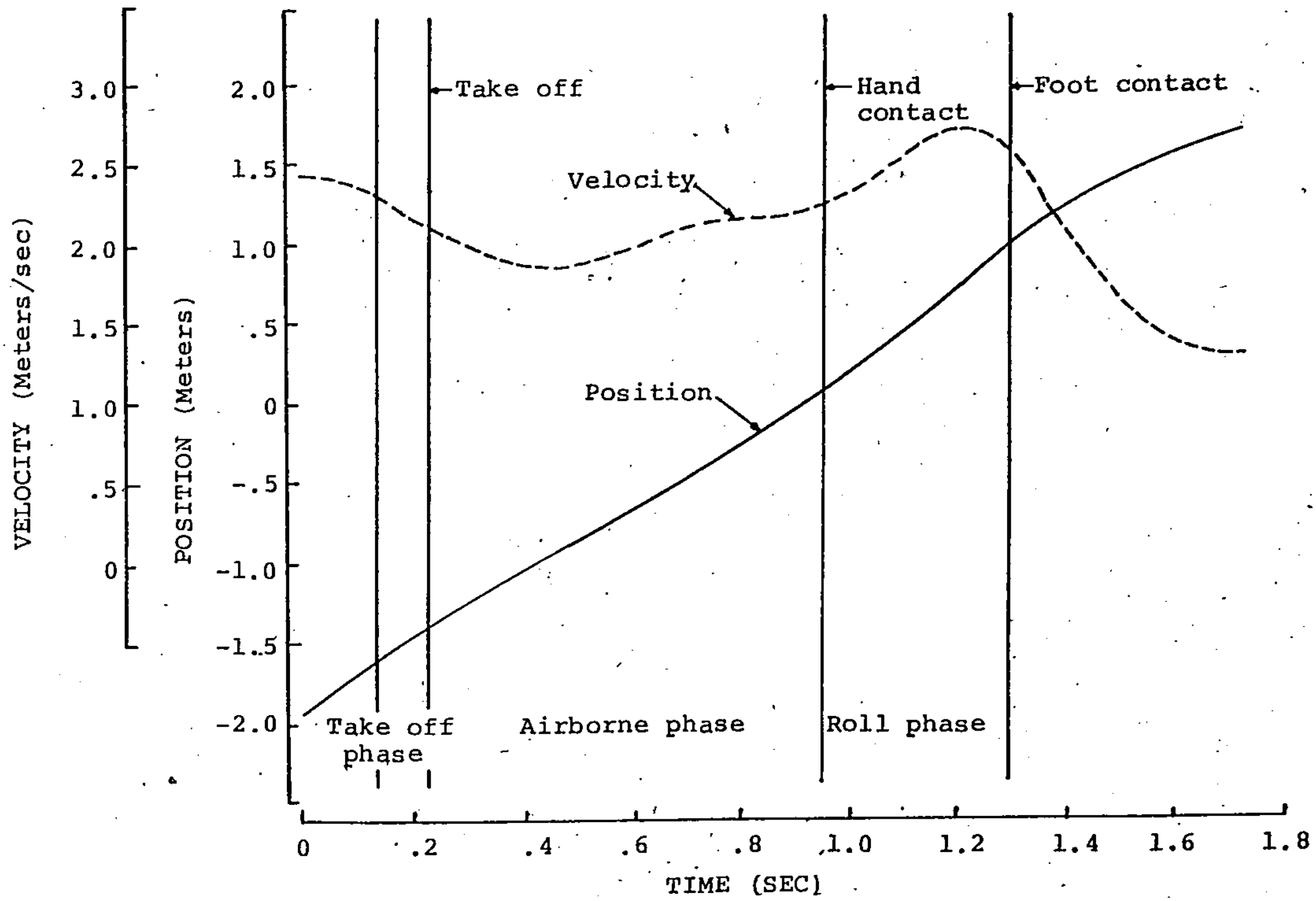
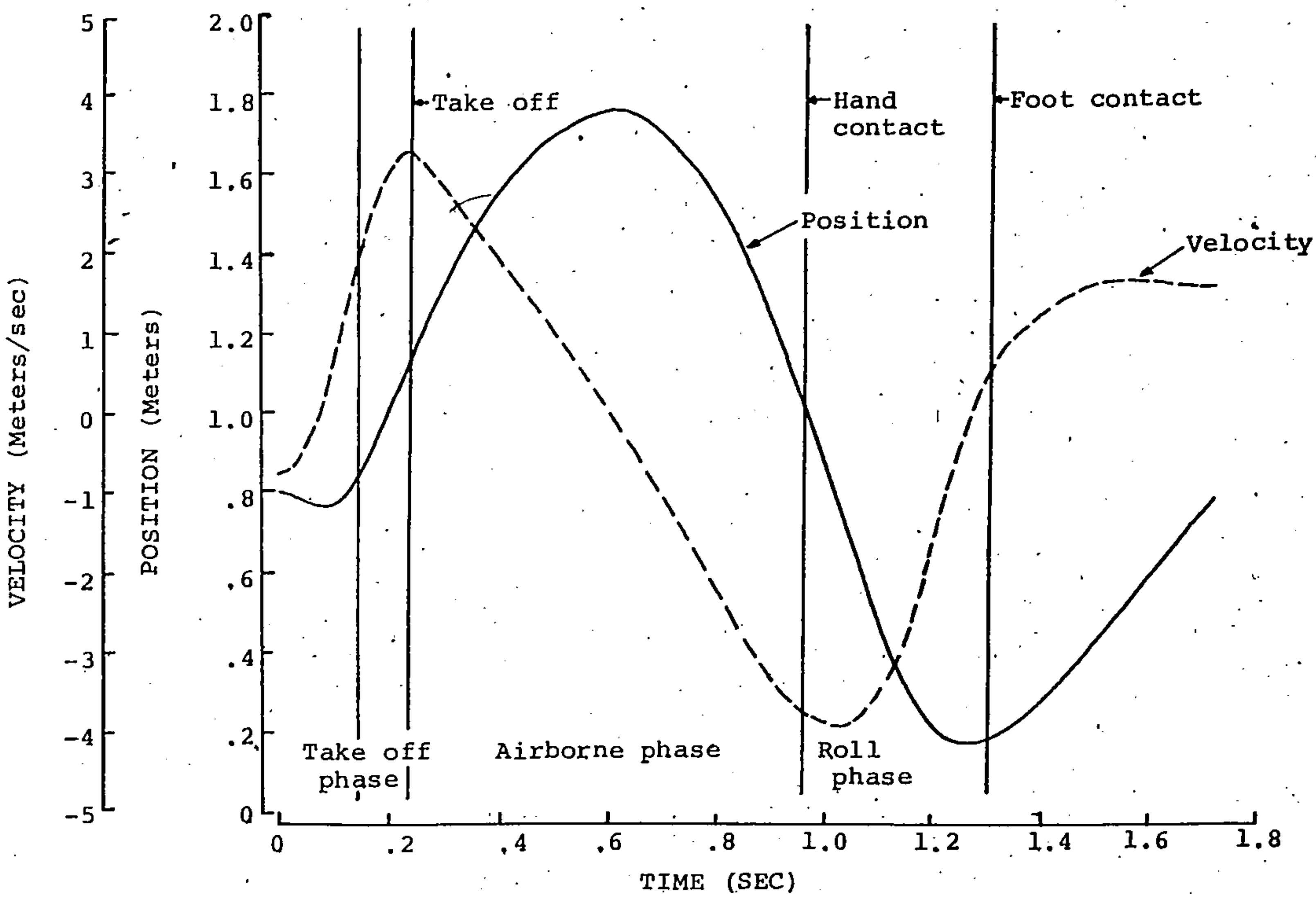


CENTER OF GRAVITY HORIZONTAL DIRECTION SUBJECT 3



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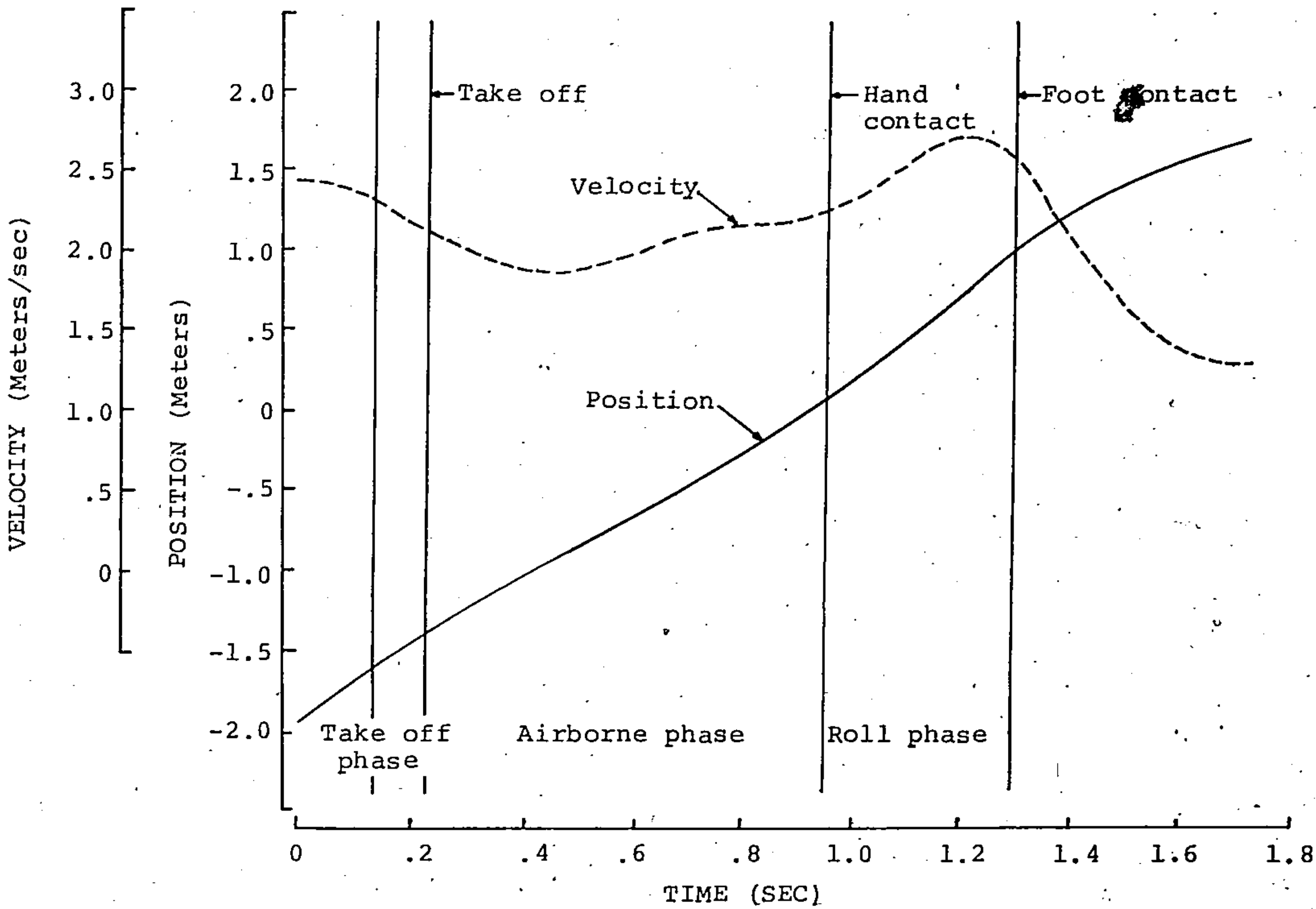

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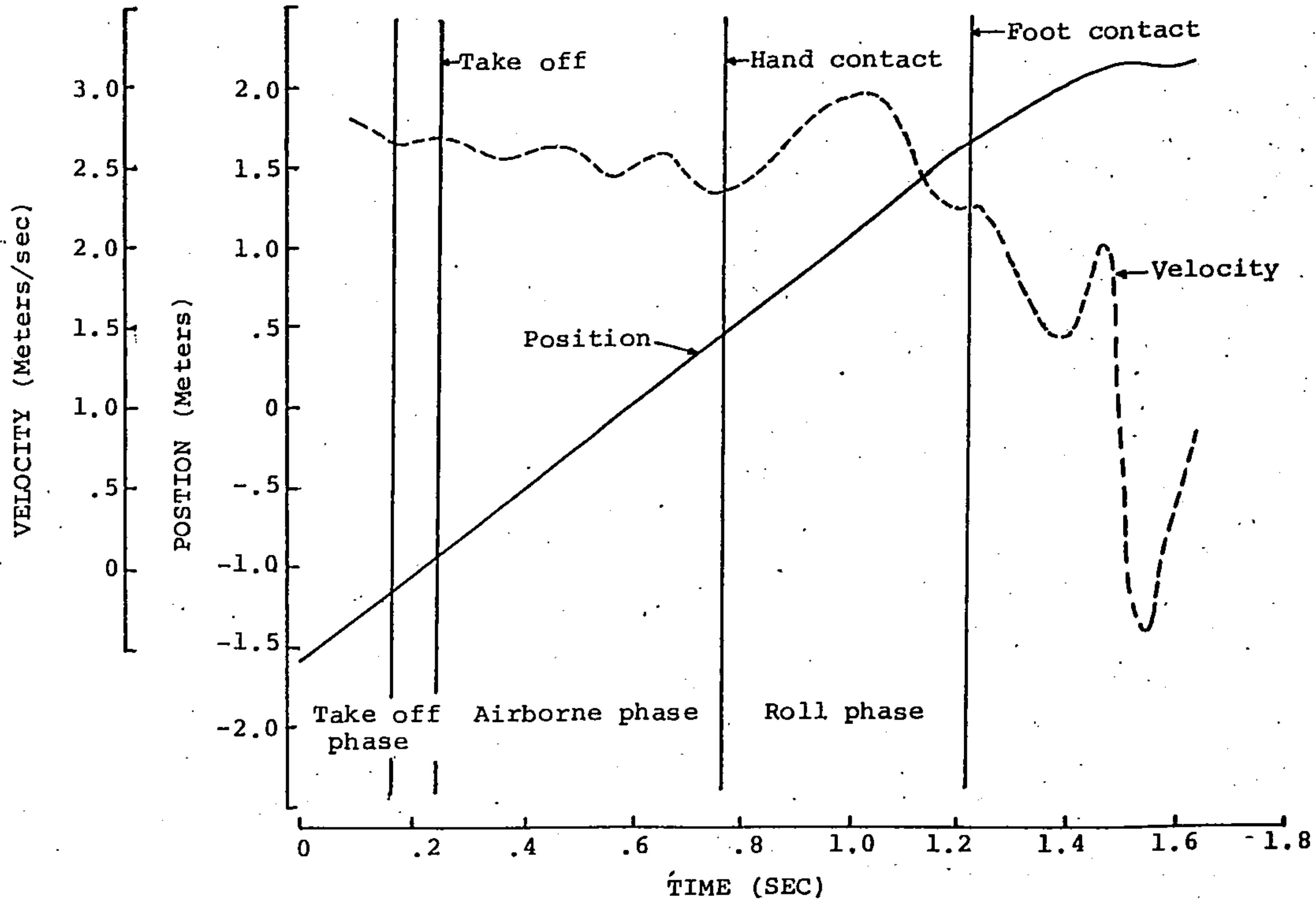

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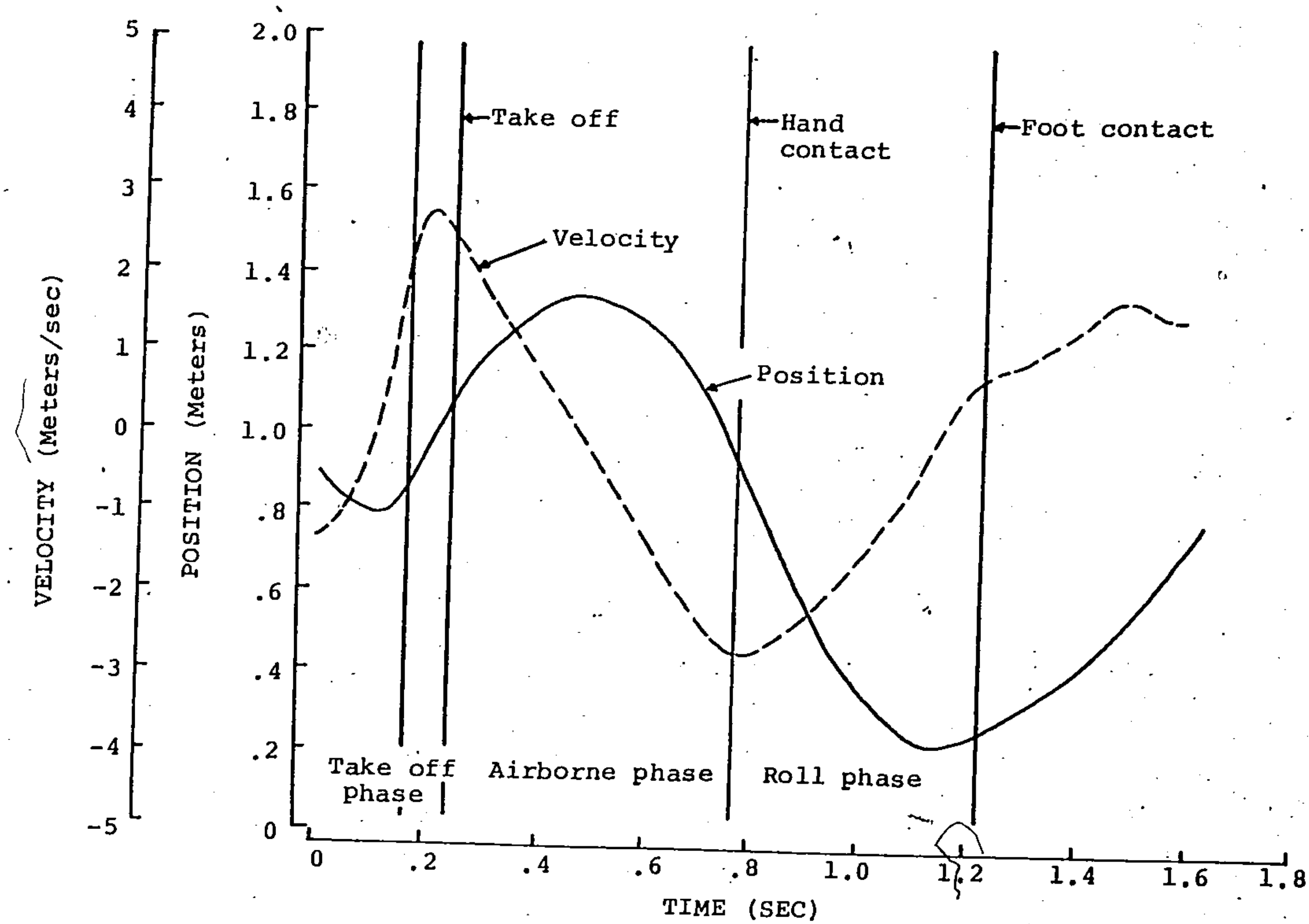

