IMPROVING SPRINGBOARD DIVING THROUGH BIOMECHANICAL ANALYSES AND KNOWLEDGE BASED EXPERT SYSTEM APPLICATION

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by

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FOREWORD

The material prepared for this thesis focused on enhancing human performance as related to the sport of springboard diving. The thesis research has advanced in several directions; primarily, the modeling of the athlete, appropriate representation of the springboard, mathematical description and computer simulation of the diver-springboard system, subsequent optimization of athletic performance, and the development of a heuristic-based coaching assessment procedure. Techniques of applied rigid body dynamics, numerical computation, finite element analysis, linear optimization and knowledge based expert systems have been applied in the following research.

Due to the range of research topics, the material has been organized into sections. One module describes modeling and simulating the dynamics of the diver-springboard system. The other module discusses the application of knowledge based expert system technology to skill analysis of springboard diving.

Although a substantial amount of research has been devoted to the aforementioned areas, this thesis examines a unique application of these principles for improving springboard diving performances. Wherever appropriate, references have been cited from published literature. In many cases, generalization based on the work of others have been postulated. These generalizations and resulting extensions have been expressed both implicitly and explicitly.

ABSTRACT

Springboard diving, like most sports, optimizes certain aspects of human performance through skill development. To assist with achieving proficiency in the execution of a skill, a systematic method of evaluating a skill to detect errors and to deduce corrections is required. The purpose of this thesis was to study such skill assessment for forward, nontwisting dives, from both a quantitative and qualitative perspective.

Research focussing on the quantitative aspect of the diver-springboard system was based on applied mechanics. A mathematical model was developed to simulate the vertical component of springboard-diver motion. The model was designed to incorporate learned movement skills and permitted an evaluation of the effects of varying a given parameter on the overall performance. Specifically, by altering the timing of execution of these sub-skills, the height achieved by the diver during the flight phase can be maximized.

The qualitative analysis focused on emulating coaching strategies relating to skill assessment. Both the determination of the attributing cause of a major performance error and suggestions for correcting this error were accomplished by applying knowledge based expert system technology. The resulting system was a springboard diving skill analysis program. It produced appropriate and valuable advice in a user acceptable format. These results suggest that application of knowledge based expert system technology to the skill assessment aspect of coaching is a viable method for disseminating coaching expertise.

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NOMENCLATURE

The following is a brief glossary of notation appearing in the thesis.

m_i	mass of the ith segment
m_t	mass of the model
$\ddot{y}_i$	vertical acceleration of the ith segment
$\dot{y}_i$	vertical velocity of the ith segment
y_i	vertical displacement of the ith segment
$\dot{y}_{CG}$	vertical velocity of the center of gravity of the system
y_{CG}	vertical displacement of the center of gravity of the system
h	vertical height obtained by the diver (m)
g	acceleration of gravity (-9.81 m/s^2)
t	time
R_i	resultant absolute force acting on the ith segment
F_i	absolute force acting between the ith and the i+1 segments
SF_i	internal system force acting between the ith and the i+1 segments
f_i	relative forces acting between the ith and the i+1 segments
a_k	acceleration of the kth segment where k refers to the entire body, arms, head&torso, or leg segments
I	mass moment of inertia (unless otherwise noted)

M	mass of the springboard	
K	stiffness parameter	
B	damping coefficient	
ϕ	phase shift in the motion	
EI	flexure rigidity where	
	E	represents Young's Modulus of Elasticity
	I	represents the moment of inertia of the cross-sectional area with respect to a line perpendicular to the x- and y-axis passing through the center of mass of the cross-sectional area
S	cross-sectional area of the springboard	
ρ	density	
$P(x,t)$	load force acting on the springboard as a function of position and time	
$w(x,t)$	load force per unit length acting on the springboard as a function of position and time	
$M(x)$	bending moment as a function of horizontal position	
F_D	damping force	
C_d	coefficient of drag	
A	cross-sectional area of the springboard	
v	the relative velocity between two objects.	

NOTE: The subscript i indicates rigid body segment where i may have the following correspondence:

1	arms
2	head and torso
3	upper legs
4	lower legs
5	feet
6	springboard

Chapter One

INTRODUCTION

Enhancing human performance is a primary focus in most sports. For an athlete to become proficient in a sport, his skills need to be evaluated and he needs to be informed as to how to improve his performance. Such skill assessment is usually provided by the athlete's coaches. This thesis examines skill assessment from two perspectives.

One method of evaluating skills is based on a subjective, qualitative approach. At a recreational level where the focus is on fundamental skills, such assessment can be adequately based on observation of skill performances. For relatively simple skills, this ability to examine performances based on observation can be easily acquired. However, with more complex skills, the ability to effectively perform such qualitative analysis is shared by only a few individuals. Usually, their expertise for judging skills has evolved from years of experience. As an athlete develops, quality coaches who can provide effective skill assessment are necessary. Unfortunately, the availability of such elite coaches is limited.

Secondly, an objective, quantitative assessment that is based on applied mechanics may be conducted. Often quantitative investigations involve cine representation with the resulting descriptions and analyses providing insight about the skill mechanics. Through examining the performances of elite athletes, standard references for directing skill development may be established. In springboard diving, the literature reports on various studies which focus on the performances of experienced or elite athletes. For example, dives done by junior competitors were used to record forces and torques developed at take-off [Bergmaier, Wettstein, and Wartenweiller, 1979]; Greg Louganis' performances have been used for extensive biomechanical research [Ariel, 1980; Miller and Munro, 1985a & 1985b; Miller, Jones, and Pizzimenti, 1988]; skills completed by members of the Canadian National Team provided data for investigating the translational and rotational requirements of springboard diving take-offs [Miller, 1981]; dives executed by competitors from Texas A&M were reviewed in studying twists [Bartee and Dowell, 1982]; maneuvers performed by competitors at the 1979 Fort Lauderdale Invitational Meet and the 1982 Canadian National Diving Championships furnished data for studying torque patterns of non-twisting dive take-offs [Miller, 1983] and body segment contributions during take-offs for attaining height in the flight phase [Miller and Munro, 1984]; 1980 Olympians filmed at the Colorado National Sports Festival V provided data for discerning biomechanical characteristics of the final approach step, hurdle, and the take-off steps [Miller, 1984]; and dives done by members of the Saskatoon club were examined to determine when an arm swing should begin [Paquette, 1985]. Unfortunately, quantitative descriptions and analysis of the dynamics of performed skills have not only focused primarily on elite athletes but also have been restricted to research centers.

To further understand a skill, mathematical models formulated on applied mechanics have been developed. Through solving the related differential equations of motion, individual components of a skill may be isolated to understand their overall contribution to the skill. This approach is useful when maneuvers become too complicated to permit intuitive analysis or extrapolation from relatively simple, well-understood principles [Walton and Kane, 1978]. Furthermore, by simulating performances, risks to the athletes are reduced, since results can be predicted without human experimentation.

Several, mathematical models associated with springboard diving have been developed. For example, in researching the mechanics of twist, equations of motion have been derived for a six segment model [Van Gheuluwe, 1981], and subsequent modeling of an eleven segment model [Yeadon, 1987] has been completed. Simulation models to effect temporal optimization have been formulated. These simulations provide an understanding of when an athlete should move parts of his body relative to each other for achieving a desired performance result [Sprigings and Watson, 1983; Sprigings et al., 1986]. The accuracy of mathematical models may be evaluated using actual performances and cinematographic techniques. Nonetheless, a need to translate results attained from such research into information usable by coaches is still required.

To address the problem of providing suitable skill assessment, an analysis should involve collaborating both qualitative and quantitative procedures. The qualitative assessment process could emulate the strategies of elite coaches. From past experiences, these expert coaches seem capable of innately assessing a skill based on observation. They can quickly determine the attributing causes of a fault and suggest appropriate correction techniques. Their analysis is directed by a personally developed set of *ad hoc* rules or heuristics. In contrast, the quantitative analysis yields an understanding of the skills based on the related mechanical principles. Often this aspect is poorly understood by coaches [Walton et al., 1978]. Quantitative assessment may focus on studying given performances of an athlete or on developing a simulation model. After completing biomechanical and/or statistical analyses of the performances of an athlete or of a selected model, comparisons may be drawn. In simulating maneuvers, the influence of varying parameters on the performance of a skill may be studied. For example, models and appropriate algorithms may be developed to investigate the effects of altering the timing of execution of sub-skills (ie. initiating the arm swing sooner); the results of incorporating different movement skills (ie. increasing the amount of leg flexion); or the interaction between the athlete and his environment when environmental parameters are varied (ie. altering the stiffness of the springboard). To personalize the simulation to the athlete and his executed skill, the necessary input kinematic data may be derived from actual performances. Together, qualitative and quantitative analyses would provide a comprehensive assessment tool for enhancing springboard diving performances.

To increase the availability of quality skill analysis, a comprehensive assessment process that can be accessed by coaches of various levels needs to be developed. Computer-aided technology provides a tool for meeting this challenge. Through the programming methods of knowledge based expert systems, a skill assessment package may be developed. Knowledge based expert systems are computer programs that can access knowledge to solve problems with the same level of sophistication as a human expert [Joyce, 1986]. Thus, novice coaches with the aid of such a system will be able to provide quality skill analysis.

If the strategies of elite coaches and principles of applied mechanics for skill analysis can be contained in a knowledge based expert system, then operation of the system will provide a comprehensive skill assessment tool. This will allow less skilled coaches the opportunity to tap the expertise of elite coaches and to provide analysis at a near expert level. Since the coaching application of knowledge based expert systems may be developed for implementation on a microcomputer, the problem of readily accessing expert advice is limited merely by the availability of the software package and access to a compatible computer. With the increased availability and low costs associated with microcomputers, this limitation is being reduced further. Hence, expertise is more readily available, even in isolated geographical regions. Also, in developing a knowledge based expert system, a comprehensive, permanent, reliable and affordable system to analyze skills is created [Waterman, 1986]. Therefore, the knowledge based expert system offers a solution for providing consultant assessment services to enhance springboard diving performances.

At present, the amalgamation of qualitative and quantitative assessment processes for a coaching application using knowledge based expert systems has not been completed. Research in the application of knowledge based expert system technology to the domain of problem solving [Alty, 1984] supports an application to the qualitative or heuristic aspects of coaching. Success in supplementing this qualitative analysis with quantitative analysis is restricted by the state of current research [Tsotsos, 1985]. Limitations exist in the understanding of springboard diving dynamics, in available data acquisition mechanisms, as well as in the development of the framework for integrating these analyses. Thus development of a comprehensive and operative system involves:

1. effective modeling of the diver-springboard system and an understanding of the diver dynamics so as to develop efficient algorithms for quantitative assessment of a performance;

2. developing a method of 'near' real-time data acquisition for providing appropriate kinetic data for the numerical analysis since the technique of digitizing anatomical landmarks is a tedious and laborious task;

3. establishing a system to incorporate quantitative analysis with qualitative analysis within the knowledge base expert system shell. This is plausible especially when the developing program language of the knowledge based expert system shell remains accessible and permits numerical analysis; as has been shown with the tool kit Expert-2[1] [Sargent et al., 1986; Watson, 1987]; and

4. integrating qualitative descriptions and coaching strategies with quantitative analysis. Although efforts have been directed at basing qualitative analysis on applied mechanical principles [Hay, 1980] minimal efforts have been directed at combining these assessment processes. This task will require either a close working relationship between the mathematical analysts/researchers and the coaches or an intermediary who can facilitate translation of the technical aspects of the model to terminology understood by coaches and vice versa [Walton et al. 1978].

Such advancements need to be achieved so that a sophisticated scheme can be designed to integrate these analytic processes.

To summarize, the purpose of this thesis is to enhance human performance for the sport of springboard diving with a focus on forward,

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[1] Expert-2 is a tool kit originally developed by Jack Park [Park, 1984].

non-twisting dives. The objectives are directed at advancing the assessment procedures of springboard diving and may be stated as follows:

- to develop a simulation model to improve the understanding of spatio-temporal relations of diver dynamics; the analysis examines the effects of varying the timing of the execution of performed movement skills on achieving maximum height in the flight phase; and
- to develop a qualitative skill assessment process through designing a knowledge based expert system formulated on the heuristics of elite coaches.

Chapter Two

APPLIED MECHANICAL ANALYSIS TO SPRINGBOARD DIVING

2.1. Introduction

Quantitative assessment may be used to examine athletic performances. Such assessment applies principles and methods of mechanics to analyze the human system. Fortunately, human motor activities, even with their seemingly unlimited variability, obey the laws of science [Dyson, 1977]. For example, springboard divers who are somersaulting in space and possessing angular momentum about one axis can change their body position to initiate spin about another axis without applying any external torque [Frohlich, 1979]. However, the complexity associated with the human athlete and the involved constraints of related motion, makes detailed analysis arduous. Hence, the growing body of sport research findings have been channeled at specific areas. In the sport of springboard diving, the challenge of biomechanical investigation has led to specialized focuses; such as studies on: "rip" entry, flight phase trajectories, accomplishment of twists, and establishment of angular and linear momentum at take-offs [Miller et al., 1988].

Biomechanical analysis of athletic performance and subsequent simulation of the skill are essential coaching tools. This objective analysis permits one to determine cause and effect relations and to distinguish between possible and impossible maneuvers for a given skill [Dyson, 1977]. Therefore, theoretical studies of the mechanics involved in performing skills can benefit the sport [Soong, 1975], both in the understanding of the skill and in developing better techniques [Hubbard, 1980].

Complete biomechanical analysis may be difficult; however, approximations made in modeling can often provide sufficient accuracy for the analysis to be of value for coaching. For example, gross motor activities can be investigated by modeling the human body as a system of rigid, linked segments and by mathematically describing related motion by applying Newton's Laws [Andrews, 1974]. With springboard diving both the diver and his motion and the springboard and its motion need to be modeled.

Although many aspects of human motion can be studied, this chapter will focus on springboard diving. In particular, the problem of poor performance being attributed to an athlete's "timing being off" is addressed. This chapter discusses the optimization of motion by adjusting the coordination of segmental movement patterns of an entire skill. A criteria of performance, a model of the athlete and the springboard, a mathematical description of the motion of the diver-springboard system and an optimization process needed to be developed. For this study to be practical, the results for enhancing skill performance had to be readily understandable by coaches and athletes. Also, the physical constraints of not exceeding an athlete's demonstrated capabilities were to be incorporated into the model. This chapter examines modeling the diver-springboard system and studies the effects of varying the timing of executing learned movement patterns on the overall performance.

2.2. Modeling The Human Body

Biomechanical analysis and subsequent simulation of human motion requires modeling of the human body. A complete model would require representing the complex neuromusculoskeletal system with appropriately selected segmental, articular, morphometric, myodynamic and myocybernetic parameters [Hatze, 1977]. However, gross motion analyses and simulations commonly model the human being as a system of interconnected, rigid-body segments. A few examples, where this approach has been applied, include gait and rehabilitation studies, the analyses of sports performances, the study of astronaut maneuvers during space flight, and vehicle crash simulation investigations [Ramey and Yang, 1981].

In rigid body modeling, each anatomical segment, such as: head, torso, arms, legs or feet, corresponds to a rigid body. When segment modeling is employed, the changes in body configurations that occur during a movement can be taken into account. The number of segments selected for modeling movement will depend on the maneuver being analyzed. For example, completed studies of human motion analyses for gait employed a five segment model [Hardt and Mann, 1980], for springboard diving used a six segment model [Miller, 1984], and for crash simulations used a fifteen segment model [Bartz, 1973].

The equations of motion can be derived for a segment model by applying Newton's Laws (as done in the analysis of gymnastic maneuvers

[Spaepen et al., 1982]) or by applying Lagrangian equations (as done in the modeling of the dynamics of front crawl [Bourgeois and Lewille, 1983]). From the kinematics of each segment, the kinematics of the center of gravity of the total body can be determined by applying the theorems of Varignon [Meriam, 1978].

Rigid body modeling of anatomical segments assumes that each segment has a fixed mass; the mass of each segment is located as a point mass; the location of this center of mass remains fixed on the segment throughout a motion; and the mass moment of inertia of each segment remains constant [Winter, 1979]. The skeletal structure of any anatomical segment conforms to this model. However, the surrounding tissue is deformable and deviates from this model. Since the changes in size and shape of this tissue are relatively small in comparison to the motion of the segment, rigid body segment modeling provides a good compromise between the actual complexity and an accurate representation of the true motion.

When rigid body segment modeling is employed, physical parameters, such as: the mass of each segment and the location of the center of mass of each segment, need to be specified. Determining these body segment parameters is difficult, since experiments involving dissection to acquire actual physiological data are not feasible.

Some of the methods used to approximate these parameters include percent mass ratio, *in vivo* experiments, mathematical modeling and kinetic optimization techniques. Percent ratio techniques, based on mean data or regression equations on data derived from cadaver studies [Dempster, 1959; Clauser, McConnville, and Young, 1969], are probably prone to error since most of the subjects were old and characterized by a loss of bone and muscle mass. *In vivo* experiments, involving reaction board tests for determining mass values and locations of center of masses, require assuming one parameter in order to determine the other [Bernstein, 1967]. Mathematical models, based on anthropometric measurements of a subject, geometric properties of solids and density measurements, provide an alternative method to determine the physical parameters [Havana, 1964; Hatze, 1980]. Another technique to determine body segment parameters is by optimizing equations describing related motion of the subject [Dainis, 1980; Vaughan, Andrews, and Hay, 1982]. An analysis comparing percent mass ratio techniques (Dempster and Clauser) and the mathematical technique (Hatze) for predicting the total body center of mass for an airborne maneuver [Sprigings et al., 1987], favors the latter approach. Unfortunately, this technique is burdened with providing 242 personal anthropometric measurements.

In the simulation of the dynamics of a springboard diver (Section 2.3 Springboard Modeling), basic body parameters were first approximated using Dempster's percent mass ratio method. By using an inverse dynamic approach the kinetics were derived from the observed kinematic data. Since a variation between the simulated motion and the observed motion existed, refinement of these estimated, physical body parameters was made. A kinetic optimization approach similar to the technique described by Dainis [1980] was used (Appendix C). The mass for each segment was evaluated by deriving an objective function that was minimized through selecting appropriate segment mass values. One criterion for this objective function was based on the recorded motion of the diver during the airborne phase. The relation among the kinetics of the segment to the center of gravity of the total body, as governed by the equations of motion for free fall is given in Equation 2.2.1. The second constraint was that the sum of the masses of each segment be equivalent to the total body mass. Mathematically this function may be stated as:

$$\left[\sum_{i=1}^{n} m_i y_i - [m_t(y_{cgo} + \dot{y}_{cgo} t - g t^2/2)] \right]^2 + \left[\sum_{i=1}^{n} m_i - m_t \right]^2 = 0 \tag{2.2.1}$$

Details of the development of this function are presented in Appendix C. As discussed in Appendix C, a further constraint that was required, involved imposing an acceptable range for each segmental mass value. The resulting segment's mass values as evaluated during the aerial phase of a forward one and a half pike somersault performance are presented in Table 2-1. The adjustments of the mass values for each segment improved the relation between the digitized and the simulated kinematic data.

Table 2-1: Comparison of Percent Segment Mass Values expressed as a percentage of total body mass

Segment	Segment Mass as calculated by Dempster's Method	 Optimization Method
Arms	10.0%	10.0%
Head and Torso	57.8%	56.5%
Upper Legs	20.0%	20.7%
Lower Legs	9.3%	10.1%
Feet	2.9%	2.7%

Preliminary investigations demonstrated that adjusting these parameters provides for an improved correlation between the observed and the simulated diver kinetics. However, the merits of this technique need to be studied further. The motion of a rigid body system, where the exact segment masses can be determined, should be analyzed to verify this process.

2.3. Springboard Modeling

Dynamic analyses of sport performances involve complete system modeling and include not only the athlete but also the equipment. In diving, the success of a dive is contingent on developing sufficient linear and angular momentum during the board contact phases [Hamill, Ricard, and Golden, 1986]. Therefore, when modeling springboard diving performances, the simulation should include the complex interaction between the diver and the springboard. A simulation that begins at the instant of departure would be characterized as an initial condition problem and pertinent factors affecting a performance would be overlooked. Thus, analyses of the dynamics of springboard diving must include modeling the springboard as well as the athlete. This section examines modeling the springboard for the final board contact phase of the springboard-diver interaction.

Research on diver-springboard interaction has focused on the kinematics of divers during board contact [Miller, 1981; Miller, 1984, Miller et al., 1985a and 1985b]; on the developed torque and force patterns during the take-off phase [Bergmaier, et al., 1979; Miller, 1983]; and on a comparison between the resultant kinematics of the diver and the springboard [Miller et al., 1988]. To the author's knowledge, investigations of springboard behavior have been limited to modeling the deflections of a Maxiflex[2] springboard

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[2] Duraflex and Maxiflex are registered trademark of aluminum springboards manufactured by Duraflex International Corporation.

[Cromwell, 1984] and to an experimental evaluation of a parameters for a Duraflex springboard [Sprigings, Stilling and Watson, 1988]. In this section, a more thorough modeling and verification of the model of a springboard is undertaken.

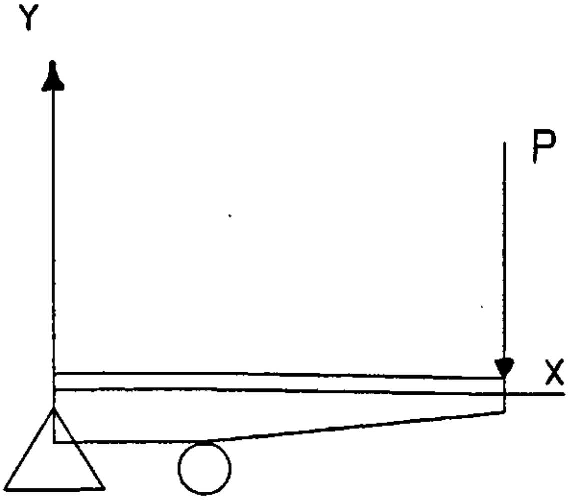


Figure 2-1: Springboard modeled as a propped, hinged beam

Since 1958, the springboards used exclusively in major national and international competitions have been Duraflex and Maxiflex boards. Duraflex International Corporation, formerly Arcadia Air Products, manufactures the boards from an aluminum alloy (6070-T6) whose minimum tensile yield strength is 345 MPa. The boards are manufactured as an extruded, basic ribbed, single-piece, heat-treated beam with a second extrusion, called a torsion box, riveted underneath the full length of the beam. Duraflex boards are machine tapered from the fulcrum region to the free end; Maxiflex boards are tapered both from the fulcrum section to the free end and from the fulcrum section to the fixed end. This taper creates a variable cross-sectional area. Other nominal, physical dimensions of the Duraflex springboards include: length of 4.88 m, width of 0.50 m, and mass of 61 kg. In mounting the springboard parallel to the water surface, one end is hinged to the diving standard with an adjustable fulcrum supporting the board at mid-length. In the range of fulcrum adjustment, 0.58 m, vinyl channels are attached to the underside of these ribbed extrusions for protecting the springboard [Duraflex International Corporation, 1987] Therefore the diving board can be approximated as a "propped, hinged beam" as illustrated in Figure 2-1.

Through applying classic beam theory the dynamics of the springboard can be calculated. The governing differential equation for transverse vibration of a beam [Vierck, 1979] may be stated as:

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2 y}{\partial x^2} \right) + \rho S\frac{\partial^2 y}{\partial t^2} = w(x,t). \tag{2.3.1}$$

However, with the complex geometry of the springboard, solving the exact solution in closed form is difficult. Even for a simple beam with uniform cross-sectional area the solution for the transverse deflection for free vibration is involved [Seto, 1964]. The general solution may be expressed as:

$$y(x,t) = \Big(A\cos(w_n t) + B\sin(w_n t)\Big) \Big(C_1 \cos(kx) + C_2 \sin(kx) + C_3 \cosh(kx) + C_4 \sinh(kx)\Big) \qquad \textbf{(2.3.2)}$$

where y is the transverse deflection of the beam; w_n is the natural frequency of the beam; k is the product of natural frequency and properties (material and geometric) of the beam; A and B depend on the initial deflection and velocity of the beam. The coefficients, C_1, C_2, C_3, and C_4, are determined from the boundary condition of the problem. For a springboard of length, L, with the hinge located at $x = 0$ and the fulcrum located at a distance $x = a$, the existing boundary constraints include:

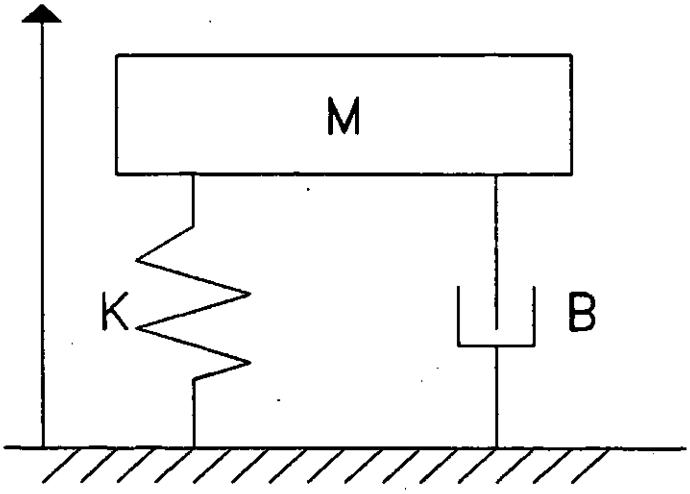
$$y(x=0,t) = 0 \qquad \textbf{(2.3.3)}$$

$$y(x=a,t) = 0 \qquad \textbf{(2.3.4)}$$

$$\frac{d^2y(x=0,t)}{dx^2} = 0 \qquad \textbf{(2.3.5)}$$

$$\frac{d^2y(x=L,t)}{dx^2} = 0 \qquad \textbf{(2.3.6)}$$

Since an exact solution, in closed form, appeared unwieldly for modeling the behavior of the actual springboard, a simpler model to account for the behavior of board motion was sought. An equivalent, single degree of freedom, lumped spring-mass-damper system, was developed to model the springboard. For such a model, as illustrated in Figure 2-2, the dynamics of the springboard could be mathematically described by a second order ordinary differential equation. For this lumped parameter model to closely



The solution for vertical deflection of the mass follows:

$$M\,\ddot{y} = -B\,\dot{y} - K\Delta\,y$$

$$y(t) = A\,exp\left(\frac{-B}{2M}t\right)\ sin\left[\sqrt{\left(\frac{K}{M} - \frac{B^2}{4M^2}\right)}\,t + \phi\right]$$

Figure 2-2: Lumped spring-mass-damper model of the springboard.

approximate the dynamic properties of an actual springboard, appropriate values for the parameters needed to be determined. A solution for the continuous beam equation was required to established the variation of these board parameters during an oscillation of the springboard. Also, the results of this solution provided a basis to approximate values for the springboard parameters of mass, damping and stiffness. Furthermore, the factors affecting these parameters could be identified. To confirm the magnitude of the modeling parameters, their values were determined experimentally through investigating the behavior of a Duraflex, Model A, springboard [Sprigings, et al., 1988].

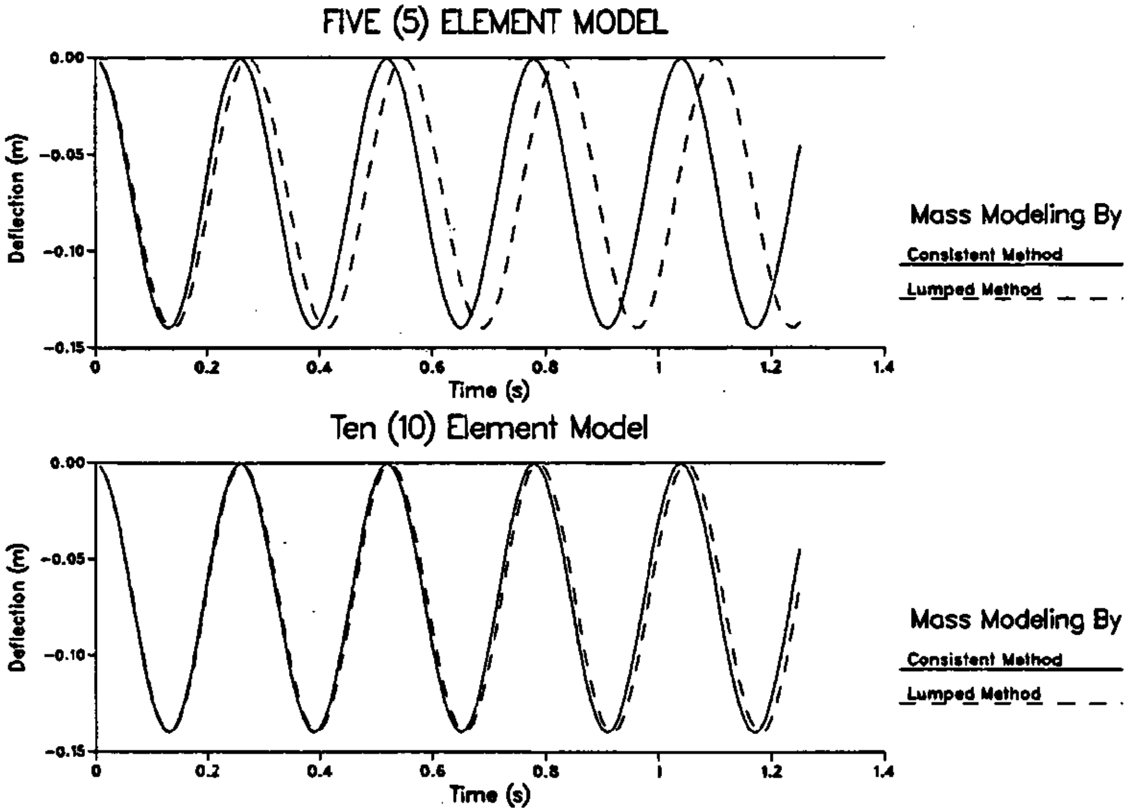
The solution of the classic differential equation for transverse vibration of a propped, hinged beam was completed numerically using the finite element method. This method provides a systematic procedure to approximate the solution of problems whose analytical solution is difficult to to obtain [Reddy, 1984]. The finite element formulation of a problem involves solving a system of algebraic equations to provide an acceptable solution for discrete points of a system. In comparison, an analytic solution of the differential equation provides a solution that will be valid for any location within the system [Logan, 1986]. The dynamics of the springboard, at given locations, were investigated by using the finite element method to solve for the transverse vibration of the springboard.

For modeling the characteristics of the springboard, the board was discretized into as a number of a finite elements. Next, the appropriate equations were formulated for each element; these were then combined and solved. For a beam, the finite element solution converges to the exact solution if the coarseness of the model is sufficiently reduced [Reddy, 1984]. This enables the transverse vibration of a specific point along the springboard to be accurately simulated.

To define the differential equations for analyzing transverse vibration of the beam, stiffness and inertia matrices need to be derived as governed by the geometry of the problem. The stiffness elements for a simple beam

[Logan, 1986] account for both the transverse and rotational deflections. Both the consistent-mass and lumped-mass derivations of the mass matrix [Logan, 1986] were used. Since the actual cross-sectional area of the springboard varies, average values for mass, cross-sectional area moments of inertia, and mass moments of inertia for each element were used to determine the element matrix values. The applied load was assumed to be a concentrated load acting at a selected node. Next, a global matrix equation was assembled by superposition of the elements matrices as related by the interelement continuity of nodal displacements and accelerations. Since an overhanging beam appropriately represents the springboard, the boundary constraints of the fixed end (zero translational deflection) and of the support (negligible vertical deflection) were imposed. In solving the resultant system of equations two software packages were used. One was Swanson's Finite Element computer program, ANSYS, [DeSalvo and Johnston, 1987] which generates an appropriate system of algebraic equations for the specified problem. This program defaults to employing a consistent-mass matrix approach. Secondly, an appropriate system of equations was derived using the lumped-mass matrix approach. These equations were solved with the aid of the subroutine package, Livermore Solver for Ordinary Differential Equations with Automatic method switching for stiff and nonstiff problems, LSODA, [Hindmarsh, 1982].

Although the consistent mass approach generally produces more accurate results than the lumped mass method, the developed system of equations for the consistent mass representation are more complicated. When employing the consistent mass matrix, an upper bound property is established on frequency. Conversely, the lumped mass matrix establishes a lower limit on frequency [Hughes, 1987]. Therefore, based on frequency, an



For finite element modeling, a consistent mass matrix model establishes an upper bound on frequency; whereas, the lumped mass matrix model provides a lower bound on frequency [Hughes, 1987]. Shown are the nodal deflection for the free end of the beam for discretizations of five and ten elements. Hence from the frequency perspective, a model of ten or more elements using a lumped mass matrix will produce the same results as one using a consistent mass matrix.

Figure 2-3: Frequency bounds of consistent and lumped mass finite element matrices for modeling a propped, hinged beam appropriate discretization can be determined by matching the frequencies of consistent and lumped mass matrix solutions as shown in Figure 2-3.

For investigating the behavior of the Duraflex, Model A, springboard, a finite element model consisting of thirteen uniform beam elements was used. The fulcrum position was assumed to be centered in its adjustable range. The nodes of the elements were located at 0.00, 0.20, 0.40, 0.60, 0.80, 1.00, 1.38, 1.88, 2.38, 2.88, 3.38, 3.88, 4.38, and 4.88 m from the free end of the springboard. As dictated by the geometry of the variable cross-sectional area of the extruded, tapered springboard, geometric parameters for each element were calculated (Table 2-2).

Table 2-2: Geometric Parameters of Each Element

Element	Length (m)	Moment of Inertia[3] (x 10^{-8} m^4)	Cross-sectional Area (x 10^{-4} m^2)
1	0.20	41.12	53.97
2	0.20	42.67	56.02
3	0.20	45.16	58.07
4	0.20	48.78	60.12
5	0.20	53.17	62.18
6	0.38	63.49	65.15
7	0.50	85.21	69.67
8	0.50	121.50	74.80
9	0.50	162.63	79.08
10	0.50	162.63	79.08
11	0.50	162.63	79.08
12	0.50	162.63	79.08
13	0.50	162.63	79.08

To calculate the stiffness and mass matrix elements, Young's Modulus of Elasiticity was assumed to be 69 GPa and the density of aluminum was assumed to be 2710 kg/m^3.

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[3] The moment of inertia of the cross-section is with respect to the neutral axis.

In analyzing the elastic behavior of the springboard, the relation between the transverse deflection and the applied load indicates the board stiffness. The deflection of the board can be studied, through reducing the beam vibration equation to the beam flexure equation [Beer and Johnston, 1981], as follows:

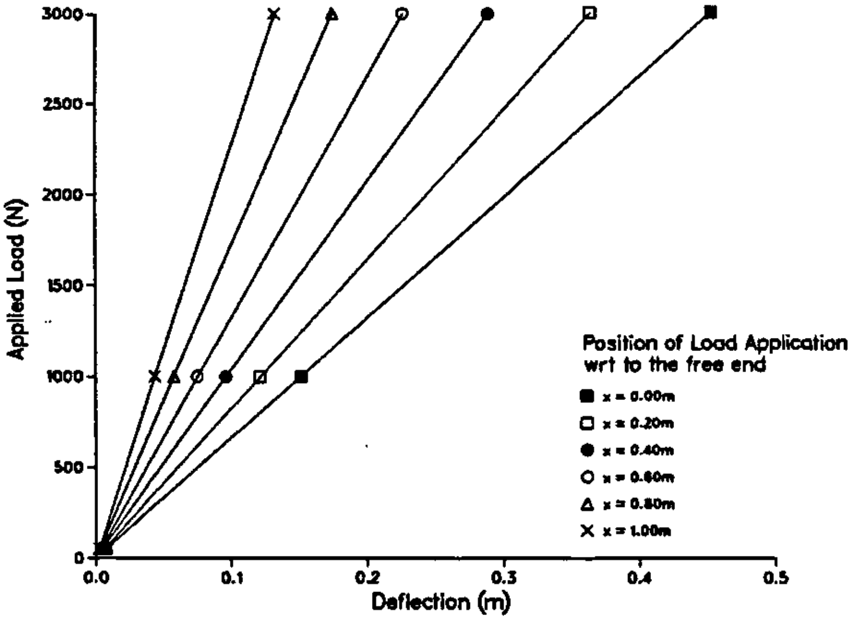
$$\frac{d^2y \,/\, dx^2}{[1 + (dy/dx)^2]^{1.5}} = \frac{M(x)}{E\ I} \qquad (2.3.7)$$

For small slopes, the curvature may be approximated by a second order derivative. By modeling the overhanging portion of the springboard as a cantilever and applying the numerical results for large deflections of a cantilever beam [Mattiasson, 1981], this approximation appeared valid for the deflections studied. For the diving board, the error that was associated with this approximation of the radius of curvature, was less than 2%. Hence, as a reasonable approximation, the flexure equation can be expressed as:

$$\frac{d^2y}{dx^2} = \frac{M(x)}{E\ I} \qquad (2.3.8)$$

As shown by the solution of the simplified case of a propped, hinged beam with uniform cross-sectional area (Appendix D), a linear relation between load and deflection exists for each location of load application and positioning of the fulcrum.

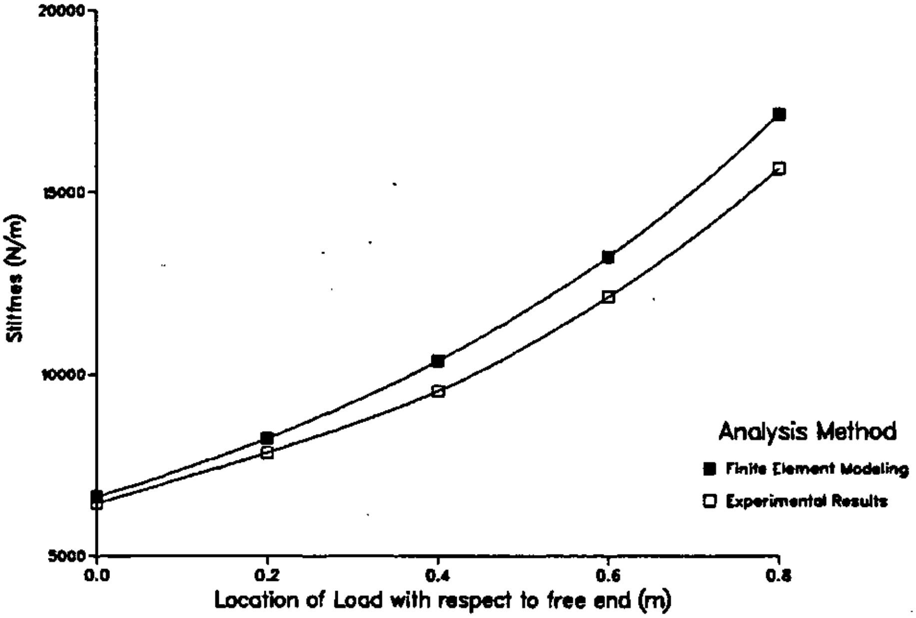
The finite element approximation of springboard deflection, when point loads were applied near the free end, showed a linear relation between load



These results were determined using finite element modeling of the springboard with the fulcrum being centered. As illustrated, the springboard stiffness was linear.

Figure 2-4: Springboard stiffness

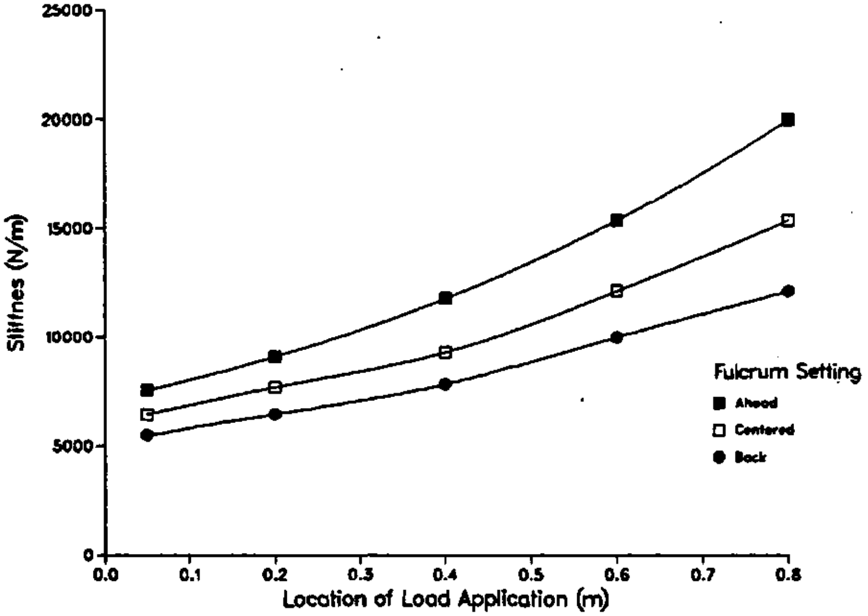
and deflection (Figure 2-4). Experimental verification of this linearity involved incremental loading of the springboard; the range of the load varied from 0 to 1600 N which was applied in 200 N increments (Appendix E). The static vertical deflections along the Duraflex springboard were recorded. For each selected fulcrum setting and load application placement, a unique linear relation existed. A close correlation between the finite element model and experimental results exists as illustrated in Figure 2-5. The slight deviation may be attributed to experimental errors in recording deflection of the board, the placement of the load, and in the estimation of the cross-sectional area and cross-sectional area moment of inertia as required in the finite element model.



The following stiffness results were derived from experimental and from finite element results with the fulcrum of the springboard being centered.

Figure 2-5: Relation between springboard stiffness and load application position

Both the location of the load and the fulcrum setting affected the value of board stiffness. The relation between the stiffness and the location of load application, which corresponds to the point of diver contact, should be nonlinear as predicted by the solution for transverse deflection of a uniform cross-sectional area, propped beam (Appendix D). For the actual diving board, the taper affected this relation further. As illustrated in Figure 2-5, the relation between stiffness and location of load application was nonlinear. The effects of fulcrum position on the stiffness as related to load application are represented in Figure 2-6. The results indicate that the spring constant depends both on the fulcrum setting and on the location of board contact.



The following stiffness results were derived experimentally.

Figure 2-6: Springboard Stiffness as affected by load application position and fulcrum setting

Dynamic analysis of the springboard enabled the parameters of mass and damping to be examined. Since an elastic member possessing mass will vibrate if disturbed, the characteristics of the vibration can be analyzed to evaluate effective mass and damping coefficient values for the member. The frequency and the rate of decay of the amplitude of vibration relate to the mass and damping parameters. As easily shown [Ogata, 1970], for a simple lumped parameter spring-mass-damper system, the frequency of oscillation is described by the following expression:

$$\sqrt{\frac{K}{M} - \left(\frac{B^2}{4M^2}\right)} \qquad (2.3.9)$$

and the rate of decay of the oscillation is expressed as:

$$\frac{B}{2M} \qquad (2.3.10)$$

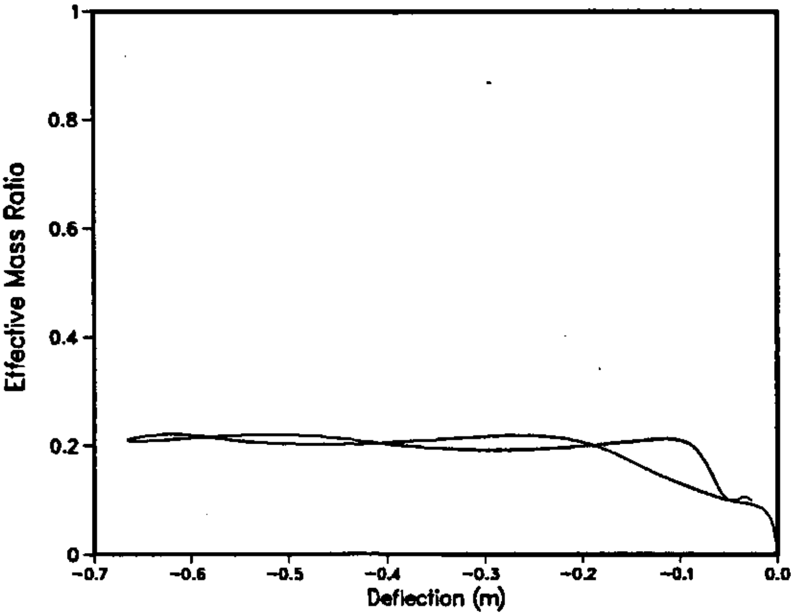
Thus, mass and damping parameters can be determined if the stiffness and deflection history are known.

To study the board's dynamic behavior, negligible damping was assumed for the consistent mass matrix derivation of the finite element model of the springboard. In the model, thirteen elements were used and the fulcrum position was assumed to be centered. By applying an impulse load at a specific node, the springboard was deflected and the solution for each node of the vibrating board was obtained. The nature of the mass parameter was reflected in the resulting motion of the nodes.

By calculating the participating effective mass during an oscillation of the board, the nature of springboard mass parameter was determined. This participating effective mass ratio was defined as the normalized, total contribution of the board dynamics from each node with respect to the dynamics of the point of loading. Mathematically, this can be expressed as:

$$\frac{\sum_{i=1}^{n} m_i \; y_i}{m_t \; y_x} \qquad (2.3.11)$$

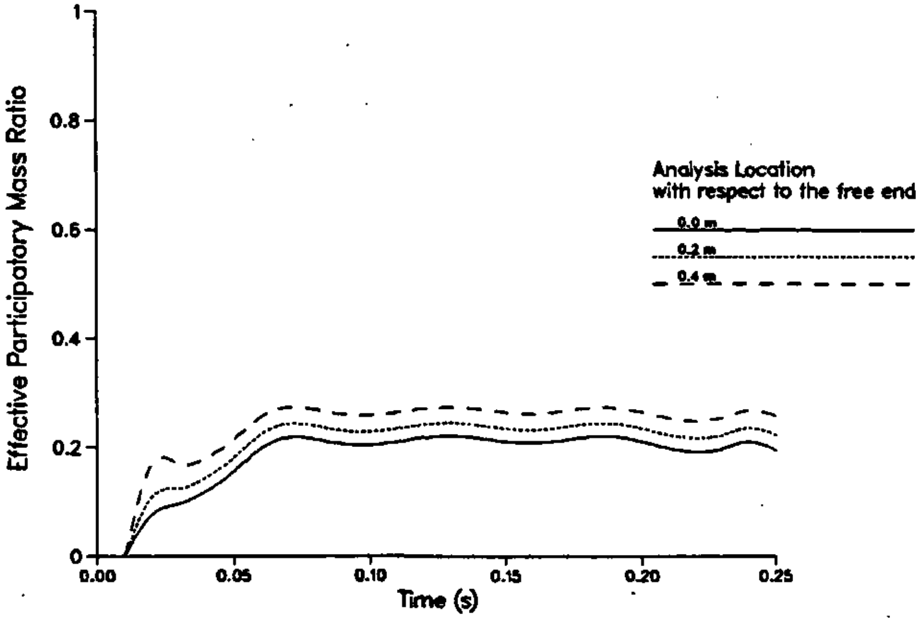
where m_i represents the elemental mass; y_i, nodal kinematic data; m_t, total board mass; and y_x, kinematic data at the assumed loading point. As shown, in the time-dependant (Figure 2-7) and the deflection-dependant



The participatory effective mass for the free end is shown for a typical oscillation of the springboard. The result was calculated from the finite element solution of the springboard.

Figure 2-7: Participatory Effective Mass

(Figure 2-8) relations, the effective mass ratio apparently remains constant after the onset of springboard motion. Since this near constant value was obtained during a typical oscillation for the given geometry, load location and fulcrum setting, only these considerations appeared to be essential in defining the effective board mass.

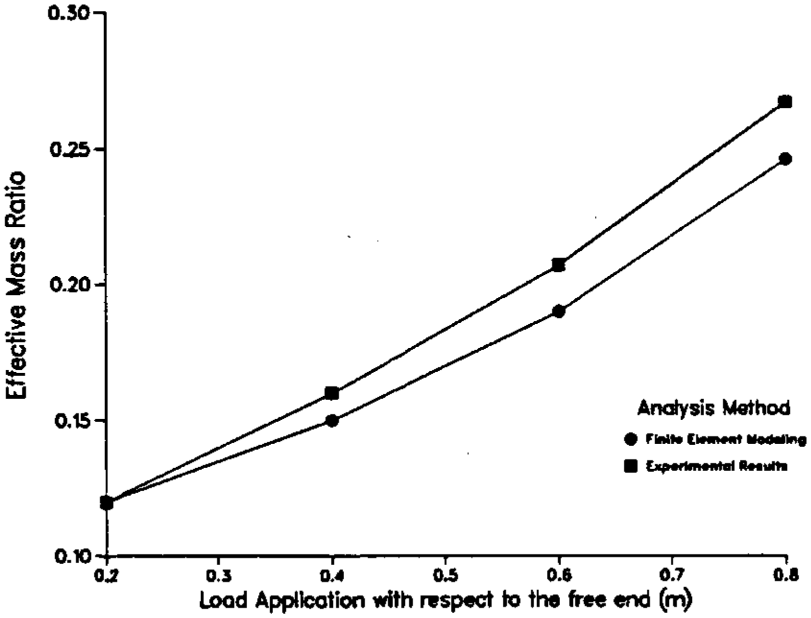


The participatory effective mass values for three nodes, located at 0.0, 0.2, and 0.4 m away from the free end, are shown for a typical oscillation of the springboard. These results were determined from the finite element solution of the springboard.

Figure 2-8: Participatory Effective Mass

Characteristically, the effective participating mass ratio calculated using displacements does not instantaneously assume its steady-state value, Figure 2-8. In modeling the springboard-diver interactions, the springboard mass must reflect this characteristic; during the initial phase of board contact, the mass value of the springboard must be reduced. Once motion of the springboard is initiated, a constant value may be used to approximate its mass.

The equivalent, effective board mass values, for positions along the board, were evaluated from the frequency of vibration of each node as



The illustrated nonlinear relation between the effective mass and the location of load application was performed with the fulcrum being centered.

Figure 2-9: Effective Mass and Load Location relation (Experimental and Finite Element Results) calculated from the finite element solution. The relation between the location being analyzed and the effective mass ratio was nonlinear (Figure 2-9). Effective mass ratio values were calculated from the recorded vibration incurred by releasing the board from a deflected position. In this experiment, accelerometers were positioned along the board to record transverse deflections with the output signal permitting measurement of peak acceleration values and frequencies (Appendix E). The effective mass values as computed from the experiment and the finite element solution for the condition of the fulcrum being centered, were similar, as illustrated in Figure 2-9. From the experimental results, as the point of analysis was selected nearer to the fulcrum, the effective mass ratio increased. More of the board had undergone motion. The effects of adjusting the fulcrum on the equivalent mass values are pictured in Figure 2-10 for the extreme fulcrum settings. Consistently, the effective board mass decreased as the fulcrum was moved forward. Apparently, the amount of overhang, the distance between the fulcrum and free end, was a determining factor of the effective board mass value. The further back the fulcrum was placed, the greater the effective mass value. Since the amplitude of nodal displacements for positions between the fixed end and the fulcrum were significantly less than those for points between the fulcrum and the free end, the overhang portion appeared to be the major contributor to the effective mass of the springboard.

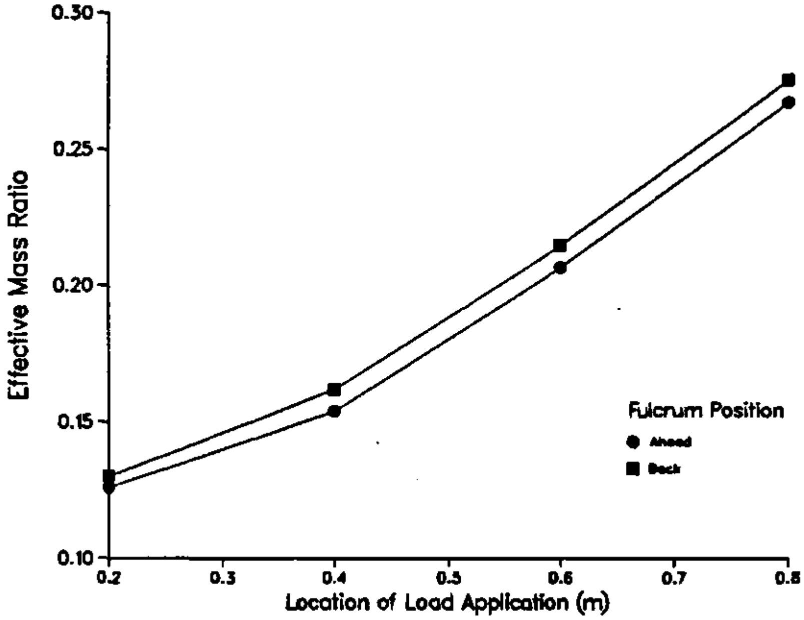
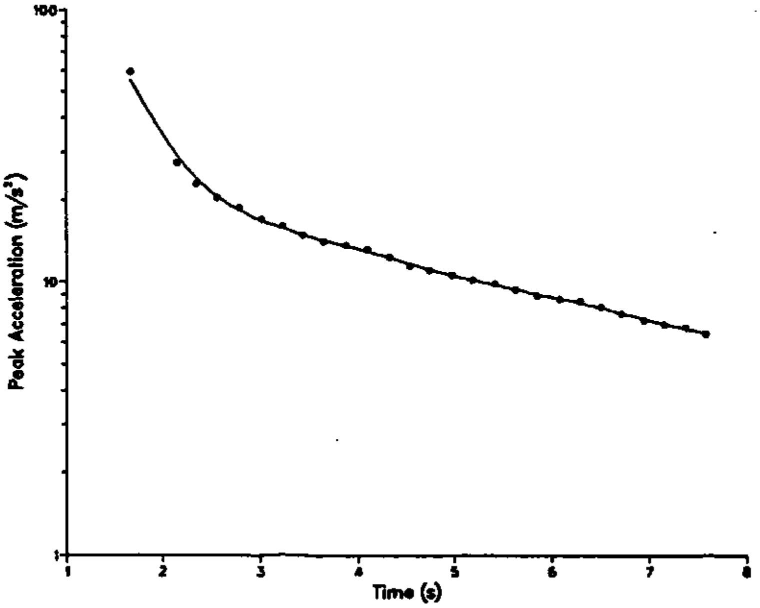


Figure 2-10: Effects of fulcrum position and load location on the effective mass value (experimentally obtained)

During the experimental test when the board was released from a deflected position, the magnitude of the acceleration peaks decayed with respect to time. For the trial where the board was deflected approximately 0.15 m, the relation between acceleration amplitudes and time, as illustrated in Figure 2-11, was obtained. In this trial, the fulcrum was centered and the position under investigation was 0.2 m from the free end. The damping coefficient was evaluated and varied from 29 N-s/m to 4 N-s/m. As a result of inconsistencies in the experimental trials, no precise relation between the magnitude of damping and other parameters were evident (Appendix E).



At the beginning of the trial the damping coefficient was approximately 29 N-s/m and near the end the value diminished to 4 N-s/m.

Figure 2-11: Experimental Evaluation of Damping Coefficient

The potential sources of damping for a springboard include internal and viscous damping of the springboard and the related damping from the collisions of the freely vibrating board against the fulcrum. Assuming negligible internal damping of the aluminum alloy of the springboard [Jastrzebski, 1987; Lazan, 1968[4]]. Since the springboard remains in contact with the fulcrum for a short period during the board contact phase, the damping of the rigid, vinyl channels was neglected. Thus, air resistance

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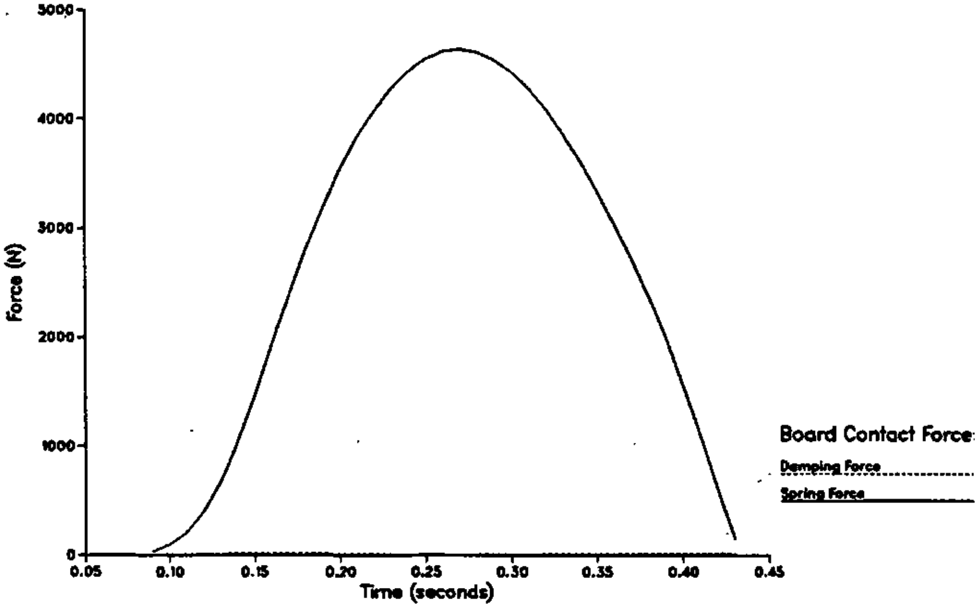
[4] For various aluminum alloys, the loss coefficient is reported to be about 10^{-5} [Lazan, 1968].

must account for any observed damping. This force of viscous damping arises from the pressure difference due to the relative motion of the diving board through air [Fox and McDonald, 1978] and is characterized by the equation:

$$F_D = \frac{C_d \ \rho \ A \ v^2}{2} \tag{2.3.12}$$

By approximating the overhanging portion of the springboard as a flat plate and over-estimating the above parameters of the drag force equation, an approximation of the drag force can be obtained. By assuming that the relative air flow velocity over the board was 5 m/s, a maximum drag force of 31 N was calculated. This damping force appears to be negligible; especially, when considering the dynamics of the springboard during board contact. In modeling the springboard as a parallel arrangement of a lumped-mass, spring and dashpot (Figure 2-2), the damping force will be negligible in comparison to the spring force after the initial onset of motion. As illustrated in Figure 2-12, the magnitude of the damping force is significantly less than the spring force. The kinematics of the board during the board contact phase of an actual performance and a stiffness value of 9850 N/m and a damping coefficient of 29 N-s/m were used in deriving the forces associated with damping and stiffness. Hence, for simulating springboard and diver dynamics, the effects of damping were considered negligible.

If the experimental tests cannot be conducted and if the appropriate finite element matrices cannot be approximated, then the parameters may be evaluated based on optimization techniques. Through examining the kinetics



The comparison has been made during the board contact phase with the board kinematic data acquired from an actual performance. The performance was a forward, one and one-half pike somersault.

Figure 2-12: Comparison of Springboard Damping and Spring Forces

of the springboard-diver system, independent expressions for the board reaction forces can be derived explicitly in terms of either the board kinetics or the diver kinetics. These equations form an objective function that can be minimized by an appropriate selection of parameter values (Appendix C).

This same protocol may be used to evaluate the dynamics of other springboards and to determine appropriate modeling parameter values. Current competitions boards are manuafactured with perforations located at the free end (Maxiflex, Model B). Since divers have been able to deflect these boards further, these boards appear to be more flexible. Through applying the discussed analyses a lower stiffness value would likely be determined for such boards. Hence, by using the experimental procedure (Appendix E) or finite element modeling, design changes of the springboard which affect diving performance may be evaluated.

To conclude, the springboard can be represented as a lumped parameter system. As shown, appropriate magnitudes for the modeling parameters can be determined based on the location of diver contact and fulcrum position. These values have been derived from experimental evaluations and finite element solutions of the dynamics of the springboard. As shown (Figure 2-6 and 2-10), the values of these parameters depend on the geometry of the situation: the values are affected by the location where the diver contacts the board and the setting of the fulcrum. To conclude, a lumped spring-mass model can be used to model the behavior of a selected node of the springboard.

2.4. Modeling Human Motion

When modeling human motion, usually the human body is represented by a system of interconnected, rigid body segments [Miller, 1979] as described in Section 2.2, Modeling the Human Body. The dynamics associated with each segment are often derived using an inverse dynamic approach. An inverse dynamic approach deduces the causes of motion from the observed outputs of the system [King, 1984]; that is, force and/or torque patterns are inferred from the kinematics of the segments.

The differential equations describing the dynamics of each segment may be formulated by applying Newton's Laws of Motion [Preiss, 1984]. The Newtonian approach for analyzing the system usually involves a simple repetition of applying forces to the free body models of each segment.

In detail, the Newtonian approach involves dismembering the system into free body models of each segment. Then, at the joints between segments appropriate reaction forces and moments are applied according to Newton's Third Law. Each segment is assumed to act independently under the influence of the forces present. Therefore, the associated differential equations can be derived by applying Newton's Second Law to each segment [Andrews, 1974]. Using the inverse dynamic procedure, the applied joint reaction forces can be derived from the observed kinematic history profiles of each segment.

The Newtonian approach of applying forces and moments at the joints of segments lumps the effects of muscle forces, ligament forces, tendon forces, bone-on-bone contact forces and external forces together [Winter, 1979]. Thus, the attributes of the contributing forces are hidden in the joint reaction forces.

The intended application for the model of human motion, optimizing skill performance (Section 2.5 Spatio-Temporal Optimization), provided motivation to modify the above model. The model of human motion must not only reproduce observed motion but also provide a means to effect performance optimization. To facilitate application in sport, the parameters of the model needed to be easily understood and the optimization technique needed to be translated to a coaching strategy. Furthermore, the optimization method should incorporate an individual's demonstrated ability; this would avoid the difficulties associated with performing 'ideal' force/torque patterns. The challenge was to model human motion for performing optimization in a more functional manner than the described, resultant force model of motion.

Initially, the external forces were segregated from the diver and the skill-specific, internal forces. The internal forces were believed to represent learned movement skills and were expressed in terms of relative motion of one segment with respect to another. The external forces included the force of gravity and forces resulting from interactions with the environment.

Previous efforts in examining body segment contribution to a skill performance [Miller, 1981; Miller, 1982; Miller et al., 1984] have defined relative acceleration or force terms. Isolating the effects of acceleration of the lower extremities (legs), head and torso, and the upper extremities (arms), from the influence of one another was attempted by referencing accelerations of these segments to the metatarsal phalangeal, as illustrated in Figure 2-13. Then, appropriate 'active'[5] acceleration components were extracted to complete the analysis [Miller et al., 1984]. This model incorrectly assumed that the motion of an upper extremity does not affect the motion of segments beneath itself. In gait analysis [Philips, Roberts, and Huang, 1981], motion of segments were shown to affect the motion of the other linked segments. Furthermore, in the work of Miller and Munro [1984] each acceleration was referenced to a non-inertial frame of reference, the metatarsal phalangeal joint.

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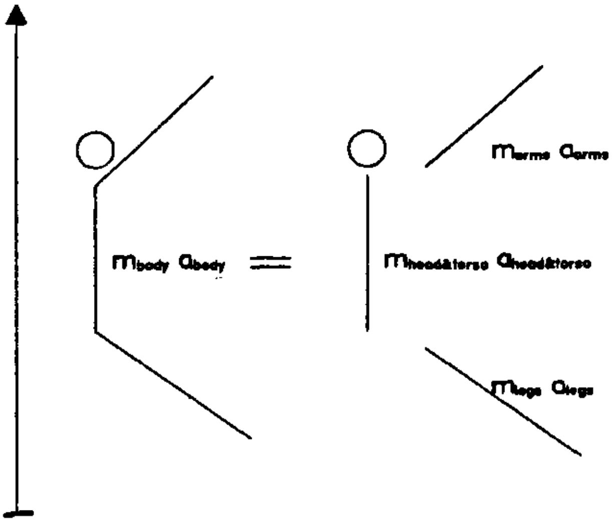
[5] Active accelerations were defined as the difference in acceleration between adjacent segments [Miller et al., 1984].



Analysis of the vertical component of segment motion expressed the resultant force that acted on the diver as the sum of the accelerations of each segment in proportion to its segmental mass; this may be expressed mathematically as:

$$m_{body}a_{body} = m_{arms}a_{arms} + m_{head\&torso}a_{head\&torso} + m_{legs}a_{legs}$$

Research by Miller and Munro [1984] has attempted to isolate the acceleration terms for each segment as derived below:

$$m_{body}a_{body} = m_{arms}[(a_{arms} - a_{head\&torso}) + (a_{head\&torso} - a_{legs}) + a_{legs}] + m_{head\&torso}[(a_{head\&torso} - a_{legs}) + a_{legs}] + m_{legs}a_{legs}$$

Figure 2-13: Analysis of the vertical component of motion for a three segment model

An extension of this relative acceleration approach was employed in temporal optimization of two and three segment models of a springboard diver [Sprigings et al., 1983; Sprigings et al., 1986]. This model introduced internal forces, F_i, which accelerated segments with respect to each other. These internal forces were independent of external forces, such as gravity and springboard reaction forces. The differential equations for each segment could be defined explicitly in terms of external and internal forces. Since these internal force terms could not be conveniently measured, relative forces were introduced. These relative forces were defined in terms of acceleration differences between adjacent segments:

$$f_i = m_i(\ddot{y}_i - \ddot{y}_{i+1}) \tag{2.4.1}$$

where f_i represented the relative force between the upper segment, i, and the adjacent, lower segment, $i+1$; m_i represented the mass of the ith segment; and $\ddot{y}_i$ and $\ddot{y}_{i+1}$ represented the absolute accelerationof the ith and $i+1$ segments, respectively. The absolute segment acceleration terms were expressed in terms of relative accelerations which were referenced to the lowest segment of the model. For a three segment model the resulting differential equation of motion would be derived as follows:

Differential Equation for Upper Segment, 1

$$F_1 - m_1 g = m_1 \ddot{y}_1 \tag{2.4.2}$$

$$F_1 - m_1 g = m_1 (\ddot{y}_{1/2} + \ddot{y}_{2/3} + \ddot{y}_3) \tag{2.4.3}$$

$$F_1 - m_1 g = f_1 + \frac{m_1}{m_2} f_2 + m_1 \ddot{y}_3 \tag{2.4.4}$$

Differential Equation for Middle Segment, 2

$$-F_1 + F_2 - m_2 g = m_2 \ddot{y}_2 \qquad (2.4.5)$$

$$-F_1 + F_2 - m_2 g = m_2 (\ddot{y}_{2/3} + \ddot{y}_3) \qquad (2.4.6)$$

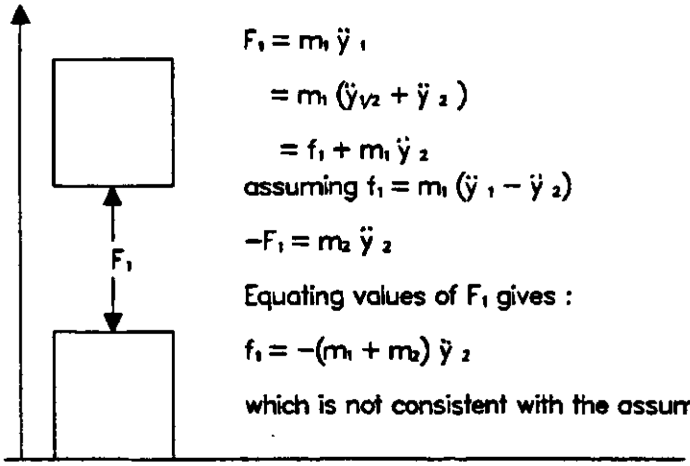
$$-F_1 + F_2 - m_2 g = f_2 + m_2 \ddot{y}_3 \qquad (2.4.7)$$

Differential Equation for Lower Segment, 3

$$-F_2 - m_3 g = m_3 \ddot{y}_3 \qquad (2.4.8)$$

where $\ddot{y}_{1/2}$ and $\ddot{y}_{2/3}$ represents the relative acceleration between the indicated segments as denoted by 1, 2, or 3. From this system of equations, the internal forces, F_i, could be defined in terms of relative forces, f_i. The resulting calculations of relative forces between segments implied that a frame of reference was being attached to the lower adjacent segments. Again, this model failed to accurately represent motion. Firstly, the affects of motion of a segment on nonadjacent segments was not apparent. Secondly, segmental accelerations were not taken with respect to an inertial frame of reference which caused the defined relative force to be inappropiately scaled as illustrated in Figure 2-14.

An alternate approach was developed to resolve this difficulty [Stilling, Watson, and Sprigings, 1988]. This pseudo inter-segment force approach for modeling motion has been applied to a three member system that has force generating units (actuators) positioned between adjacent members as shown in Figure 2-15. For the various cases that are to be considered, only one direction of motion will be analyzed.



$$F_1 = m_1 \ddot{y}_1$$

$$= m_1 (\ddot{y}_{1/2} + \ddot{y}_2)$$

$$= f_1 + m_1 \ddot{y}_2$$

assuming $f_1 = m_1 (\ddot{y}_1 - \ddot{y}_2)$

$$-F_1 = m_2 \ddot{y}_2$$

Equating values of F_1 gives :

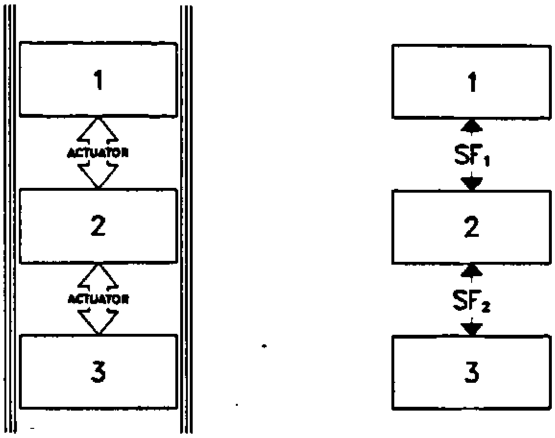
$$f_1 = -(m_1 + m_2) \ddot{y}_2$$

which is not consistent with the assumed value

The two segment model of the vertical component of motion shows the inconsistency of employing relative forces when an non-inertial frame of reference is selected.