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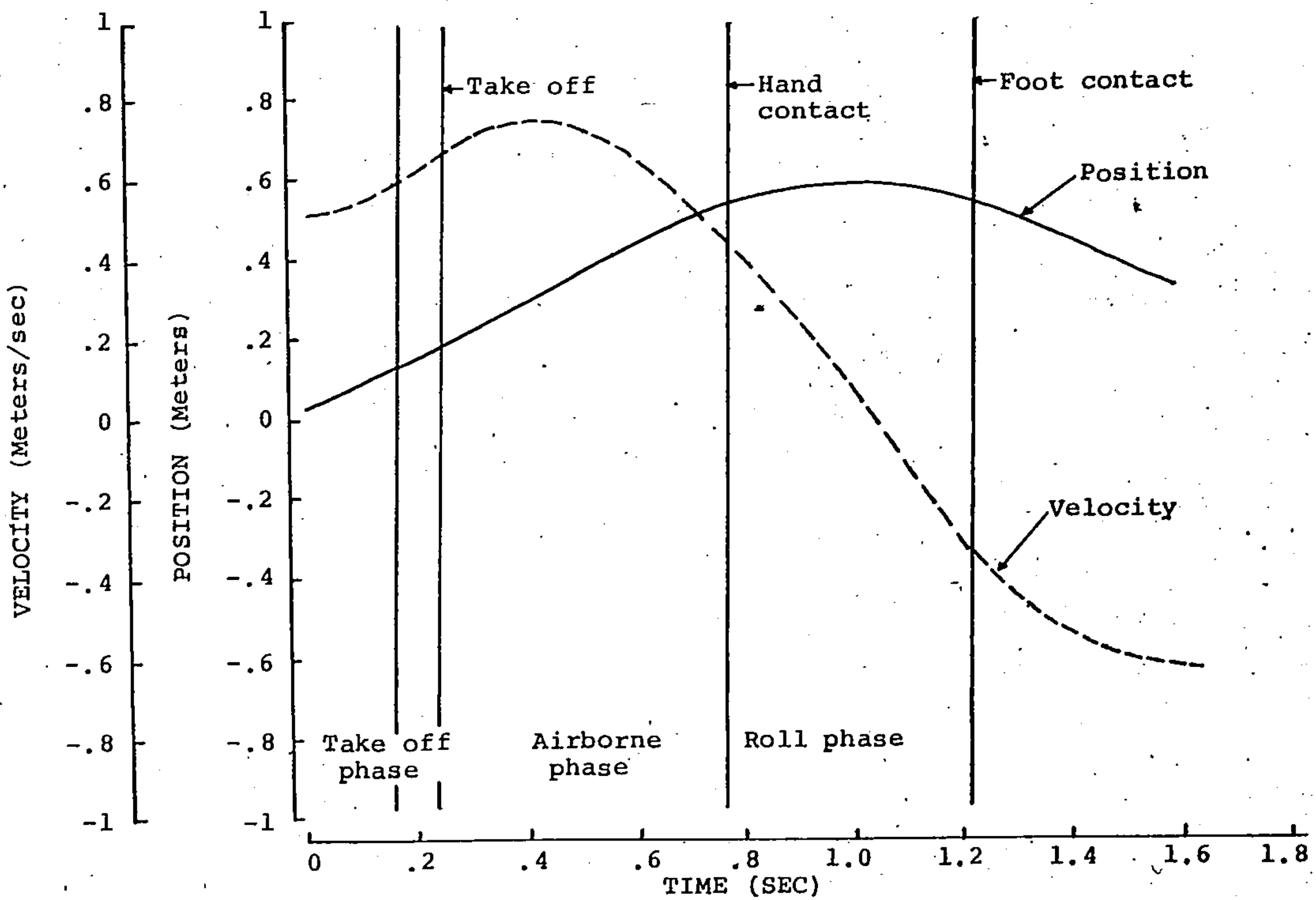

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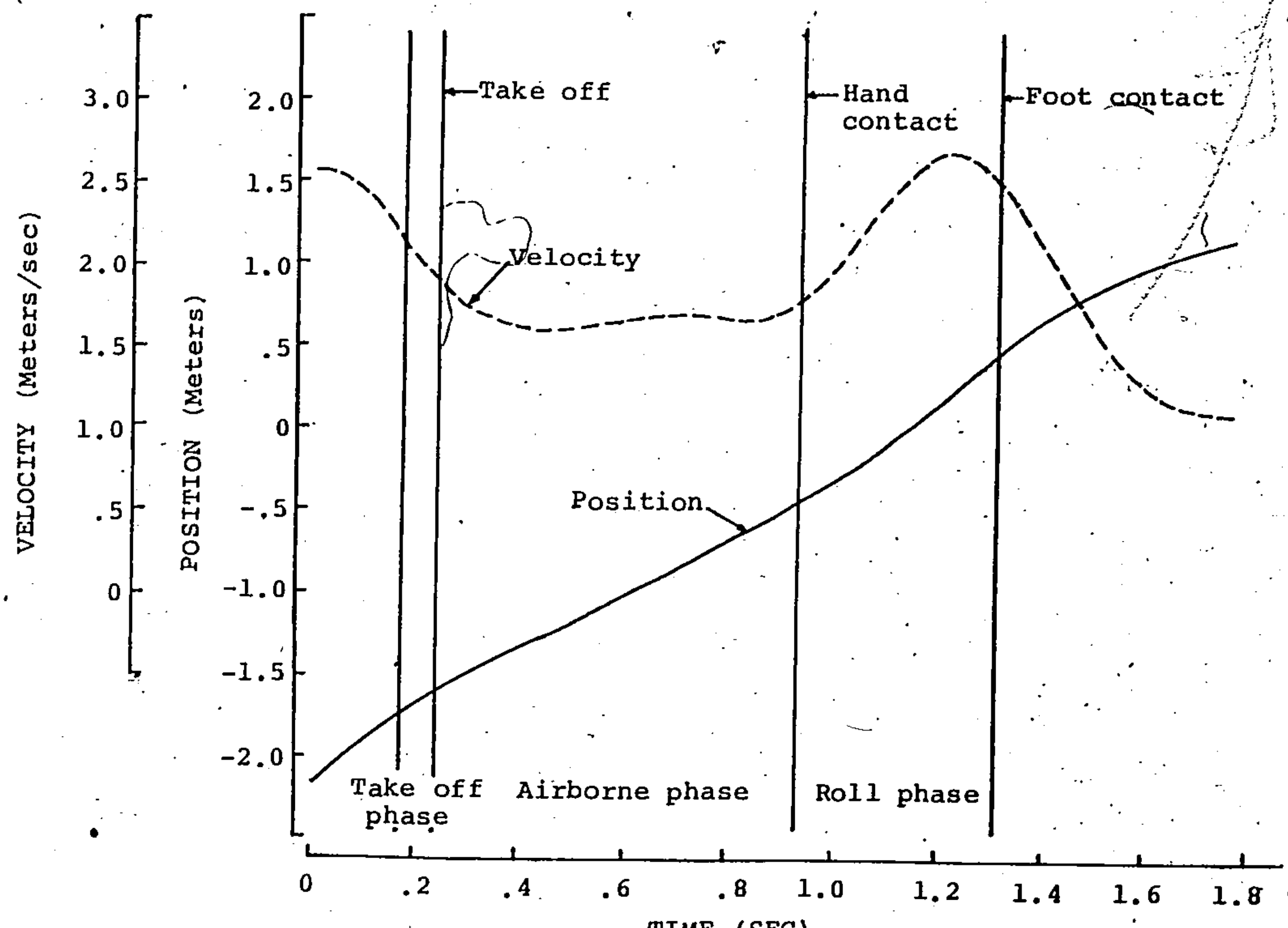

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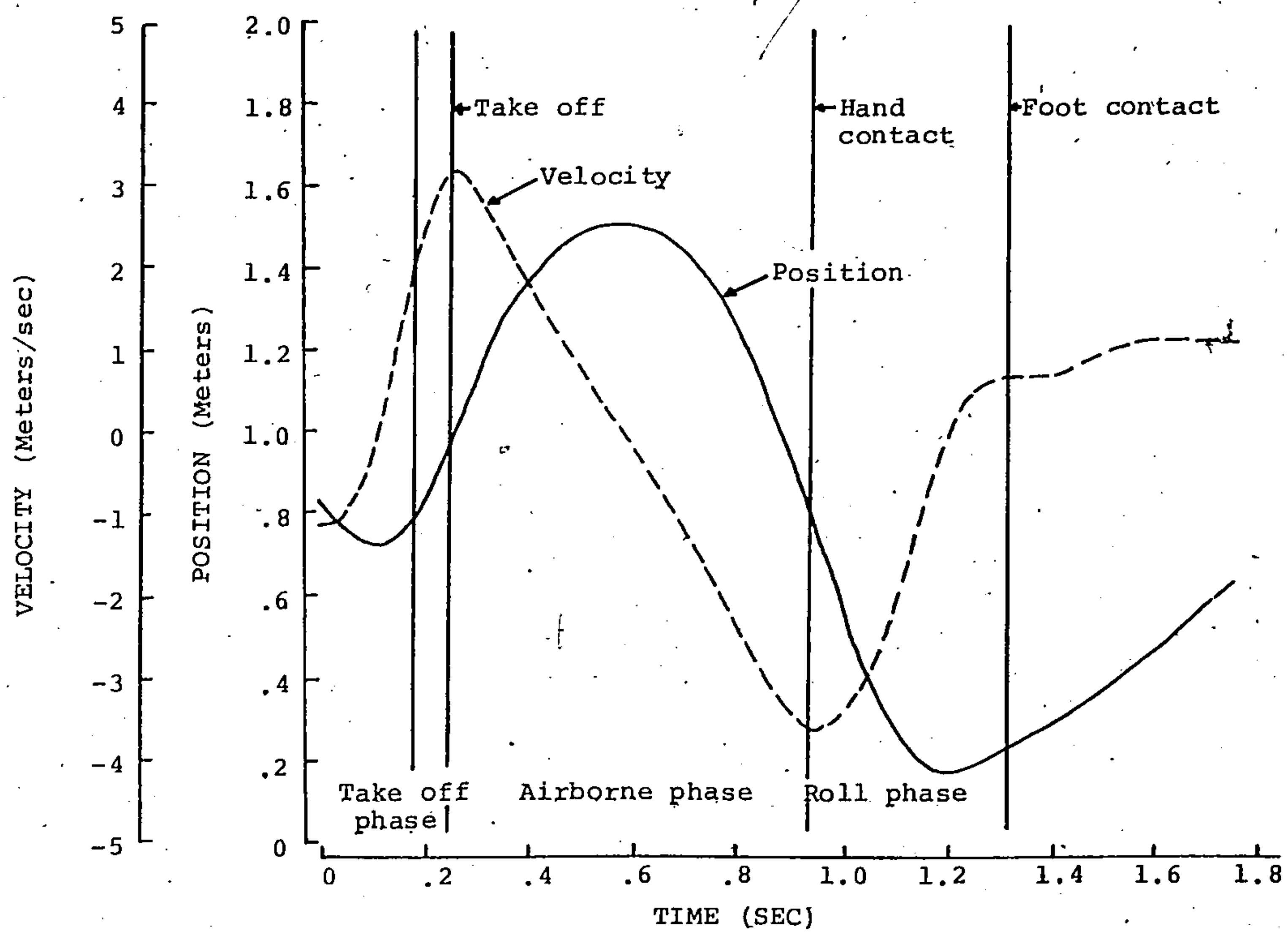

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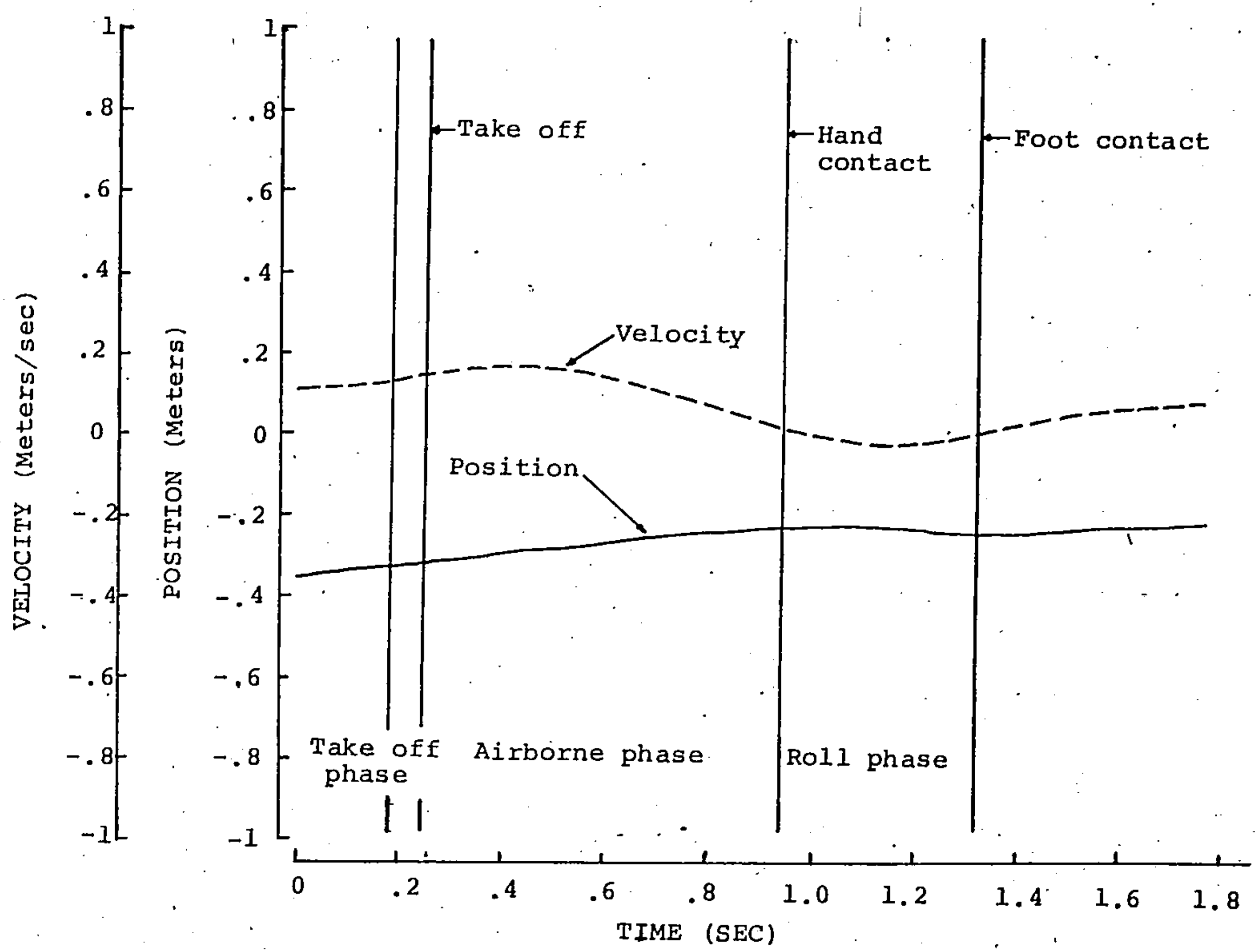

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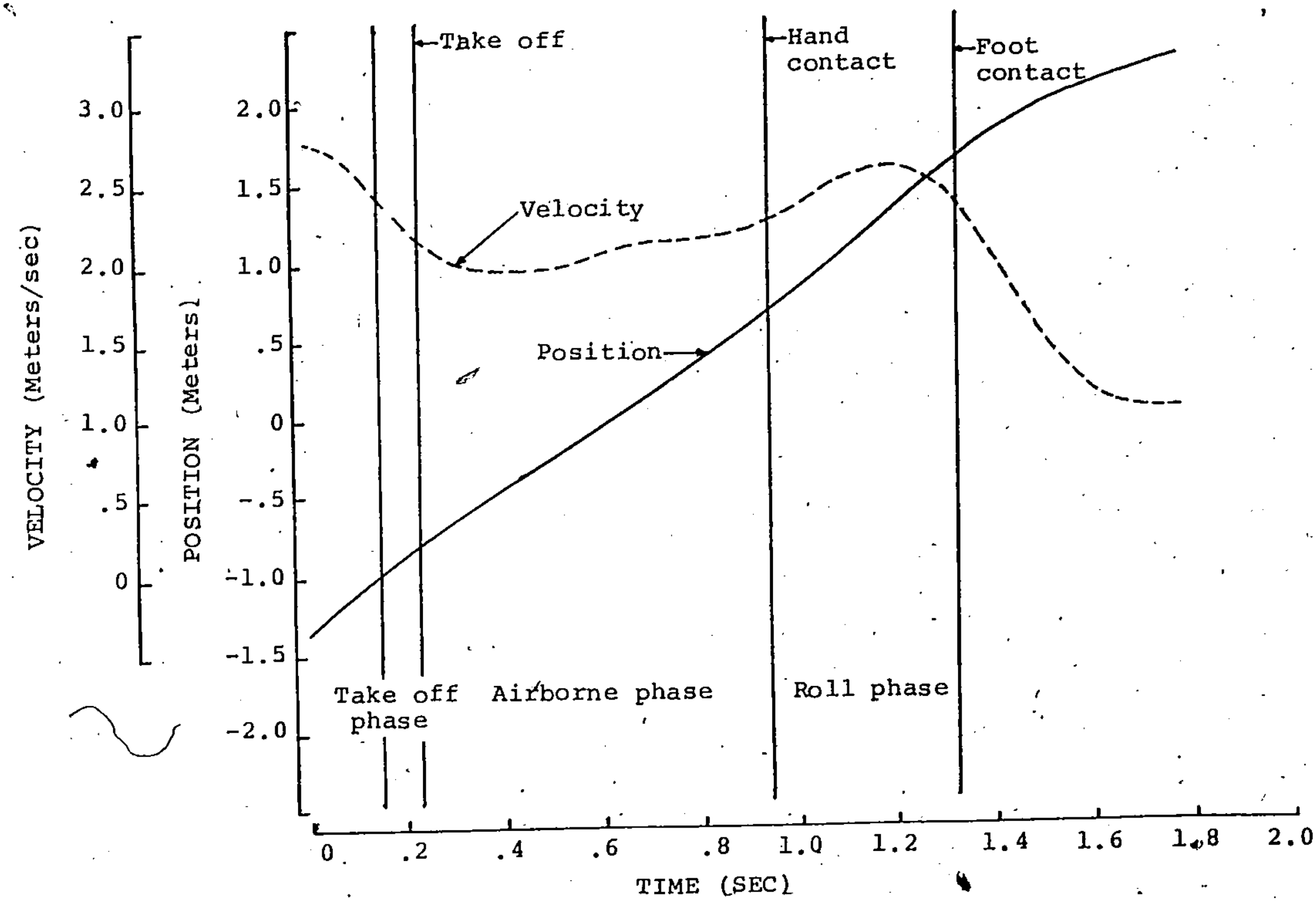

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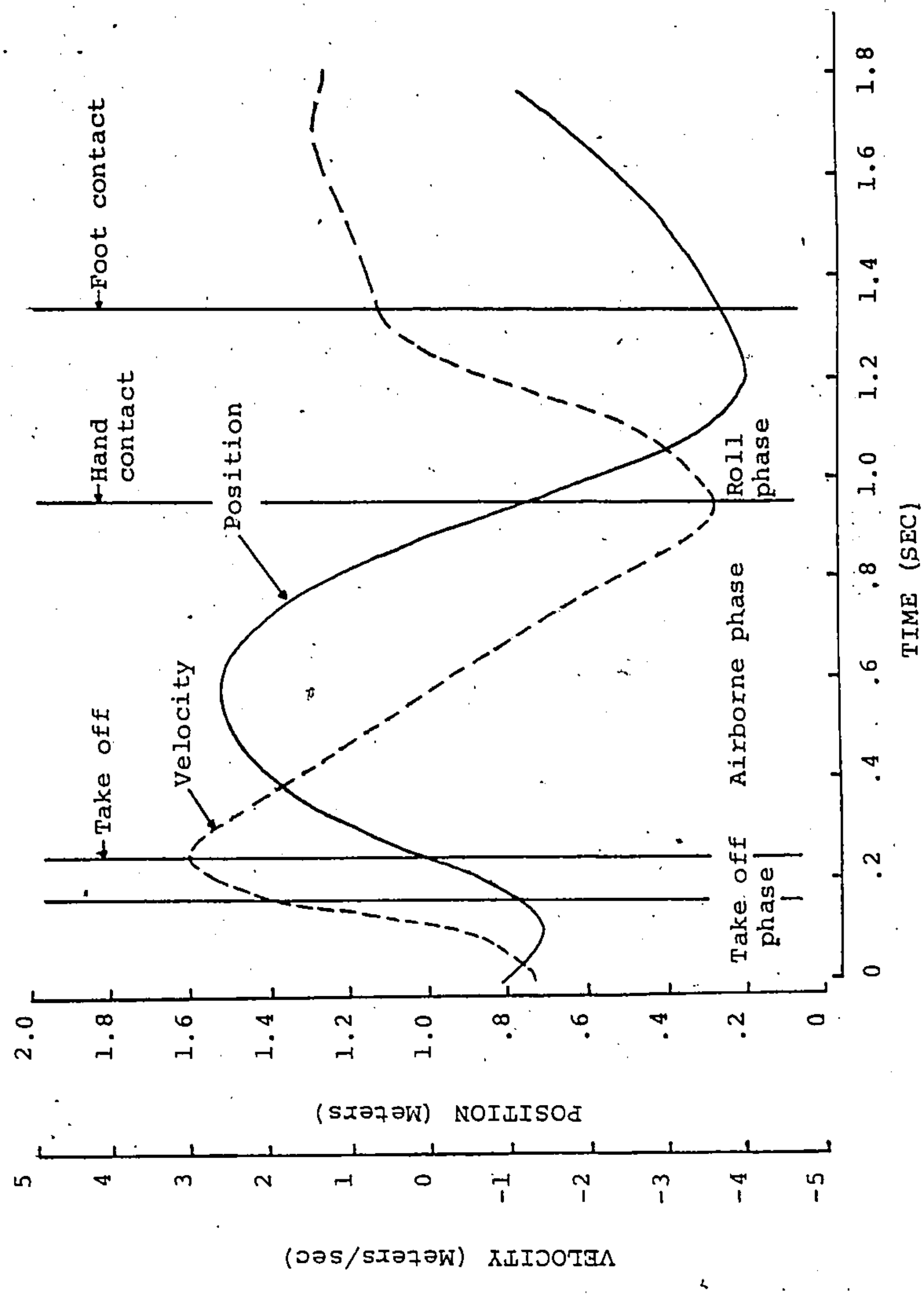

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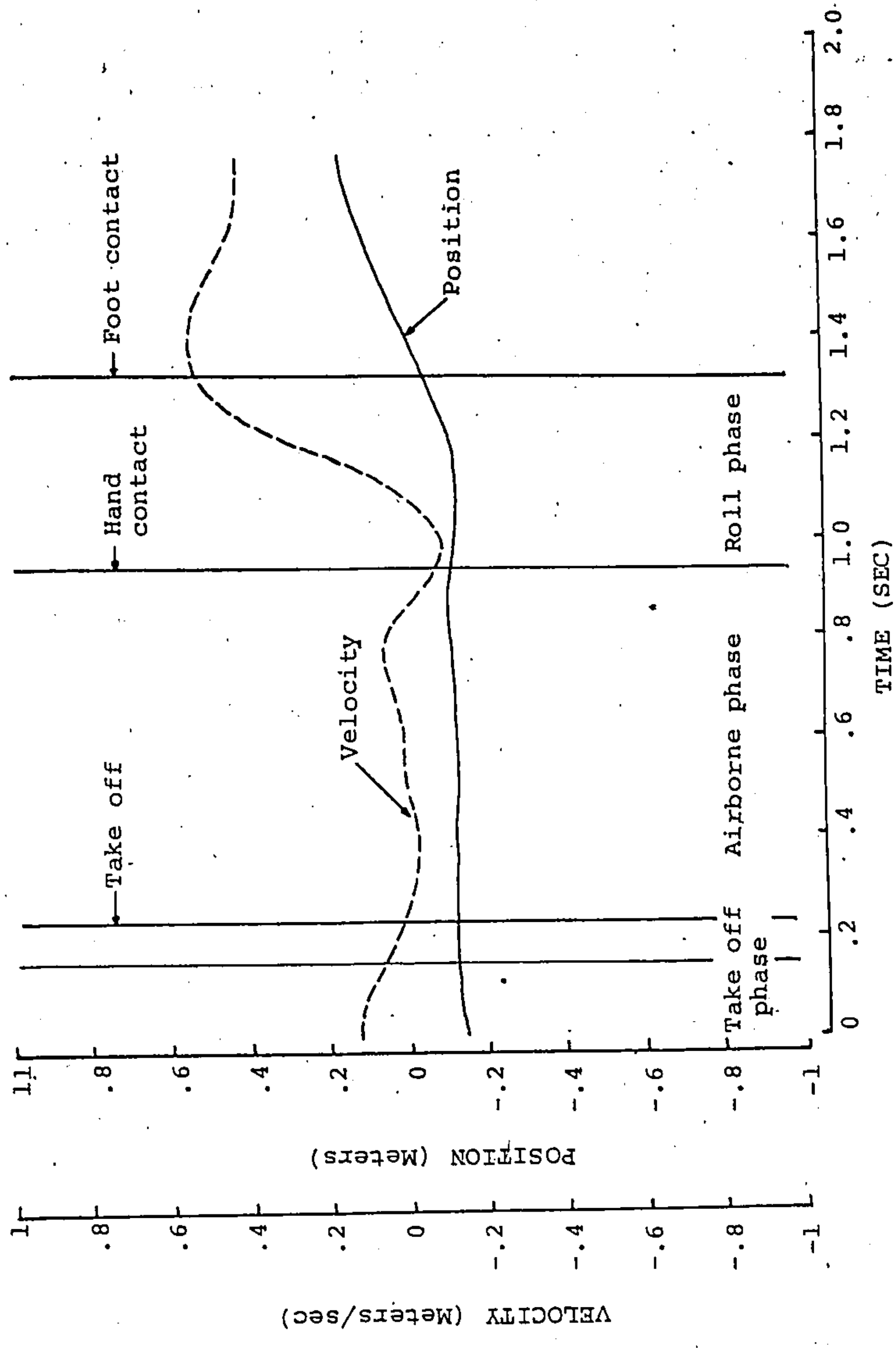

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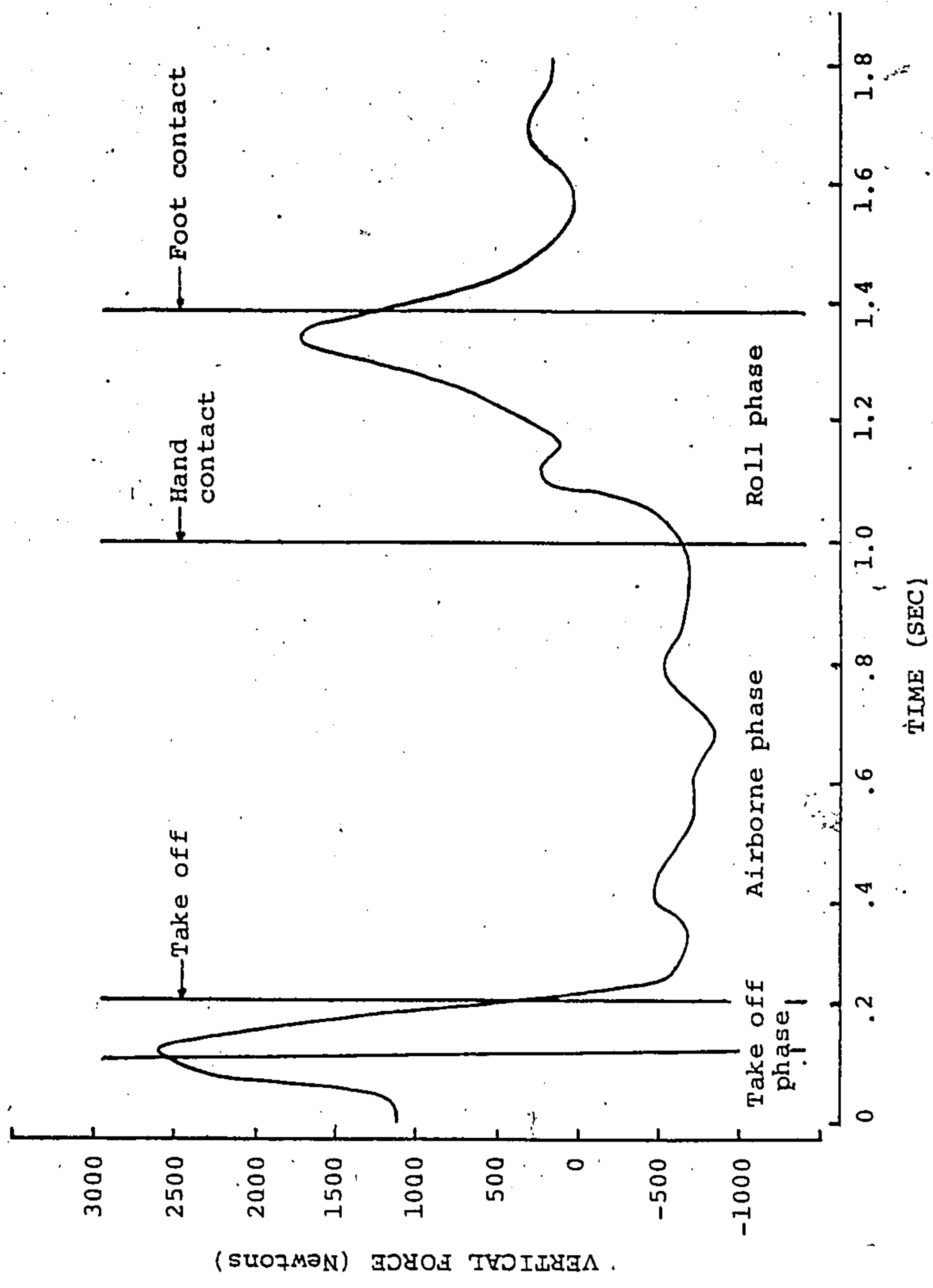
APPENDIX D

VERTICAL FORCE CURVES



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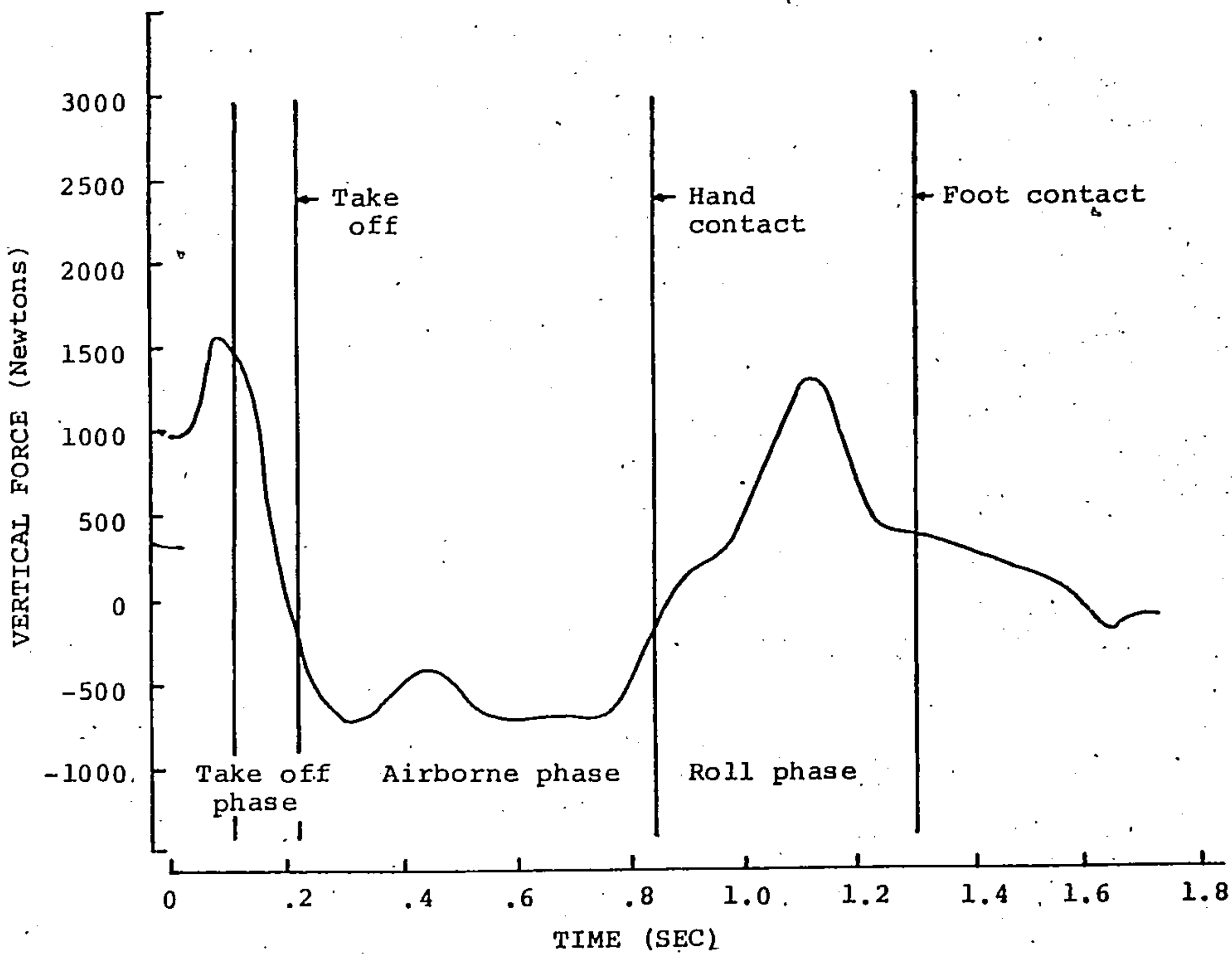