Figure 2-14: Inconsistent relative force model of motion for two segment system

The forces generated by the actuators cause motion within the system and will be referred to as internal system forces, SF_i. These generated forces are assumed to be known and their nature is such that the magnitude of the displacements between adjoining members is limited. Also, the mass of the actuators will be considered negligible in comparison to the mass of the members. Lastly, the actuators are assumed to link members together and to transmit forces without causing attenuation. In other words, the actuators do not possess any damping characteristics or energy storage capabilities.

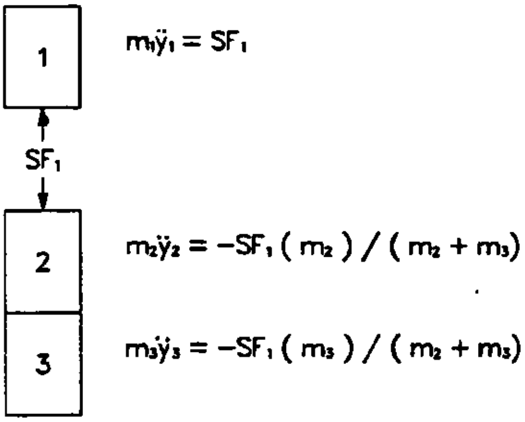


(a) (b)

The above three member system with its two actuators was constructed to demonstrate the effects of internal system forces on the motion of each member. For the rest of this discussion, the free body diagram shown in (b) will be used to represent the schematic pictured in (a).

Figure 2-15: Three member system with two actuators

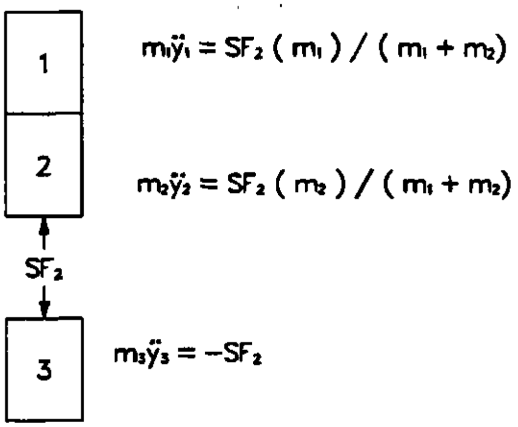
Although an internal system force acts between adjacent members, it affects the motion of all members of the system. For example, if the actuator between members one and two is active and the other actuator is not active, then member one will move with respect to the other segments. For clarity, all external forces have been neglected. Examining this case (Figure 2-16), from an inertial frame of reference, one observes that the internal system force, SF_1, acts directly on member one and acts in the opposite direction on the rest of the system. Since no force attenuation occurs across the actuator located between members two and three, these members are essentially linked and will move together. This is evident especially if the system begins from a state of rest. For members two and three to move together, the internal system force must be distributed between them. Since no relative acceleration exists between segment two and three, the distribution can be expressed as a mass ratio, as shown in Figure 2-16.



Case 1 -- The actuator between members one and two is active. The internal system force, SF_1, affects the motion of each segment.

Figure 2-16: Case 1 -- Active upper actuator

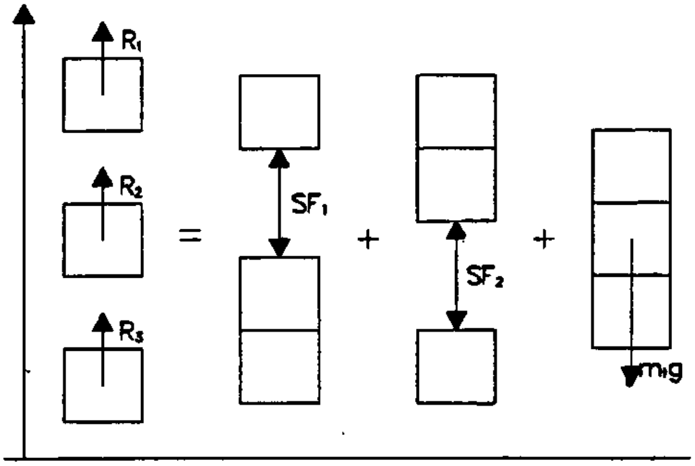
Similarly, if the system begins from rest and only the actuator between members two and three is active, then motion of member three towards or away from members one and two will occur. Members one and two will appear to be linked by the passive actuator that joins them. The internal system force, SF_2, as generated by the actuator, acts on member three and can be distributed in a mass ratio to members one and two, as shown in Figure 2-17. Again, all external forces have been neglected to best illustrate the effects of the internal segment force.



Case 2 -- The actuator between segment two and three is active. The generated force, SF_2, is shown to affect the motion of each member of the three body system.

Figure 2-17: Case 2 -- Active lower actuator

For the case when both actuators of the system are active (Figure 2-15), then two internal system forces will be generated, SF_1 and SF_2. These forces will have an affect on the motion of each member of the system. Since the actuators have been assumed to have no damping or



By superposition of these free body diagrams, the resultant force, R_i, and the related differential equations of motion for each segment can be derived as follows:

Segment 1:

$$R_1 = m_1 \ddot{y}_1 = SF_1 + \frac{m_1}{m_1 + m_2} SF_2 - m_1 g$$

Segment 2:

$$R_2 = m_2 \ddot{y}_2 = \frac{-m_2}{m_2 + m_3} SF_1 + \frac{m_2}{m_1 + m_2} SF_2 - m_2 g$$

Segment 3:

$$R_3 = m_3 \ddot{y}_3 = \frac{-m_3}{m_2 + m_3} SF_1 - SF_2 - m_3 g$$

Figure 2-18: Case 3 -- Both actuators are active.

energy storage capabilities, the internal system forces are distributed among the members as previously discussed (Figure 2-16 and Figure 2-17). Through superposition of the analyses of the actuators which were acting separately, a model for the case when both actuators are operative can be completed. For the three member system, external and internal system forces are shown to act independently. The internal system forces act between adjacent members as illustrated in Figure 2-18. Each force is apportioned in a mass ratio to each member.

To determine the kinematic profiles of an individual member or of the entire system, the initial kinematic state of each member must be known. In addition, the force profiles of each actuator are required. These force profiles can be determined from the actual, observed motion of each member using an inverse dynamic approach or from understanding the mechanism of the actuator.

To summarize, this approach introduces the concept of internal system forces that act between adjacent segments and affect the motion of each segment. Each internal system force, SF_i, is distributed among all of the segments. An internal system force acts on the array of segments above and below the point where it is generated, as though each array was a single unit. The internal system forces are distributed to each segment of the unit based on a mass ratio. Appropriate equations of motion for each segment can be derived by summing the internal system forces and external forces acting on the segment. Thus, for an n-member system, the equation of motion for the ith segment, when external forces F_{ext} are present, can be expressed as:

$$R_i = m_i\ddot{y}_i =$$

$$m_i\left[\sum_{j=1}^{i-1}\frac{-SF_j}{\sum_{k=j}^{n-1} m_{k+1}} + \sum_{j=i}^{n-1}\frac{SF_j}{\sum_{k=1}^{j} m_k} + \frac{F_{ext}}{\sum_{l=1}^{n} m_l}\right] \qquad (2.4.9)$$

The internal system forces affect the motion of all segments and account for intersegment motion within the system. Relative motion occurs at the point where the internal system force acts. For modeling human motion, the profiles of the internal system forces can be evaluated using an inverse dynamic approach. That is, the force profiles are determined from observed motion rather than trying to estimate the force histories based on physical ability and related biomechanical contraints. For human motin, these forces have been assumed to represent learned movement patterns between segments. By algebraic simplification of the resultant differential equations of motion, the internal system forces can be defined as a function of relative accelerations. Each internal system force in an n-member system can be expressed as:

$$SF_i = \frac{\sum_{j=1}^{i} m_j \sum_{k=i+1}^{n} m_k}{\sum_{l=1}^{n} m_l}\left(\ddot{y}_i - \ddot{y}_{i+1}\right) \qquad (2.4.10)$$

In calculating each acceleration term, $\ddot{y}_i$ and $\ddot{y}_{i+1}$, an inertial frame of reference was used.

As is evident from equation (2.4.9), the number of terms of the derived differential equations of motion increases as the the number of segments used to model the human body increases. The increase in the number of terms in the differential equations is due to the introduction of additional internal system forces.

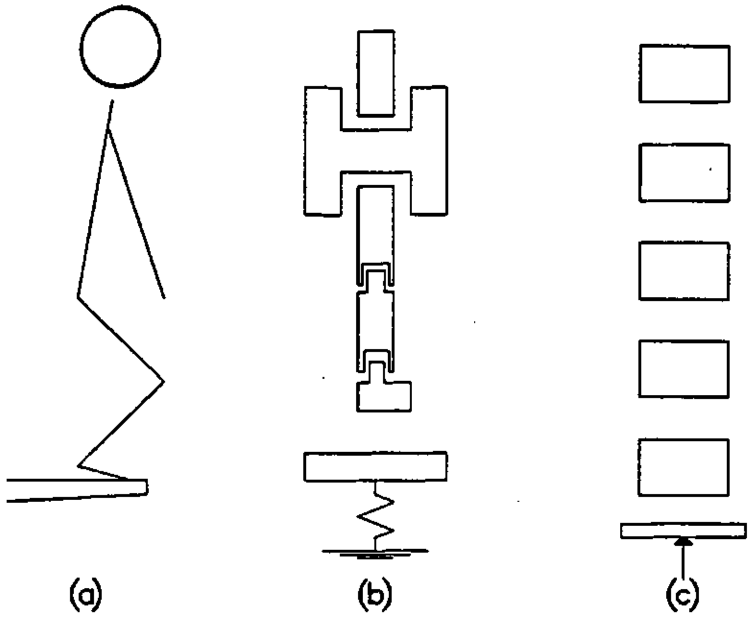
To conclude, the modeling of human motion utilizes an interconnected, rigid-body segment model for the human body. By applying Newton's Laws of Motion, the differential equations describing the motion of each segment were derived. Segregating internal system forces, SF_i, from external environment forces, F_{ext}, produced a more functional model than one that models only absolute motion through the use of resultant forces. The internal segment forces permit segments to accelerate with respect to adjacent segments and to affect the motion of other segments. If learned movement skills are reflected by relative motion between segments, then this model incorporates demonstrated ability because the internal system forces can be expressed in relative accelerations terms. As previously described, these internal system forces were distributed among the segments in proportion to the segmental masses. The inter-segment force approach enables absolute segmental forces or accelerations to be determined from the known internal system forces and external forces.

The solution of the differential equations of motion for each segment will depend on the nature of the external forces. For an airborne maneuver, the only external force acting on each segment will be the constant force due to gravity; thus, solving for acceleration histories for each segment reduces to simple algebra. Essentially, the absolute segment accelerations can be calculated based on the relative acceleration values between each segment. The segmental velocity or displacement profiles can be generated through integrating the calculated absolute segmental acceleration history curves and accounting for the initial kinematics of each segment. Furthermore, total body kinematics can be determined by applying the principles of Varignon to the segmental data.

2.4.1. Application to Modeling Springboard Motion

In simulating the motion of a springboard-diver system during the board contact and flight phases, the pseudo inter-segment force approach, as previously described, was employed. The springboard diver system may be represented as shown in Figure 2-19. Generally, five segments are easily identifiable during these phases of motion. Since the motion of bilateral segments are symmetrical and coordinated, their motion may be modeled together as a single, rigid segment. Therefore, the diver may be modeled as a system of five interconnected, rigid-body segments. Anatomically, the segments correspond to the arms (1), the head and torso (2), the upper legs (3), the lower legs (4), and the feet (5), as shown in Figure 2-19. The springboard is represented as a lumped spring-mass system as discussed in Section 2.3, Springboard Modeling. Analysis of the springboard-diver system was restricted to the vertical component of motion.

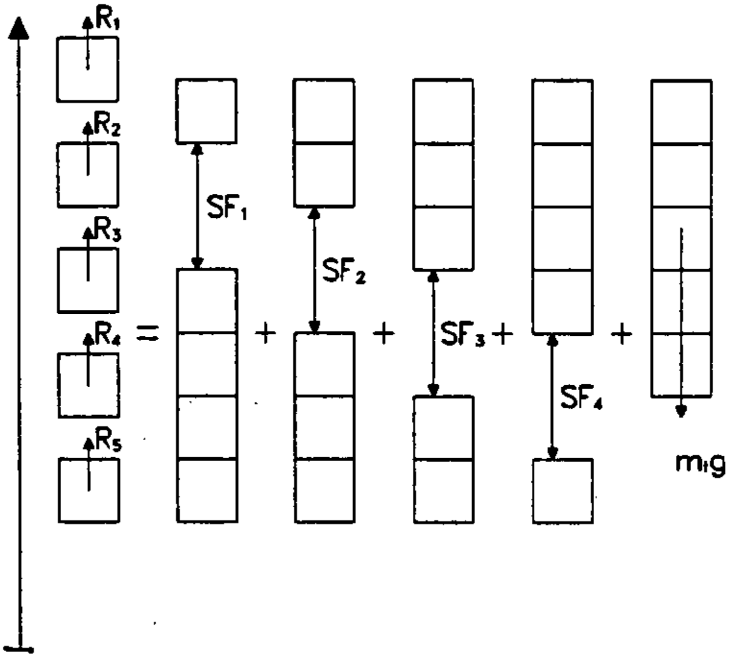
In describing the dynamics of the flight phase and the board contact phase, differential equations of motion were generated from the *pseduo* free body diagrams of Figure 2-20 and Figure 2-21. For both phases, the skill-specific, internal system forces can be interpretated as follows: SF_1 indicates arm motion with respect to the head and torso; SF_2, hip extension-flextion; SF_3, knee extension-flexion; and SF_4, ankle extension-flexion.



The stick figure used to represent the diver-springboard system shown in (a) may be viewed as a series of masses that are restricted to move in the vertical direction as shown in the schematic (b). For simplicity, a block digaram will be used to represent each mass and and a force vector will indicate the springboard reaction force, as shown in (c).

Figure 2-19: Representation of the diver-springboard system

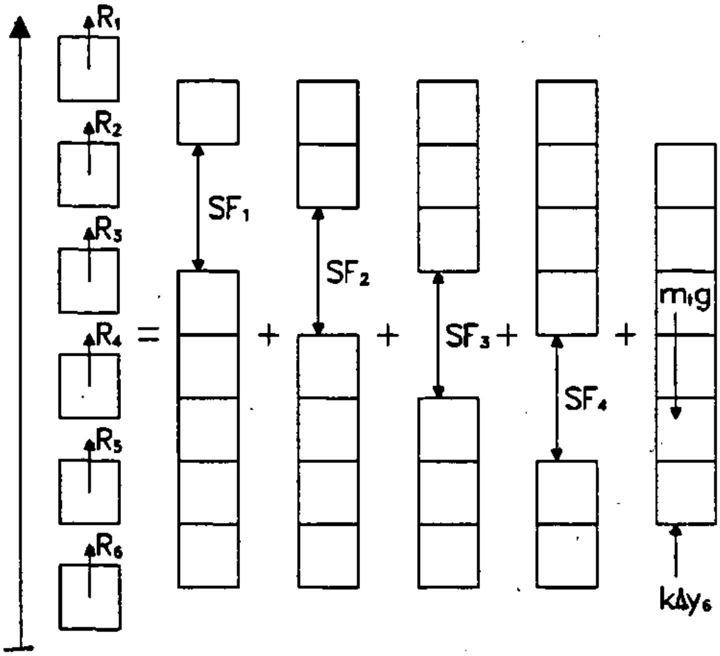
A practical approach for numerically solving these equations of motion, for performing subsequent integrations, and for calculating other results was to use a digital computer. The FORTRAN code for simulating the performance of a springboard diver can be found in Appendix G.



For the flight phase, the differential equations used to model the motion of each segment were derived by superposition of the illustrated pseudo free body diagrams. The differential equations governing segment motion can be expressed as follows:

$$R_i = m_i \ddot{y}_i = m_i \left[\sum_{j=1}^{i-1} \frac{-SF_j}{\sum_{k=j}^{n-1} m_{k+1}} + \sum_{j=i}^{n-1} \frac{SF_j}{\sum_{k=1}^{j} m_k} - g \right]$$

Figure 2-20: Modeling airborne phase of springboard diver motion



For the board contact phase, the differential equations used to model the motion of each segment were derived by superposition of the illustrated pseudo free body diagrams. The differential equations governing segment motion can be expressed as follows:

$$R_i = m_i \ddot{y}_i =$$

$$m_i \left[\sum_{j=1}^{i-1} \frac{-SF_j}{\sum\limits_{k=j}^{n-1} m_{k+1}} + \sum_{j=i}^{n-1} \frac{SF_j}{\sum\limits_{k=1}^{j} m_k} - g - \frac{K\,\Delta y_6}{\sum\limits_{l=1}^{n} m_l} \right]$$

Figure 2-21: Modeling board contact phase of diver-springboard motion

Performances of a vertical layout jump and of a forward one and one-half pike somersault were captured using high speed cinematography and then analyzed (Appendix B). Actual position data was attained from these records by digitizing the cinefilm. Manipulation of the position history data provided the input kinematic data for the simulation (Appendix F). Details regarding the data acquisition are addressed in Appendix B.

The program input parameters required for the simulation included: appropriate segmental body parameters (Section 2.2), proper board parameter values (Section 2.3), initial segmental kinematic conditions, and the relative acceleration history curves that are used to define the internal system forces (Appendix F) which represent learned movement skills. These relative acceleration profiles have been discerned from actual performances. The simulation process involved solving absolute kinematics of each segment from the relative acceleration history curves. Since the action of all segments are considered simultaneously in determining the motion of each segment, a direct dynamic approach was employed.

The simulation process for modeling the performance of the springboard-diver system follows. At the onset of the simulation the athlete was airborne in the hurdle phase. The diver was in a static, reach position and the initial kinematics of each segment were known. For this phase, segmental accelerations were calculated from the flight phase differential equations of motion as derived in Figure 2-20. Numerical integration using Simpson's rule [Burden and Faires, 1985] was used to compute velocity and displacement profiles from the generated absolute segmental acceleration history data and the initial segmental kinematic conditions. The next phase of the simulation, the board contact phase, modeled the motion of the diver and the springboard according to the equations of motion as derived in Figure 2-21. The instant of board contact was determined by tracing the position of the lower segment for each flight phase interval. At board contact, the board was assumed to be at rest and conservation of momentum between the feet segment and the effective board mass[6] was applied to initiate motion of the springboard. A more elaborate model of the springboard would be required to simulate actual board vibration which does occur. During the board contact phase, the diver depresses the board downward. Presumably, the diver will maintain contact with the board, and the kinematics of his feet and the springboard will be the same. Next, the board returns upward during the recoil phase until the diver separates from the board. This instant of board departure was required as the final toggle back to the conditions modeling the flight phase. By monitoring the kinematics of the board, the instant when the springboard reaction force no longer affects the diver could be determined. The conditions for determining this instant of separation were when the computed acceleration of the diver's feet exceeded the upward acceleration of the board in an unloaded state or when the board returned to a reference deflection. The first criterion applies to cases where the diver lifts his feet away from the board causing separation which occurs when the diver causes his feet to accelerate upward faster than the effective mass of the springboard due to the spring force. The second criterion infers that the diver departs when the board returns to

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[6] At board contact, the effective board mass was reduced as indicated by the analysis of the participatory effective mass, Figure 2-8.

its point of static deflection. The springboard may vibrate past this position and appear to move upward with the diver; however, the the board cannot impart a force to the diver as the spring extends passed its equilibrium position. As modeled, the feet were not attached to the board, so as the spring is stretched it will retard only the motion of the effective board mass and the only external force acting on the diver will be gravity. The appropriate equations of motion for the diver, again, become the flight equations as used in the initial portion of the simulation. In simulating actual springboard motion, the springboard will vibrate free of the fulcrum support; this motion would require the effective mass of the board to be increased which would also retard the upward motion of the board. Thus, the diver separation, as observed in actual performances will occur before or near the board's equilibrium position.

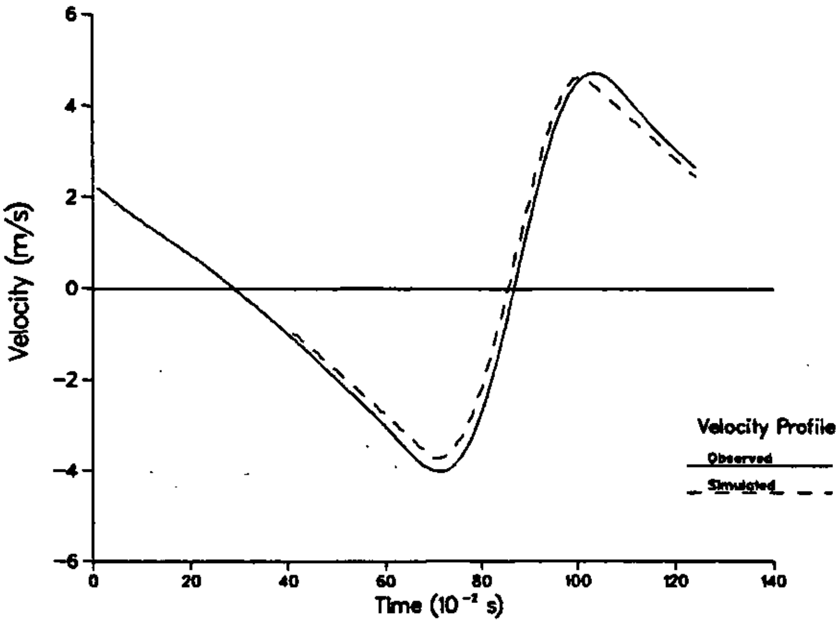
Data for the simulation was acquired at 100 frames per second. However, numeric stability of the computer algorithms was tested by interpolating the data to provide intermediate values at time intervals of 0.001 seconds. No discernible difference in the computed results between the simulations that used 0.01 and 0.001 second time intervals existed; therefore, analyses of dive performances were conducted at the recorded rate of 100 frames per second. (Appendix B: Data Acquisition).

As mentioned, computations for determining absolute segmental accelerations for the flight phase merely involved algebraic calculations among the intersegment forces. However, the board contact phase required special attention. The motion of the springboard was described by a second order, nonhomogeneous, stiff differential equation. Solving this differential equation involved selecting an initial value, numerical solver. In the simulation, the Livermore Solver for Ordinary Differential Equations with Automatic method switching for stiff and non-stiff problems (LSODA) as developed by Petzold and Hindmarsh was used [Hindmarsh, 1982]. This solver employs a multi-step Adam's method to solve the differential equation. The generated absolute segmental kinematics and the related diver center of gravity kinematics agreed closely with the observed (digitized) performance; a comparison between the computer solution to the observed velocity of the diver's center of gravity is shown in Figure 2-22. The excellent correlation supports using the modeling method as described above. In addition, this modeling approach is attractive for performing optimization to enhance skill development.

2.5. Spatio-Temporal Optimization

In springboard diving, the success as well as the aesthetics of a performance depends on the height achieved by the diver in the flight phase. Increasing the height attained during the aerial phase provides the athlete with more time to execute somersaults and/or twists at the greatest height prior to preparing for entry. Thus, a fundamental performance criterion of springboard diving is to maximize the height of the flight phase trajectory.

Once the diver departs from the board, the kinematic state of his center of gravity determines the subsequent flight phase trajectory. Therefore, maximizing the height achieved in the flight phase involves producing optimal initial conditions for this phase. These kinematic



The close correlation between the observed and the simulated vertical component of velocity of the center of gravity of the diver validates the described modeling process of distributing internal and external segment forces to each segment. The simulation begins during the hurdle phase rather than at the time where the observed data was collected.

Figure 2-22: Comparison between observed and simulated Diver Velocity

conditions of take-off are affected by the interaction between the diver and the springboard during the board contact. Thus, the focus of analysis for maximizing the height in a performance involves studying the dynamics of the diver-springboard system during board contact.

Previous research [Miller et al., 1984] on the analysis of performances of elite divers reported that the magnitude of the vertical velocity at board departure consistently exceeded the magnitude at board contact; thus supporting the hypothesis that during board contact the diver does not passively *ride* the board as an inert mass. Other analyses have shown that the musculature of the diver does affect the springboard external reaction force [Miller, 1981]. For example, as the arms accelerate upward with respect to the rest of the body, then the board will be deflected downward. Desirably, the upward relative acceleration of the arms should coincide with board depression to maximize the deflection and increase the energy stored in the springboard-diver system [Sprigings et al., 1983]. Initial optimization in springboard diving performance has focused on optimizing the vertical take-off velocity and investigating the relation between board deflection and the departure velocity [Sprigings et al., 1983; Sprigings et al., 1986]. In continuing the quest for optimizing springboard diving performance, whereby the height of the flight phase trajectory is maximized, the effects of the timing of execution of component skills on the entire maneuver were examined. The previously described models of the athlete, of the springboard, and of human motion (Section 2.2, 2.3 and 2.4) were employed. Therefore, this section reviews the spatio-temporal relations involved in performing springboard diving skills.

To advance skill technique for springboard diving, the effects of adjusting the timing of execution of component skills on the entire performance were examined. In completing this analysis, the model of human motion was customized for springboard diving, as previously described in Section 2.4.1. By simulating segment motion, the effects of changing the timing of execution of sub-skills were studied. This approach permitted varying the performances without jeopardizing the safety of the athlete. Also, the simulation incorporated demonstrated abilities: the segment movement patterns of the athlete. New, unfamiliar sub-skills would not require learning. Furthermore, such optimization did not tamper with presupposed capabilities associated with maximizing segment forces [Hatze, 1984]. Hence, from the perspective of both coaches and athletes, this method of examining the coordination of sub-skills was comprehensive and facilitated ease in suggesting and implementing corrections.

In simulating springboard diving performance (Section 2.3), the diver was modeled as five, rigid, inter-connected segments and the board was represented by a lumped spring-mass system (Figure 2-19). The differential equations describing the springboard-diver kinetics were generated from Newtonian Laws of Motion. Segment motion was caused by external forces of gravity and/or springboard reaction forces and by internal (athlete-generated) system forces. These internal system forces represented the sub-skills of an armswing, hip extension-flexion, knee extension-flexion, and ankle extension-flexion. These forces were apportioned in a mass ratio to each segment. Through simple algebraic manipulation of these equations, the system of equations can be expressed in terms of relative accelerations which represent learned movement skills. For example, the arm swing was expressed as the difference in acceleration between the centers of gravity of the arm segment and the head and torso segment; similarly, hip extension-flexion was defined as the acceleration difference between the centers of gravity of the head and torso segment and the upper legs; knee extension-flexion, as the acceleration difference between the centers of gravity of the upper and lower leg segments; and ankle extension-flexion, as the difference in acceleration between the centers of gravity lower legs and the feet segments. These relative acceleration history curves (Appendix F) were obtained through digitizing cinefilm, smoothing the data using a natural, quintic spline [Woltring, 1986], numerically differentiating the data and further algebraic manipulation of the data (Appendix B).

The height attained during the aerial maneuver was determined from the diver's kinematic state at departure. From the equations of motion, both the velocity and the configuration of the diver affect the attained height of the flight phase trajectory. Mathematically, this may be expressed as:

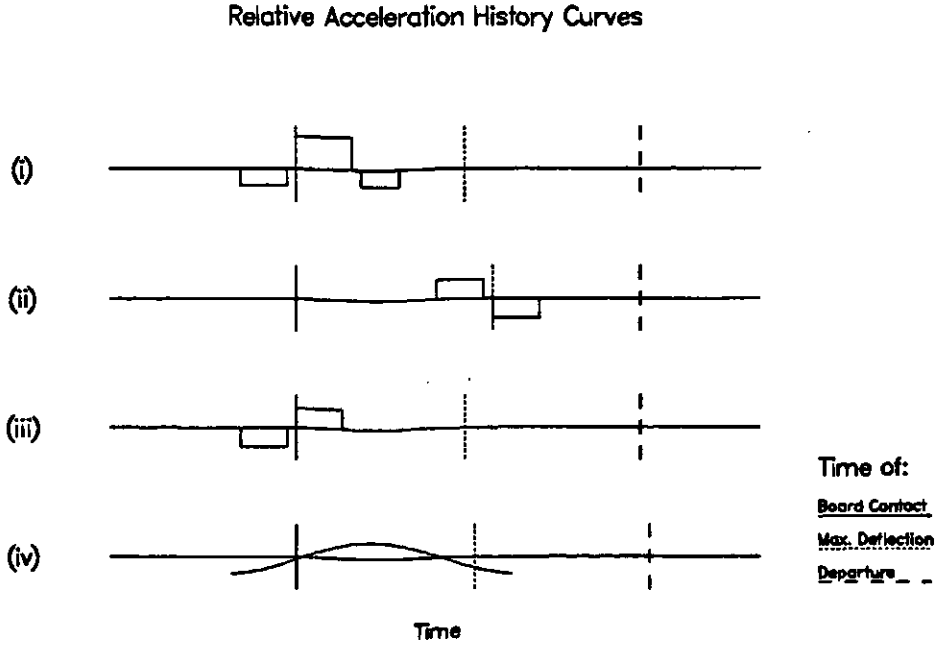
$$h = \frac{\dot{y}_{CG}^{\,2}}{2g} + y_{CG} \qquad (2.5.1)$$

where h represents the height (m); $\dot{y}_{CG}$ and y_{CG} represent the velocity (m/s) and the displacement (m) of the center of gravity of the diver at departure; and g represents the acceleration of gravity (-9.81 m/s^2). Hence departure velocity and position of the center of gravity of the diver are the pertinent factors affecting the developed height.

Maximizing this performance criterion was done by varying the coordination of the learned movement skills. Mathematically, this translated to shifting the relative acceleration history curves in time; this phase shift to these curves affected the resultant motion. Therefore, shifting corresponded to executing a movement pattern either earlier or later and altered the resultant performance.

A variety of techniques are available to determine the optimal coordination among the movement patterns of arm swing, hip extension-flexion, knee extension-flexion, and ankle extension-flexion. Two search methods that showed rapid convergence involved a generalization of the Jacobi method and a generalization of the Gauss-Seidel approach. The *best position* for executing a movement pattern was defined as the phase of the curve that results in maximizing the performance criterion of height. The generalization of the Jacobi approach involved independent time-shifting of each curve to determine its *best* position while the other segment history curves were fixed at their executed position. The second technique converged to an optimal sequence by repetitive, time-stepping of a segment history curve while the other segment history curves were set at their determined *best* positions. For both procedures, the entire coordinated sequence was shifted to determine when the system of learned movement patterns should be initiated.

To verify the optimization process, the motion of a two-segment diver for the board contact phase was considered. These optimized results were easy to interpret and to compare with results of previous work [Sprigings et al., 1983]. With this model, the segments of the diver corresponded to the arms and the rest of the body; hence, the relative acceleration curve represented an arm swing. The simulation of diver motion was initiated at the instant of board contact and the optimization process involved time-stepping the relative acceleration curve until a condition for attaining maximum height was achieved. Curves i) and ii) of Figure 2-23 correspond exactly with the reported research of Sprigings and Watson [1983]. Characteristically, the optimized positioning of the arm swing curve had the positive acceleration of the arms with respect to the body occurring during the board depression phase. This positioning improved departure kinematic values for the diver; consequently, the height attained by the diver in his flight trajectory was maximized.



Each curve is proportional to the intersegment force which is representative of the arm swing. By simulating only the board contact phase, the shown optimal position of each curve was obtained for maximizing the height achieved in the ensuing flight phase.

Figure 2-23: Optimization for a two segment diver model, during board contact

In conducting the simulation and subsequent optimization for a five segment model of the diver, two skills were reviewed; they were a forward one and one-half pike somersault and a forward layout jump. Initial analyses examined the effects of the coordination of learned movement patterns during the board contact phase. Further work extended the analyses to also include the final phase of the hurdle. The related assumptions and the results for each of these focuses follow.

The analysis simulating only the board contact phase involved initiating the simulation at the instant of board contact. For each simulation, the diver was assumed to be capable of contacting the board with the same body configuration and set of initial segmental velocities. These initial kinematic conditions were obtained from the actual skill performances being simulated. In comparison to the executed performance, a 7.2% increase in height for the forward one and one-half pike somersault could be achieved by performing: the arm swing as executed, the hip extension-flexion sequence 0.03 seconds earlier, the knee extension-flexion sequence 0.01 seconds later, and the ankle extension-flexion sequence 0.05 seconds later. Similarly, a 7% increase in the height may be obtained for the performance of a forward layout jump; the change in coordination involves a delayed execution of the arm swing by 0.03 seconds, a delayed execution of hip extension-flexion by 0.03 seconds, a delayed execution of knee extension-flexion by 0.02 seconds, and an earlier execution of ankle extension-flexion by 0.03 seconds. A summary of the affects of optimizing the individual movement skill on these skills appears in Table 2-3 and Table 2-4; all results have been normalized with respect to the observed performance.

When the analyses were extended to include the final portion of the

Table 2-3: Effects of Optimal Positioning of Movement Skills for a Forward One and one-half Pike Somersault

Movement Skill	Shift	Y_{CG}^*	$\dot{Y}_{CG}^*$	Height
Arm Swing	0.00	1.000	1.000	1.000
Hip Extension-Flexion	0.03	1.009	1.027	1.027
Knee Extension-Flexion	-0.01	1.004	1.000	1.003
Ankle Extension-Flexion	-0.05	1.027	1.036	1.045
As executed	-n/a-	1.000	1.000	1.000
Optimized coordination performance	-n/a-	1.041	1.059	1.072

* Take-off Center of Gravity kinematics of the diver.