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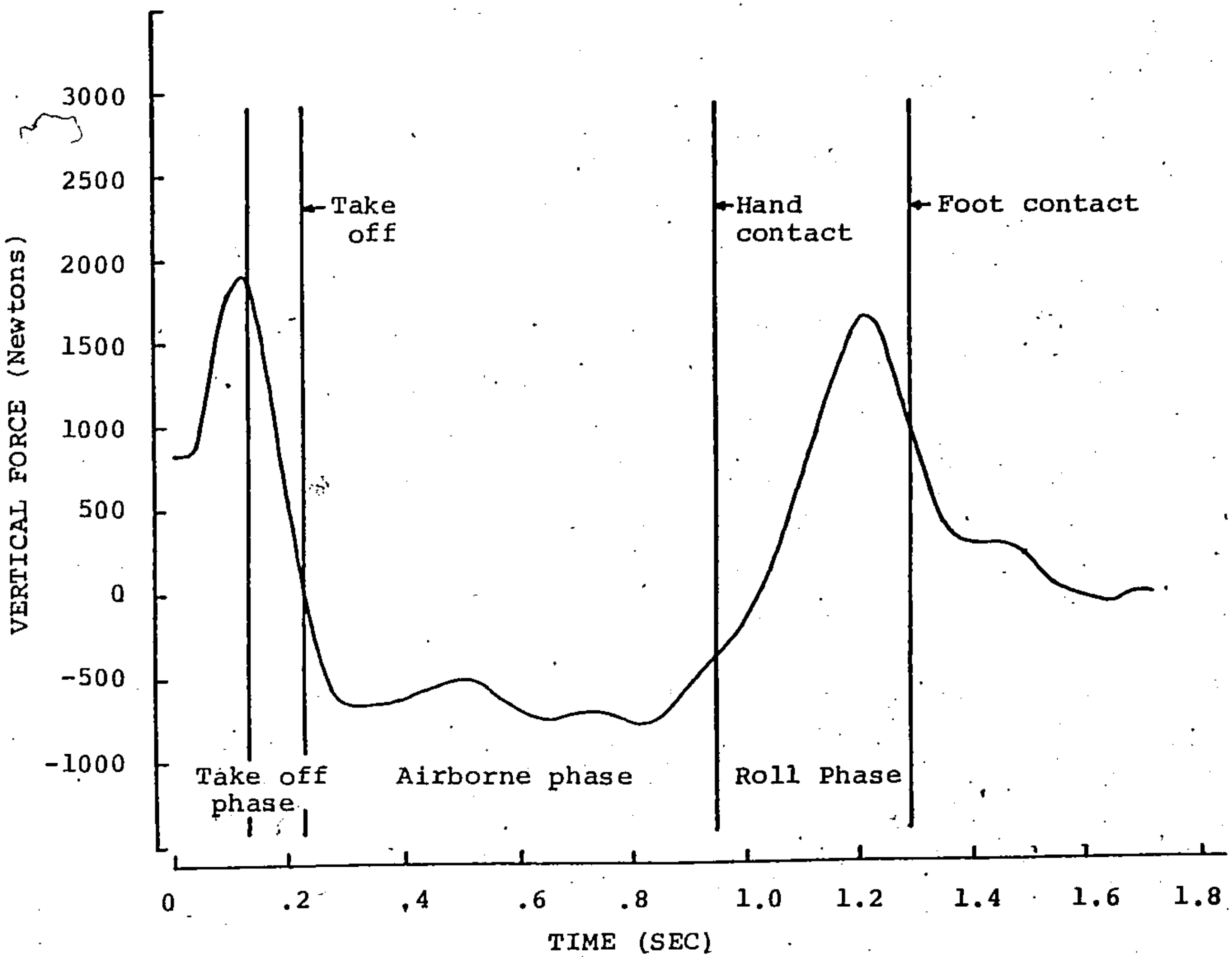

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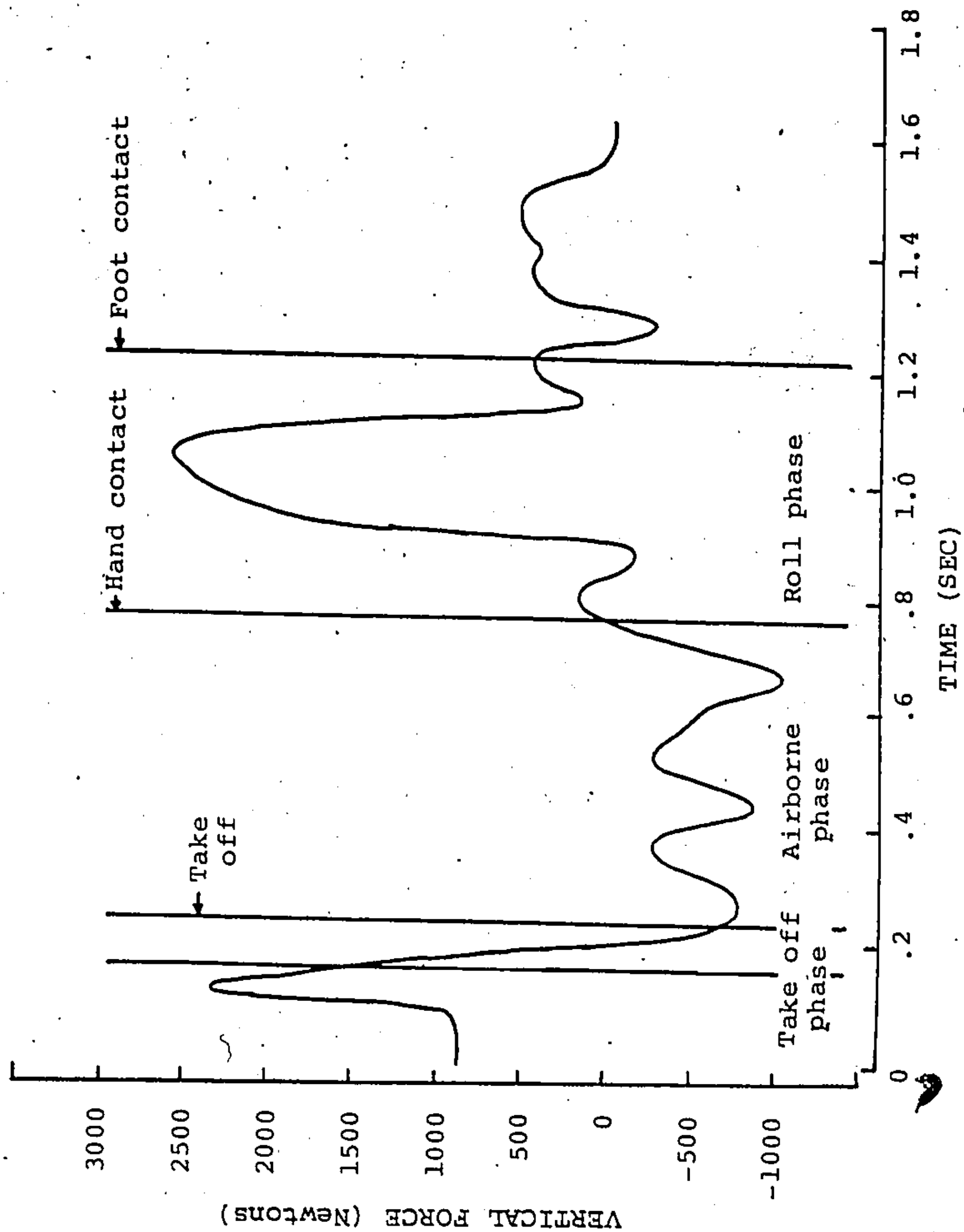

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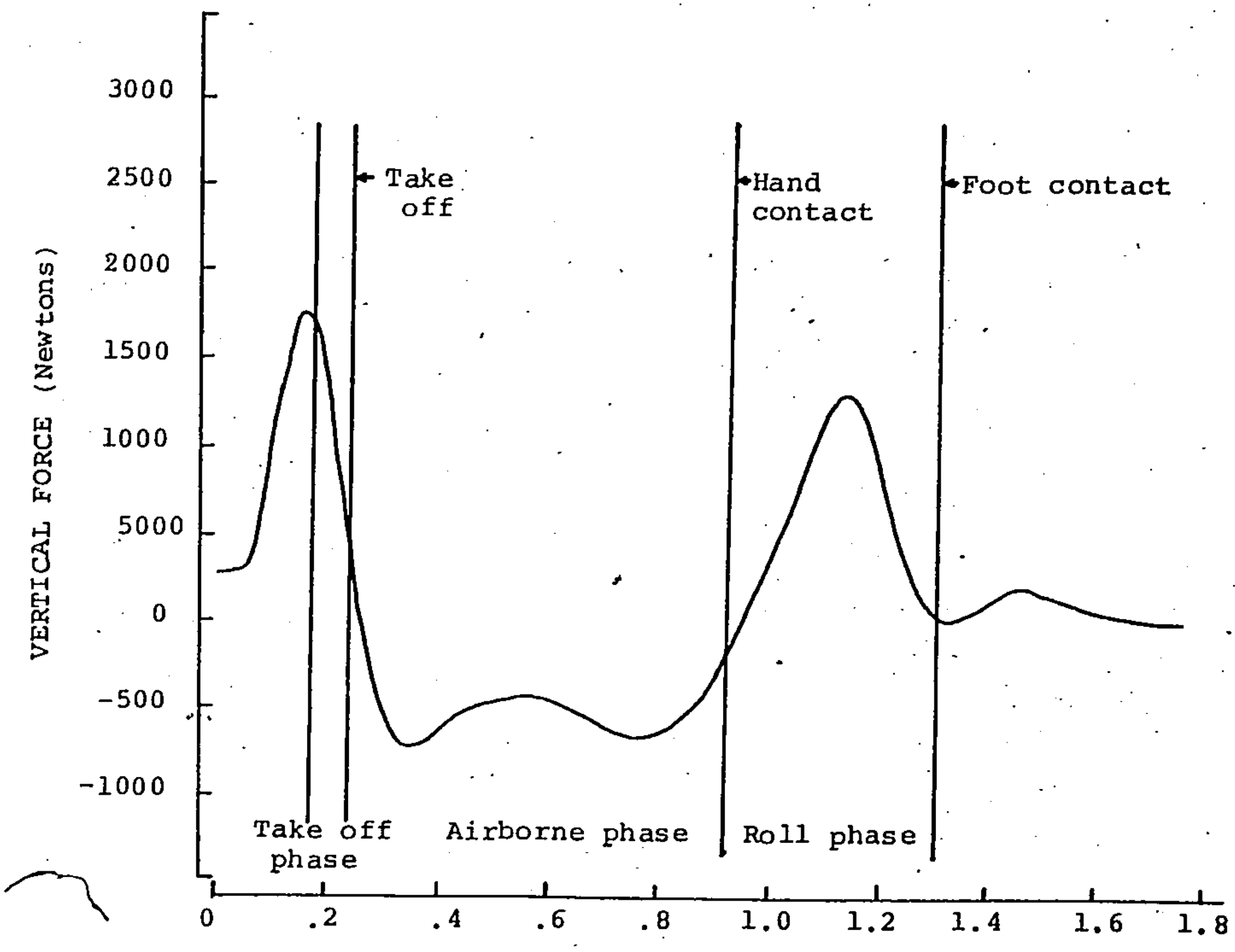

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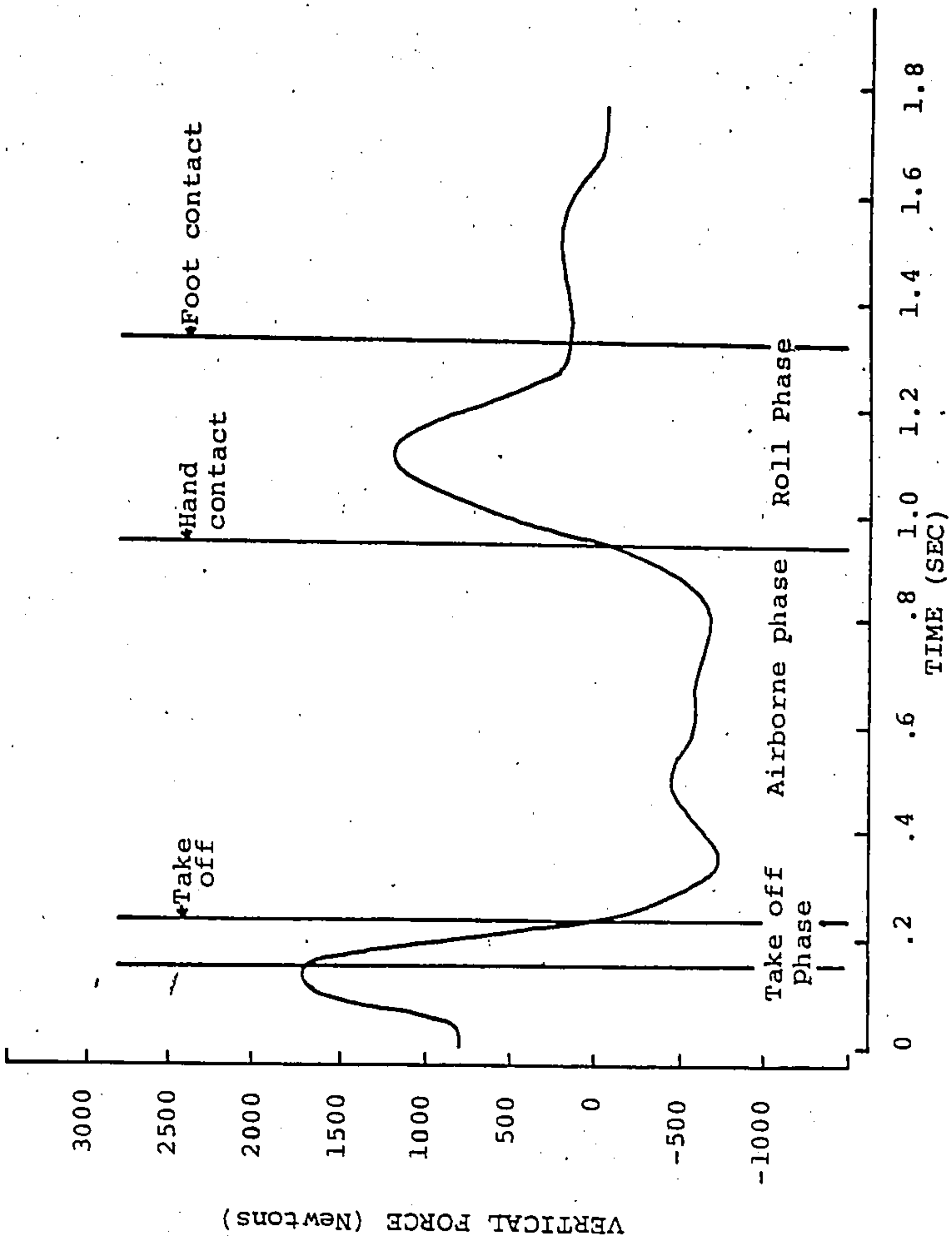