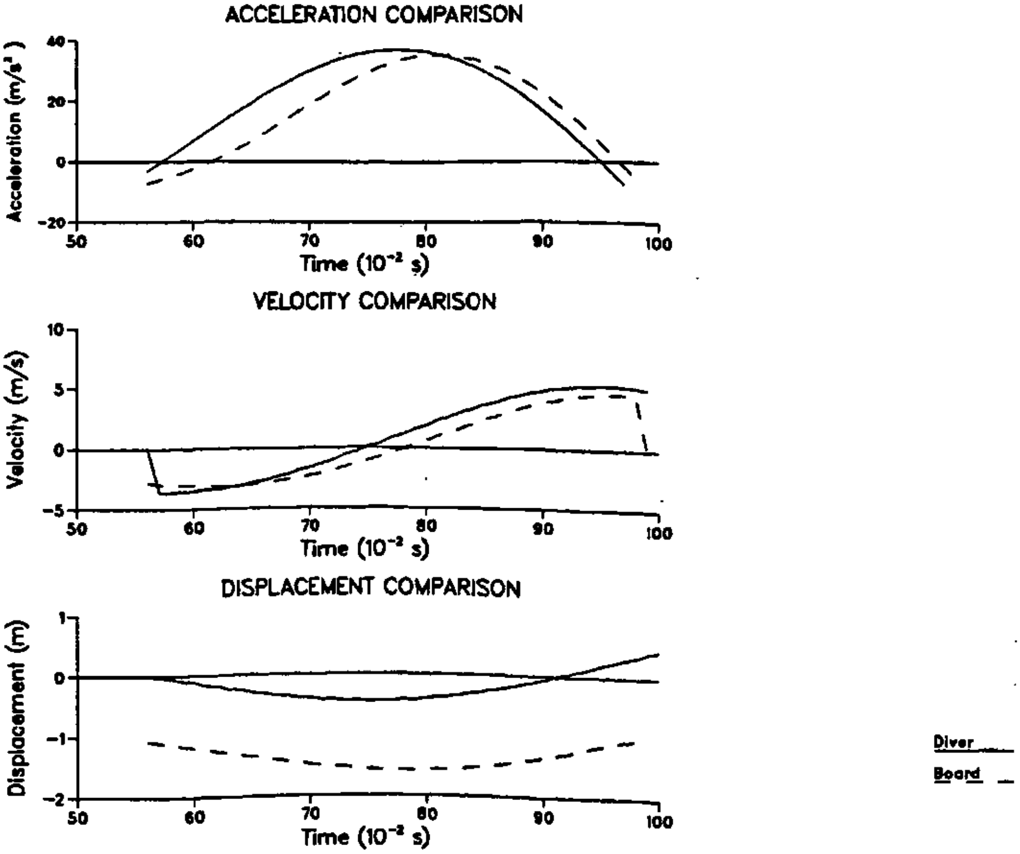
Table 2-4: Effects of Optimal Positioning of Movement Skills for a Forward Layout Jump

Movement Skill	Shift	Y_{CG}^*	$\dot{Y}_{CG}^*$	Height
Arm Swing	0.03	1.117	1.000	1.022
Hip Extension-Flexion	0.03	1.123	1.009	1.038
Knee Extension-Flexion	0.02	1.116	0.998	1.019
Ankle Extension-Flexion	-0.03	1.034	1.001	1.009
As executed	-	1.000	1.000	1.000
Optimized coordination performance	-	1.115	1.029	1.070

* Take-off Center of Gravity kinematics of the diver.

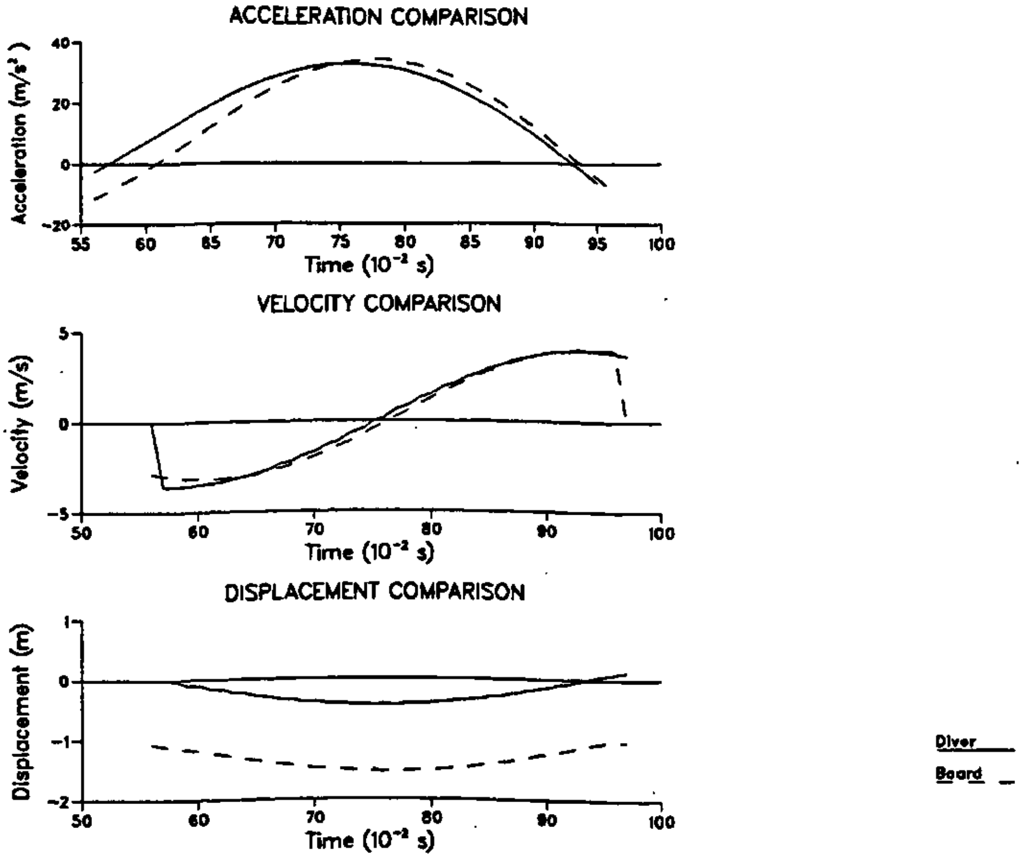
hurdle phase, the temporal optimization showed a significant increase in the height that could be attained. The effects of coordinating learned movement patterns associated with not only the board work but also the final airborne stage of the hurdle phase were examined. In simulating the performance, phase changes in the movement patterns resulted in altering the configuration of the diver and the segmental kinematic conditions at board contact. The diver was assumed to be in a static configuration during the onset of the simulation; thus initial conditions for each segment could be predicted for phase increments of the movement patterns by applying the equations of motion modeling free fall. The results of temporal optimization for the forward one and one-half dive produced an 8.6% increase in the height compared to the actual performance. These adjustments to the movement skills involved an earlier initiation of the arm swing (0.02 s), a delay in the hip extension-flexion (0.02 s), an earlier initiation of the knee extension-flexion sequence (0.02 s), and an earlier execution of the ankle extension-flexion (0.03 s). With the performance of the forward layout jump the improvement in the achieved height was 19%. The deemed optimal performance involved an earlier execution of all movement sequences as follows: arm swing by 0.11 seconds, hip extension-flexion by 0.06 seconds, knee extension-flexion by 0.06 seconds, and ankle extension-flexion by 0.08 seconds.

The differences between the results that were obtained from the analyses of the board contact phase and those, from the analyses of the hurdle and board contact phases were significant; especially, for the performance of the forward layout jump. This difference, in the maximum height that can be achieved, may be attributed to variations in the segmental kinematics at board contact. The optimization that simulates the hurdle and board contact phases, allowed the diver to contact the board at different instances in time. This permitted phase changes in the temporal patterns to affect the board contact velocity and configurations of the diver. Research has shown that elite divers who contact the board with a greater vertical velocity will attain greater height during the flight phase [Miller et al., 1988; Sanders and Wilson, 1988]. For the forward layout jump, the initial momentum at board contact (the feet and the board segments) for the board phase optimization was 27.3% lower than this momentum for the hurdle through board contact simulation. Therefore, an increase in the velocity of the diver at board contact results in increasing the height that can be achieved in the flight phase.



The optimization was conducted by time shifting each movement skill until the height achieved during the flight phase was maximized. The above results are taken from board contact simulations. This illustration represents results of optimized coordination sequence of the movement skills associated with the forward layout jump.

Figure 2-24: Comparison of diver and springboard kinematics for optimal performance.



The optimization was conducted by time shifting each movement skill until the height achieved during the flight phase was maximized. The above results are taken from board contact simulations. This illustration represents results from a typical nonoptimal coordination sequence of the movement skills associated with the forward layout jump.

Figure 2-25: Comparison of diver and springboard kinematics for nonoptimal performance.

To better understand this temporal optimization procedure and its implication to the sport of diving, a biomechanical understanding of the skill being performed is necessary. An ideally executed take-off where the height of the flight phase trajectory is maximized is governed by the following factors. An increase in the magnitude of board contact velocity of the diver will increase the height of the flight phase trajectory. The contact velocity of the diver may be increased if the instant of board contact can be delayed; the diver may crouch or lift his feet prior to contact. At board contact, the diver begins extending to deflect the springboard. Also, a comparison between the kinematics of the diver's center of gravity and of the springboard for an optimal and non-optimal performance, as illustrated in Figures 2-24 and 2-25, respectively, reveals other factors associated with optimizing performance.

As reported in the studies of the performance of elite divers, the diver actively depresses the springboard rather than passively "riding" it [Miller et al., 1988]. As illustrated (Figure 2-24), during the initial phase of board depression, a positive acceleration difference between the center of gravity of the diver and the springboard exists. This acceleration difference results from the diver actively deflecting the springboard. Theroretically, the magnitude and duration of this period of positive acceleration should be maximized to increase the height that can be achieved [Sanders et al., 1988]. At the onset of board depression, the diver flexes his hips, knees, and ankles causing his center of gravity to move downwards faster than the springboard (Figure 2-24 -- velocity profile). As board depression continues, the diver extends his legs and continues his arm swing resulting in the center of gravity of the diver moving upward faster than the springboard. The result is a positive acceleration difference between the diver and the springboard with the board being depressed further. If the diver increases the amount of flexion prior to and during the initial stage of board contact, his range of extension to perform work on the board increases. However, the optimal amount of knee flexion is also limited by muscle mechanic constraints which governs the magnitude of the generated joint torque. As shown, the duration of this phase of positive acceleration exists for the entire board depression phase for optimal performance of a forward layout jump. Results from the analysis of skills, which involve rotation, showed this phase of positive relative acceleration occurs only for a portion of the springboard depression phase [Miller et al., 1988]. The later phase of board depression is characterized by a negative relative acceleration.

At maximum board deflection, the velocity of the diver is upward. This indicates that the diver is extending and moving away from the springboard. From Figures 2-24 and 2-25, optimal performance appears to be characterized by a greater positive velocity of the center of gravity of the diver for this instant.

During the recoil phase, a negative acceleration difference exists between the diver and the springboard. Miller [1988] states that to gain adequate height this difference should be minimized. A nonoptimal performance would involve the diver flexing; this results in the upward motion of the springboard exceeding the diver's. However, minimizing this difference to increase the height achieved in the flight phase, may not be evident. The optimization of height involves all of the aforementioned factors which appear to be interrelated. Therefore, an ideally executed take-off where the height of the flight phase is maximized appears to be influenced by the board contact velocity and the magnitude and duration of the relative acceleration between the diver and the springboard during board contact. Optimal performance requires that the velocity of the springboard does not exceed the velocity of the center of gravity of the diver at departure.

Therefore, an ideally executed take-off where the height of the ensuing flight phase is optimized involves maximizing the velocity at board contact and adjusting the acceleration difference between the center of gravity of the diver and the springboard. The result is the relative velocity and displacement of the center of gravity of the diver with respect to the board is maximized at departure.

To conclude, the discussed temporal optimization simulates performance to study the effects of timing of execution of learned movement patterns on the overall performance. As shown by the studied performances, the results obtainable indicate that changes to the coordination of these skills may enhance the attained height of the flight phase. As expected, the performance of the forward one and one-half somersault, as completed by a provincial caliber athlete, had near optimal coordination of the movement skills. Whereas, a knee injury had hampered the performance of the forward layout jump; therefore the coordination of the movement skill was nonoptimal and the height was improved considerably, by adjusting the timing of the movement skills.

2.6. Discussion

Through investigating the mechanics associated with springboard diving, factors affecting the performance were reviewed for advancing the sport. This chapter discussed a method for simulating performances and determining an optimal performance. Ideal performance was defined as maximizing the height achieved during the flight phase and optimization involved the altering of the timing of executing movement skills. Analyses were limited to the vertical component of motion. As presented in the proceeding sections, the springboard performances were modeled from a mechanical perspective with the kinetics of the diver-springboard system being represented by a set of differential equations. Through solving these equations various simulations of dive performances were reviewed.

A number of factors were considered in developing the simulation model that was used to analyze the vertical component of motion of the springboard-diver system. The proposed models included representing the athlete as a system of linked, rigid bodies; approximating the springboard by a single, degree of freedom, lumped spring-mass system; and accounting for athletic ability and resultant motion using a system of internal and external system forces. By applying Newtonian Laws of Motion, diver and springboard motion were expressed mathematically.

The simulation of springboard performances incorporated demonstrated ability that was defined by the athlete's movement patterns of each segment. Specifically, arm motion, hip extension-flexion, knee extension-flexion, and ankle extension-flexion were defined in terms of acceleration differences between adjacent segments. Movement patterns were employed to generate the resultant segmental motion. The computed motion essentially reproduced the observed performances of a forward, layout jump and a forward, one and one-half pike somersault dive. This technique was applied to investigate the effects of timing of execution of movement skills on the overall performance. The adjusting of the timing translated to time-stepping these sub-skills and generating the corresponding resultant motion of the diver.

The derived optimal performance was defined as achieving maximum vertical height during the flight phase. Generally, optimal performance as compared to an nonoptimal performance involved the diver contacting the board with a higher velocity. Higher contact velocities could be achieved by delaying the instant of board contact. During the initial stages of board depression a positive acceleration difference between the center of gravity of the diver and the springboard existed; this corresponds to the diver extending to deflect the springboard. During recoil, the diver maintains board contact; this translates to a negative acceleration difference between the diver and the board.

To conclude, the approach for simulating performance may serve as a valuable coaching aid. First, the modeling parameters related well to skill performance terms; for instance, the relative acceleration of the arms with respect to the head and torso segment was used to define the intersegment force representing the arm swing. Other movement skills were defined in a similar manner. Secondly, the model is performance orientated; demonstrated ability that is specific to the dive being analyzed is incorporated when modeling a performance. As well, the approach is tailored to each individual; idiosyncrasies of an individual's performances are reflected in the input, performance data. Thirdly, the approach provides a means of accurately simulating performances. Furthermore, relations for advancing the skill development may be identified, as illustrated with the evaluation of the effects of timing of execution of various movement skills on the achievement of height in the flight phase. The approach is tractable, since other factors affecting the resultant motion can be reviewed. For example, the affects of positioning the fulcrum can be analyzed by modifying the springboard parameters as described (in Section 2.3); different acceleration curves may be used to study the effects of varying movement patterns; for instance, effects of the speed of executing a sub-skill or the amount of joint extension or flexion may be reviewed. Hence a flexible modeling system has been developed.

A few avenues for continued development of the proposed analysis process would include extending the modeling of motion to two or three dimensions. Complete modeling of a performance would include the simulation of the approach sequence through to the hurdle phase to the board contact and the subsequent flight phase. To model this complex interaction, a more elaborate model of the springboard would be necessary; an improved understanding of the board dynamics would be required to represent diver-springboard vibration during the approach. Adding real-time data acquisition, incoporating related data smoothing routines and supplementing the code to provide an interactive interface would create a more comprehensive and independent system. In creating an interactive system to be used by coaches or athletes, a graphic interface would be desirable for providing visual cues.

Chapter Three

KNOWLEDGE BASED EXPERT SYSTEMS APPLICATION TO SPRINGBOARD DIVING PERFORMANCE ANALYSIS

3.1. Introduction

Coaches assist in an athlete's development. One crucial facet of coaching is skill assessment: the analysis of performance and the offering of related corrections. As an athlete improves, more experienced and knowledgeable coaches are sought for providing skill assessment. Unfortunately, these elite coaches are few in number; hence, a need to increase the accessibility to expert skill analysis exists.

Qualified or elite coaches possess a seemingly innate ability to analyze skills. Almost intuitively, they can identify the faults, related causes, and can suggest effective methods to correct the performance. Based on experiences, they have assimilated the characteristics of optimal performances for directing skill development. Their understanding of the skills has evolved from years of experience and an understanding of elementary mechanics that relate to their sport. Their judgement and subsequent corrections for a given performance are based on a set of personal heuristics of causal relations. Since athletic skills are learned through kinesthetic sensation, often descriptive language, rather than numerical results derived from algorithms of applied mechanics, is used when coaching [Dyson, 1977]. Apparently, skill assessment is cognitive and qualitative in nature.

In order to enhance springboard diving performances, the demand for quality skill assessment must be satisfied. To develop coaches who will be proficient at skill analysis, requires an efficient transfer of knowledge from elite coaches who are adept at this facet of coaching. The process should be accessible to the majority of the developing coaches, thus creating the potential to increase the number of quality coaches. In developing the skill assessment of novice coaches, the related knowledge and analytical background to be acquired needs to be easily accessed, logical, and accurate.

One method of learning assessment skills is through apprenticeship programs. Apprenticing provides the opportunity for the developing coaches to learn the techniques of the master coach. The interaction between the apprenticing and the master coach is valuable in understanding each skill and the essential factors affecting the execution of a skill. The success of an apprenticeship program is contingent on a number of factors; for example, effective transfer of knowledge will depend on the teaching ability of the master and the learning receptivity of the apprentice. Unfortunately, conventional apprenticeship programs are limited in the number of individuals trained and are quite time consuming.

Alternatively, the Coaching Association of Canada has developed a five level National Coaching Certification Program to assist in developing coaches and increasing their effectiveness. Each level contains a theoretical, technical, and practical component. The theoretical component provides exposure to topics such as: leadership, motivation, training, coaching philosophies, and teaching methods. The technical courses offer training related to skills, drills, progressions, and regulations relating to the sport. Whereas the practical aspect involves gaining experience through requiring a certain number of coaching hours and/or the development of a certain caliber of athlete. The program provides the opportunity for an individual to be exposed to all aspects of coaching [Music, 1984]. Since this coaching program was designed for a variety of sports, the criteria for the practical component and the content of the technical courses are developed by each sport governing association. Many of these associations have yet to complete the development of these components for each level. Furthermore, due to the great number and varied location of theoretical and technical courses offered by national and/or provincial government and national and/or provincial sport associations, respectively, a consistent, quality level of instruction cannot be guaranteed. The sport of springboard diving currently has only four fully certified level five coaches in Canada. The highest certification of diving coaches practicing in Saskatchewan is only level two. As well, this program attempts to cover the complete spectrum of coaching and does not facilitate training for one to become adept at skill assessment. Thus, the need to effectively develop the skill assessment ability of coaches remains.

Another possibility to effect development of skill analysis techniques may be through applying knowledge based expert systems technology. Knowledge based expert systems enable less skilled coaches the opportunity to access skill assessment expertise economically. By operating the program, novice coaches can provide a near-expert level of skill assessment. Furthermore knowledge based expert systems provide a comprehensive, systematic, permanent, reliable, and affordable source of expertise [Waterman, 1986].

Firstly, in developing a knowledge based expert system the knowledge can be collected from a number of sources and/or experts. This access to more than one elite coach is not always feasible when human experts are considered. As well, the development of the knowledge base can be verified through applying mechanical principles. Often, access to this information is limited since few expert coaches possess a solid biomechanical background.

Secondly, creating the knowledge base also creates a permanent collection of coaching strategies. This information can be retained indefinitely and easily duplicated through copying the software package. Human expertise is mortal and the level of expertise may deteriorate or be lost through mental fatigue, physical exhaustion, lack of use, ineffective transfer of knowledge to a successor, or death.

Thirdly, a knowledge based expert system produces consistent results for identical situations. This is unlike human experts who may sometimes focus on only a particular aspect of the skill or may overlook other contributing factors. Knowledge based expert systems provide a systematic skill analysis process.

Lastly, access to expertise by using knowledge based expert systems is relatively inexpensive in comparison to human expertise whose services may be quite costly. The operational costs of a knowledge based expert system consist of the nominal computer cost of running the program. This low operating cost offsets the high development cost.

Despite these seemingly superior traits the role of a knowledge based expert system should be to augment the user's skills; that is to serve as a decision support system [Elmaghraby and Jagannathan, 1985]. Most of the current applications of knowledge based expert systems cannot replace or out perform human experts. The problem solving capabilities of humans remains superior in focusing on a number of areas, in processing a variety of sensory experiences, in dealing with conflicting factors, in reprocessing information, in synthesizing knowledge, in creating new relations, in adapting to unique conditions and in learning new concepts [Waterman, 1986]. However, knowledge based expert systems can serve as valuable assistants [Dietz, 1986].

Coaching, primarily the heuristic nature of skill assessment, appears to be an appropriate application of knowledge based expert system technology. This chapter examines the development and merits of applying knowledge based expert systems to skill analysis, particularly, to the sport of springboard diving. In an attempt to capture the expertise of elite coaches, their knowledge and assessment processes have been formulated into a comprehensive and systematic analysis process. The resulting knowledge based expert system offers the potential to increase the availability of quality skill analyses of forward, non-twisting springboard dives.

3.2. Background on Knowledge Based Expert Systems

Knowledge based expert systems are computer programs or systems that represent human expertise in a given domain. The knowledge based expert system can manipulate knowledge to solve problems with the same level of sophistication as a human expert [Waterman, 1986]; that is, they emulate human reasoning.

Successful implementations of knowledge based expert system technology vary in the selected knowledge domain and in the type of problem solving. Applications have been reported in the following areas: agriculture, chemistry, computer science, education, electronics, engineering, geology, information management, law, manufacturing, mathematics, medicine, meteorlogy, military services, physics, process control and space technology. The function of some of these applications to non-numerical problems along with a developed system and its principal researcher(s) follow[7]:

diagnosis	MYCIN: Shortcliffe[A,B,C,D,E]
prediction	PROSPECTOR: Hart and Duda[A,B,C,D,E]
identification	DENDRAL: Lindsay and others[A,D,E]
speech understanding	HEARSAY: Erman and others[A,B,E]
design	XCON, RA, XSEL: McDermott[A,B,D,E]
repairing	DELTA/CATRS-A: Bonissone and Johnson[B,E] TQMSTUNE: Wong and Lanning[B,E]
problem identification	DRILLING ADVISOR: Hollander & Iwasahi[B,E] CRIB: Hartley[C,E]
monitoring	REACTOR: Nelson[E]
planning	CARGuide: Sugie and others[E]
debugging	ACE: Vesonder and others[E]
instruction	ANSYST: Watson[F] NEOMYCIN: Clancey[C,D,E] CADHELP: Cullingford and others[E]

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[7] Consult references, as indicated by the superscript, for a full exposition on the indicated application. These references may cite other reports for providing further detail. As follows the references are [A] Alty and Coombs, 1984; [B] Harmon and King, 1985; [C] Johnston and Keravnou, 1985; [D] Slatter, 1987; [E] Waterman, 1986; [F] Watson, 1988.

	SOPHIE: Brown and Burton^{E}
control	ECESIS: Dickey and Toussuint^{E} VM: Fagman and others ^{A,E}.

Despite an apparent lack of applications to the domain of coaching, the skill assessment tasks of coaching are characterized by some of the aforementioned functions that knowledge based expert systems have been developed to perform. For example, the traits of skill analysis fit the problem solving categories of interpretation, diagnosis and instruction, since a coach compares athletic performance to desired performances, identifies performance faults by observation, infers the attributing causes, and provides advice to remedy the fault. Therefore, an application of a knowledge based expert system to skill assessment appears viable.

Conceivably, a knowledge based expert system applied to performance analysis may aid in increasing access to elite coaching strategies and in improving the skill analysis ability of novice coaches. Since knowledge based expert systems manipulate knowledge, they may be able to replicate the consultant tasks of elite coaches for assessing and for offering suggestions to enhance athletic performances. Novice coaches access this information through interactively supplying the information necessary to direct the search for additional information and for drawing inferences. Upon receiving or interpreting information, the knowledge based expert system may compile appropriate recommendations [Johnston et al., 1985]. Hence, novice coaches can readily tap the expertise of elite coaches embodied within the knowledge based expert system. Secondly, through repetitive use of the system, the coaching ability of a novice may be advanced. For example, a systematic process for acquiring information is presented by the system; this may assist in proceduralizing the novice's ability to logically acquire task-related knowledge. In addition, the decision making process of the developing coach may be refined to incorporate the heuristics and expertise of the system. Also, the correlation between the drawn inferences and recommended correction can be learned. Thus, knowledge based expert systems are a viable solution not only for increasing the availability of quality performance analysis, but also for serving as a teaching tool to reduce the expensive, lengthy, and laborious process of acquiring expertise.

Since most applications of knowledge based expert systems have been developed independently in each domain, unique techniques and software tools have been devised. Nonetheless, the basic concepts of such systems are similar; each knowledge based expert system application embodies a knowledge base (data and facts), an inference engine (reasoning and search techniques), and a user-interface [Wolfgram, 1987].

The knowledge base contains the information or data specific to the problem. Knowledge representation can be implemented in a variety of ways; some of the predominant schemes include predicate calculus, frames, associative networks, and production schemes [Johnston et al., 1985; Harmon et al., 1985]. The inference engine is the decision making mechanism that interprets the knowledge base. Again, a variety of inference methods may be used with the actual implementation mechanism dependent on the representation scheme. Searches may be directed in parallel with provided data or in a serial process through backward and/or forward chaining. The user interface enables collection of data. The two basic modes of interaction are 'user-initiated': the system responds to the user's requests; and 'system-initiated': the user responds to the system's requests. Usually, the interface for human interaction with a knowledge based expert system employs a keyboard and terminal; however, other methods of data acquisition may be used to interact with the system.

Many commercially available tool kits have evolved from applications and are designed to simplify the task of constructing a knowledge based expert system [Tello, 1987]. These shells are high level programming languages that generally provide knowledge processing and debugging utilities along with an inference engine. Shells permit application programming since they contain only the skeletal structure of the knowledge based expert system and therefore are able to cope with a range of domain knowledge [Park, 1984]. Hence when creating a knowledge based expert system with a shell, efforts can be concentrated on translating human expertise into an appropriately coded knowledge base. However, tool kits may be restrictive; for example: KS300 tool kit assists with building only rule based systems using a backward chaining, monotonic, single line of reasoning architecture [Hayes-Roth, 1986]. Another advantage that supports the use of shells is cost reduction. Firstly, the shells are often designed for use on existing low cost hardware, such as, microcomputers. Secondly, development costs are reduced since Artificial Intelligence programing expertise is not required in constructing each specific application [Dietz, 1986]. Since tool kits can be developed in any language [Butler, Hodil, and Richardson, 1986], the transportability of the software and developed application can be extended through using a shell developed in a portable high level language. Also the use of conventional languages eases the burden of integrating the knowledge based expert system with other developed computer applications. Furthermore, because the knowledge base and inference engine are segregated, tool kits permit incremental development and testing. This feature enables the expertise of a number of individuals to be aggregated. To conclude, the "power of tools [are derived] from the paradigm, architecture, representation, inference engine, utilities and programming systems they embody"[8].

This project employed a version of the Expert-2 Toolkit. The tool kit is extremely powerful and flexible. The original tool kit, developed by Jack Park, uses the MVP dialect of the high level language Forth. The knowledge representation scheme incorporated by the Expert-2 Toolkit uses production rule methodology with the inference engine being goal or hypothesis driven (consequent reasoning). The programming structures of this shell are production rules (which express the knowledge and direct the decision making process) and analytical subroutines (which manipulate the information) [Park, 1984].

The Expert-2 Toolkit was selected based on availability, affordablity, transportability, flexibility and familiarity. The low cost software package was developed in Forth and hence can be easily programmed on a number of hardware systems. The University of Saskatchewan, Mechanical Engineering Department, has a number of versions operating on a variety of machines; such as: Commodore C-64, Macintosh, Apple II, Atari ST, IBM-PC and related compatibles. The required hardware is minimal; requirements include

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[8] Hayes-Roth, Frederick "The Knowledge Based Expert System: A Tutorial" in *Computer* 1986, p. 21.

a disk drive to access the software package, a computer with sufficient memory to load the software and to operate the program, and a terminal-keyboard for a user interface [Westman, 1987]. Access to the underlying development language provides ease for making modifications. This access and the provided source code permits features to be created and actual tailoring of the tool kit for specific applications. [Sargent, et al., 1986]. In addition, the elegance of the inference engine makes creating a rule base relatively simple. The syntax associated with coding expert knowledge for the knowledge base can be expressed in a near English format. As explained in *MVP-Forth Expert System Toolkit* [Park, 1984], the syntax involves operators and information strings. Some of the operators of the Expert-2 Toolkit include context operators (if, and, or, not, then); subroutine caller operators (ifrun, andrun, andthenrun), hypothesis operators (thenhyp) and explanatory operators (becauserun). Furthermore, the features of and extensions to the shell have been explored through the design of a number of prototype applications at the University of Saskatchewan; such as: Stainless Steel Selection, Coaching of Long Jump, Hydraulic circuit design and others.

To conclude, the application of knowledge based expert system for the skill assessment tasks of coaching appears viable. The modified Expert-2 Toolkit was employed to create a prototype for analyzing forward, non-twisting springboard performances.

3.3. Development of the Knowledge Based Expert System

Construction of an effective knowledge based expert systems requires the knowledge and reasoning strategies related to a specialized domain to be captured. Through collaborating with a human expert(s), an understanding of how the expert organizes, incorporates, interprets, acts on and presents his knowledge may be elicited. When employing the tool kit, Expert-2, this acquired, domain-specific knowledge and decision making processes are formulated into procedural rules [Park, 1984]. The development of a knowledge based expert systems that performs as competently as its human counterpart is an iterative, time-consuming process [Waterman, 1986].

Typically, the development and resulting knowledge based expert system tend to be application dependent. Factors, such as: the intended role, secondary functions, characteristics of the domain knowledge, and the selected user group mold the development of the system. Nonetheless, the underlying purpose remains that the resultant product achieves a near-expert level of performance for the specified domain.

Designing a knowledge based expert systems for coaching springboard diving was initiated primarily for improving the availability of quality skill analysis. As previously stated, the skill assessment function of coaching involves identifying performance errors, then, subsequently inferring attributing causes and providing corrective advice. Since knowledge based expert systems are potentially capable of increasing accessibility to expertise [Park, 1984], the main intent was to provide an effective performance analysis system that is accessible to a broad base of coaching personnel. Furthermore, the system should facilitate training to assist in improving the ability of novice coaches to analyze performances. To educate novice coaches, the salient factors in analyzing the skill for deducing the probable causes of a performance error or weakness along with the reasoning sequence employed in reaching such a conclusion should be user-accessible. To encapsulate, the purpose of the knowledge based expert system is to assist in the development of quality performance analysis for springboard diving and thereby improve the availability of quality coaching.

The characteristics of skill assessment must be reviewed in order to fashion the knowledge representation and associated search techniques for the system. Published literature reveals many approaches to accumulate knowledge [Slatter, 1987]. For this project, prior to gathering the expertise of elite coaches, a working background knowledge was gained through assisting with the coaching of athletes at both recreational and competitive levels, from reviewing resources ranging from introductory materials [Smith, 1973; Batterman, 1969; O'Brien, 1968 McGavern, 1976; McGavern, 1977] to advanced research literature on applied biomechanical analysis of performances of elite athletes [Miller et al., 1988; Yeadon, 1987], and by initiating modeling of springboard diving performances (Chapter 2). Further skill assessment expertise was elicited from three national coaches [Lambie, 1988; Music, 1988, Boulanger, 1988] using standard knowledge acquisition techniques of interviewing, observing coaching sessions and skill protocol analyses of performances of athletes from their clubs. Assimulating the expertise of more than one elite coach enabled commonalties among skill assessment to be generalized and the idiosyncrasies associated with a coaching style to be accommodated. The three elite coaches who participated in this project were Jim Lambie of Winnipeg, Dany Boulanger of Quebec, and Glen Music of Calgary.

Through discussions and correspondence prior to knowledge elicitation, a good working rapport was established. As well, to dull the competitive edge whereby coaches tend to withhold information, the focus was limited to assessing forward, non-twisting dives. An informal interview revealed the individual coaching philosophies. For example, one coaching philosophy focused on factors affecting athlete safety foremost with secondary emphasis on the features of the board contact phase [Music, 1988]; whereas, another philosophy directed corrections to skills requiring the longest time to master, such as: maintaining firm musculature throughout the entire maneuver [Boulanger, 1988]. As well, the interview enabled a basic framework for structuring the domain knowledge to be formulated [Slatter, 1987]. Next, observing practice sessions, although time demanding, provided a natural working environment for accessing expertise; for acquiring insight into the domain of skill assessment and for gaining ideas for the required interface [Waterman, 1986]. As was evident, vision appeared to be the primary sensory input in skill analysis; analysis was based on detecting deviations of a performance to the elite coach's perceived standard of ideal performance. Their perception seemed so advanced that deviations were detected nearly instantaneously. To assist in detecting these deviations in performances, the knowledge based expert systems will likely need to be used in conjunction with a video play-back unit to permit reviewing of performances. As well, the interface must quickly cue the user on areas to look for such deviations. Furthermore, graphics should be employed to provide a reference of what is ideal performance. Thirdly, the laborious task of analyzing athletic performances with the elite coaches verbalizing his assessment provided transcripts for extracting the knowledge base and the related decision making strategies. Through this process, the information necessary for designing a knowledge based expert system for skill analysis of forward, non-twisting dives was acquired.

The phase following this priming of knowledge involved processing and interpreting it. Realizing human expertise is fallible, this phase of distilling the verbal data into a functional knowledge base required sifting, selecting, re-representing, gap-filling of the taken-for-granted principles, and eliminating any ambiguities of the transcripts. The elicited knowledge and general skill assessment processes were conceptualized in a number of ways to develop an approach to effect springboard diving skill analysis.

A modular structuring of the knowledge base appeared to be most desirable. This approach seemed to meet design criteria of efficiency, modifiability, simplicity, understandability, and accuracy [Slatter, 1987]. With a modular approach, fundamental features can be grouped together. An advantage of using a modular concept was that it provides for complete analysis of complex skills to be simplified through examining more manageable components. This enables creating a more robust system. Also, the flexibility of adding, amending or deleting rules to develop accuracy is easily facilitated, since fewer rules are associated with each component. Furthermore, adjusting the knowledge of a module has a minimal effect on the remainder of the knowledge of the system, thus permitting refinement of the knowledge base. Extensions are permitted since different skills may involve incorporating a different subset and/or combination of existing modules. Efficiency will be enhanced since the search sequence of the knowledge based expert system will be reduced because only the required rules belonging to a given module are invoked. In addition, memory can be conserved since only the rules associated with the appropriate module need to be accessed. Therefore, employing a modular approach reduces the cumbersomeness of the rule base and can decrease operation time.

In arranging the rules associated with analyzing springboard diving performances, the skills were examined from a performance perspective. The distinctions among the six groups of dives (namely: forward, backward, reverse, inward, twisting, and armstand) and the similarities of execution phases (such as: approach, hurdle, take-off, aerial positions of tuck, pike, layout or free, aerial maneuvers, and entry) among the groups motivates the structuring of modules based on performance. For example, the performance of forward and reverse dives are similar during the approach through to the hurdle phase; hence the analysis for the approach through to the hurdle phase may incorporate the same skill assessment modules. Next, the causal relations among the faults of the various performance phases need to be classified. In developing a comprehensive skill assessment scheme for all dives, this approach seems viable; however, the measure of springboard performances suggests another structuring scheme for representing skill assessment techniques.

In competitive springboard diving, individuals perform according to set regulations before a panel of judges who rate each performance, hence the criteria of performance may be best encapsulated as achieving the best score as awarded by the judges. The perceived factors that influence the scoring of a dive provided an alternate motivation for structuring the knowledge base. This enabled rules to be based on observable errors that judges focus on when rating a dive. Essentially, a dive is evaluated on grace and poise during the performance, the completion of somersaults and/or twists, the height attained by the diver, the entry alignment being vertical, and the point of entry relative to the board. Since judging dives focuses on analysis by observation, gross performance errors served as a framework for structuring the knowledge base. Such errors are easily observed, yet the causes of these errors are more obscure. The skill assessment technique of elite coaches provided insight into identifying the causes of these performance errors. Hence the framework of the knowledge based expert system applied to performance analysis of forward, non-twisting dives involved developing independent modules for each major, easily identified, performance error. As agreed by the interviewed coaches, the easily observed, major performance faults include: the entry alignment being either short of long of vertical, the point of entry being either too close to or too far away from the board, a twist occurring at entry and the performance being poor aesthetically. However, to facilitate ease in expanding the analysis to other skills the underlying organization of the rules within a module remained based on the previously described, performance phases. By structuring the decision network within each module on the basis of performance phases enabled the reasoning process of the system to follow the sequential execution of the dive. The evaluation of the approach phase, hurdle, take-off position, aerial maneuver and the entry position was paralleled for all of the modules.

This systematic analysis approach promotes the mastering of a dive, since the hierarchy of the rules focused on perfecting the fundamentals of a skill in the order of execution. That is, the analysis traces the cause of an error to the first executed and detectable deviation from optimal performance, rather than examining a later phase of the performance that may have been influenced by an earlier executed error. This analysis is objective rather than reflecting an individual coaching philosophy that may focus the analysis on determining either the error(s) associated with sub-skills that take a long time to master, the error(s) easiest to correct, the error(s) that once corrected yield the greatest improvement, or the error(s) that affect the athlete's safety.

The procedural rules that capture the domain knowledge and the structure for skill analysis are presented in Appendix H. These rules may also serve as a resource of skill analysis protocol and of related coaching techniques.

In constructing the knowledge based expert system, the selected user group and their needs directed the tailoring of the interface. "[It is] widely acknowledged that the acceptance of an expert system can critically depend on the system being designed in accordance with the expectations, knowledge, and preferences of the intended user"[9]. Thus, the features of the user interface are critical.

To enhance user acceptance of the knowledge based expert system and to achieve a near-expert level of performance, the Expert-2 Toolkit has been

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[9] Slatter, Philip E. (1987) *Building Expert Systems: Cognitive Emulation*, Ellis Harwood Limited: Chichester, Gr. Br. p.14

tailored to incorporate many supplemental features. These attributes were incorporated to increase the friendliness of the system by improving the program's comprehensiveness, its intelligibility, its efficiency, and its usefulness.

Like many software packages, efforts were directed at developing a complete, independent package. For example, introductory information explaining the intent of the program and providing concise operation instructions have been included. This information is presented while the program is being loaded and does not infringe on program run time. The intent of this information was to enhance the ease of interaction, thus creating a self-contained system.

The usefulness of the system is reflected in its provided output. The program not only identifies the contributing cause of a springboard performance error, but also provides an explanation based on the fundamental laws of science and offers practical suggestions for correcting the fault. Such output reflects the completeness of the system.

To increase comprehensibility, the knowledge base incorporated springboard diving terminology, both in the questions posed and the supplemental advice given. Secondly, ambiguities associated with the qualitative descriptions were reduced by stating concepts in alternate ways. Thirdly, to accommodate for the anticipated heterogeneity in user background knowledge, a supplementary feature, called "definitions" was created. During program operation, this feature can be invoked to allow the user to enter terms that he requests be clarified. The knowledge based expert system's text indicates the defined terms in upper case. Furthermore, this feature provides a description of the desired mechanics of the fundamental sub-skills. Also, rudimentary graphics have been added to increase clarity in some of the definitions. Incorporating the vernacular of the user and the option to have terms explicitly defined improves the intelligibility of the system.

The unique structuring of the knowledge base streamlined program operation and provided user control of the search sequence. Each module contains rules related to an easily identifiable performance error. During program operation, the user is prompted to indicate the major performance error; then, the associated rules are loaded to direct the analysis. This approach narrows the focus of analysis, and consequently, reduces the asking of irrelevant questions. Such organization emulates forward chaining and reduces the cumbersomeness of the rule base. Furthermore, the hierarchy within each module posed questions in a logical order that followed the execution of the dive. Hence, the structuring of the knowledge base and the loading of only pertinent rules increases program efficiency.

Contrary to the mode of operation of most expert systems that reach only one conclusion, this system provides the user with the option to continue analysis. A contributing cause of more than one major error of a given performance may be determined. Through loading subsequently selected modules contiguously, the responses to previously posed questions are retained. This capability was made possible by the MORERULES modification [Westman, 1987]. This feature and its implementation enables conducting a more complete analysis of a given performance in an efficient manner.

Other features of the modified Expert-2 Toolkit [Sargent et al., 1986] that enhance program performance include *trace*, *why*, *change previous response* and *quit* options. The *trace* function discloses the complete reasoning sequence leading to the present conclusion or question. The *why* feature permits the user to interrogate the current reasoning strategy. The *change previous response* option facilitates the modifying of entered user responses and then allows program operation to resume. This is valuable if the user answers incorrectly or desires to pursue another line of evaluation. The *quit* capabilities permits the user to abort from the working session [Westman, 1987].

To conclude, the skill assessment knowledge has been formulated as procedural rules. These rules have been structured into modules associated with easily detectable performance errors. Each module focuses on identifying the contributing cause of the observed error in a consistent manner that is based on the fundamentals associated with each phase of skill execution. Also, during the development considerations were given to the needs of the intended user group and supplemental features were developed and/or incorporated to improve user acceptance.

3.4. Validation of the Knowledge Based Expert System

Although the literature acknowledges that no consensus exists on the methods of evaluating a knowledge based expert system [Hayes-Roth, Waterman, and Lenant, 1983], the criteria for evaluation should be based on the intent of the application [Harmon et al., 1985]. As outlined in the previous section, the primary purpose of the system was to increase the availability of expert skill analysis and assist in developing this analytic ability in coaches. In fulfilling this objective, the system must replicate expert analysis; therefore, one evaluation criterion is the systems's ability to accurately analyze forward, non-twisting springboard performances. In order that the system be a viable alternative to human expertise, usage of the system is imperative; hence a second set of criteria focuses on user acceptance. The ease of operations, comprehensiveness, responsiveness and usefulness of the system are important measures of the performance and acceptability of the system. Thus, in the validation process, two modes of evaluation were necessary for examining accuracy and user acceptance.

3.4.1. EVALUATION OF PERFORMANCE ACCURACY

Validating that the knowledge based expert system can emulate the problem solving expertise and provide meaningful coaching advice involved comparing the analyses provided by the system to that of its human counterpart. An elite Saskatchewan Diving coach, Mr. Brent Grisdale, participated in this phase of evaluation. This coach provided an impartial measure of the performance of the system since he was not directly involved in developing the knowledge base. The process involved reviewing eight forward, non-twisting dive performances that were recorded on video-tape. The performances analyzed were recorded at regular practice sessions, thus providing unbiased, test cases. Each scenario exemplified at least one easily observed error. Mr. Grisdale provided a detailed analysis of the performance and identified the contributing cause of observed performance errors. Next, with the aid of the Springboard Diving Skill Assessment Knowledge Based Expert System, these same performances were reassessed.

To further validate the system, Mr. Grisdale explored the performance of the program by analyzing a variety of self-posed, hypothetical situations. Lastly, a review of the knowledge base provided a more comprehensive evaluation of the accuracy of the system.

In comparing the responses of the springboard analysis system and those of Mr. Grisdale, the primary difference lies in the inherent attribute of the knowledge based expert system. The knowledge based expert system identifies only one contributing cause of a performance error and provides the associated coaching advice.[10] In contrast, the human expert provided a more thorough analysis. However, this attribute does not mar the accuracy of the system; Mr. Grisdale viewed the output from the system as appropriate and technically correct for each trial. Furthermore, a more thorough analysis of a performance can be achieved by employing the *change previous response* feature.

In reviewing the performance of the system on various cases not only the inferences drawn by the system, but also the path of reasoning could be evaluated. From these analyses and a review of the procedural rules of the knowledge base, Mr. Grisdale made some recommendations to improve the system. In regards to content, he suggested that the rules reflect the desired mechanics associated with each of the three optional configurations of the pike position, rather than a generic description of pike position. To improve clarity, some of the descriptions required expanding, particularly, the

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[10] Recommended coaching practices suggest analysis focus on the basic contributing parts of a skill and attempt to analyze only one performance error and provide possible solutions for correcting this fault [McGavern, 1976].

explanations formulated on fundamental mechanical principles. These recommendation have since been incorporated into the program.

Although this evaluation of accuracy was not exhaustive, the close correlation between the system and human analyses along with the review of the knowledge base indicates that the Skill Analysis Springboard Diving Knowledge Based Expert System can emulate a near-expert level of skill assessment of forward, non-twisting dives. Thus, making the system acceptable for use as a valid alternative to human consultation.

3.4.2. EVALUATION OF SYSTEM ACCEPTANCE

The user acceptance of the Springboard Diving Skill Assessment Knowledge Based Expert System was evaluated by potential users whose diving background varied from recreational divers through to a certified Level Two diving coach. Three performances of forward, non-twisting dives with gross fundamental errors, that had been video-taped, served as case studies for this evaluation. The users assessed each performance with the aid of a video play-back unit.[11] Next, the analyses of the same performances were compiled with the aid of the Springboard Diving Skill Assessment Knowledge Based Expert System. Afterwards, they were asked to complete a questionnaire evaluating various aspects of the program operation. A copy of the questionnaire is contained in Appendix I. This task was completed by five people in both individual and group testing sessions. Also, a sample

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[11] This preliminary assessment served as a measure of the participant's skill analysis ability for evaluating their comments relating to the performance of the knowledge based expert system.

session with the Knowledge Based Expert System for Springboard Diving Skill Analysis has been recorded in Appendix J.

The consensus among these users regarding program operation was the system was easy to use, easy to understand and presented information in a logical manner. The user viewed the resulting diagnosis and supplemental coaching advice as appropriate, valuable and extensive. The details explaining the related mechanics associated with skill analysis occasionally were too technical and required further translating to common springboard diving terminology. A common suggestion to enhance the system was improvement of the graphics; recommended extensions ranged from supplementing the posed questions with illustrations to providing animation of desired performances.

One user felt that the system should provide a more thorough analysis; all causes contributing to a performance error should be presented. As previously noted, the system was designed to identify one contributing cause to an observed fault. However, through repeated analysis with modified responses a more thorough analysis of a given performance could be achieved. Also, the *change previous response* feature permits chronological backtracking through the user's responses and provides the opportunity to retract any of these responses, then resume program operation to evaluate another line of analysis.

The observed interaction between the user and the system attests to its friendliness. The simplistic nature of the interface coupled with the preliminary instructions provided sufficient information for each user to run the program. This ease of program use may be partially attributed to the fact that all of the users have had some previous exposure to computers. However, after completing a diagnosis, the user required a reminder on how to begin a new analysis. This problem has been addressed by providing brief instructions on initiating another run at the end of each analysis.

The response time of the program was adequate. The program was efficient in holding the user's attention. Since the user responses require entering the <return> key, the user can, for the most part, control the speed of operation. However, the initial loading of definitions, graphics, rules, and the expert inference engine of the program was found to be time consuming. In general, the run-time operation appeared to be efficient with analysis taking only a few minutes.

Also, from observing the testing session, the full extent of the capabilities of the system had not been explored. For instance, only one person employed the definition function without being prompted; this user had the least amount of dive-related experience. The change previous response option was not utilized at all. Also, the features providing access to an explanation of the decision process were not fully examined. Perhaps, the clarity of information presented or the nature of the testing session contributes to a lack of use and feedback on these features. That is, the testing session should not only emulate the intended working conditions, but also facilitate evaluation of the capabilities of the system.

In general, the feedback received from the user holds much praise for the knowledge based expert system application to performance analysis of forward, non-twisting, springboard dives. The comment that this program is a preferred reference source as compared to searching for information in manuals suggests that the program can serve as a viable teaching tool. Also, the results that were obtained by this test group when using the Springboard Diving Skill Assessment Knowledge Based Expert System agreed with at least one of the errors as identified by Mr. Grisdale. This feedback serves as an incentive for continued research and development of the springboard diving skill analysis program.

3.5. Discussion

The knowledge based expert system demonstrated considerable skill in assessing springboard diving performances of forward, non-twisting dives. The accuracy of the results and the acceptance by the participants during the testing session affirms the feasibility of applying knowledge based expert system technology to the skill assessment aspect of coaching. This original application provides developing coaches the opportunity to tap the skill assessment expertise of elite coaches; that is, novice coaches can provide skill analysis at a near expert level.

The subjective nature of springboard diving coupled with the numerous interrelating factors involved in performing a dive accounts for various philosophies in coaching and in assessing performance. In developing the knowledge base, an objective analysis process was designed to avoid reflecting an individual, coaching philosophy. The diagnostic ability of three elite coaches supplemented with available resources was amalgamated to form this skill analysis package. A contributing cause of a gross performance error was determined by examining each phase of the performance. In producing an efficient system and to avoid asking of irrelevant questions, a modular approach was used to structure the rules. This modular approach enabled the program to acknowledge its inability to identify the cause of a performance error by providing the option to continue analysis with another module. Other considerations in the development of the knowledge based expert system focused on enhancing its acceptability, the usefulness of results, the ease of interaction, and the ease of understanding.

Some of the benefits resulting from the development of the knowledge based expert system included the development of a comprehensive, skill assessment process. The knowledge of more than one elite coach was accumulated and formulated into the procedural rules. Hence, the expertise of more than one elite coach can be accessed in a simple and relatively inexpensive manner. In addition, the procedural rules were verified by applying fundamental laws of science. Secondly, the knowledge base serves as a permanent collection of skill assessment strategies; these strategies can be retained indefinitely (barring a devastating failure of the storage device) and are easily duplicated by copying the software program. Thirdly, the program employs a systematic and consistent analysis process in determining the cause of an error. Thus, this application of knowledge based expert systems has provided a comprehensive, permanent, reliable and affordable means of accessing expert skill assessment abilities for forward, non-twisting dive performances.

Limitations of the developed system exist. Firstly, its narrowed focus of analyzing only forward, non-twisting dives restricts its use to this group of dives. Secondly, its inherent ability to identify only one contributing cause of a performance error detracts from its ability to completely analyze a performance. Although the system directs the user to examine various facets of a performance, the system relies on the users perception to identify the existence of a stated deviation. Despite these limitations, the system can serve as a valuable aid to augment the skill assessment capabilities of the user.

Recommendations for future studies in this section involve refinement and expansion of the program. The system should be subjected to a more comprehensive evaluation process to ensure completeness and accuracy of its knowledge base; especially, if the package is destined for commercial production. According to the results of these evaluation sessions, the identified deficiencies would need to be remedied. As suggested, additional graphics could be incorporated to clarify the questions posed to the user and to augment explanations. Furthermore, the knowledge base should be expanded to include analysis of backward, reverse, inward, and twisting dive performances; due to the selected structuring of the knowledge base many of the rules have already been developed and could be incorporated. A more elegant process of identifying more than one contributing cause should be developed. Also, to increase the flexibility of the system, modifications of the knowledge base should be made more accessible; an iterative interface would need to be developed to permit adding and modifying the procedural rules. Incorporating these recommendations would greatly enhance the system.

Chapter Four

CONCLUSIONS AND RECOMMENDATIONS

The thesis has discussed efforts made to improve human performance relating to the sport of springboard diving. Analysis has been completed from both a quantitative and qualitative perspective. Dynamic analysis of the diver-springboard system and application of the knowledge based expert system have been employed in researching the skill assessment aspect of coaching springboard diving.

The applied mechanical analysis focused on the vertical component of motion for forward dive performances. The effects of altering the timing of executing movement patterns (such as: arm swing, hip extension-flexion, knee extension-flexion and ankle extension-flexion) on the overall performance were examined. Primarily, the attained height of the aerial phase of the performance was maximized. To complete this optimization, the diver-springboard system was examined. Modeling the human subject, investigating springboard behavior to determine an appropriate model, and developing an approach to simulate human motion and to facilitate optimization of springboard diving motion were necessary. The resulting mathematical representation involved a system of rigid, linked segments to model the human subject, a lumped mass-spring system to describe the springboard, and the distribution of external and internal forces to each free body segment. As previously discussed, this model permits the optimization to be personalized not only to the skill but also to the demonstrated ability of the athlete.

Optimization, maximizing the attained height during execution of a given performance, was conducted by examining the timing of executing movement patterns associated with the skill. The resulting optimal performance exhibited the following features: achieving maximum height during the flight phase correlated with maximizing the board contact velocity and adjusting the acceleration difference between the center of gravity of the diver and the springboard so that the relative velocity of the center of gravity of the diver with respect to the board is maximized. These parameters appear to be interrelated.

The conducted quantitative research provides insight into the mechanics of springboard diving and can serve as a valuable coaching tool since observed motion can be accurately simulated. Furthermore, the effects on overall performance due to variations in the movement patterns can be analyzed, as was illustrated in the optimization of height by adjusting the timing of execution of the movement skills.

Although this simulation is flexible in permitting the analyses of a variety of diving skills from numerous perspective (such as: timing of execution, changes in movement patterns, or changes to the springboard), its value can be improved by extending the analyses to three dimensions. If the program were supplemented by animation, its usefulness as a coaching tool could be more greatly appreciated, since the coach/athlete would be provided with visual cues to interpret the analysis. Also, incorporating ‘near’ real time data acquisition would make the system more practical for coaching applications.

The qualitative aspect of skill assessment was investigated by applying knowledge based expert system technology. The intent of the system was to increase the availability of expert skill analysis for forward, non-twisting dives. The coaching strategies of three, practicing coaches along with those gleaned from the current coaching manuals were synthesized into a comprehensive skill assessment process. This assessment scheme was encoded using a modified version of the Expert-2 Toolkit. In designing an efficient program the skill assessment strategies were structured into modules that related to an easily identifiable performance error; each module examined the performance phases of the skill to determine the cause of the selected error. Realizing that the system's achieving a near expert level of performance is insufficient to guarantee user-acceptance, features to enhance user acceptance were incorporated. These features included using the terminology of the user group, providing the option to review ideal performance or have definitions presented, supplementing descriptions using graphic support, and presenting an applied mechanical explanation of the performance fault.

Recommendations for furthering the Springboard Skill Analysis Knowledge Based Expert System are to increase the supplementary graphics and to expand the rule base to all groups of dives.

Future research should examine the development of a complete assessment process through linking quantitative and qualitative skill analyses. To effect this comprehensive assessment package a number of advancements need to be made. Firstly, diver-springboard dynamics need to better understood. For instance, the developed simulation model if extended to three dimensions could examine the trade-off effects between angular momentum which governs the number of somersaults that can be completed, and linear momentum which affects the height achieved in a dive. Near real-time data acquisition would be required to supply kinematic input data for the quantitative analysis of individual performances to effect immediate feedback. A mechanism to integrate algorithms with heuristics of coaching for discerning ideal performance must also be developed. As continued research reduces these barriers, the potential for integrating qualitative and quantitative skill analyses exits.

REFERENCES

Alty, J.L. and M.J. Coombs. (1984). *Expert System Concepts and Examples.* Great Britain: National Computing Center Limited.

Andrew, James, G. (1974). "Biomechanical Analysis of Human Motion", In *Kinesiology IV.* Washington, D.C.: Committee on Kinesiology of Physical Education Division. pp. 32-42.

Ariel, G. (1980). "Can Computers Win Gold Medals", In *New Scientists.* 87(1211):282-284.

Bartee, H. and L. Dowell. (1982). "A cinematographical analysis of twisting about the longitudinal axis when performers are free of support", *Journal of Human Movement Studies.* 8(1):41-54.

Bartz, J.A. (1973). "Validation of a three dimensional mathematical model of the crash victim." In In W.F. Kind and H.J. Mertz (eds.) *Human Impact Response--measurement and simulation.* New York: Plenum Press. pp. 345-379.

Batterman, Charles. (1969). *The Techniques of Springboard Diving.* Cambridge, Massachusetts: Massachusetts Institute of Technology.

Beer, F.P. and E.R. Johnston. (1981). *Mechanics of Material.* New York: McGraw-Hill, Inc. pp. 396-398.

Bergmaier, G., A. Wettstein, J. Wartenweiler. (1979). "Diving Measurement and Analysis of the Take-off", In Lewille and Clays (eds.). *Biomechanics of Swimming, Waterpolo, and Diving.* Brussels: Universite Libre de Bruxelles Labortoire de l'effort. pp. 243-247.

Bernstein, N. (1967). *The Coordination and Regulation of Movements.* Great Britain: Pergamon Press. pp. 9-27.

Boulanger, Dany. University of Laval Diving Club, In conversation on May 5, 1988, in Quebec City, Quebec.

Bourgeois, M.A. and L.A. Lewille. (1983). " Mathematical Model and Lagrangian Analysis for the Dynamics of the Human Body in the Crawl Stroke", In Matsuie and Kobayashi (eds.), *Biomechanics VII.* Champaign, Illinois: Human Kinetics Publishers, Inc.

Burden, Richard L. and J. Douglas Faires. (1985). *Numerical Analysis.* Boston: Prindle, Weber & Schmidt Publishers.

Butler C.W., E.D. Hodil, G.L. Richardson. (1986). "Buidling Knowledge-Based Systems with Procedural Languages", In *IEEE Expert.* (Summer, 1986):47-59.

Clauser, C.J., J. McConnville, J. Young. (1969). "Weight Volume and Center of Mass Segments of the Human Body". In *AMRL-TR-690-70.* Wright-Patterson Air Force Base, Ohio.

Cromwell, S. Daniel. (1984). *Computer-aided Analysis of Aluminum Diving Board.* (Senior Project). UNR:[unpublished work].

Dainis, A. (1980). "Whole Body and Segment Center of Mass Determination From Kinematic Data". In *Journal of Biomechanics.* 13:647-651.

Dempster, W. (1955). "Space requirements of seated operators." *WADC Technical Report 55-159.* Wright-Patterson Air Force Base, Ohio.

DeSalvo, G.J. and E.R. Johnston. (1981). *ANSYS: Engineering Analysis System User's Mannual.* Volume I and II. Huston, Texas: Swanson Analysis Systems, Inc.

Dietz, P.W. (1986). "Artificial Intelligence: Building Rule-based Expert Systems", In *Design Magazine News.* 3(386):137-144.

Duraflex International Corporation. (1987). *Duraflex Aluminum Springboard Specifications (66-231-300).* Sparks, Nevada.

Dyson, Geoffrey. (1977). *The Mechanics of Athletics.* 7th edition, London, Great Britain: Hodder and Stoughton.

Elmaghraby, A.S. and V. Jagannathan. (1985). "An Expert System for Simulationists", In Graham Birtwistle (ed.), *AI Graphics and Simulation.* La Jolla, California: Society for Computer Simulation (Simulation Concils, Inc.).

Fox, Robert W. and Alan T. McDonald. (1978). *Introduction to Fluid Mechanics.* Second edition. New York, New York: John Wiley & Sons.

Frohlich, Cliff. (1979). "Do Springboard Divers Violate Angular Momentum Conservation?", In *American Journal of Physics.* 47(7):583-592.

Hamill, Joseph, Mark D. Ricard, Dennis M. Golden (1986). "Angular Momentum in Multiple Rotation Nontwisting Platform Dives". In *International Journal of Sport Mechanics.* 2:78-87.

Johnson, L. and E.T. Keravnou. (1985). *Expert System Technology.* Cambridge, England: Abacus Press.

Joyce, John, D. and Ramasamy Uthurusamy. "Knowledge Systems: Promises and Pitfalls", In *Automotive Engineering.* 94(5):70-75.

King, A.I. (1984). "A Review of Biomechanical Models". In *Journal of Biomechanical Engineering.* 106:97-104.

Lambie, Jim. Pan Am Diving Club, In conversation on June 2, 1988, in Winnipeg, Manitoba.

Lazan, Benjamin J. (1968). *Damping of Materials and Memabers in Structural Mechanics.* Oxford, Great Britain: Pergamon Press. p. 205-209.

Logan, Daryl L. (1986). *A First Course in The Finite Element Method.* Boston, Massachusetts: Prindle, Weber & Schmidt Publishers.

Marasco, Joe (1986a). "Math: A Variable Metric Minimizer", In *Dr. Dobbs Journal of Software Tools.* (March, 1986) 11(3):24-34.

Marasco, Joe (1986b). "Math: A Variable Metric Minimizer", In *Dr. Dobbs Journal of Software Tools.* (April, 1986) 11(4):84-110.

Mattiasson, Kjell. (1981). *Numerical Results From Large Deflection Beam And Frame Problems Analysed By Means of Elliptic Integrals.* [Short communication]. Toronto, Ontario: John Wiley & Sons, Ltd.

M^{c}Gavern, Don. (1976). *C.A.D.A. Diving Instruction Manual: Instructor II.* Kingston, Ontario: Maxwell Printers.

M^{c}Gavern, Don. (1977). *C.A.D.A. Diving Instruction Manual: Instructor I.* Kingston, Ontario: Maxwell Printers.

Meriam, J.L. (1978). *Engineering Mechanics Statics and Dynamics.* Toronto, Ontario: John Wiley & Sons.

Miller, Doris I. (1981). "Body segment Contributions of Female Springboard Dive Take-offs", In J. Borms, M. Hebbelinck, and A. Venerando (eds.), *The female athlete -- A Socio-psychological and Kinathropometric Approach.* Karger: Basel. pp. 266-215.

Miller, Doris, I. (1982). "Arm Contribution to Springboard Diving Take-offs". In *CSB Conference of Human Locomotion II.* pp. 24-28.

Miller, Doris I. (1983). "Springboard Reaction Torque Patterns during Nontwisting Dive Take-offs", In H. Matsui and K. Kobayashi (eds.), *Biomechanics VIIIB*. Champaign, Illinois: Human Kinetics Publishers, Inc. pp. 822-827.

Miller, Doris I. (1984). "Biomechanical Characteristics of the Final Approach Step, Hurdle, and Take-off of Elite American Springboard Divers", In *Journal of Human Movement Studies.* 10(4):189-212.

Miller, Doris I. and Carolyn F. Munro. (1984). "Body segment contibutions to height achieved during the flight of a springboard dive", In *Medicine and Science in Sports and Exercise* 16(3):234-242.

Miller, Doris I. and Carolyn F. Munro. (1985a). "Greg Louganis' Springboard Take-offs: I. Temporal and Joint Position Analysis", In *International Journal of Sport Biomechanics.* 1:209-220.

Miller, Doris I. and Carolyn F. Munro. (1985b). "Greg Louganis' Springboard Take-offs: II. Linear and Angular Momentum Considerations", In *International Journal of Sport Biomechanics.* 1:288-307.

Miller, D.I., I.C. Jones, and M.A. Pizzimenti. (1988). "Taking Off: Greg Louganis Diving Style", In A. Selreg (ed.), *SOMA.* 2(4):20-28.

Music, Glen (ed.). (1984). *C.A.D.A. Diving Coaching Technical Manual -- Level I.* Canada.

Music, Glen, Calary Diving Club, In conversation on June 2, 1988, in Calgary, Alberta.

O'Brien, Ronald F. (1968). *Fundmentals of Springboard Diving.* Columbus, Ohio: Merrill Sport Series.

Ogata, Katsuhiko. (1970). *Modern Control Engineering.* Englewood Cliff, New Jersey: Prentice-Hall Inc.

Park, Jack (1984). "MVP-Forth Expert System Toolkit: Knowledge Based Inference Program", In Glen Haydon (ed.) *MVP-Forth Series.* Vol. 4. Mountain View Press: California.

Paquette, Sharon. (1984). *Optimizing the Temporal Pattern of the Armswing in Springboard Diving.* Master Thesis at the University of Saskatchewan: College of Physical Education.

Paquette, Sharon. (1985). "When should The Armswing Begin?", In *Coaching Review.* (May-June):48-51.

Phillips, Sally J., Elizabeth M. Roberts, T.C. Huang. (1983). "Quantification of Intersegmental Reactions During Rapid Swing Motion". In *Journal of Biomechanics.* 16(4):411-417.

Preiss, R. (1984). "The Theory of Models Describing The Two-dimensional Movements of Airborne Systems Consisting of Rigid Segments". In *Journal of Human Movement Studies.* 10(4):231-238.

Ramey, M.R. and A.T. Yang. (1981). "A Simulation Procedure for Human Motion Studies". In *Journal of Biomechanics.* 14(4):203-213.

Reddy, J.N. (1984). *An Introduction to the Finite Element Method.* New York, New York: McGraw-Hill Book Co.

Sanders, Ross H. and Barry D. Wilson. (1988). "Factors Contributing to Maximum Height of Dives After Takeoff From the 3m Springboard", In *International Journal of Sport Biomechanics.* 4(3):231-259.

Sargent, C. M., L.G. Watson, R.T. Burton, R.M. Westman. (1986). "Some Experiences with Expert 2", In *Proceedings of the 1986 Rochester Forth Conference on Real Time Artificial Intelligence.* Rochester, New York: The Institute for Applied Forth Research. pp. 235-238.

Seto, W. (1964). *Mechanical Vibrations: Schaum's Outline Series.* Toronto, Ontario: McGraw-Hill Book Company.

Slatter, Philip E. (1987). *Building Expert Systems: Cognitive emulation.* Chichester Great Britain: Ellis Howard Limited.

Smith, Dick and J.H. Bender. (1973). *Inside Diving.* Chicago, Illinois: Henry Regnery Company.

Soong, Tsai-Chen. (1975). "The Dynamics of Javelin Throw." In *Journal of Applied Mechanics.* 42(2):257-262.

Spaepen, A.J. V.V. Stijnen, E.J. Willems, M. Van Leemputte. (1983). "Two-dimensional Simulation of Human Movements during Take-off and Flight Phases". In Matsui and Kobayashi (eds). *Biomechanics VIIIB.* Champaign, Illinois: Human Kinetics Publishers. pp. 997-1004.

Sprigings, E.J. and L.G. Watson (1983). "A Mathematical Search for the

Optimal Timing of the Armswing During Springboard Diving Take-offs" IN D.A. Winter, R.P. Wells, K.C. Hayes, A.E. Datia (eds.), *Biomechanics IX-B* Champaign, Illinois: Human Kinetics Publishers. pp. 389-394.

Sprigings, E.J., L.G. Watson, E. Haseganu, D. Derby. (1986). "A Model for Optimizing the Timing of the Relative Foprce Patterns of the Arms, Torso, and Legs During Springboard Diving Take-offs", In *Proceedings of North American Congress on Biomechanics.* pp. 39-40.

Sprigings, E.J., D.B. Burko, L.G. Watson, W.H. Laverty. (1987). "An Evaluation of Three Segmental Methods Used to Predict the Location of the Total Body CG for Human Airborne Movements", In *Journal of Human Movement Studies.* Edinburgh: Teviot Scientific Publications, 13:57-68.

Sprigings, E., D. Stilling, G.Watson. (1988). "Measurement of the Modeling Parameters For a Duraflex Aluminum Springboard", In C.E. Cotton, et al. (eds). *Proceedings of Fifth Biennial Conference and Symposium.* Ottawa, Ontario. pp. 144-145.

Stilling, D.S.D., L.G. Watson, E.J. Sprigings. (1988). "Temporal Optimization in Human Movement through Coordinating Relative Acceleration Patterns". In *Proceedings of the Ninth Symposium on Engineering Applications of Mechanics.* London, Ontario: University of Western Ontario. pp. 306-313.

Ramey, M.R. and A.T. Yang. (1981). "A Simulation Procedure for Human Motion". In *Journal of Biomechanics.* 14(4):203-213.

Tello, Ernest T. (1987). " What Progress Is Being Made in AI?", In *Dr. Dobbs Journal of Software Tools.* (February, 1987) 10(2):108-120.

Tsotsos, John. (1985). *Computational Intelligence.* Ottawa, Ontario: National Research Council of Canada. 1(1):16-32.

Walton, S. and R. Kane (1978). "Interactive computer graphics – a new coaching aid", In P.E. Assmussen, K. Jorgensen (ed.), *Biomechancics VIA.* Baltimore: University Park Press. (439-444).

Waterman, Donald R. (1986). *A Guide To Expert System.* Reading, Massachusetts: Addison-Wesley Publishing Company Inc.

Watson, L. Glen. (1987). "Adding Probabilistic Decision Making to EXPERT 2", In Jim Basiler et al. (eds.), *The Journal of Forth Applications and*

Research. Rochester, New York: Institute for Applied Forth Research. Inc. 5(1):229-232.

Watson, L. Glen. (1988). "Developing a Computer Assisted Learning Program for Finite Element Analysis". In *Proceedings of the 1988 ASME International Computers in Engineeering Conference and Exhibition.* San Francisco, California: 2:581-583.

Westman, R. M. (1987). *A Knowledge Based Expert System for Hydraulic Circuit Design,* Master Thesis. University of Saskatchewan: College of Engineering.

Winter, David A. (1979). *Biomechanics of Human Movement.* Toronto, Ontario: John Wiley & Sons.

Wolfgram, Deborah H., Teresa J. Dear, Craig S. Gralbraith. (1987). *Expert Systems for the Techinical Professional.* Toronto: John Wiley & Sons.

Van Gheuluwe, B. (1981). "A biomechanical simulation model for airborne twist in backward somersaults", In *Jorunal of Huamn Movement Studies* pp.1-22.

Vaughan, C.L., J.G. Andrews, and J.G. Hay. (1982). "Selection of Body Segment Parameters by Optimization Methods". In *Journal of Biomechanical Engineering.* 104:38-44.

Vierck, Robert K. (1979). *Vibration Analysis.* Second Edition. New York, New York: Harper & Row, Publishers, Inc. pp. 395-410.

Yeadon, F. R. (1987). "Theoretical Models and Their Applications to Aerial Movement", In B. Van Gheluwe (ed.) *Medicine and Sport Science (25) Cuurent Researcch in Sports Biomechanics.* Basel, Switzerland: Karger. pp. 86-106.