VERTICAL FORCE SUBJECT 7

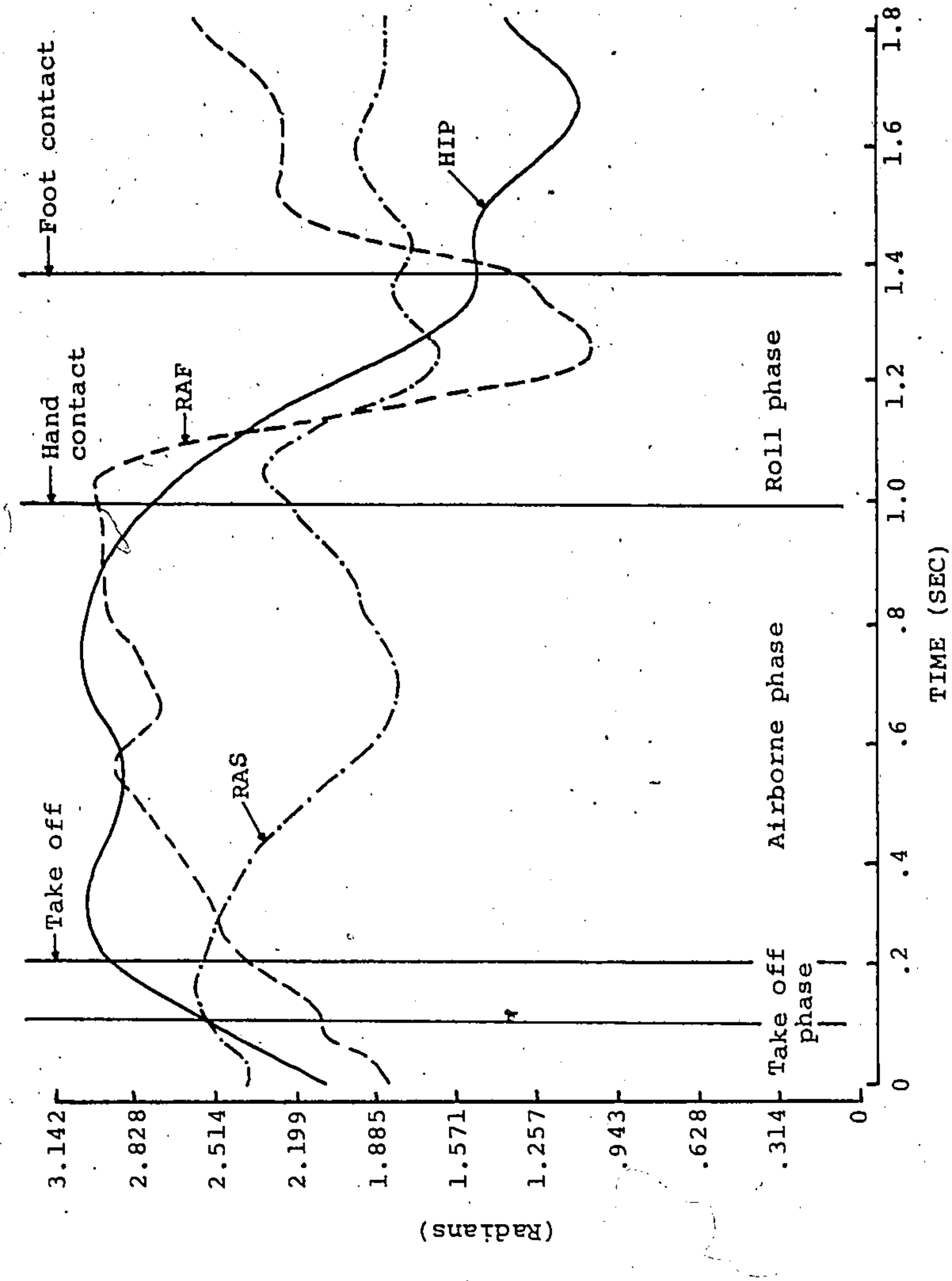
APPENDIX E

SEGMENTAL ANGLES

ABBREVIATIONS

In the graphs on segmental angular displacements, the angles are abbreviated as follows:

1.	HIP	Trunk Thigh Angle
2.	HEAD	Head Trunk Angle
3.	RAS	Right Arm Side Angle
4.	LAS	Left Arm Side Angle
5.	RAF	Right Arm Flexion Angle
6.	LAF	Left Arm Flexion Angle
7.	RAX	Right Arm Across Angle
8.	LAX	Left Arm Across Angle
9.	STR	Straddle Leg Angle



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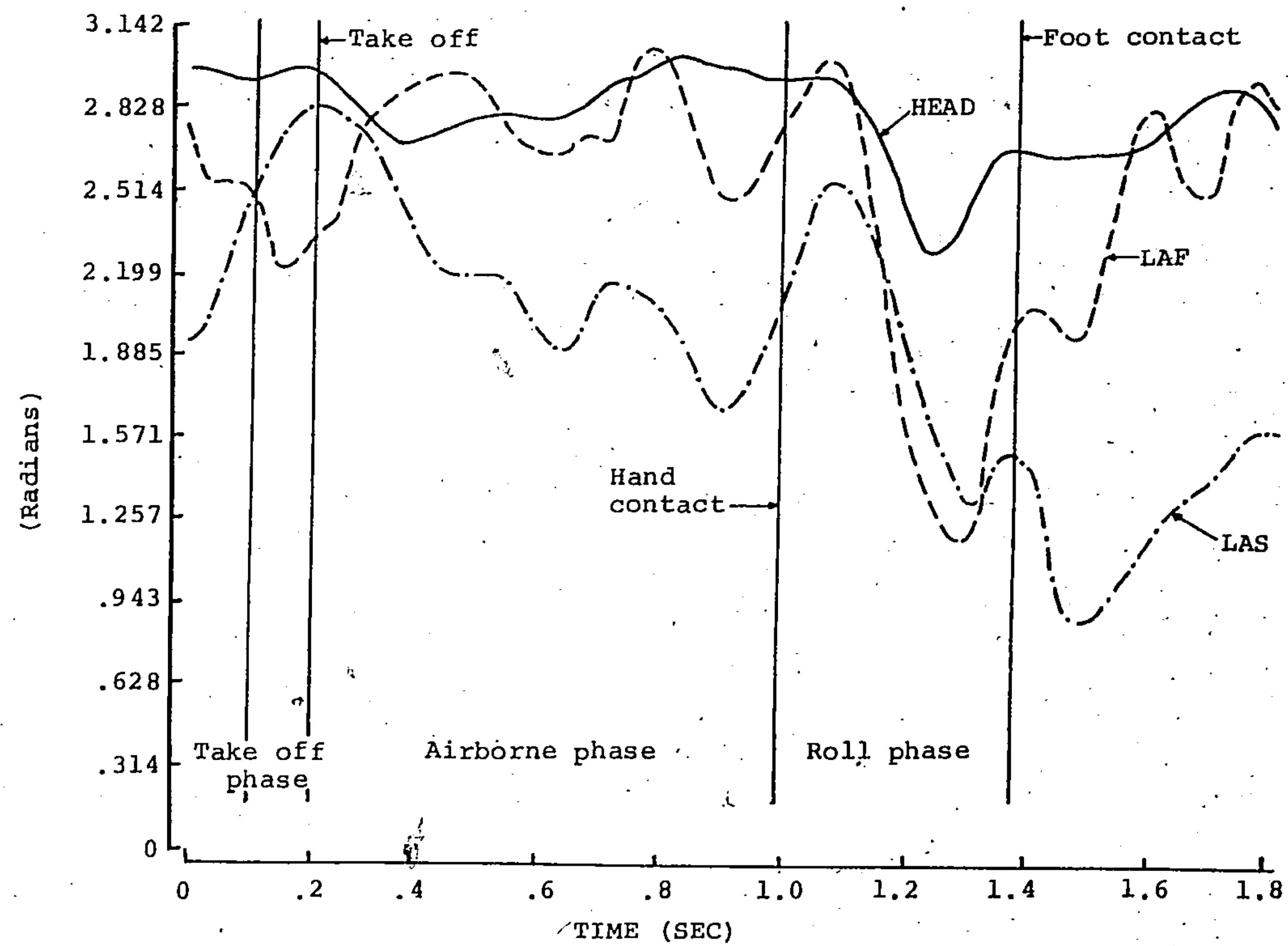

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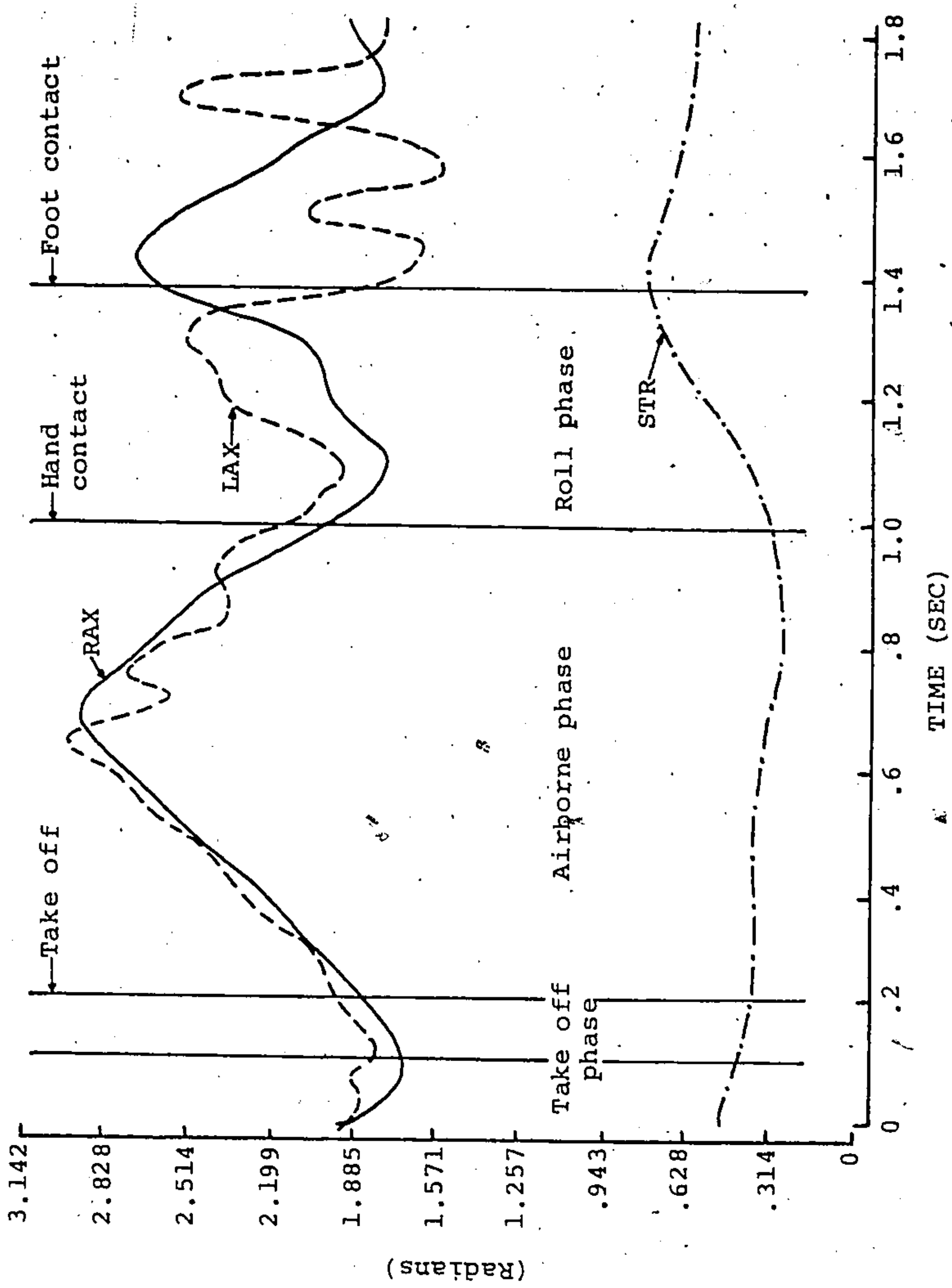

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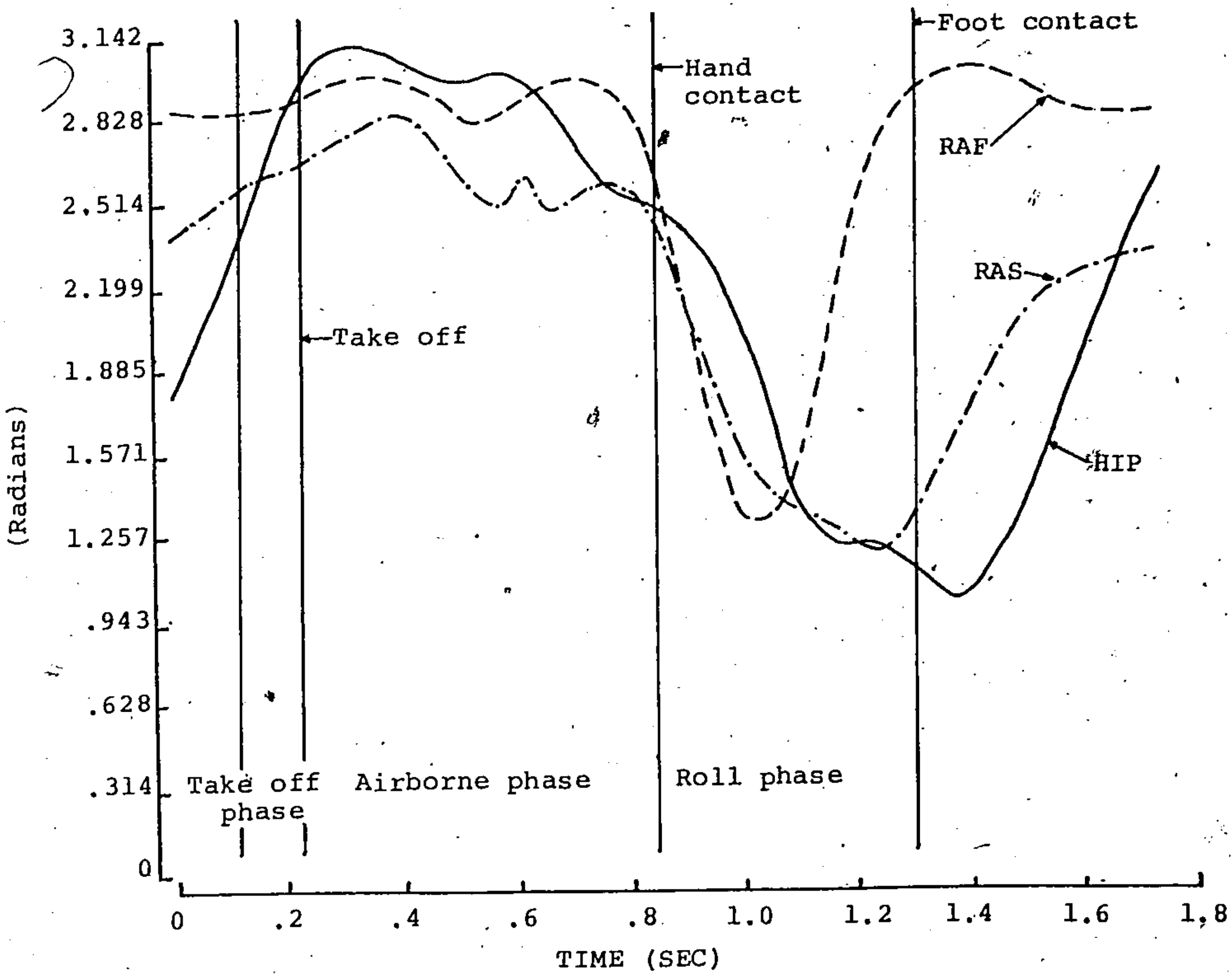

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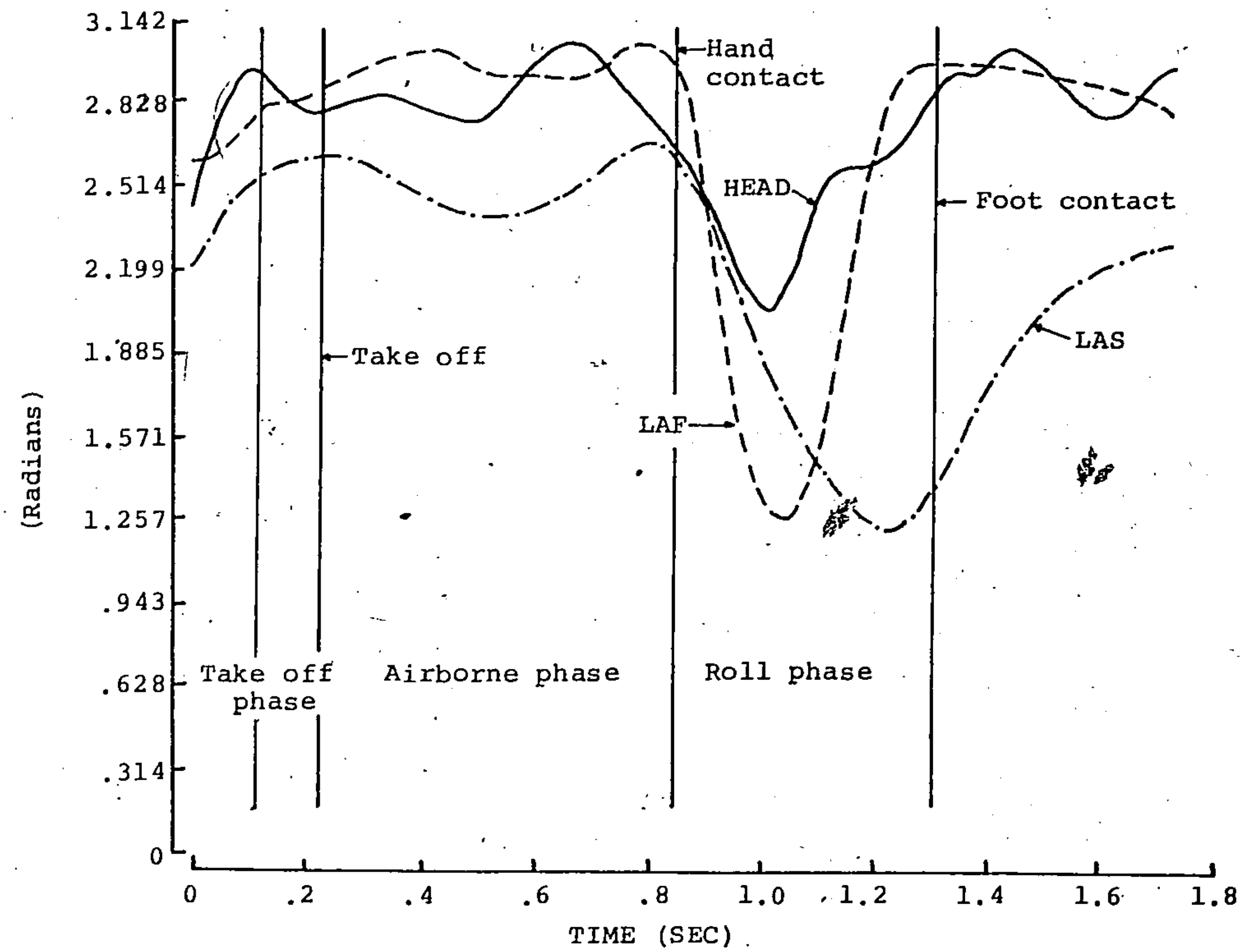