Appendix A

GLOSSARY OF TERMINOLOGY

A.1. Springboard Diving Terminology

AERIAL PHASE	time spent in the air that begins from the instant of board departure to dive entry, during this phase the diver may performs aerial maneuvers of twists and/or somersaults.
APPROACH PHASE	all forward and reverse dives are initiated with this phase which includes approach steps and hurdle.
APPROACH STEPS	three or four controlled steps taken prior to the hurdle; the length of each stride should equal that of a normal walking step.
ARM SWING	the pattern of arm motion where the arms are extended and swing simultaneously around the shoulder; arm swing is performed during the hurdle and during board contact phases. The **arm press** is the downward motion of the arms; the **arm lift** is the upward motion of the arms.
BOARD CONTACT	the instant the feet contact the board after the execution of the hurdle; this point marks the end of the approach phase and commencement of the board contact phase.
BOARD CONTACT PHASE	the period where the diver contacts the board with both feet following the hurdle; the board deflects to its maximum position and recoils until the diver departs.

BOARD DEPRESSION	the period of downward deflection of the springboard occurring during the board contact phase, this period begins with board contact and ends at maximum board deflection.
DEPARTURE	the instant the diver separates from the board, this point terminates the board contact phase and initiates the flight phase.
DIVE	any *dive* where the entry is head first.
DIVING ATTENTION/POSTURE	basic diving position performed with the diver standing erect with legs extended and together, arms are straight and aligned with the trunk; entire body musculature is firm.
ENTRY	the final phase of dive performance occurring from the instant the diver contacts the water until he is completely submerged; body position should be near vertical in a straight position. Head first entries will have the arms stretched with hands grasped together beyond the head aligned with the body (flat hand entry). Foot first entries are performed in diving posture.
F.I.N.A.	Federation Internationale de Nation Amateur, regulation governing body for the sport of diving.
FLAT HAND GRASP	this is the hand placement used in the stretch position. The arms are extended with elbows locked and the hands grasp one another as described. The palms are turned outward and away from the diver, then the thumbs interlock and one hand grasps the back of the other.
FLIGHT PHASE	time spent in the air that begins from the instant of board departure to diver entry, during this phase the diver may performs aerial maneuvers of twists and/or somersaults.
FREE END OF THE BOARD	refers to the overhanging end that is free from support and extends over the water.

HURDLE PHASE	final phase of the approach; the diver jumps to the end of the board by pressing off one leg (press leg) while driving the other (hurdle leg) knee forward and through; the diver is air-borne and attains the reach position as he prepares for a two-foot landing near the end of the board prior to the final board contact phase.
JUMP	any *dive* where the entry is feet first.
KICKOUT	after completing the aerial maneuver of the flight phase, the diver extends from his pike/tuck position to either stretch position (for a dive entry) or diving attention (for a jump entry) in preparing for entry.
LAYOUT	aerial body position resembling diving posture except the arms are extended laterally away from the body at shoulder height.
MAXIMUM BOARD DEFLECTION	the lowest point that the board is deflected to during board contact.
OVERHANGING BEAM	describes the structural configuration of the springboard (propped, hinged beam).
PIKE	flight phase body position where the diver bends at the hips with legs and arms extended, the arms may be either extended perpendicular to the body (OPEN PIKE), grasp the legs (CLOSED PIKE) or reach for the toes (SEMI-CLOSED PIKE).
PROPPED, HINGED BEAM	describes the structural configuration of the springboard
REACH POSITION	basic diving position involving the arms extended above the head and slightly forward of vertical; the legs are together and extended with the body musculature remaining firm.
RECOIL	the period where the board returns from its maximum deflected position until the diver departs from the board.

STRETCH POSITION	body position used in executing dives, the body posture resembles the reach position except the double hand grasp is employed.
TAKE-OFF	see departure
TUCK	flight phase body position involving the hand grasping the lower legs and knees are bent and drawn into the chest; the head is in line with the trunk.

A.2. Knowledge Based Expert System Terminology

ALGORITHM	formal, detailed procedure used to produce correct or optimal solution.
BACKWARD CHAINING	an inference strategy that involves working from conclusions to check if the conditions that make the conclusions true are satisfied.
DATA/EVENT DRIVEN REASONING	see forward chaining.
FORWARD CHAINING	an inference strategy that builds from the available data about a problem to deduce conclusions.
FRAME	knowledge representation where the structure for storing data are called frames. Frames represent stereotyped situations and not only store information but include instruction on its use.
HEURISTICS	rules of thumb methods that aid in problem solving; such rules tend to be useful in the majority of the cases.
HYPOTHESIS/GOAL DRIVEN REASONING	see backward chaining.
KNOWLEDGE BASED EXPERT SYSTEMS	a computer program that accesses expert knowledge to

	attain high levels of performance in a narrow problem area. Usually, humans require years of special training and experience to perform at this level. These systems typically consist of a knowledge base, an inference engine and a user interface.
PROCEDURAL REPRESENTATION	knowledge is contextually embedded in the procedure; employs production rules.
PRODUCTION RULES	facts and relations used in procedural representation; the usual form is IF (attribute) THEN (consequent).
SHELLS	see tool kit.
TOOL KIT	program language or support package to be used in constructing knowledge based expert systems.
USER GROUP	person(s) for whom a knowledge based expert system has been designed for and will be used by.

REFERENCES

Harmon, Paul and David King. (1985). *Expert Systems.* Toronto, Ontario: John Wiley & Sons, Inc.

M^{c}Gavern, Don. (1976). *C.A.D.A. Diving Instruction Manual: Instructor II.* Kingston, Ontario: Maxwell Printers.

M^{c}Gavern, Don. (1977). *C.A.D.A. Diving Instruction Manual: Instructor I.* Kingston, Ontario: Maxwell Printers.

Music, Glen (ed.). (1984). *C.A.D.A. Diving Coaching Technical Manual -- Level I.* Canada.

Waterman, Donald R. (1986). *A Guide To Expert System.* Reading, Massachusetts: Addison-Wesley Publishing Company Inc.

Appendix B

DATA ACQUISITION

Traditional methods for investigating temporal kinematics of human performances often employ photo-electronic instrumentation. In analyzing springboard diving, Chapter 2, cinematology was used to acquire the necessary data for the biomechanical analysis. From filming dive performances, temporal kinematic or kinetic data can be derived. This data permits quantifying the factors affecting the skill and allows for validating the simulation models.

As described in Chapter 2, the performances analyzed included a Forward 1 1/2 Pike Somersault Dive and a Forward Layout Jump. The former skill was recorded in 1982, as executed by a provincial caliber diver. The filming was done at the outdoor, City of Saskatoon Lathey swimming pool [Pacquette, 1984]. The latter skill was filmed in 1987 at the indoor, University of Saskatchewan Physical Education pool. The Saskatchewan diving coach and former national competitor performed this introductory skill in spite of a knee injury.

A Locam, variable high speed 16mm camera captured the performances. For the purpose of computing actual film operating speed, an internal light emitting diode operating at 10 Hz during the filming marked the edges of the film. Linear scaling was possible since a 1.83 m surveyor's range pole marked in 0.5 m divisions provided a means to convert filmed image distances to actual values. The scaling factors were 1:5.64 and 1:8.34 for the Forward 1 1/2 Pike Somersault and Forward Layout Jump, respectively.

In filming the Forward 1 1/2 Pike Somersault, the camera was equipped with a 2.25 factor shutter and operated at 102 frames per second with an f-stop of 5.6. Kodak Tri-X Reversal 200 ASA film was used. The camera was located approximately 12.5 m away from and perpendicular to the plane of motion and was aligned with the free end of the diving board [Paquette, 1984]. Whereas, with the Forward Layout Jump, the camera was operated using a 2.25 shutter factor at 100 frames per second with an f-stop of 1.6. Kodak Ektachrome high speed 100 ASA colored film along with a N°80A filter was used. Two *Pallite VIII* 2400 W quartz lights supplemented the available lighting. The camera was positioned perpendicular to the plane of motion at a distance of 20 m; once again, alignment was with the free end of the springboard.

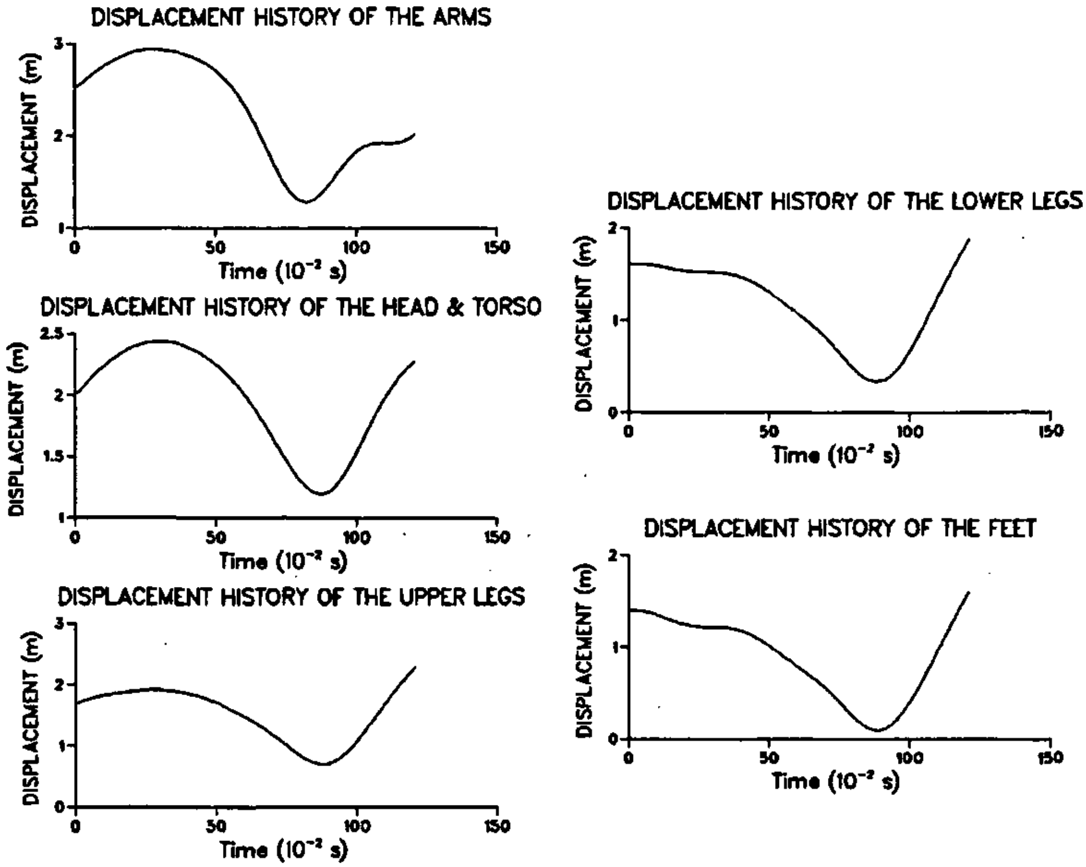
The recording of spatio-temporal data involved digitizing approximately 150 consecutive frames for each trial. The computerized digitizing system consisted of a *Graf/Pen Sonic Digitizer* (GP-6 model 40) that was linked on-line to the University of Saskatchewan VAX Cluster (VAX 8600). The frames that were analyzed captured the diver during the hurdle phase, the board contact phase and the initial stages of the flight phase.

The displacement data consisting of x- and y-coordinates for 16 anatomical positions in the sagittal plane were recorded. The sequence of digitizing used the following landmarks: right ear, right shoulder, right elbow, right wrist, right fingertip, left shoulder, left elbow, left wrist, left fingertip, right hip, right knee, right ankle, right toe, left knee, left ankle, and left toe. These coordinates defined the end points of segments and permitted defining the configuration of a 14 segment model of the human body.

Since the raw positional data was noisy, it was appropriately reduced and smoothed using a series of software packages. First, the data was linearly scaled. Next, smoothing using an optimally regularized, natural quintic spline [Woltring, 1984 & 1986] was employed. Then, calculations of the center of gravity of each segment was computed from the displacement data of these segmental end points along with normalized percent locations of segmental center of gravity as defined by Dempster [Winter, 1979]. Reducing the model to a five segment model, where the segments corresponding to the arms, head and torso, upper legs, lower legs and feet, was accomplished by applying the principle of Varignon using Dempster's segmental mass proportions. The displacement history curves for each of these segments is illustrated in Figure B-1 and B-4. Numerical differentiation of the displacement history curves generated velocity and acceleration time profiles for each segment. The software employed a central difference technique except for the initial and final values which used a forward difference and backward difference method, respectively. The resulting velocity and acceleration time profiles for each segment are illustrated in Figures B-2 and B-5, and Figures B-3 and B-6, respectively.

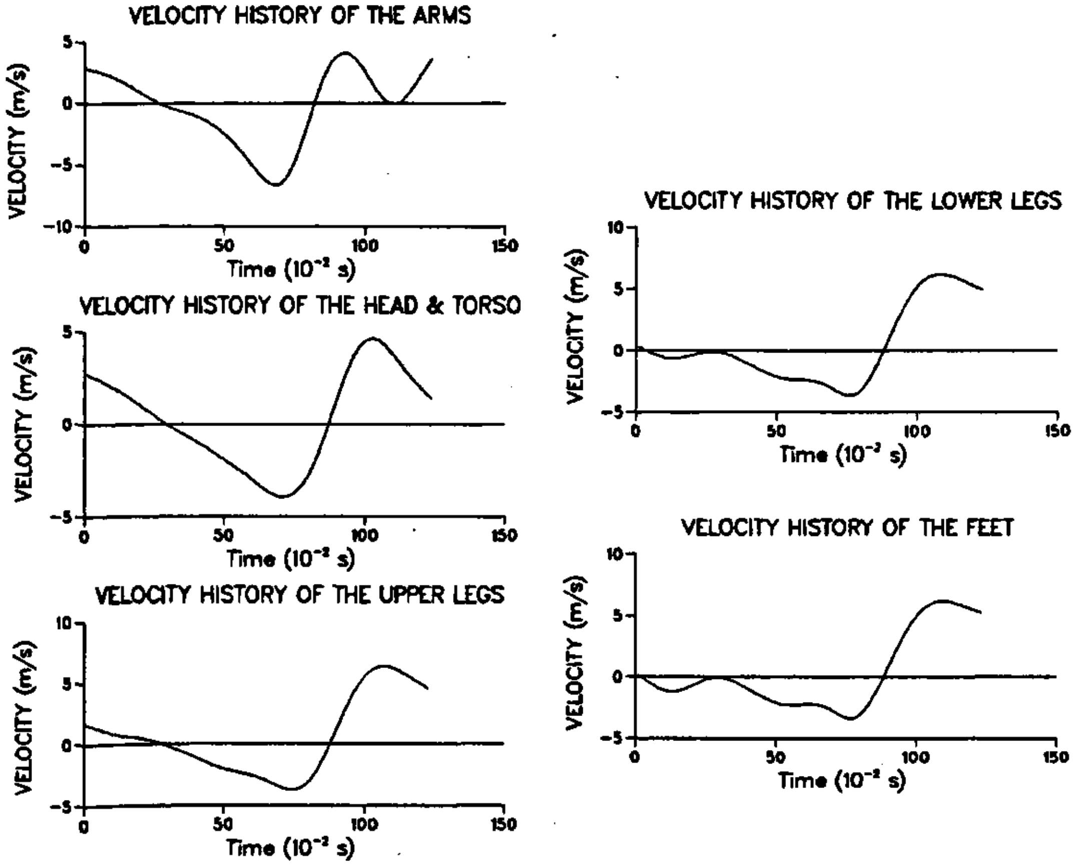
The required input kinematic data used in the optimization program was the acceleration differences between adjacent segments. This data is displayed in Appendix F.

This task of digitizing a filmed performance is a tedious and error prone procedure. One digitizing inconsistency that resulted in error is caused by poorly estimating the segmental end points. The selecting of these points is further complicated when, during the skill, motion of a segment results in hiding another landmark. Perspective problems arise when motion of a segment is not in the vertical filming plane. Furthermore, filtering to eliminate these random errors may also conceal important attributes. Nonetheless this technique quantifies a performance in providing kinematic data for model verification and simulation purposes.



The above data was acquired from the performance of the Forward 1 1/2 Pike Dive. As performed, board contact occurred at 0.69 s and board departure occurred at 1.01 s.

Figure B-1: Displacement History Profile for Each Segment



VELOCITY HISTORY OF THE ARMS

VELOCITY HISTORY OF THE HEAD & TORSO

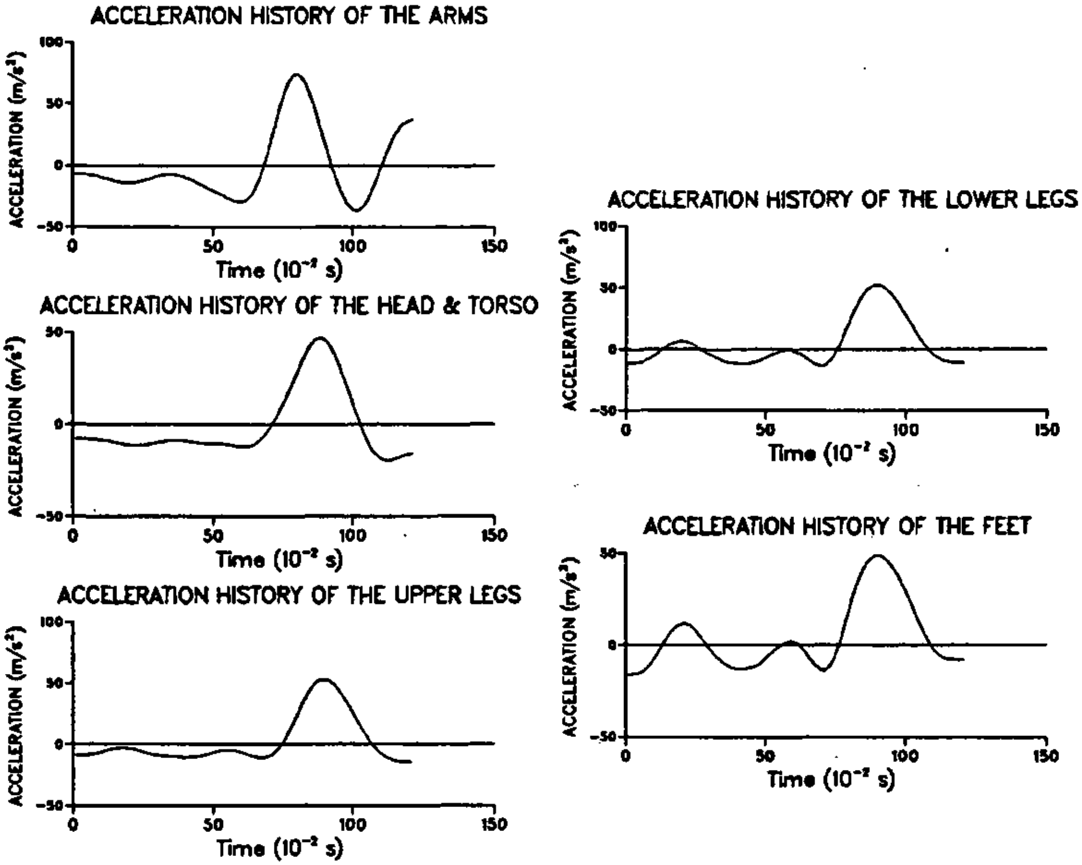
VELOCITY HISTORY OF THE UPPER LEGS

VELOCITY HISTORY OF THE LOWER LEGS

VELOCITY HISTORY OF THE FEET

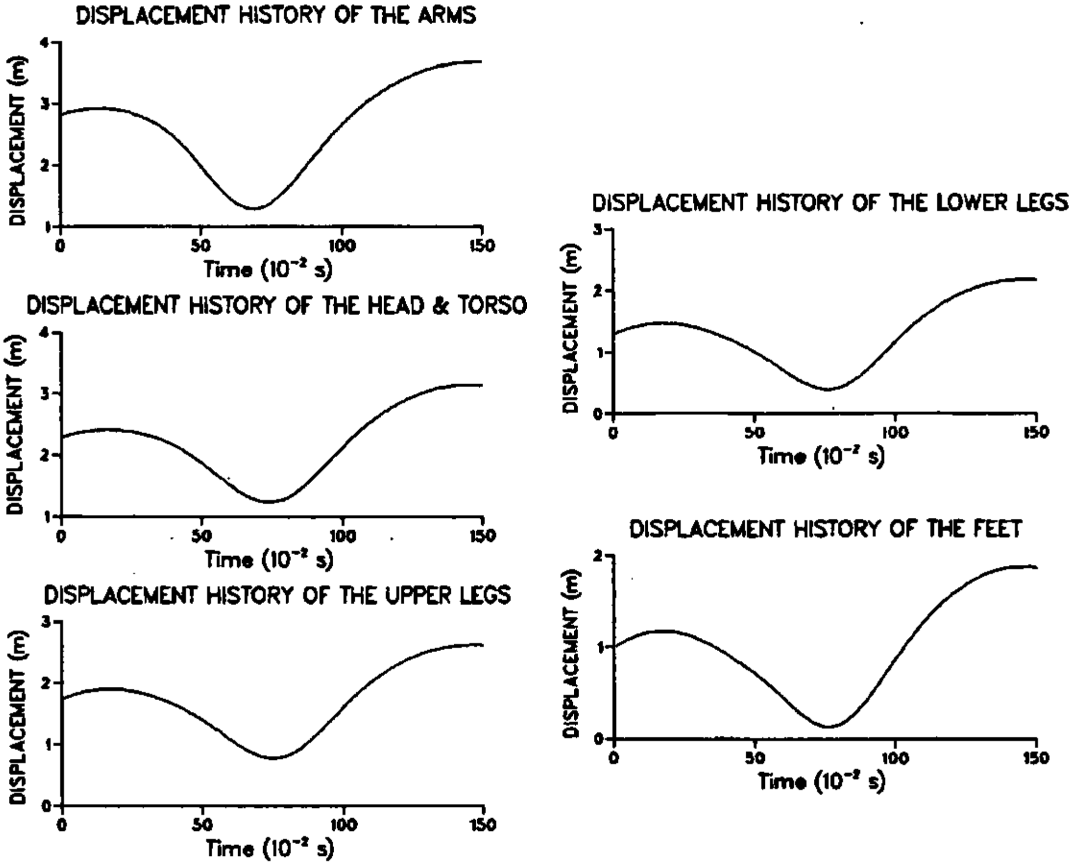
The above data was acquired from the performance of the Forward 1 1/2 Pike Dive. As performed, board contact occurred at 0.69 s and board departure occurred at 1.01 s.

Figure B-2: Velocity History Profile for Each Segment



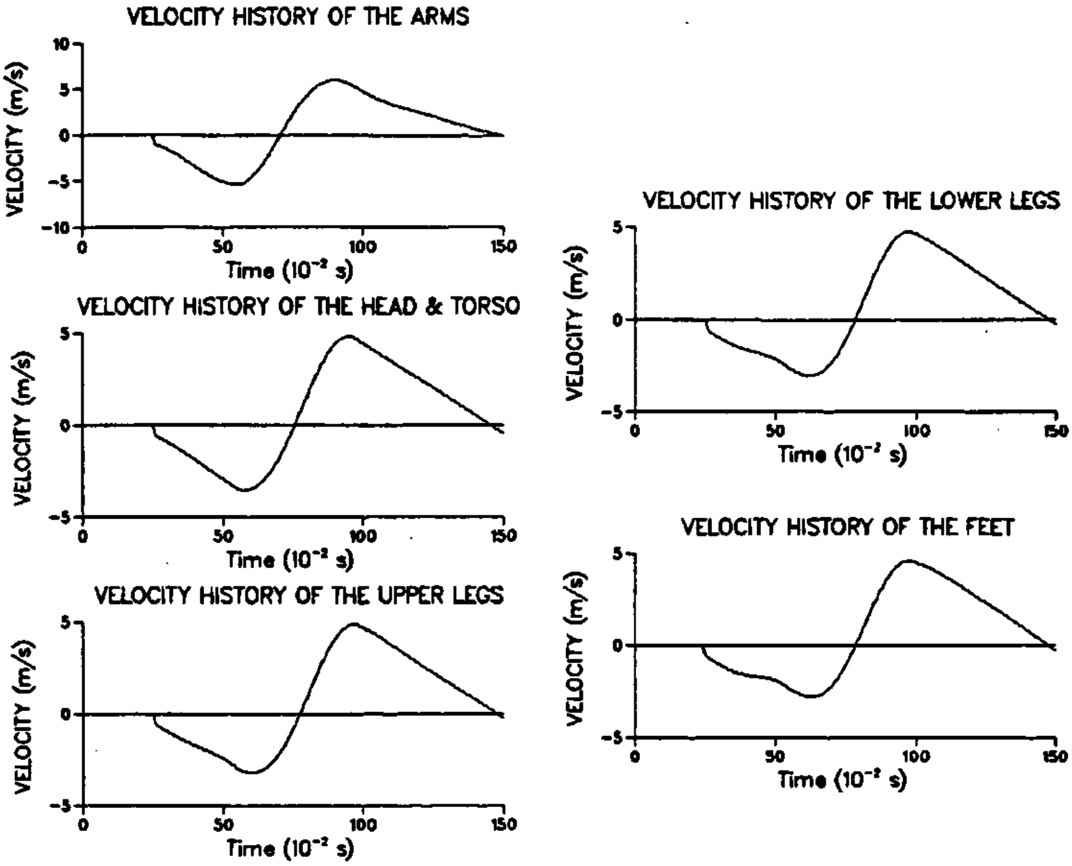
The above data was acquired from the performance of the Forward 1 1/2 Pike Dive. As performed, board contact occurred at 0.69 s and board departure occurred at 1.01 s.

Figure B-3: Acceleration History Profile for Each Segment



The above data was acquired from the performance of the Forward Layout Jump. As performed, board contact occurred at 0.54 s and board departure occurred at 0.96 s.

Figure B-4: Displacement History Profile for Each Segment



VELOCITY HISTORY OF THE ARMS

VELOCITY HISTORY OF THE HEAD & TORSO

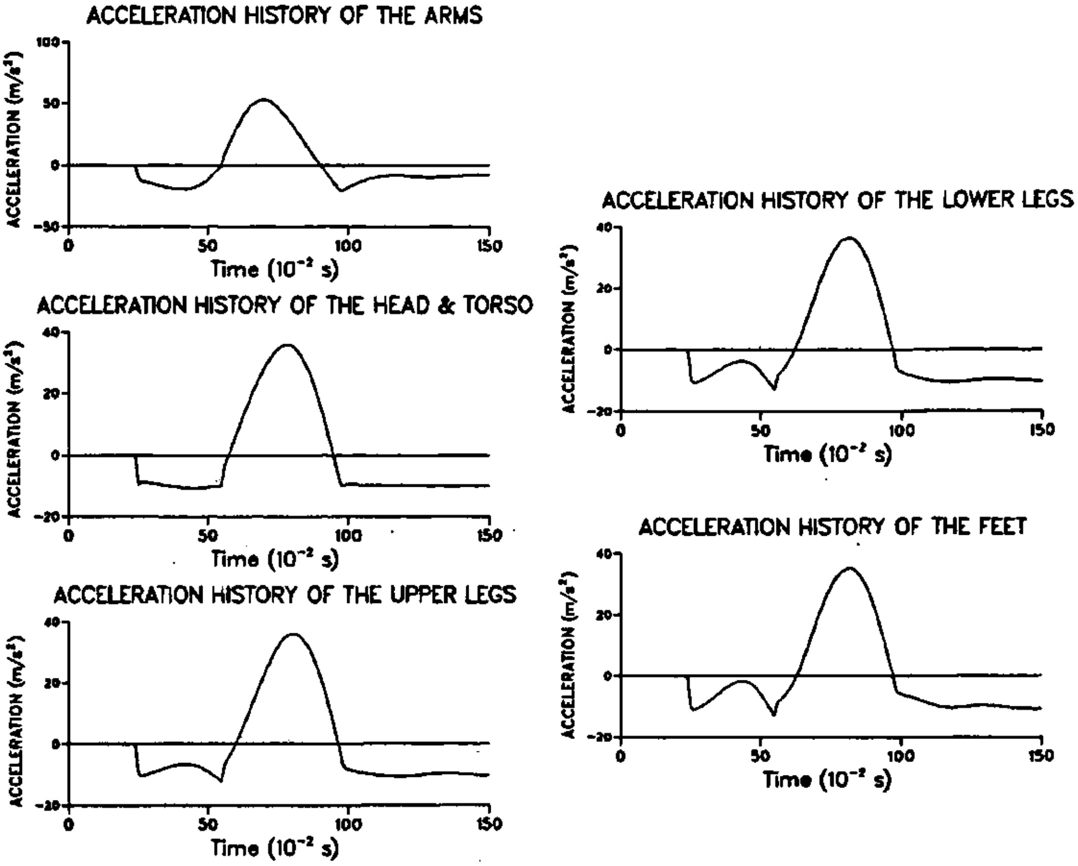
VELOCITY HISTORY OF THE UPPER LEGS

VELOCITY HISTORY OF THE LOWER LEGS

VELOCITY HISTORY OF THE FEET

The above data was acquired from the performance of the Forward Layout Jump. As performed, board contact occurred at 0.54 s and board departure occurred at 0.96 s.

Figure B-5: Velocity History Profile for Each Segment



The above data was acquired from the performance of the Forward Layout Jump. As performed, board contact occurred at 0.54 s and board departure occurred at 0.96 s.

Figure B-6: Acceleration History Profile for Each Segment

REFERENCES

Paquette, Sharon. (1984). *Optimizing the Temporal Pattern of the Armswing in Springboard Diving* Master Thesis at the University of Saskatchewan: College of Physical Education.

Woltring, Herman J. (1985). "On Optimal Smoothing and Derivative Estimation From Noisy Displacement Data in Biomechanics". In *Human Movement Science.* 4(3):229-245 North Holland: Elsevier Science Publishers B.V.

Woltring, Herman J. (1986). "A Fortran Package for Generalized, Cross-validatory Spline Smoothing and Differentiation". In *Advances Engineering Software.* 8(2):104-113. United Kingdom: Computational Mechanics Publications.

Winter, David A. (1979). *Biomechanics of Human Movement.* Toronto, Ontario: John Wiley & Sons.

Appendix C

MODELING PARAMETER EVALUATION BY APPLYING OPTIMIZATION TECHNIQUES

Optimization involves the selection of the best alternative for a stated set of criteria. In describing the alternatives and the criteria, a set of variables and their relations may be mathematically modeled in terms of an objective function. The solution of best values for these alternatives can be determined in a variety of ways.

Minimization is one type of optimization that consists of selecting alternative(s) that reduce the value of the given objective function to the greatest possible extent. In estimating modeling parameters, such as: body segment mass values, springboard stiffness and its mass coefficient, for the quantitative analysis discussed in Chapter 2, this approach was employed.

To perform minimization, the software package, "Variable Metric Minimizer", originally programmed by Joe Marasco [Marasco,1986a and 1986b] and adapted for the Atari ST by Dr. L.G. Watson, was used. The program handles unconstrained minimization of *n*-dimensions through examining the global topography of the problem (Hessian Matrix) and local information (gradient at the point). To attain quick convergence to a minimum, the user can select an algorithm; the choices include: steepest decent, David-Fletcher-Powell, and Broyden-Fletcher-Powell-Shanno method.

As with most minimization algorithms the limitations lies in its tendency to converge to a local minimum.

C.1. Evaluation of Body Segment Mass Values

To better approximate the values for the mass of each segment for use in the modeling of the human body (Section 2.2) an optimization process was used. The derivation of an objective function whereby parameterization of segmental mass involved both examining the kinematics of the flight phase trajectory and realizing that the total segmental mass is a constant value.

The development of the objective function required the nature of the kinetics of the activity be understood. By applying the Theorem of Varignon to the segments, the total body (center of gravity) kinetics can be calculated during an airborne phase. The body will be in a state of free fall; hence, if aerodynamic drag is neglected, the center of gravity of the body will be accelerating at the uniform rate of -9.81 m/s^2. This enables the vertical component of the trajectory to be calculated, as expressed by:

$$\sum_{i=1}^{n} m_i \ddot{y}_i = m_t (y_{CGo} + \dot{y}_{CGo} t - g t^2/2) \tag{C.1}$$

Through combining this condition with the constraint that the sum of the mass of the segments equals the mass of the body,

$$\sum_{i=1}^{n} m_i - m_t \tag{C.2}$$

forms the basis of the objective function. To create a positive objective function both conditions were squared; thus yielding the following objective function:

$$R = \left[\sum^{n} m_i y_i - m_t \left(y_{CGo} + y_{CGo}\, t - g t^2/2\right)\right]^2 + \left[\sum^{n} m_i - m_t\right]^2 \qquad \text{(C.3)}$$

By selecting appropriate segmental mass parameters, m_i, the value of the function may be minimized.

As deduced from the published results on optimization used to determine segmental mass values [Vaughan, 1982] and as observed in initial unconstrained optimization, segments that undergo the greatest range of motion tend to be assigned a lower mass value. Therefore, a further condition which constrained the parameters was necessary. An acceptable range for each segmental mass was defined.

The computed values expressed as a percentage of total body mass for each segment are compared to Dempster's values [Winter, 1979] as given in Table C-1. The analyzed kinematic data was taken from the aerial phase of the performance of a one and one-half pike somersault.

Table C-1: Comparison of Segment Mass Values [Percentage of Total Body Mass]

	Segment Mass as calculated by:	
Segment	Dempster's Method	Optimization Method
Arms	10.0%	10.0%
Head and Torso	57.8%	56.5%
Upper Legs	20.0%	20.7%
Lower Legs	9.3%	10.1%
Feet	2.9%	2.7%

C.2. Evaluation of Board Parameters

Another application of minimization is for estimating the value of parameters used in modeling the springboard as a lumped mass-spring system. The coefficients of mass and stiffness may be approximated, from the kinetics of the diver and the springboard during the board contact phase. Using a reverse Newtonian approach, the interaction force between these two systems can be derived from kinematic data. As illustrated in Figure C-1, the free body diagrams permit the defining of the reaction force in terms of observed system motion of either the diver or the springboard. The motion of the diver during board contact is a function of the board reaction force, the motion of each segment, and gravity. Whereas, the resultant motion of the springboard involves the reaction of the diver, the board spring force, and its weight. Thus, the reaction force may be defined in terms relating to the motion of the diver as:

$$\sum_{i=1}^{n} m_i \ddot{y}_i + m_t g \tag{C.4}$$

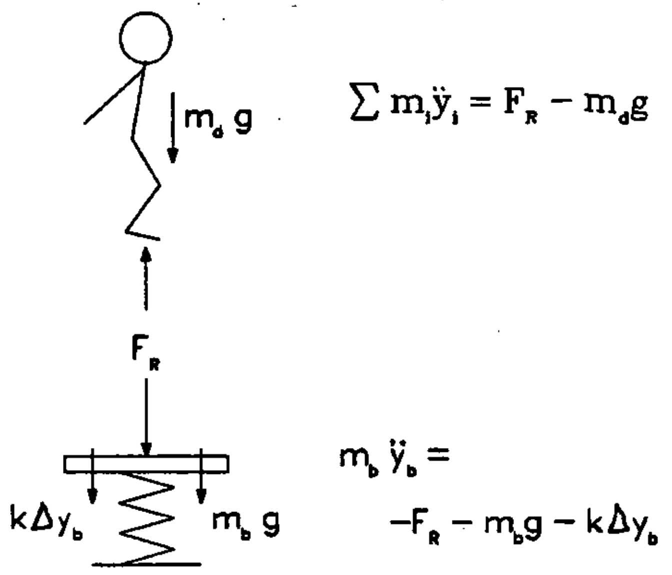
or in terms associated with the kinetics of the springboard given as:

$$m_{board}[\ddot{y}_{board} + g] - k\Delta y_{board} \tag{C.5}$$

Together these expressions for the diver-springboard interaction force form an objective function. Each term is squared to produce a positive residual for the minimization calculations. The objective function to be optimized can be stated as:

$$R = \left[\sum_{i=1}^{n} m_i \ddot{y}_i + m_t g\right]^2 + \left[m_{board}(\ddot{y}_{board} + g) - k\Delta y_{board}\right]^2 \tag{C.6}$$

Using kinematic data of the diver and the springboard during the board contact phase, this function is minimized by selecting appropriate values for m_{board} and k.



The interaction force acting between the diver and the board, F_R, can be expressed in either diver of springboard kinematic terms.

Figure C-1: Springboard-Diver Interaction Force

The springboard parameters of mass and stiffness for the forward layout jump and the one and one-half pike somersault were evaluated using this optimization approach. The necessary kinematic data was derived from cinefilm. For the forward layout jump, the fulcrum was centered and the diver contacted the board near the free end of the board. The computed estimates for the stiffness and effective board mass were 7000 N/m and 13.75 kg, respectively. For the forward one and one-half pike somersault, the diver contacted the board near its free end and the fulcrum was positioned in its furthest back position; the calculated values for stiffness and effective mass were 9850 N/m and 8.5 kg, respectively. The value of these coefficients correlate well with the experimentally derived values (Appendix E).

REFERENCES

Marasco, Joe (1986a). "Math: A Variable Metric Minimizer", In *Dr. Dobbs Journal of Software Tools.* (March, 1986) 11(3):24-34.

Marasco, Joe (1986b). "Math: A Variable Metric Minimizer", In *Dr. Dobbs Journal of Software Tools.* (April, 1986) 11(4):84-110.

Vaughan, C.L., J.G. Andrews, and J.G. Hay. (1982). "Selection of Body Segment Parameters by Optimization Methods". In *Journal of Biomechanical Engineering.* 104:38-44.

Winter, David A. (1979). *Biomechanics of Human Movement.* Toronto, Ontario: John Wiley & Sons.

Appendix D

BEAM DEFLECTION

The translational deformation of a member due to bending for the elastic range of the material is governed by the following equation [Beer and Johnston, 1981]:

$$\frac{\frac{d^2y}{dx^2}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{1.5}} = \frac{M\ (x)}{E\ I} \tag{D.1}$$

For the case of a cantilever beam with a vertical point load applied at the free end, the numerical solution for large deflections has been computed [Mattiasson, 1981]. As indicated by the published results when the translational deflection exceeds 15% of the length of the beam an error of approximately 7% exists when the slope of the beam is neglected from the flexure equation. Therefore, for small deflections the slope of the curve of the beam is negligible and the equation may be reduced to the following second order differential equation:

$$\frac{d^2y}{dx^2} = \frac{M\ (x)}{E\ I} \tag{D.2}$$

By modeling the springboard as a propped, hinged beam of uniform cross-sectional area with a concentrated, vertical load acting at the free end, the closed-form solution for the deflection can be easily obtained as shown.

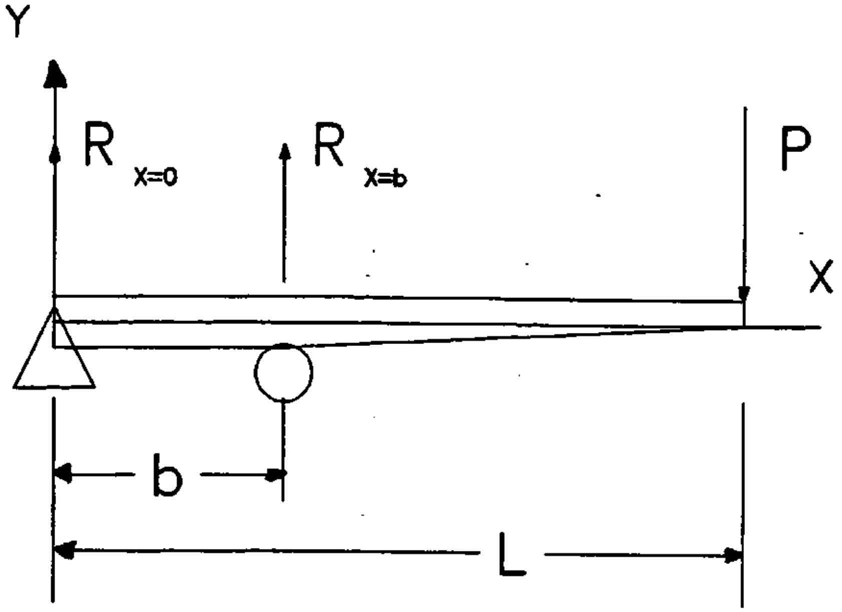


Figure D-1: The springboard modeled as an overhanging beam

From the free body diagram of the beam (Figure D-1) the reaction forces can be calculated to be $R_{x=0} = -P\left(\frac{L}{b} - 1\right)$ and $R_{x=b} = P\left(\frac{L}{b}\right)$, Figure D-1. Thus, the corresponding bending moment equation may be defined as:

for $0 < x < b$ $$M(x) = -P\left(\frac{L}{b} - 1\right)x \tag{D.3}$$

and for $b < x < L$ $$M(x) = -P\left(\frac{L}{b} - 1\right)x + P\left(\frac{L}{b}\right)(x-b) \tag{D.4}$$

Thus using the singularity function notation[12] the elastic deflection equation becomes:

$$E\ I\,\frac{d^2y}{dx^2} = -P\left(\frac{L}{b} - 1\right)x + P\left(\frac{L}{b}\right) <x-b> \tag{D.5}$$

For a uniform cross-sectional area of a homogeneous material, the flexure rigidity, $E\ I$, is independent of position and the integration process yields:

$$E\ I\,\frac{dy}{dx} = \frac{-P}{2}\left(\frac{L}{b} - 1\right)x^2 + \frac{P}{2}\left(\frac{L}{b}\right)<x-b>^2 + C_1 \tag{D.6}$$

$$E\ I\ y(x) = \frac{-P}{6}\left(\frac{L}{b} - 1\right)x^3 + \frac{P}{6}\left(\frac{L}{b}\right)<x-b>^3 + C_1x + C_2 \tag{D.7}$$

From the given constraints of the member, namely the board is affixed at $x=0$ and at $x=b$ and the corresponding translational deflections will be zero; thus the integration constants may be solved as shown:

---

[12] The singularity notation infers $<x-b> = \begin{cases} (x-b), & x \geq b \\ 0, & x < b \end{cases}$.

$$y(x = 0) = 0 \quad \Rightarrow \quad C_2 = 0 \tag{D.8}$$

$$y(x = b) = 0 \quad \Rightarrow \quad C_1 = \frac{P}{6}\left(Lb - b^2\right) \tag{D.9}$$

Hence the equation for elastic curvature becomes:

$$y(x) = \frac{-P}{6\ E\ I}\left[\left(\frac{L}{b} - 1\right)x^3 - \left(\frac{L}{b}\right)<x-b>^3 - \left(Lb - b^2\right)x\right] \tag{D.10}$$

As evident, the deflection for a given position of the fulcrum, b, and given placement of the load, x, will vary linearly with the magnitude of the load. For example for $x = L$ the deflection can be computed as:

$$y(x = L) = \frac{-P\ L}{3\ E\ I}\,(L-b)^2 \tag{D.11}$$

and the board stiffness, the rate at which deflection varies with respect to the load, can be defined as:

$$k = \frac{3\ E\ I}{L\,(L-b)^2} \tag{D.12}$$

This illustrates that stiffness is a function of load application, positioning of the fulcrum, and the geometric properties of the board.

Nomenclature

y	transverse deflection axis
x	horizontal position along the beam
$E\ I$	flexure rigidity where:

E	Young's Modulus of elasticity of the material
I	moment of inertia of the cross-sectional area with respect to a line perpendicular to the x- and y-axis passing through the center of mass of the cross-sectional area
L	length of the springboard/beam
b	distance between the fulcrum and the hinge
$P(x,t)$	applied load as a function of position and time
$R_{x=0}$	vertical reaction force at the hinge
$R_{x=b}$	vertical reaction force at the fulcrum
$M(x)$	bending moment for the beam

REFERENCES

Beer, F.P. and E.R. Johnston. (1981). *Mechanics of Materials.* New York, New York: McGraw-Hill, Inc.

Mattiasson, Kjell. (1981). *Numerical Results From Large Deflection Beam And Frame Problems Analysed By Means of Elliptic Integrals.* [Short communication]. Toronto, Ontario: John Wiley & Sons, Ltd.

Appendix E

SPRINGBOARD PARAMETER INVESTIGATIONS

E.1. Introduction

In representing the springboard as an equivalent, linear, lumped-parameter mass-spring-damper system, the coefficients may be determined through investigating the characteristic behavior of a springboard. Experimental procedures focused on examining static deflection and load relations to evaluate stiffness and on analyzing kinematic history patterns of springboard vibrations to approximate mass and damping coefficients. Therefore, through analyzing the behavior of a Duraflex, Model A springboard, the parameters of stiffness, mass and damping were evaluated.

E.2. Procedure

The procedure for evaluating the stiffness parameter involved measuring the change in vertical deflection of the springboard for various load configurations. The datum for calculating changes in deflection was the equilibrium position of the unloaded board. Using a tape measure with 1 mm divisions, the vertical deflection of the loaded springboard were recorded at the position where the load was acting. The loading range of 0 to 800 N was applied in 200 N increments by positioning Weilder International weights at a set location. The set of locations that were examined, were 0.05 m, 0.20 m, 0.4 m, 0.6 m, and 0.8 m from the free end of the springboard. Data for each of the above locations were recorded for three positions of the fulcrum: fulcrum at maximum forward position, centered, and at furthest back position.

Secondly, the equivalent mass and damping coefficient were determined by examining springboard oscillations. Disturbing the springboard by releasing it from an initially deflected position, caused the springboard to vibrate. The acceleration history profiles of the vibrations were recorded for each of the three fulcrum settings of ahead, centered, and back at five positions along the board which were 0.0 m, 0.2 m, 0.4 m, 0.6 m, and 0.8 m from the free end of the board. The apparatus involved clamping an accelerometer (Statham linear accelerometer with an operating range of ±10 g) with its sensitive direction perpendicular to the board surface. Accelerometer output was fed to an ultra-violet, Honeywell Visi-corder. The analog recorder employed a 100 Hz filter. Its paper feed rate was 50 mm/s. A 10 Hz timing pulse generated by the recorder enabled time calibration of the output. By inverting the accelerometer from its mounted configuration a 2 g range could be measured for calibrating the accelerometer.

E.3. Data Analysis

The analysis for the stiffness evaluation involved plotting load-deflection curves for the analyzed loading range for each location of the load and each fulcrum setting. The linear relation enabled Hooke's Law to be applied for evaluating the stiffness parameter. The results, as calculated using linear regression, are summarized in Table E-1.

The frequency of the oscillation, $f = \frac{1}{2\pi}\sqrt{\frac{k}{m} - \frac{B^2}{4M^2}}$, and the rate of decay of the amplitude of the oscillations, $\frac{B}{2M}$, made possible the calculating of effective mass and damping coefficients. From the accelerometer tracing, the period of oscillation can be read directly, and the logarithmic plot of peak acceleration with respect to time furnished information on the decay.

For the various positions along the springboard under different configuration, the results of the evaluated coefficients have been summarized in Table E-2. The evaluated range of stiffness was from 6400 to 19000 N/m and the range for effective mass values was from 8.5 to 20 kg.

E.4. Discussion

As previously discussed (Section 2.3 Springboard Modeling), the unique relations among the stiffness, mass and damping coefficients with respect to load application and springboard configuration existed. Firstly, the stiffness can be modeled as a linear spring for the examined load range of 0 to 800 N. The magnitude of the spring constant is affected by both the position along the springboard and the fulcrum setting. As the load position is located farther away from the free end or as the fulcrum is moved closer to the free end, the stiffness increased. These relations of stiffness with respect to fulcrum setting or with respect to location of measurement are nonlinear, as predicted from the beam flexure equation (Appendix D).

Similarly, these parameters of position along the board and fulcrum setting affected the magnitude of the equivalent mass. The examined positions nearer to the free end for a given fulcrum setting had a correspondingly lower effective mass values. Apparently, a more compliant board involved less effective mass. However, as the fulcrum was moved forward towards the free end, creating a stiffer board, the effective mass decreased. Apparently, less of the springboard mass was effective. This is evident by examining the overhanging section of the springboard; as the fulcrum is moved forward the length of overhang is reduced and less of the board undergoes large oscillations. These relations of effective mass with respect to position along the board or fulcrum setting were nonlinear.

Lastly, the evaluated damping coefficients did not exhibit well-behaved relations with respect to either the fulcrum setting or position. The initial displacements of the free end used to initiate springboard oscillation were not constant; this variability may account for the lack of a consistent relation between the damping coefficient with respect to board configuration. Generally, as the fulcrum setting was adjusted to be farther from the free end and the examined position was closer to the fulcrum the damping coefficient decreased.

The results of Table E-2 provide approximate values for the stiffness, mass and damping coefficients associated with the Duraflex, Model A springboard. For example, from Table E-2, if the diver contacts the board at 0.2 m from the free end, the effective mass and stiffness parameters will be 8.8 kg and 7850 N/m, respectively, if the fulcrum is centered and 9.4 kg and 6425 N/m, respectively, for the fulcrum set at its furthest back position. The indicated relations among coefficient magnitude and geometric configuration of the springboard are valuable in modeling the springboard behavior and understanding diver-springboard interaction. However, the experimental evaluation of parameters provides only approximate values for the coefficients, due to the inherent experimental errors. For example, an error in the value of the spring constant may be due to inaccurate readings of the deflection as a result of poor resolution, failure to attain a true vertical deflection measurements, and poor placement of the load. Also, the paper feed of the strip chart recorder occasionally malfunctioned resulting in errors in recording time-dependent behavior for evaluating mass and damping coefficients. Nonetheless, the results provide estimates for the coefficients used in modeling the springboard as a lumped mass-spring system for various modeling situations employing a Duraflex, Type A, springboard.

Table E-1: Load-Deflection Measurements

A. FULCRUM POSITION: AHEAD

Load	Difference in Deflection (cm) measured at Load Application x			
N	x=0.20m	x=0.40m	x=0.6m	x=0.8m
0	0	0	0	0
200	2.2	1.9	1.5	1.3
400	4.7	3.9	2.9	2.4
600	6.8	5.6	4.3	3.4
800	9.0	7.3	5.6	4.3
Evaluation of Stiffness(N/m)	8851	10802	14127	17926

B. FULCRUM POSITION: CENTERED

Load	Difference in Deflection (cm) measured at Load Application x			
N	x=0.20m	x=0.40m	x=0.6m	x=0.8m
0	0	0	0	0
200	2.3	2.1	1.7	1.3
400	4.9	3.9	3.3	2.4
600	7.5	6.1	4.9	3.7
800	10.1	8.3	6.6	5.1
Evaluation of Stiffness(N/m)	8024	9800	12185	16002

C. FULCRUM POSITION: BACK

Load	Difference in Deflection (cm) measured at Load Application x				
N		x=0.20m	x=0.40m	x=0.6m	x=0.8m
0	0	0	0	0	0
200		3.3	2.5	2.2	1.4
400		6.3	5.0	4.3	3.1
600		9.4	6.7	6.3	4.6
800		12.5	10.2	8.3	6.3
Evaluation of Stiffness(N/m)		6397	8174	9568	12912

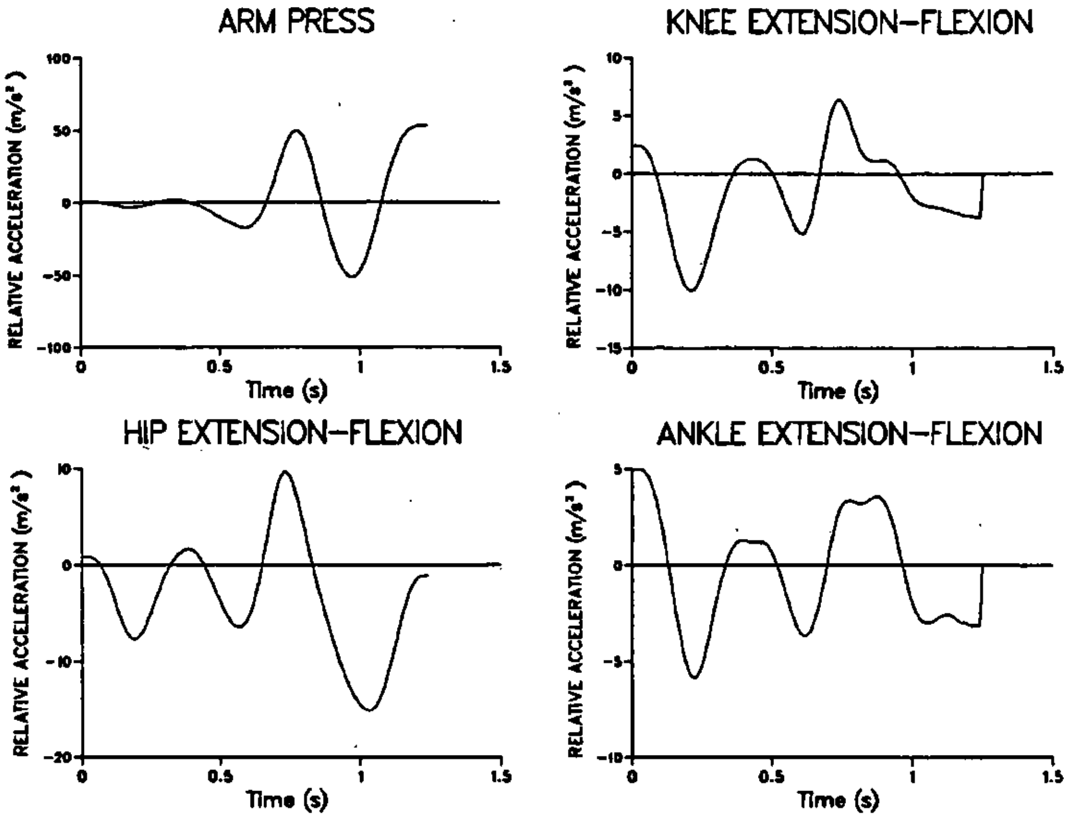
Table E-2: Board Parameter Relations

Location	Fulcrum	Period	Slope	K	B	M
0.2	Ahead	0.20	-0.154	8975	2.79	9.09
	Center	0.21	-0.108	7850	1.90	8.77
	Back	0.24	-0.105	6425	1.97	9.37
0.4	Ahead	0.20	-0.158	10950	3.51	11.09
	Center	0.22	-0.134	9550	3.14	11.71
	Back	0.24	-0.096	8000	2.25	11.67
0.6	Ahead	0.20	-0.228	14750	6.84	14.95
	Center	0.22	-0.109	12150	3.24	14.90
	Back	0.25	-0.075	9800	2.33	15.51
0.8	Ahead	0.20	-0.176	18975	6.76	19.21
	Center	0.22	-0.133	15700	5.11	19.25
	Back	0.25	-0.104	12525	4.11	19.83

Appendix F

MOVEMENT SKILLS: RELATIVE ACCELERATION PATTERNS

As discussed in Section 2.4 Modeling Human Motion and Section 2.5 Spatio-temporal Optimization, relative acceleration patterns are used to define internal segment forces. These relative accelerations are representative of learned movement skills. This research defines an arm swing as the acceleration difference between the center of gravity of the arm segment and the center of gravity of the head and torso segment. Similarly, hip extension-flexion is defined as the difference in acceleration between the head and torso segment and the upper leg segment; knee extension-flexion is defined as the difference in acceleration between the upper and lower leg segments, and ankle extension-flexion is the difference in acceleration between the lower legs and the feet segments. For the analyzed performances these movements skills are pictured on the following pages.



ARM PRESS

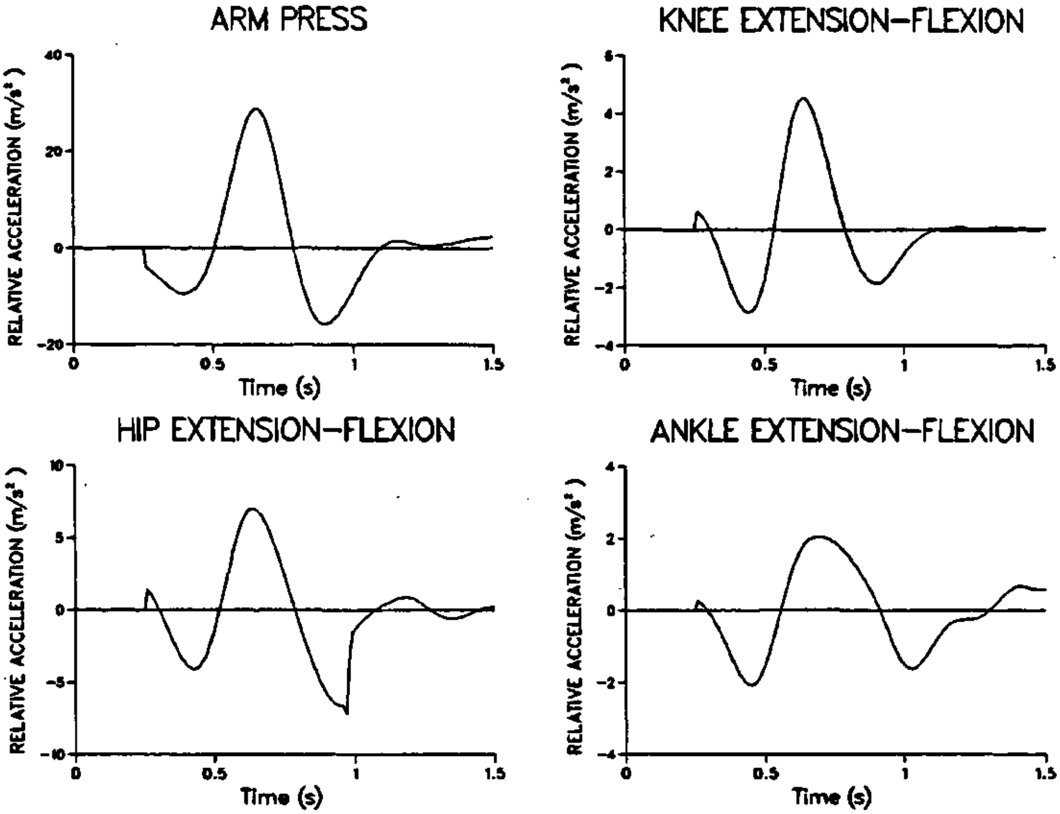
KNEE EXTENSION–FLEXION

HIP EXTENSION–FLEXION

ANKLE EXTENSION–FLEXION

As performed, the diver contacted the board at 0.69 s; maximum board deflection occured at 0.87 s; the diver departed from the board at 1.01 s.

Figure F-1: Demonstrated Movement Skills of Forward 1 1/2 Pike Dive



As performed, the diver contacted the board at 0.54 s; maximum board deflection occured at 0.76 s; the diver departed from the board at 0.96 s.

Figure F-2: Demonstrated Movement Skills of Forward Layout Jump

Appendix G

SIMULATION SOURCE CODE

The simulation and optimization of performance of the springboard diving skills was completed with the aid of the following computer software program. The program, coded in FORTRAN, performs computation using double precision arithmetic. The only external routine accessed is the Livermore Solver for Ordinary Differential Equations (LSODA) [Hindmarsh, 1982].

Basically, the program calculates the kinematics for each segment, the springboard, and the center of gravity of the diver for various conditions. The analysis models the hurdle phase, the board contact phase and the aerial phase. The input parameters for the program include springboard and athlete segment modeling parameters and kinematic data representing the actual skill performance which contains initial conditions for each segment.

To begin, the program calculates the relative acceleration history curves using the absolute acceleration patterns of the center of gravity of adjacent segments; this result represents learned movement skills. The input, absolute segmental accelerations, is performance-specific and may be obtained using cinematography. The simulation is initiated during the hurdle phase; calculation of resultant motion is performed according to the flight phase trajectory equations (Section 2.5 Spatio-Temporal Optimization). At each time step of the hurdle phase, the displacement of the feet is traced to determine the instant of board contact. During the board contact phase the segmental motion is governed by equations modeling springboard-diver interaction (Section 2.5 Spatio-Temporal Optimization). The instant that the diver departs is assumed to occur when the board returns to the position of static deflection or when the feet of the diver accelerate faster than an unloaded board would for the given deflection. Once the diver departs the motion of the athlete is modeled using the flight phase equations.

Complete acceleration, velocity, and displacement history curves of the body segments, springboard and center of gravity of the diver are calculated. The employed integration is based on Simpson's Rule.

In optimizing the time of execution of learned movement skills, the relative acceleration profiles are time stepped; then, as described, the resultant motion of the athlete is calculated. Next, the objective function which relates the kinematic state of the center of gravity of the diver at departure to the maximum height achievable in the flight phase is examined. (Note: the following version of the program examines the effects of arm swing execution and the output for each simulation includes: time of board contact, maximum board deflection, and the board departure; the velocity and displacement of the center of gravity of diver at departure; and the maximum height attainable in the following aerial maneuver).