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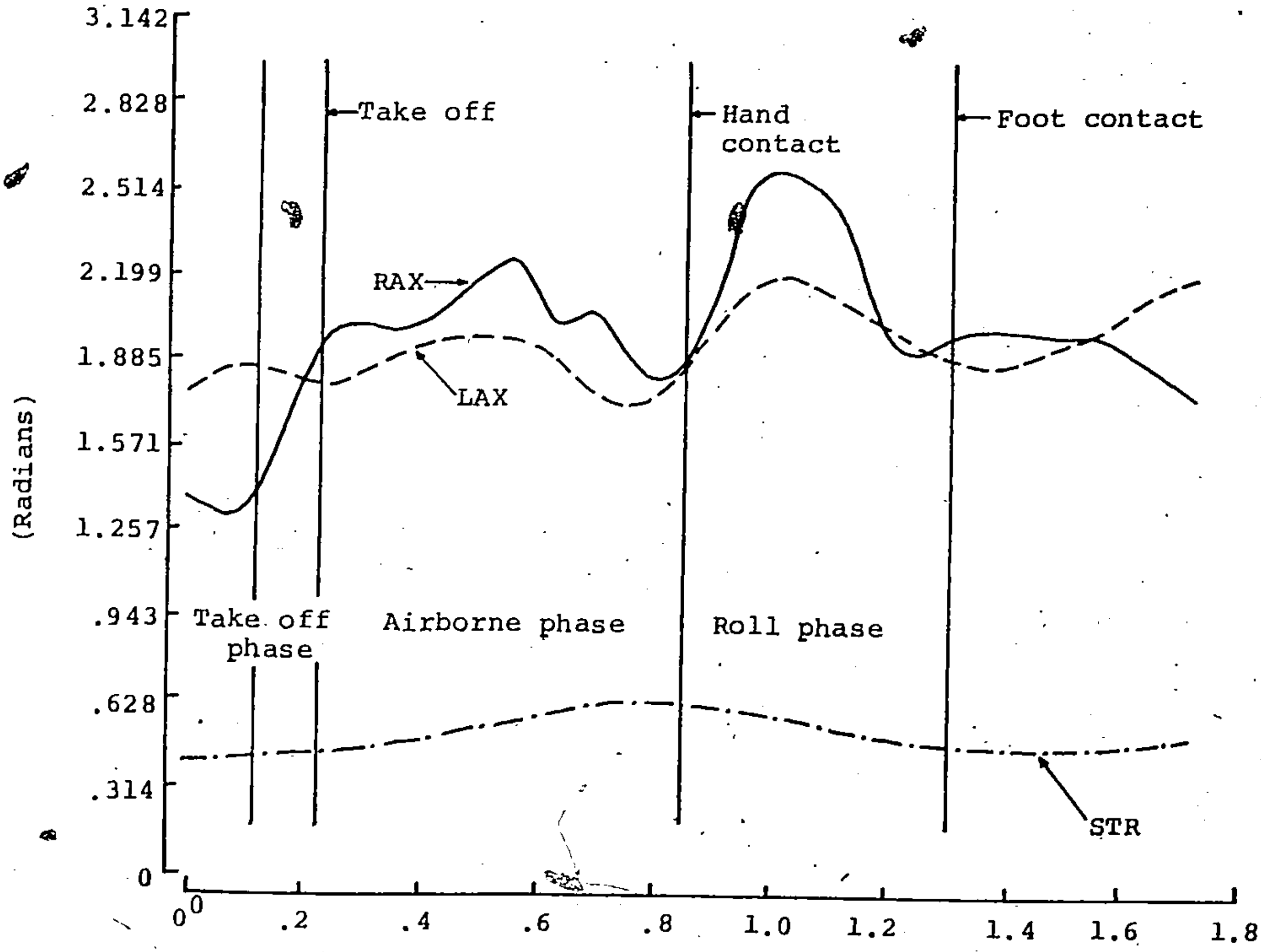

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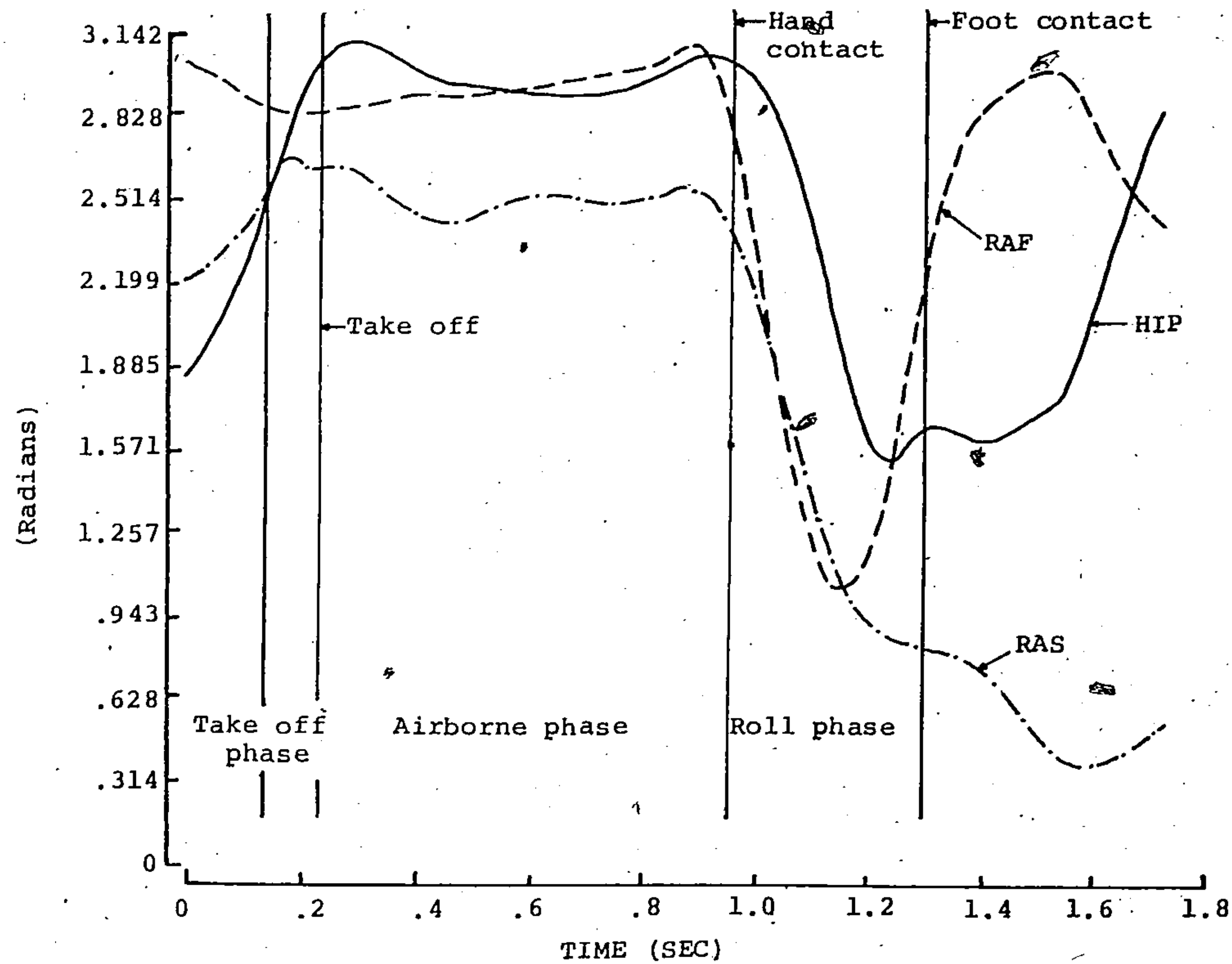

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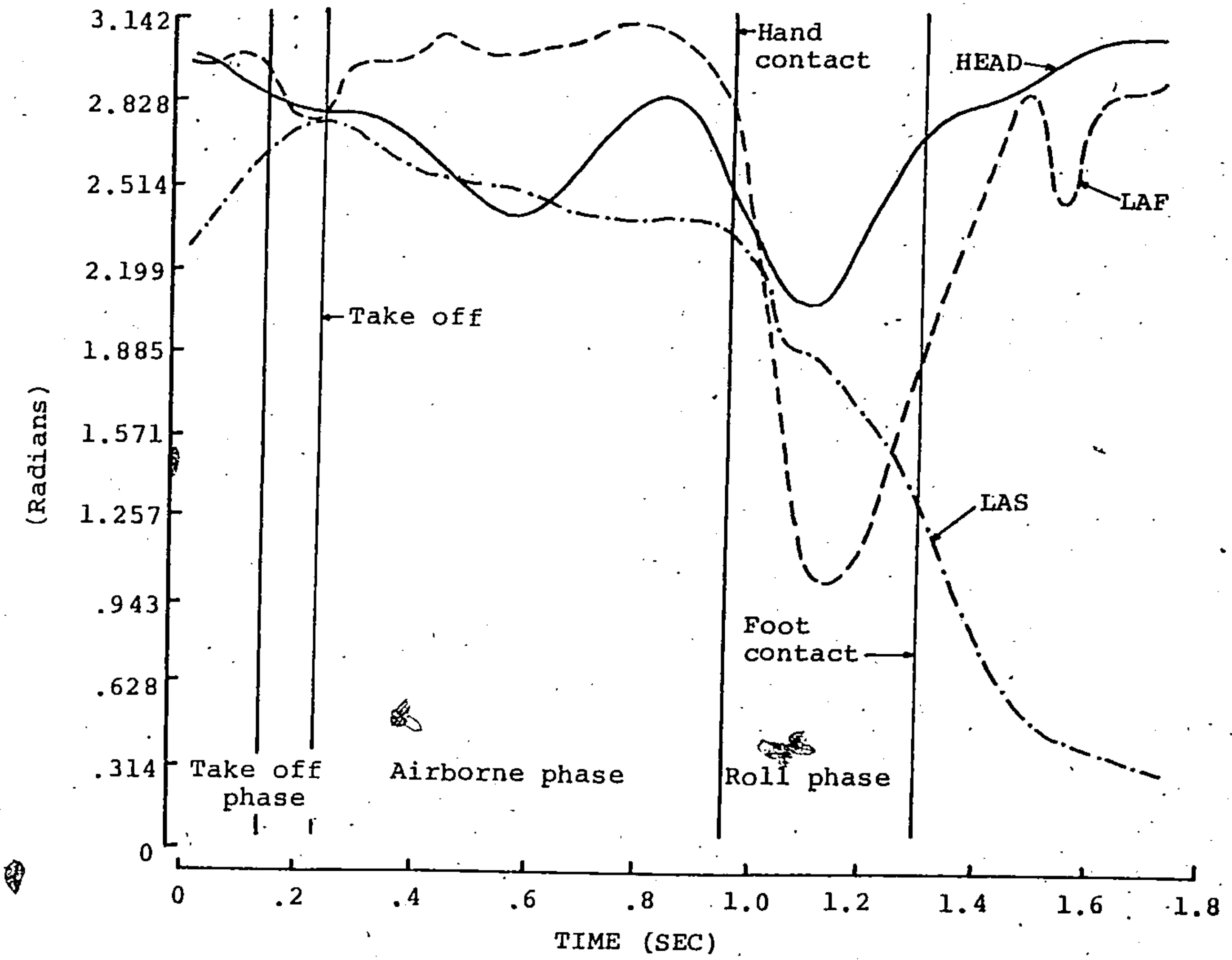

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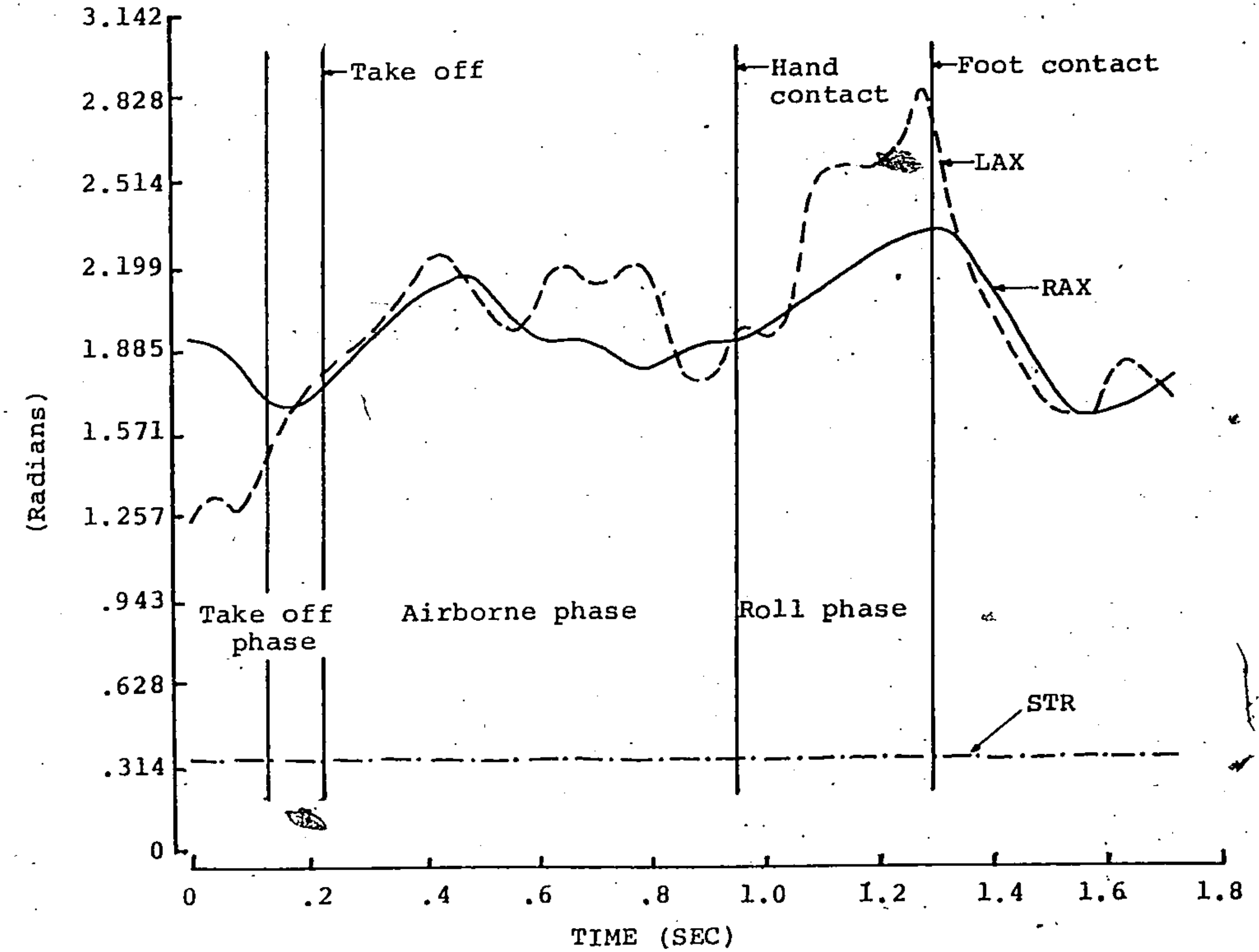

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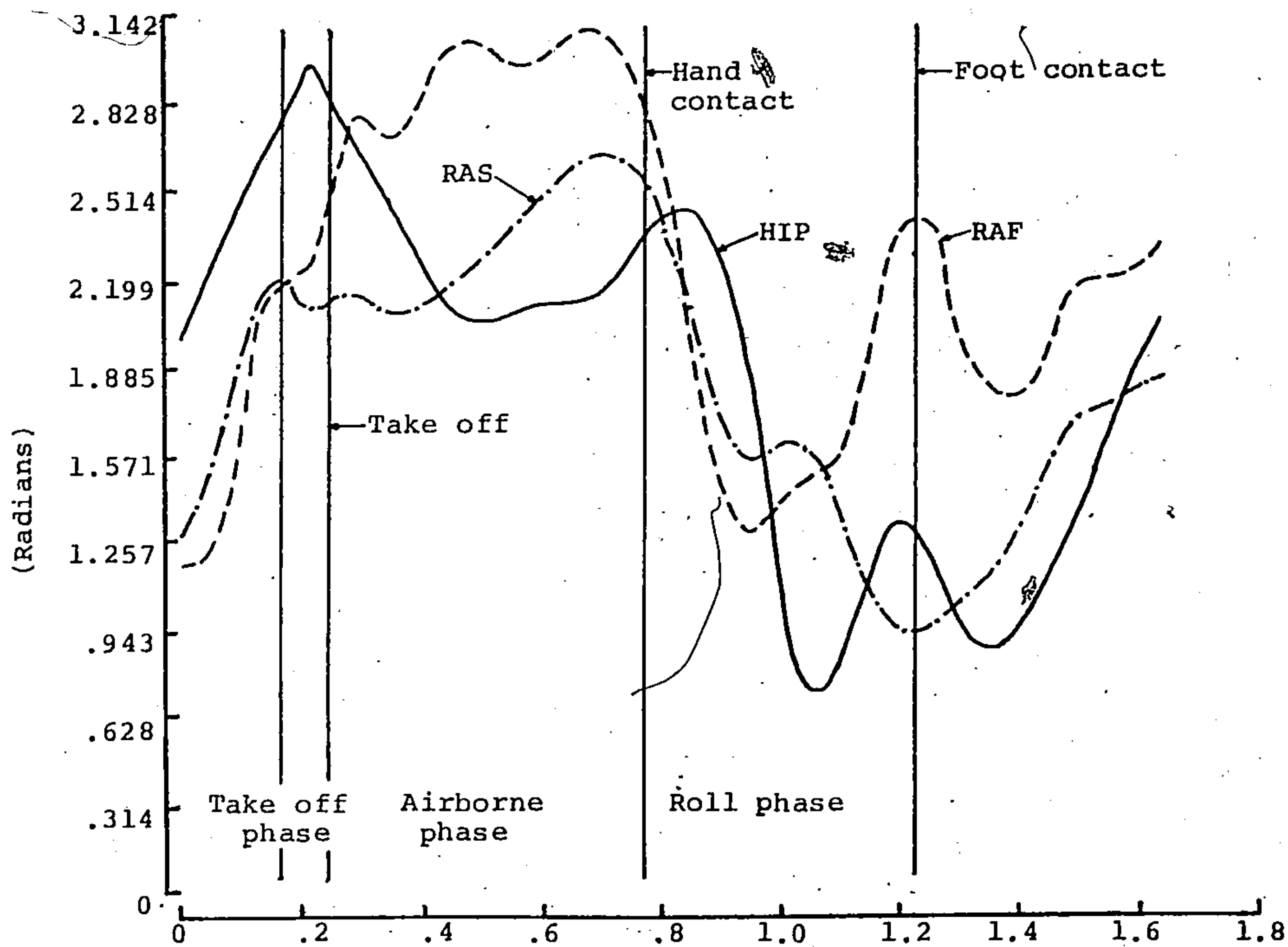

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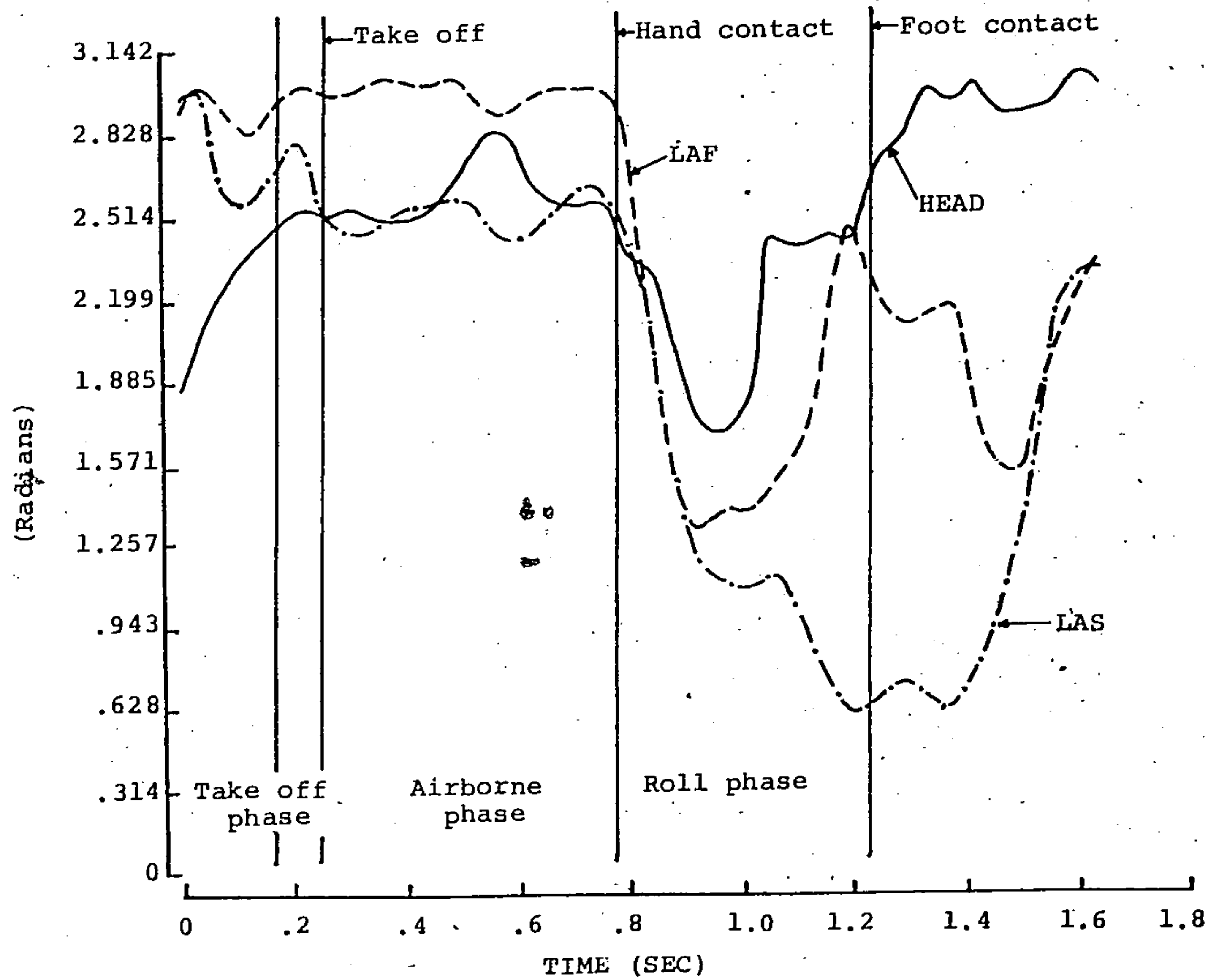

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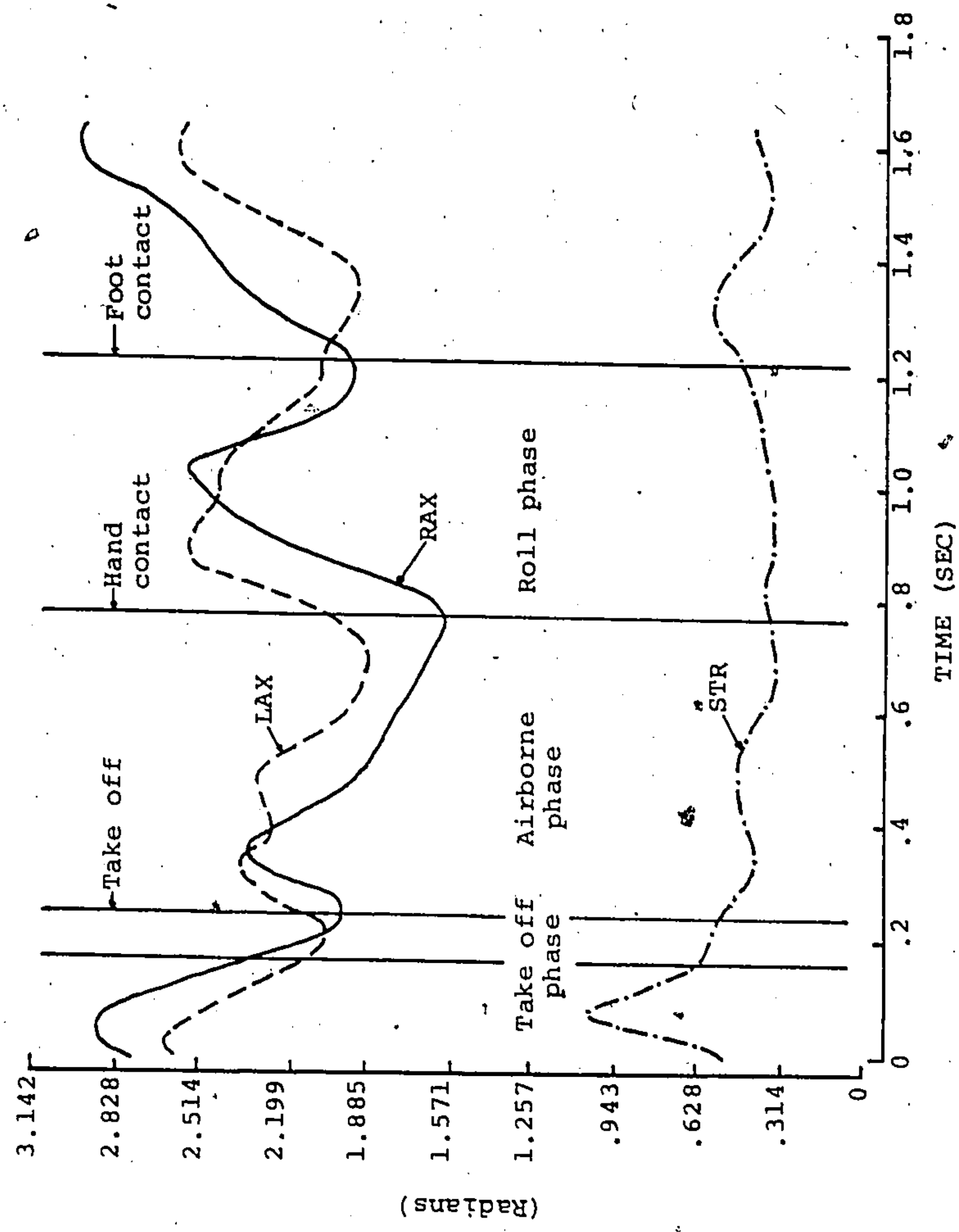

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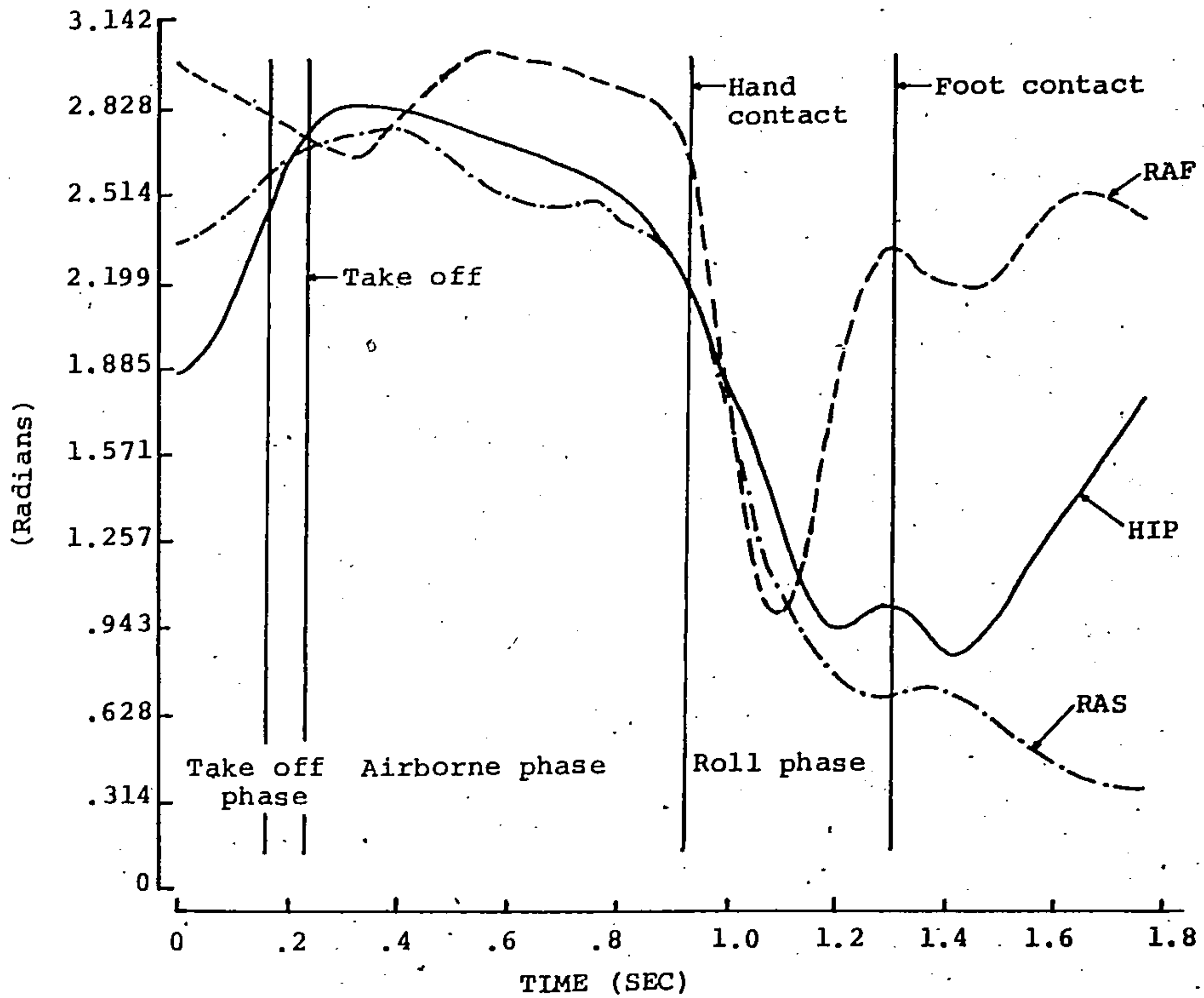

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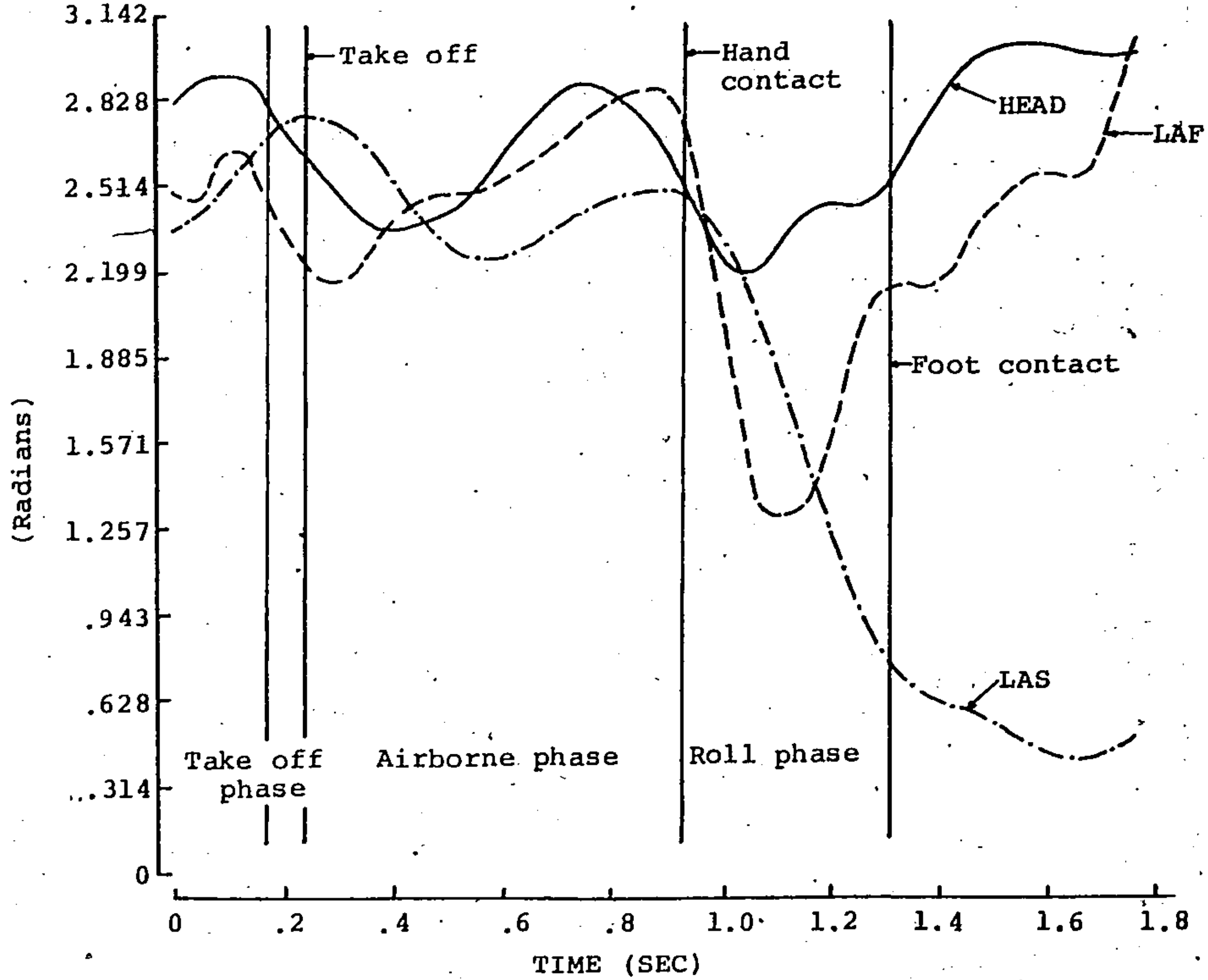

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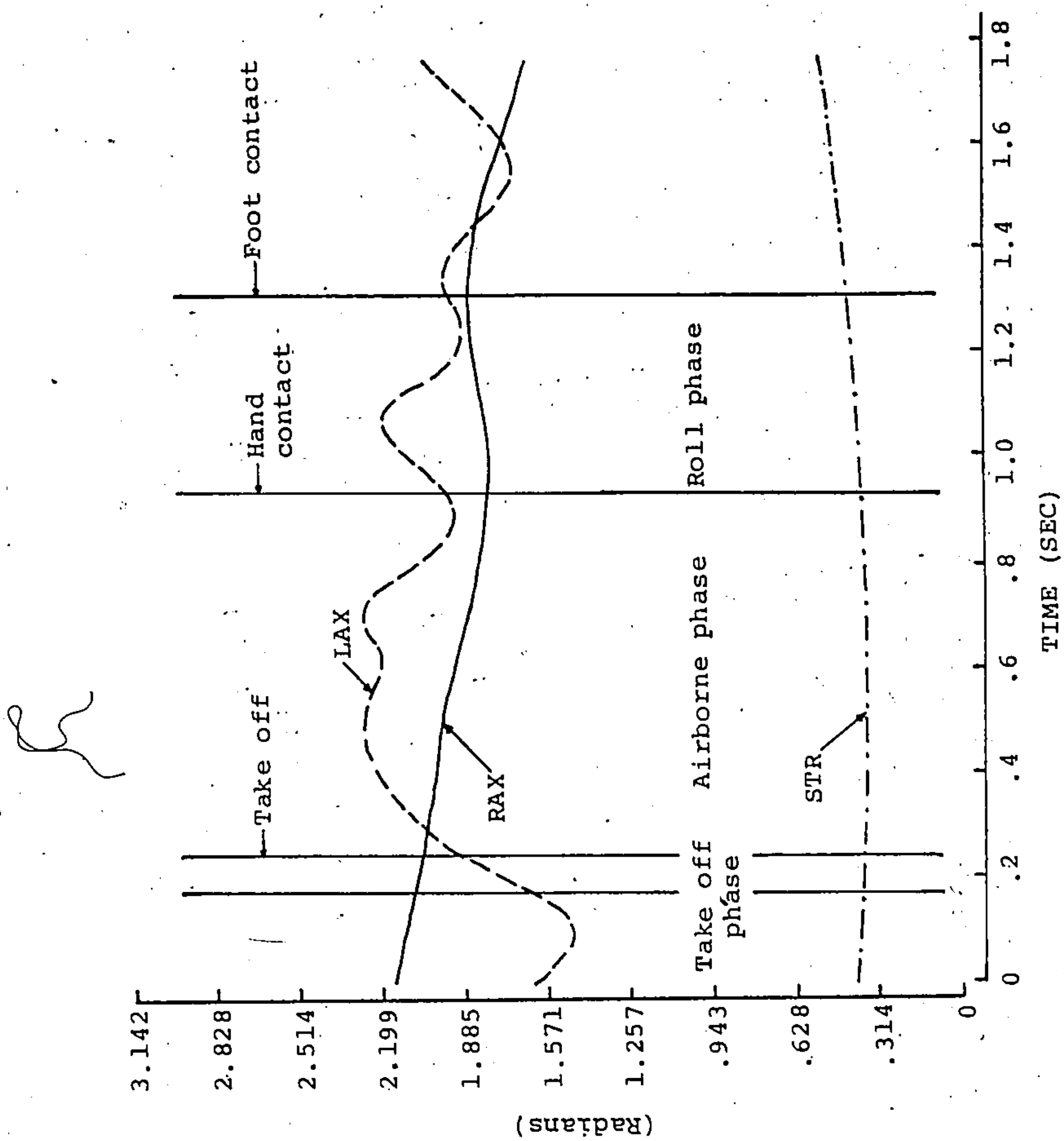

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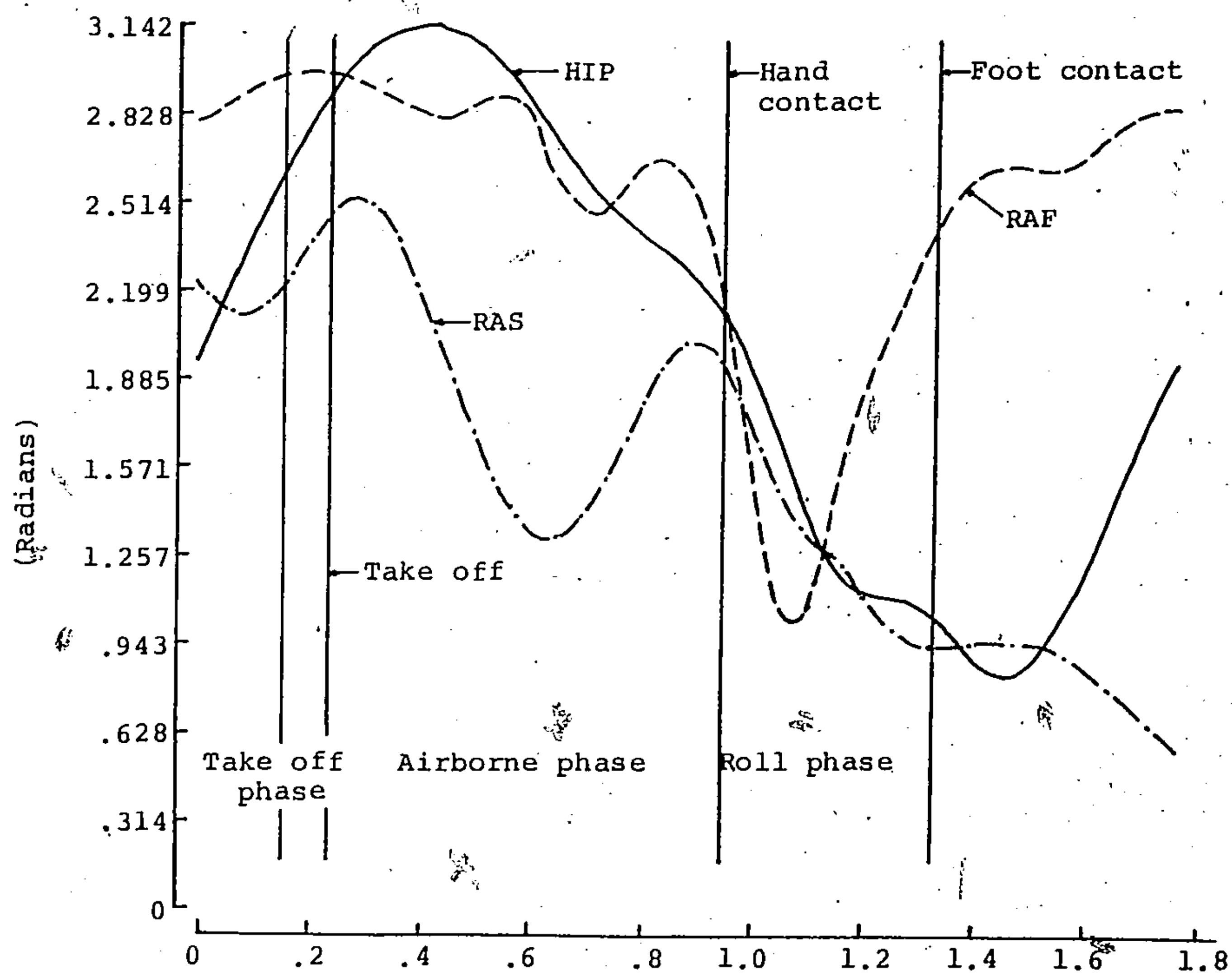

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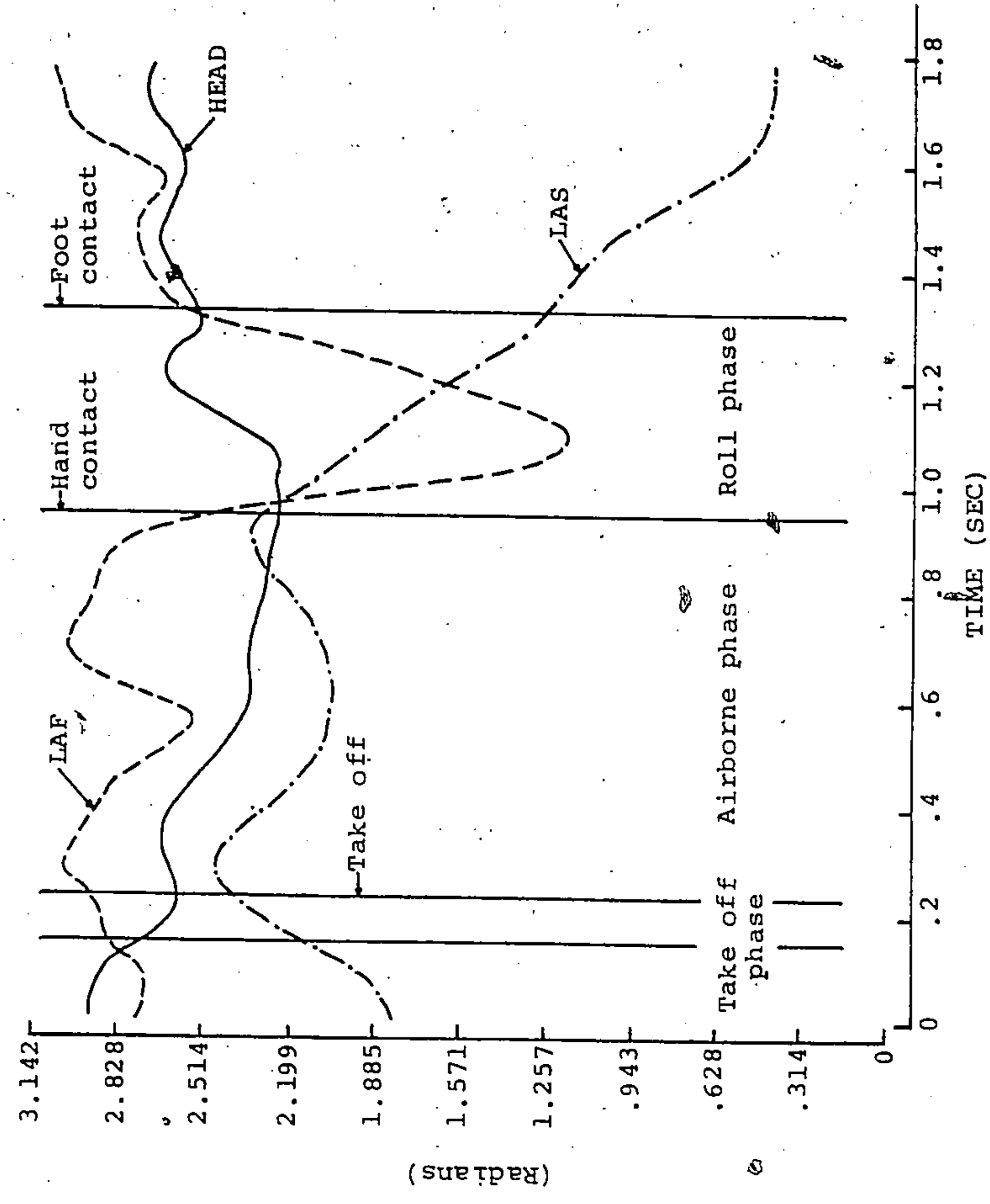

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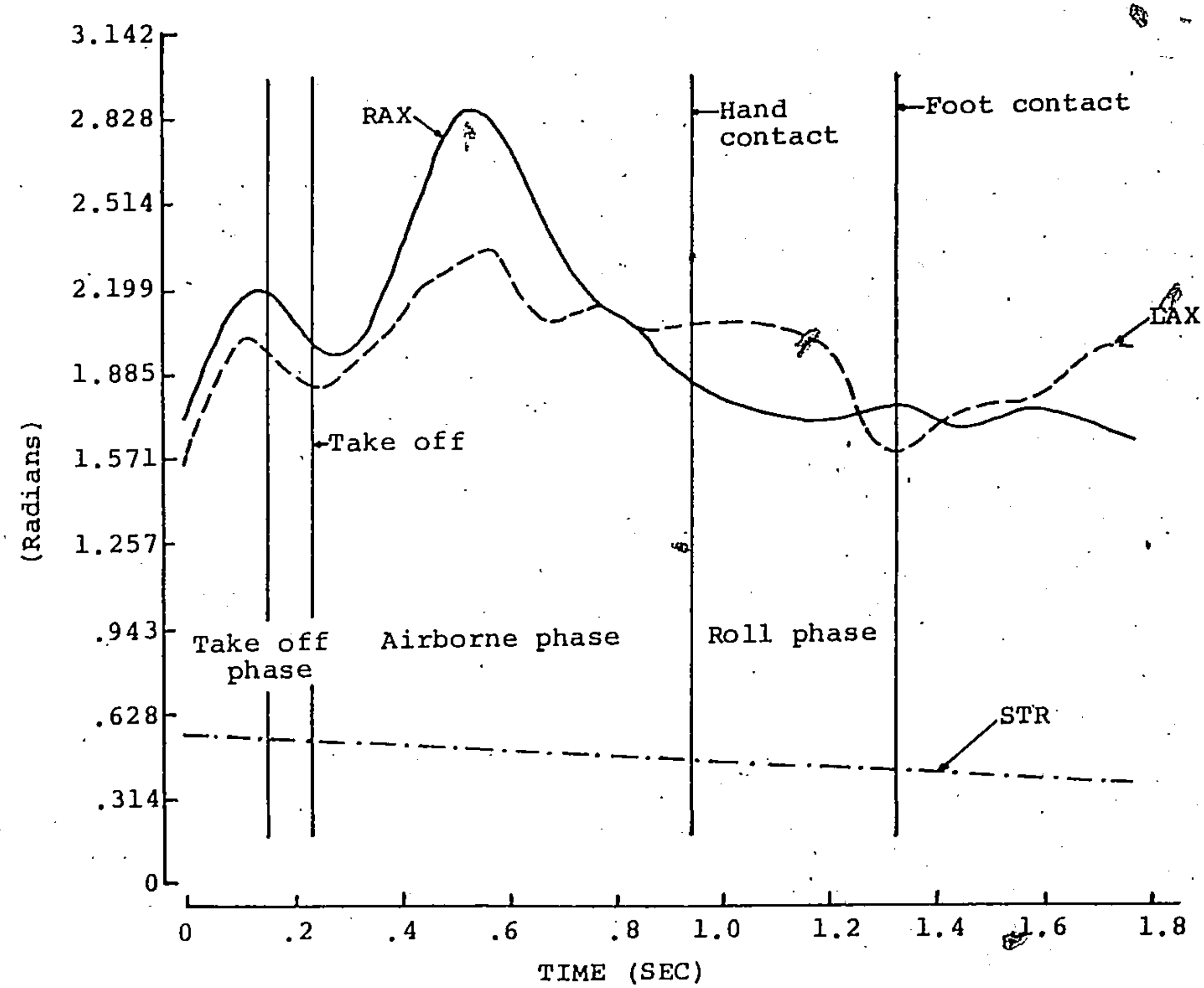

SEGMENTAL ANGLES SUBJECT 7

VITA AUCTORIS

Pierre Leo Gervais

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Marital Status:

Married: Spouse: Wendy

Education:

B.A. (Math), University of New Brunswick, 1979

B.P.E., University of New Brunswick, 1976

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Sessional Instructor, University of Windsor, 1978-80

Teaching Assistant, University of Windsor, 1978-80

Research Assistant, University of Windsor, summer 1979

Varsity Men's Gymnastics Coach, University of New Brunswick, 1977-78.

Teacher, Keswick Valley School, New Brunswick, 1977-78

Awards:

University of Windsor Graduate Summer Research Award, 1980

Federal Grant-in-Aid to Student Athletes, 1974-76.

Presentations and Publication of Research:

<u>Validation of a Three Dimensional Cinematographical Analysis Technique</u>. Pierre Gervais and G. Wayne Marino, Presented at A.A.H.P.E.R.D., Detroit, April 1980, abstract published.

<u>An Analysis of Selected Mechanical Aspects of the Stride Patterns of Cross-Country Ski Racers</u>. G. Wayne Marino and Pierre Gervais, Presented at C.A.S.S., Vancouver, January, 1980, abstract published.

A Technique Profile of the Diagonal Stride Patterns of Highly Skilled Female Cross Country Skiers. G. Wayne Marino, B. Titley and P. Gervais, Presented at The International Congress in Physical Education, Trois-Riviers, Quebec, 1979.

"A Technique Profile of the Diagonal Stride Patterns of Highly Skilled Female Cross Country Skiers." G. Wayne Marino, B. Titley and P. Gervais, published in _Psychology of Motor Behaviour and Sport_, Human Kinetics Press, 1980.

National Baseball Team Study. Report submitted to Baseball Canada, Sport Canada and the Coaching Association of Canada. 1979, contributing author.