The source code for the simulation/optimization program follows:

```
***************************************************************
**      SPRINGBOARD DIVER OPTIMIZATION PROGRAM               **
**          Denise Derby Stilling   1988 Revisions           **
***************************************************************
*  PROGRAM DESCRIPTION                                        *
*                                                             *
*       This program simulates the resultant springboard      *
*    diving performance for the hurdle to board contact to    *
*    flight phase.  The effects of time of execution of a     *
*    learned movement skill on the overall performance are    *
*    examined.                                                *
*       As is, this program examines the effects of time of   *
*    execution of the arm swing on the height attained in     *
*    the flight phase.                                        *
*       Variations of the program and output parameters may   *
*    be adjusted to investigate other factors affecting       *
*    springboard diving performances.                         *
*       Computation was completed using SI units.             *
*                                                             *
***************************************************************
*    To run program:                                          *
*         FORTRAN OPT                                         *
*         LINK OPT, LSODA                                     *
*         RUN OPT                                             *
*   Program Needs: LSODA.OBJ, AARMS.VJ1, ATORSO.VJ1,          *
*       AULEG.VJ1, ALLEG.VJ1, and AFOOT.VJ1                   *
***************************************************************
*                                                             *
*  NOMENCLATURE                                               *
*                                                             *
*   x           For the purpose of variable identification    *
*                x = I, II, III, IV, V, or VI and corresponds *
*                to arms, head&torso, upper legs, lower legs, *
*                and feet segments, and springboard,          *
*                respectively                                 *
*                                                             *
*   I J K L     Loop indices                                  *
*                                                             *
*   FLAG        Indicates phase of calculation (0-hurdle,     *
*                 1-board contact, 2-flight)                  *
*   CTRFLT      Counter of number of frames computed for the  *
*   CTRBC         the hurdle, board contact and flight phases *
*   CTRDEP        respectively                                *
*                                                             *
*   Mx          Mass (kg) of the rigid body x                 *
*   BODWT       Total mass (kg) of the athlete                *
*                                                             *
```

```
*                                                              *
*   SPK         Stiffness parameter for the springboard        *
*   GR          Acceleration due to gravity (-9.81 m/s2)       *
*                                                              *
*   DELTAT      Actual time interval between computations      *
*   SR          Film speed (frames/second)                     *
*   SHIFT/STIME Number of frames/time-shift a sub-skill        *
*                                                              *
*   NF          Number of frames to be simulated               *
*                                                              *
*   C(1/2)INV   Coefficient matrices/constants for expressing  *
*   COND(1/2)     the differential equations of motion         *
*   COEFA         or calculating resultant motion              *
*   CONST SUM                                                  *
*   SOLN  PROD                                                 *
*                                                              *
*   RACCx       Actual (input) accelertion of x                *
*   DACx        Relative acceleration curves (learned movement *
*                 skills)                                      *
*   AFx         Calculated resultant forces of x               *
*                                                              *
*   Yox         Initial displacement for segment               *
*   Y1ox        Initial velocity for segment x                 *
*   YINIT       Initial displacement between the board & feet  *
*   YSTBDEF     Static board deflection                        *
*                                                              *
*   VELx        Velocity of x from integrating acceleration    *
*   Dx          Displacement of x from integrating velocity    *
*                                                              *
*   Yx          Absolute displacement, velocity, and           *
*   Y1x           acceleration, respectively for body          *
*   Y2x           segments and springboard                     *
*   YCGD        Absolute displacement, velocity, and           *
*   Y1CGD         acceleration for the center of gravity       *
*   Y2CGD         of the diver                                 *
*                                                              *
*   STOR, ICT, IPT ISHIFT Temporary storage values of results  *
*                                                              *
****************************************************************
```

```
**************************************************************
*                                                            *
*  DECLARATION & DIMENSION BLOCK                             *

      EXTERNAL F, JAC                   ! LSODA Requirements

      INTEGER I, K, J, L, IV, N, NF, A, B, BI, SHIFT, FLAG,
     1   BEG, BEND, CTRFLT, CTRBC, CTRDEP, ICT, IPT,
     2   ISHIFT

      INTEGER IWORK(25), IOPT, ISTATE, ITASK,JT,LIW,LOUT,LRW,
     1   ML, MU, NEQ, NERR, ORD         ! LSODA Requirements

      DOUBLE PRECISION MI, MII, MIII, MIV, MV, MVI, BODWT,
     1    SPK, GR, DELTAT, SR, COEFA, CONST, YSTBDEF,
     2    Y1oI, Y1oII, Y1oIII, Y1oIV, Y1oV, Y1oVI,
     2    YoI, YoII, YoIII, YoIV, YoV, YoVI,
     3    YINIT, YVPN, VELY, SUM, PROD, DISP, STIME
     4    VelI, VelII, VelIII, VelIV, VelV, VelVI,
     5    DI, DII, DIII, DIV, DV, DVI, CLMVEL, Y2BRD

      DOUBLE PRECISION ATOL, RTOL, RWORK(60),
     1   DKY(5), T, TOUT, Y(5)          ! Requirement For LSODA

      DOUBLE PRECISION RACCI(150),  RACCII(150), RACCIII(150),
     1   RACCIV(150), RACCV(150),  RACCVI(150), DACI(150),
     2   DACII(150), DACIII(150), DACIV(150), DACV(150),
     3   AFI(150), AFII(150), AFIII(150), AFIV(150), AFV(150),
     4   AFVI(150),C1INV(5,5),C2INV(6,6),COND1(5,1),COND2(6,1),
     5   SOLN(6,1), STOR(75,5)

      DOUBLE PRECISION Y2I(150),    Y1I(150),    YI(150),
     1        Y2II(150),  Y1II(150),  YII(150),
     2        Y2III(150), Y1III(150), YIII(150),
     3        Y2IV(150),  Y1IV(150),  YIV(150),
     4        Y2V(150),   Y1V(150),   YV(150),
     5        Y2VI(150),  Y1VI(150),  YVI(150),

      DOUBLE PRECISION Y2ACCN(3), DISPVI(150),
     1   Y1CGD(150),Y2CGD(150),YCGD(150)

      COMMON I, DACI, DACII, DACIII, DACIV, DACV, SPK, MVI,
     1        SHIFT
```

```
******************************************************************
*       INPUT AND INITIALIZATION BLOCK

        DATA LOUT/6/, DELTAT/0.01/, GR/9.81/, BODWT/73.94/,
     1    MI /7.394/, MII /42.73732/, MIII /14.788/, MIV /6.876/,
     2    MV /2.14426/, MVI /13.75/, SPK /7490/, NF /150/,
     3    NERR /0/, ITOL /1/, RTOL /0.0/, ATOL/1.0D-06/, LRW/60/,
     4    LIW /25/, IOPT /0/, NEQ /2/, JT /1/, ORD /1/, ICT /0/

******************************************************************

448     FORMAT(1X,4HSHFT,1X,3H CT,3X,5H YMAX,1X,5H DEPT,5X,5HY1CGD,
     1          8X,5H YCGD,8X,9H REF DISP)
449     FORMAT(4F6.1,3F14.8)
                  WRITE(6,448)

****((************************************************************
*  OPENING BLOCK
          OPEN(UNIT=21,FILE='AARMS.VJ1',STATUS='OLD')
          OPEN(UNIT=22,FILE='ATORSO.VJ1',STATUS='OLD')
          OPEN(UNIT=23,FILE='AULEG.VJ1',STATUS='OLD')
          OPEN(UNIT=24,FILE='ALLEG.VJ1',STATUS='OLD')
          OPEN(UNIT=25,FILE='AFOOT.VJ1',STATUS='OLD')
                ! Actual Acceleration Data for each segment

******************************************************************
*  READ BLOCK
          READ(21,*) (RACCI(I),   I=1,150)
          READ(22,*) (RACCII(I),  I=1,150)
          READ(23,*) (RACCIII(I), I=1,150)
          READ(24,*) (RACCIV(I),  I=1,150)
          READ(25,*) (RACCV(I),   I=1,150)

******************************************************************
*  INITIALIZATION BLOCK
                SR     =   1.0/DELTAT
                IFR     =   25       ! Initial frame for analysis

*   Generation of Relative Acceleration Vectors
        DO 102 I = 1,150,1              ! (Learned movement skills)
                DACI(I)   = RACCI(I)    -  RACCII(I)
                DACII(I)  = RACCII(I)   -  RACCIII(I)
                DACIII(I) = RACCIII(I)  -  RACCIV(I)
                DACIV(I)  = RACCIV(I)   -  RACCV(I)
 102    CONTINUE
```

```
*****************************************************************
*   Set values of the inverse coefficient (mass) matrix
              ! pertain for free fall conditions (flight phases)
       C1INV(1,1)   =  MI*(MII + MIII + MIV + MV)/BODWT
       C1INV(1,2)   =  MI*(MIII + MIV + MV)/BODWT
       C1INV(1,3)   =  MI*(MIV + MV)/BODWT
       C1INV(1,4)   =  MI*(MV)/BODWT
       C1INV(1,5)   =  MI

       C1INV(2,1)   = -1*MII*MI/BODWT
       C1INV(2,2)   =  MII*(MIII + MIV + MV)/BODWT
       C1INV(2,3)   =  MII*(MIV + MV)/BODWT
       C1INV(2,4)   =  MII*(MV)/BODWT
       C1INV(2,5)   =  MII

       C1INV(3,1)   = -1*MIII*MI/BODWT
       C1INV(3,2)   = -1*MIII*(MI + MII)/BODWT
       C1INV(3,3)   =  MIII*(MIV + MV)/BODWT
       C1INV(3,4)   =  MIII*(MV)/BODWT
       C1INV(3,5)   =  MIII

       C1INV(4,1)   = -1*MIV*MI/BODWT
       C1INV(4,2)   = -1*MIV*(MI + MII)/BODWT
       C1INV(4,3)   = -1*MIV*(MI + MII + MIII)/BODWT
       C1INV(4,4)   =  MIV*MV/BODWT
       C1INV(4,5)   =  MIV

       C1INV(5,1)   =-1*MV*(MI)/BODWT
       C1INV(5,2)   =-1*MV*(MI + MII)/BODWT
       C1INV(5,3)   =-1*MV*(MI + MII+ MIII)/BODWT
       C1INV(5,4)   =-1*MV*(MI + MII + MIII + MIV)/BODWT
       C1INV(5,5)   =  MV



              ! pertain to springboard-diver interaction
       C2INV(1,1)   = MI*(MII+ MIII+ MIV+ MV+ MVI)/(BODWT+ MVI)
       C2INV(1,2)   = MI*(MIII + MIV + MV + MVI)/(BODWT + MVI)
       C2INV(1,3)   = MI*(MIV + MV + MVI)/(BODWT + MVI)
       C2INV(1,4)   = MI*(MV + MVI)/(BODWT + MVI)
       C2INV(1,5)   = MI*(MVI)/(BODWT + MVI)
       C2INV(1,6)   = MI/(BODWT + MVI)

       C2INV(2,1)   = -1*MII*(MI)/(BODWT + MVI)
       C2INV(2,2)   = MII*(MIII + MIV + MV + MVI)/(BODWT+ MVI)
       C2INV(2,3)   = MII*(MIV + MV + MVI)/(BODWT + MVI)
       C2INV(2,4)   = MII*(MV + MVI)/(BODWT + MVI)
       C2INV(2,5)   = MII*(MVI)/(BODWT + MVI)
```

```
C2INV(2,6)   = MII/(BODWT + MVI)

C2INV(3,1)   = -1*MIII*(MI)/(BODWT + MVI)
C2INV(3,2)   = -1*MIII*(MI + MII)/(BODWT + MVI)
C2INV(3,3)   = MIII*(MIV + MV + MVI)/(BODWT + MVI)
C2INV(3,4)   = MIII*(MV + MVI)/(BODWT + MVI)
C2INV(3,5)   = MIII*(MVI)/(BODWT + MVI)
C2INV(3,6)   = MIII/(BODWT + MVI)

C2INV(4,1)   = -1*MIV*(MI)/(BODWT + MVI)
C2INV(4,2)   = -1*MIV*(MI + MII)/(BODWT + MVI)
C2INV(4,3)   = -1*MIV*(MI + MII + MIII)/(BODWT + MVI)
C2INV(4,4)   = MIV*(MV + MVI)/(BODWT + MVI)
C2INV(4,5)   = MIV*(MVI)/(BODWT + MVI)
C2INV(4,6)   = MIV/(BODWT + MVI)

C2INV(5,1)   = -1*MV*(MI)/(BODWT + MVI)
C2INV(5,2)   = -1*MV*(MI + MII)/(BODWT + MVI)
C2INV(5,3)   = -1*MV*(MI + MII + MIII)/(BODWT + MVI)
C2INV(5,4)   = -1*MV*(MI+ MII+ MIII+ MIV)/(BODWT+ MVI)
C2INV(5,5)   =  MV*(MVI)/(BODWT + MVI)
C2INV(5,6)   =  MV/(BODWT + MVI)

C2INV(6,1)   = -1*MVI*(MI)/(BODWT + MVI)
C2INV(6,2)   = -1*MVI*(MI + MII)/(BODWT + MVI)
C2INV(6,3)   = -1*MVI*(MI + MII + MIII)/(BODWT + MVI)
C2INV(6,4)   = -1*MVI*(MI+ MII+ MIII+ MIV)/(BODWT+ MVI)
C2INV(6,5)   = -1*MVI*(MI+MII+MIII+MIV+MV)/(BODWT+MVI)
C2INV(6,6)   = MVI/(BODWT + MVI)
```

```
*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*

*  SIMULATION AND OPTIMIZATION PROGRAM

        DO  209 SHIFT= -10,10,1      ! For time step movement skills

*          Initialize Solution Vectors

                DO 101 I = 1,150
                        AFI(I)      =  0.0
                        AFII(I)     =  0.0
                        AFIII(I)    =  0.0
                        AFIV(I)     =  0.0
                        AFV(I)      =  0.0
                        AFVI(I)     =  0.0

                        YCGD(I)     =  0.0
                        YI(I)       =  0.0
                        YII(I)      =  0.0
                        YIII(I)     =  0.0
                        YIV(I)      =  0.0
                        YV(I)       =  0.0
                        YVI(I)      = -0.018009
                        DISPVI(I)   = -0.018009

                        Y1CGD(I)    =  0.0
                        Y1I(I)      =  0.0
                        Y1II(I)     =  0.0
                        Y1III(I)    =  0.0
                        Y1IV(I)     =  0.0
                        Y1V(I)      =  0.0
                        Y1VI(I)     =  0.0

                        Y2CGD(I)    =  0.0
                        Y2I(I)      =  0.0
                        Y2II(I)     =  0.0
                        Y2III(I)    =  0.0
                        Y2IV(I)     =  0.0
                        Y2V(I)      =  0.0
                        Y2VI(I)     =  0.0
101             CONTINUE
```

```
****************************************************************
*  Initial Conditions
*    with adjustments for phase change of movement skill

             STIME = SHIFT * DELTAT
             ICT = ICT + 1
             STOR(ICT,1) = SHIFT
              Y1oI    =  -0.8668        ! Initial Velocities
              Y1oII   =  -0.44758       !   (Frame 24)
              Y1oIII  =  -0.44759
              Y1oIV   =  -0.447725
              Y1oV    =  -0.492936

              YoI     =  0.98638  ! Deflection wrt
              YoII    =  0.58689  !  board contact
              YoIII   =  0.53707  !  (Fr 24-55)
              YoIV    =  0.50107
              YoV     =  0.48546
              YoVI    = -1.0080     ! distance cg (Fr 24) from
                                    ! board

              YSTBDEF  =-0.018009
              YINIT    = 0.4506086 ! Integ. Foot Vel'y
                                   ! (Fr 25-55)
              YINIT = -0.5*GR*(STIME**2)+Y1oV*STIME+YINIT
              YVPN     = YINIT

              Y1oI     = -1*GR*STIME + Y1oI
              Y1oII    = -1*GR*STIME + Y1oII
              Y1oIII   = -1*GR*STIME + Y1oIII
              Y1oIV    = -1*GR*STIME + Y1oIV
              Y1oV     = -1*GR*STIME + Y1oV

*   Initialize flags and counters

             FLAG    = 0      ! Set to 1 to examine board contact

             CTRFLT  = 0      ! Flight calculation counter
             CTRBC   = 0      ! Board contact calculation counter
             CTRDEP  = 0      ! Flight calculation counter

*   Calculation of Diver Kinematic Performance Data

             DO 201 I = 25, 150, 1
                K = I - 1
             IF (FLAG.NE.0) GOTO 27  ! program flow director
             IF(YVPN.GE.0)THEN       ! Check for board contact
```

```
*   Condition 1:  flight phase calculations
                CTRFLT = CTRFLT + 1      ! Flt Counter

*   Temporary storage array for relative acceleration terms
                        COND1(1,1) = DACI(I - SHIFT)  ! shifting
                                                      ! arm swing
                        COND1(2,1) = DACII(I)
                        COND1(3,1) = DACIII(I)
                        COND1(4,1) = DACIV(I)
                        COND1(5,1) = -1*GR

*   Calculation of Absolute Force
                        DO 896 N=1,5
                                  SUM = 0
                             DO 895 J=1,5
                                PROD=C1INV(N,J)*(COND1(J,1))
                                SUM = SUM + PROD
895                          CONTINUE
                              SOLN(N,1) = SUM
896                     CONTINUE
                           AFI(I)   = SOLN(1,1)
                           AFII(I)  = SOLN(2,1)
                           AFIII(I) = SOLN(3,1)
                           AFIV(I)  = SOLN(4,1)
                           AFV(I)   = SOLN(5,1)

*   Calculation to determine position of feet
                Y2V(I) = (AFV(I))/MV     ! Abs. acc'n of feet
                IF (CTRFLT.LT.2) THEN
                  Y1V(I) = Y1oV
                  DISP = DELTAT * Y1V(I)
                ELSE
                  A  = IFR-1
                  BI = I
                  CALL SINTEG(Y2V,A,BI,SR,VELY)
                  Y1V(I) = VELY + Y1oV  ! Abs. velocity of feet
                  CALL SINTEG(Y1V,A,BI,SR,DISP)
                ENDIF
                  YVPN = DISP + YINIT   ! Abs. disp. of feet
                ELSE
*   Condition 2: Board contact calculations
                FLAG = 1.0
27              IF (FLAG.NE.1) GOTO 28 ! Program flow control
                CTRBC = CTRBC + 1      ! Brd Contact Counter

*   Calculation of Board Acceleration
           IF(CTRBC.EQ.1) THEN  ! 1st brd contact calculation
                IMK = I
```

```
                STOR(ICT,2) = IMK
                CALL SINTEG(Y2V,A,I,SR,VELY)
                Y1V(I)  = VELY + Y1oV
*   Board Velocity calculation:
*     applying conservation of linear momentum,
*     using reduced board mass
                CLMVEL = MV*Y1V(I)/(MV + MVI*0.00001)
                        Y1VI(K) = CLMVEL
                        Y1V(K) = CLMVEL
                        YVI(K) = YSTBDEF + Y1VI(K)*DELTAT
                ELSE
                ENDIF
*   Arguments for LSODA (Initial Value Diff. Equ'n Solver) Package
                ISTATE = 1
                ITASK = 1
                T = 0.0
                TOUT = T + DELTAT
                Y(1) = YVI(K)
                Y(2) = Y1VI(K)

      CALL LSODA(F, NEQ, Y, T, TOUT, ITOL, RTOL, ATOL, ITASK,
     1               ISTATE, IOPT, RWORK, LRW, IWORK, LIW, JAC, JT)

                YVI(I) = Y(1)      ! Displacement of the board
                Y1VI(I) = Y(2)     ! Velocity of the board

      CALL INTDY(T, ORD, RWORK(21), NEQ, DKY, IFLAG)
                Y2VI(I) = DKY(2)  ! Acceleration of the board

      IF ((YVI(K).LT.YVI(I)).AND.(STOR(ICT,5).EQ.0))STOR(ICT,5)=K

*   Temporary storage array for relative acceleration terms
                        COND2(1,1) = DACI(I-SHIFT)
                        COND2(2,1) = DACII(I)
                        COND2(3,1) = DACIII(I)
                        COND2(4,1) = DACIV(I)
                        COND2(5,1) = DACV(I)
                        COND2(6,1) =-1*SPK*YVI(I)
                                        ! Board Interaction Force
*   Calculation of Absolute forces
                DO 899 N=1,6
                     SUM = 0
                   DO 897 J=1,6
                       PROD=C2INV(N,J)*(COND2(J,1))
                       SUM = SUM + PROD
897                CONTINUE
                      SOLN(N,1) = SUM
899             CONTINUE
```

```
                      AFI(I)    = SOLN(1,1) - MI*GR
                      AFII(I)   = SOLN(2,1) - MII*GR
                      AFIII(I)  = SOLN(3,1) - MIII*GR
                      AFIV(I)   = SOLN(4,1) - MIV*GR
                      AFV(I)    = SOLN(5,1) - MV*GR
                      AFVI(I)   = SOLN(6,1) - MVI*GR
                ENDIF

        Y2BRD = -1*(GR +SPK*YVI(I)/MVI)
                         ! Brd Acc'n from Spring Force

*   Condition to determine if departure occurs:
*     either the board returns to state of static deflection
*     or the feet move away at a greater accelertion than the
*     board does due to the action of the spring force.
        IF((YVI(I).GT.(-0.018009)).OR.
     1     ((YVI(I).GT.YVI(K)).AND.((Y2VI(I)-Y2BRD).GT.0.001)))THEN
                FLAG = 2.0
28              CONTINUE
                CTRDEP = CTRDEP + 1  ! Aerial flight counter
                IF(CTRDEP.EQ.1) STOR(ICT,3) = I

*   Temporary storage array for relative acceleration terms
                        COND1(1,1) = DACI(I - SHIFT)
                        COND1(2,1) = DACII(I)
                        COND1(3,1) = DACIII(I)
                        COND1(4,1) = DACIV(I)
                        COND1(5,1) = -1*GR

*   Calculation of Absolute Force
                DO 696 N=1,5
                     SUM = 0
                   DO 695 J=1,5
                       PROD=C1INV(N,J)*(COND1(J,1))
                       SUM = SUM + PROD
695                CONTINUE
                      SOLN(N,1) = SUM
696             CONTINUE
                      AFI(I)    = SOLN(1,1)
                      AFII(I)   = SOLN(2,1)
                      AFIII(I)  = SOLN(3,1)
                      AFIV(I)   = SOLN(4,1)
                      AFV(I)    = SOLN(5,1)
                ELSE
                ENDIF

201             CONTINUE
```

```
*****************************************************************
*  CALCULATION OF KINEMATICS OF THE DIVER'S CENTER OF GRAVITY
*
*   Calculating resultant, absolute, segmental accelerations
                   DO 229 K = IFR,150
                     Y2I(K)= (AFI(K))/MI
                     Y2II(K)= (AFII(K))/MII
                     Y2III(K)= (AFIII(K))/MIII
                     Y2IV(K) = (AFIV(K))/MIV
                     Y2V(K)  = (AFV(K))/MV
                     Y2VI(K) = (AFVI(K))/MVI
229                CONTINUE
*   Calculating absolute, segmental velocities
                 DO 241 K = (IFR+1), 150
                         A = IFR
                         B = K
                     CALL SINTEG(Y2I,A,B,SR,VelI)
                     CALL SINTEG(Y2II,A,B,SR,VelII)
                     CALL SINTEG(Y2III,A,B,SR,VelIII)
                     CALL SINTEG(Y2IV,A,B,SR,VelIV)
                         Y1I(K)    = VelI + Y1oI
                         Y1II(K)   = VelII + Y1oII
                         Y1III(K)  = VelIII + Y1oIII
                         Y1IV(K)   = VelIV + Y1oIV
241              CONTINUE
        DO 240 K = (IFR+1),(IFR+CTRFLT),1
                A = IFR
                B = K
                     CALL SINTEG(Y2V,A,B,SR,VelV)
                     CALL SINTEG(Y2VI,A,B,SR,VelVI)
                         Y1V(K)    = VelV + Y1oV
                         Y1VI(K)   = VelVI + Y1oVI
240     CONTINUE
        DO 242 K = (IFR+CTRFLT+1),NF,1
                A = IFR + CTRFLT
                B = K
                     CALL SINTEG(Y2V,A,B,SR,VelV)
                     CALL SINTEG(Y2VI,A,B,SR,VelVI)
                         Y1V(K)    = VelV + CLMVEL
                         Y1VI(K)   = VelVI + CLMVEL
242     CONTINUE

*   Calculation of segmental displacements
        DO 243 K = (IFR+1), NF
          A = IFR
          B = K
          CALL SINTEG(Y1I,A,B,SR,DI)
          CALL SINTEG(Y1II,A,B,SR,DII)
```

```
        CALL SINTEG(Y1III,A,B,SR,DIII)
        CALL SINTEG(Y1IV,A,B,SR,DIV)
        CALL SINTEG(Y1V,A,B,SR,DV)
        CALL SINTEG(Y1VI,A,B,SR,DVI)
         YI(K)   = YoI+DI-0.5*GR*(STIME**2)+Y1oI*STIME
         YII(K) = YoII+DII-0.5*GR*(STIME**2)+Y1oII*STIME
         YIII(K)= YoIII+DIII-0.5*GR*(STIME**2)+Y1oIII*STIME
         YIV(K) = YoIV+DIV-0.5*GR*(STIME**2)+Y1oIV*STIME
         YV(K)   = YoV+DV-0.5*GR*(STIME**2)+Y1oV*STIME
         YVI(K) = YoVI+DVI
243     CONTINUE

*   Diver's Center of gravity calculations
        CALL CGCALC(Y2CGD,Y2I,Y2II,Y2III,Y2IV,Y2V,NF)
                                                   ! Acceleration
        CALL CGCALC(Y1CGD,Y1I,Y1II,Y1III,Y1IV,Y1V,NF)
                                                   ! Velocity
        CALL CGCALC(YCGD,YI,YII,YIII,YIV,YV,NF)
                                                   ! Displacement
                IPT = STOR(ICT,3)
                        ! Calculation of the attained height
                VelDiv =  Y1CGD(IPT)
                IF (VelDiv.LT.0.0) VelDiv = 0.0
                        ! Performance criteria:  flight phase height
                STOR(ICT,4) = (VelDiv**2)/(2*GR) + YCGD(IPT)

*   Output
                TYPE 449, STOR(ICT,1),STOR(ICT,2),STOR(ICT,5),
    1             STOR(ICT,3),Y1CGD(IPT), YCGD(IPT),STOR(ICT,4)
                STOR(ICT,4) = Y1CGD(IPT)
209     CONTINUE

*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*

****************************************************************
*   Close Files

                CLOSE(UNIT=21)
                CLOSE(UNIT=22)
                CLOSE(UNIT=23)
                CLOSE(UNIT=24)
                CLOSE(UNIT=25)

                END

***************************************************************
```

The following pages contain the subroutines that are called in the above program.

```
***********************************************************
*       SUBROUTINE
*          Performs numerical integration of a function given the
*       discrete values of the function and the time interval. The
*       TRAPEZOID RULE is applied when one interval is passed,
*       otherwise SIMPSON'S RULE is used.
*          [REFERENCE: Numerical Analysis by Burden p.149ff]
*
        SUBROUTINE SINTEG(ARRAY,A,B,SR,ANSWER)
          INTEGER A, B, IV, BEG, CMPT, DIFF
          REAL RV
          DOUBLE PRECISION AH,X1O,X1ODD,X2EVEN,SUM,ANSWER,ARRAY(150)

                  AH = 1/SR

                  X1ODD = 0.0
                  X2EVEN = 0.0

                  SUM    = 0.0

                  DIFF = B - A
                  BEG  = A + 1
                  CMPT = B - 1

                  X1O = ARRAY(A) + (ARRAY(B))

         IF (DIFF.EQ.1) THEN     ! one interval: trapezoidal rule
               ANSWER = (AH/2.0)*(X1O)
         ELSE

          IF((DIFF/2.0)-(DIFF/2).EQ.0)THEN
                   ! even # of intervals: 1/3 Simpson Rule
                DO 12  I = BEG,CMPT
                      RV = I/2.0
                      IV = I/2.0
                   IF  ((RV-IV).EQ.0)THEN
                       X2EVEN = X2EVEN + ARRAY(I)
                   ELSE
                       X1ODD   =  X1ODD + ARRAY(I)
                   ENDIF
12              CONTINUE
             ANSWER = (AH/3.0) * (X1O + (4*X2EVEN) + (2*X1ODD))

          ELSE
                   ! odd # of intervals: 3/8 & 1/3 Simpson Rule
```

```
          S38 = (3.0*AH/8)*(ARRAY(A) + 3*(ARRAY(A+1) +
     1                       ARRAY(A+2)) + ARRAY(A+3))
                    IF ((A+3).LT.CMPT)THEN
                                ! more than 3 intervals
                    DO 14 I = A + 4, CMPT
                            RV = I/2.0
                            IV = I/2.0
                       IF ((RV-IV).EQ.0)THEN
                            X2EVEN = X2EVEN + ARRAY(I)
                       ELSE
                            X1ODD  =  X1ODD + ARRAY(I)
                       ENDIF
14                 CONTINUE
        S13 =  (AH/3.0) * (ARRAY(A+3) + (4*X2EVEN) + (2*X1ODD) +
     1                          ARRAY(B))
                    ELSE
                      S13 = 0.0
                    ENDIF
                ANSWER = S38 + S13
        ENDIF
      ENDIF
      RETURN
      END




*************************************************************
*  SUBROUTINE
*       External routine defines the function solved by LSODA

      SUBROUTINE F (NEQ,T,Y,YDOT)
        INTEGER NEQ
        DOUBLE PRECISION T, COEFA, CONST, Y(2), YDOT(2)
        CALL SETUP(CONST, COEFA)
        YDOT(1) = Y(2)
        YDOT(2) = COEFA*Y(1) + CONST
      RETURN
      END
```

```
************************************************************
*     SUBROUTINE
*       Computes the kinematics of centre of gravity of diver
*

        SUBROUTINE CGCALC(SOLN,Y1,Y2,Y3,Y4,Y5,NC)
           INTEGER K, NC
           DOUBLE PRECISION MI,MII,MIII,MIV,MV,NUM,BODWT
           DOUBLE PRECISION SOLN(150),Y1(150),Y2(150),Y3(150),
     1          Y4(150),Y5(150)
        DATA MI /7.394/, MII /42.73732/, MIII /14.788/,
     1    MIV /6.87642/, MV /2.14426/, BODWT /73.94/

           DO 25 K = 1,NC
             NUM = Y1(K)*MI + Y2(K)*MII + Y3(K)*MIII
     1                                  + Y4(K)*MIV + Y5(K)*MV
             SOLN(K) = NUM / BODWT
25        CONTINUE
        RETURN
        END




************************************************************
*   SUBROUTINE
*        External Subroutine computes the Jacobian for LSODA

        SUBROUTINE JAC (NEQ,T,Y,ML,MU,PD, NROWPD)
          INTEGER IND, NEQ, ML, MU, NROWPD
          DOUBLE PRECISION T, COEFA, PD(NROWPD,2), Y(2)
          CALL SETUP(CONST, COEFA)

          PD(1,1) = 0.0D0
          PD(1,2) = 1.0D0
          PD(2,1) = COEFA
          PD(2,2) = 0.0D0
        RETURN
        END
```

```
*****************************************************************
*   SUBROUTINE
*       Computes required parameters to set-up
*       board contact equation

        SUBROUTINE SETUP (CONST,COEFA)
          INTEGER I, SHIFT
          DOUBLE PRECISION COEFA,CONST,GR,C1,C2,C3,C4,C5 C6,
     1     SPK, MI, MII, MIII, MIV, MV, MVI, BODWT, DACI(150),
     2     DACII(150), DACIII(150), DACIV(150), DACV(150)

        COMMON I, DACI, DACII, DACIII, DACIV, DACV, SPK, MVI,
     1                 SHIFT

        DATA GR/9.81/, BODWT/73.94/,
     1    MI /7.394/, MII /42.73732/, MIII /14.788/,
     2    MIV /6.87642/, MV /2.14426/

* Coefficients for board contact calculations
                COEFA = -1*SPK/(MVI + BODWT)
                C1    = -1*MI/(MVI+ BODWT)
                C2    = -1*(MI + MII)/(MVI + BODWT)
                C3    = -1*(MI + MII + MIII)/(MVI+ BODWT)
                C4    = -1*(MI + MII + MIII + MIV)/(MVI+BODWT)
                C5    = -1*(MI + MII + MIII + MIV + MV)/
     1                            (MVI+BODWT)
                C6    = -1

          CONST = C1*DACI(I-SHIFT) + (C2*DACII(I)) +
     1       C3*DACIII(I) + C4*DACIV(I) + C5*DACV(I) + C6*GR

        RETURN
        END

*****************************************************************
```

REFERENCE

Hindmarsh, Allan C. (1982). "ODEPACK: A Systematized Collection of ODE Solvers". (PREPRINT UCRL-88007) For R.S. Stepleman (ed.), *Numerical Methods for Scientific Computation.*

Appendix H

PROGRAM LISTING of the KNOWLEDGE BASED EXPERT SYSTEM for SPRINGBOARD SKILL ANALYSIS

This appendix contains the source code listing related to the Knowledge Based Expert System Springboard Diving Skill Analysis program. The program language has been FORTHMACS[13]. The system has been divided into several files; each file corresponds to a specific function as summarized below.

LOAD.KES	After FORTHMACS has been loaded, this file is loaded. It directs subsequent loading of necessary files associated with the Knowledge Based Expert System Springboard Diving Skill Analysis program.
GENERAL.KES	Forth definitions used in subsequent subroutines during program operation.
SCREEN.KES	Title, introductory and instruction screens, that are displayed during the loading process, encoded as Forth definitions.
DICTION.KES	Definitions of springboard diving terminology used in the *definition* feature and the subroutine calls of Expert-2.

---

[13] A shareware implementation of Forth developed by Bradley Forthware.

EXPERT2.FTH[14]	The expert system tool kit used in developing the Springboard Diving Skill Analysis Program; a version of the MVP Expert-2 Toolkit that was originally developed Jack Park.
BASIC.RLS	The knowledge base used to determine the type of performance to be analyzed.
SHORT.RLS	The knowledge base module associated with identifying the contributing cause of an entry being *short* of vertical.
LONG.RLS	The knowledge base module associated with identifying the contributing cause of an entry being *long* of vertical.
FAR.RLS	The knowledge base module associated with identifying the contributing cause of an entry being too *far* from the board.
CLOSE.RLS	The knowledge base module associated with identifying the contributing cause of an entry being too *close* to the board.
AESTHET.RLS	The knowledge base module associated with identifying the contributing cause of an entry being poor aesthetically.
TWIST.RLS	The knowledge base module associated with identifying the contributing cause of a *twist* occurring at entry.
DCHECK.RLS	The knowledge base procedural rules used to check for incorrect entry from the introductory identification of gross performance error and to confirm exiting from the program.
File_name.GRF[15]	Forth definitions used to generated the graphics used in the program. The 'file_name' is the position being illustrated [File_name is either Approach, Armswing, Hurdle, Reach, Layout, Pike, Tuck or Stretch]. These illustrations represent ideal performance.

---

[14] The source code has not been reproduced; this code has not been released as public domain.

[15] This source code has not been included in this appendix.

FILE NAME: LOAD.KES

```
\ Loading Sequence for the SPRINGBOARD ANALYSIS K.B.E.S.


 fload general.kes        \ FORTH Definitions


 fload screen.kes         \ Introductory Information


 title.scr                \ Runs the Title Screen



\ Graphic routines -- used in procedural subroutines and definitions

 fload approach.grf        fload armswing.grf        fload hurdle.grf
 fload layout.grf          fload tuck.grf            fload pike.grf
 fload stretch.grf         fload reach.grf



 fload diction.kes        \ Springboard Diving Terminology


 disclaimer               \ Runs a Disclaimer Screen


 fload expert2.fth        \ Loads the K.B.E.S. Tool kit


 Instructions             \ presents program instructions
```

FILE NAME: GENERAL.KES

```
\ General Run Words to be used with K.B.E.S.

: dud ;

: cls erase-screen ;

: ncr ( n ---  )            \ does n carriage returns
  0 do cr loop ;

: margin   cr 4 spaces ;    \ sets up spacing for output to
: npar  2 ncr 7 spaces ;    \ the screen

: response ( c --- )        \ awaits for a keyboard response
  key drop cls ;

: 1st-non-bl-char ( $address --- c)
       count 0 do dup i + c@ dup dup
          bl = not swap printable? and
          if swap drop leave else drop then
         loop   dup 255 > if drop ascii n then ;

: keyin  ( --- c)
       pad 15 bl fill 14 pad c!
       pad 1+ 14 expect pad 1st-non-bl-char ;

: continue
  2 ncr 35 spaces dark ." . . . PRESS ANY KEY TO CONTINUE "
  light response ;


: continue1
  2 ncr 35 spaces dark ." . . . PRESS ANY KEY TO CONTINUE "
  light key drop 1 ;


: gr_continue
  npar
  ." Press any key to view illustration of the skill" response ;

\ General Graphic Words to be used with K.B.E.S.

 needs line-a-init linea.fth

 line-a-init                        \ initializes graphic mode

 variable xpixel variable ypixel
```

```
                \ display device's maximum x & y range
variable xoff   variable yoff
                \ desired offset
variable xmax   variable ymax
                \ maximum x and y range of data

get-rez ypixel ! xpixel !

: spair  \ performs inversion and coordinate to pixel scaling
   ypixel @  swap yoff @ + ypixel @ ymax @   */ -
   swap   xoff @ + xpixel @  xmax @ */  swap ;

: sdot2   \ connects two coordinate pairs with straight line
          \ leaving the last pair on the stack
   2dup 2rot spair 2swap spair draw ;

: SDOT2  sdot2 ;

: ndrop ( xx xx xx n --- )    \ drops n stack items
  0 do drop loop ;

: ndup ( xx n --- xx xx xx )  \ duplicates a stack items n times
  0 do dup loop ;
```

FILE NAME: SCREEN.KES

```
\ Introductory Screens for Springboard Diving K.B.E.S.


: title.scr              \ title screen for the program
   cls 7 ncr 15 spaces
    dark ."  Knowledge Based Expert System Application " light
   3 ncr 15 spaces 19 spaces dark ."  for " light
   3 ncr 20 spaces
    dark ."  SPRINGBOARD DIVING SKILL ANALYSIS " light
   12 ncr 22 spaces 189 emit
        ."  1989 University of Saskatchewan."
   cr 15 spaces
        ." All rights for commercial purposes are reserved."
;



: disclaimer             \ disclaimer for the program
 cls 4 ncr margin
." This software package was developed in the Department of Mechanical"
 margin
." Engineering  at the University of Saskatchewan.  The program is to"
 margin
." be used with a modified version of the MVP EXPERT-2 TOOLKIT."
 npar margin
." Financial  assistance  was  received  from  SASK SPORT BURSARY and"
 margin
." SPORT CANADA GRANT."
 npar  margin
." The  intent of  the  program  is  to explore the  applications  of"
 margin
." Knowledge Based Expert System to coaching.  This  program  assists"
 margin
." in analyzing springboard diving skill performances."
 npar  margin
." The  program  determines  the  cause  of  fundamental error(s) and"
margin
." provides advice which may serve as a guideline for directing skill"
margin
." development.  The  developers accept  no  liability  regarding the"
margin
." information presented during program use."
 continue ;
```

```
 : Instructions                  \ program instructions
 cr 5 to-column
." The program requires your response to various questions.   Based on"
 cr 5 to-column
." your response an appropriate cause of the performance error will be"
 cr 5 to-column
." identified." cr
 cr 5 to-column
." As prompted  by the program,  your  response  may be a  single  key"
 cr 5 to-column
." stroke -- either an indicated number or letter. To continue program"
 cr 5 to-column
." operation, press the <RETURN> key after your response." cr
 cr 5 to-column
." INPUT IDENTIFICATION: " 2 ncr
   10 to-column ." Y=yes   -- verifies the statement to be true"
cr 10 to-column ." N=no    -- verifies the statement to be false"
cr 10 to-column ." W=why   -- interrogates the system's rational"
cr 10 to-column ." T=trace -- reviews program rational[Not functional]"
cr 10 to-column ." Q=quit  -- allows you to exit from the program"
cr 10 to-column
        ." X=change response--permits altering previous input"
cr 10 to-column
        ." D=definition  -- provides explanation of the word(s)"
cr 27 to-column
        ." displayed in UPPER CASE of the program text"
2 ncr 5 spaces
." EXPERT-2" 189 emit ." 1983 by NIMBLE.  EXPERT-2 is NOT released as a"
 cr 5 spaces
." public domain program for wholesale duplication and distribution."
;
```

FILE NAME: DICTION.KES

```
\ Dictionary: vocabulary containing definitions & graphics

true caps !  \ desensitizes  Forth's case dependency

vocabulary  dictionary        also dictionary definitions

: return-status  previous also  ;

: Gr_Approach          cls  gapproach         continue ;
: Gr_Arm_swing         cls  garm_swing        continue ;
: Gr_Take-Off          cls  greach            continue ;
: Gr_Hurdle            cls  ghurdle           continue ;
: Gr_Open_Pike         cls  gopen_pike        continue ;
: Gr_Closed_Pike       cls  gclosed_pike      continue ;
: Gr_Semi-Closed_Pike  cls  gsemi-closed_pike continue ;
: Gr_Pike  Gr_Open_Pike  Gr_Closed_Pike  Gr_Semi-Closed_Pike ;
: Gr_Tuck              cls  gtuck             continue ;
: Gr_Layout            cls  glayout           continue ;
: Gr_Stretch           cls  gstretch          continue ;

: AESTHETICS
 npar
   ." Aesthetics refers to the diver's form and control during the"
 margin
 ." execution of a dive.  Often,  a  poorly  executed dive results"
 margin
 ." if  firm  musculature  is not maintained  or  when  basic  body"
 margin
 ." positions are improperly performed.  Straight lines attained in"
 margin
 ." the body positions are aesthetically pleasing.   This is a very"
 margin
 ." subjective area of evaluation."   return-status ;

: APPROACH
 npar
  ." All forward dives are initiated with a 3 or 4 step  approach."
 margin
 ." The approach is a controlled, smooth walk.  Good DIVING POSTURE"
 margin
 ." should be maintained throughout the walk and the length of each"
 margin
 ." stride should be comfortable (as per everyday activities). Arms"
 margin
 ." should be extended and their swing should be approximately 6 to"
 margin
```

```
 ." 8 inches away from the body.  The last  step of the approach is"
 margin
 ." onto the PRESS LEG so that the HURDLE may be performed."
 Gr_Continue Gr_Approach return-status ;

: ARM_SWING
 npar
   ." The ARM SWING is performed as part of the APPROACH sequence."
 margin
 ." It is executed in completing the HURDLE.  During the ARM SWING,"
 margin
 ." the arms (with elbows locked) are swung  simultaneously  around"
 margin
 ." the shoulder. The arms begin to circle from slightly behind the"
 margin
 ." body and continue downward toward the knees(arm press). Simult-"
 margin
 ." aneously, the diver's knees bend.  As the arms continue through"
 margin
 ." they are accelerated upward in front of the body(arm lift). The"
 margin
 ." arms are  approximately shoulder width apart and palms face each"
 margin
 ." other. As the arms accelerate upward, the legs(knees and ankles)"
 margin
 ." extend to either the REACH position or the HURDLE position."
 npar
   ." This action should be continuous  with the arms accelerating"
 margin
 ." during the arm lift phase only."
 Gr_Continue Gr_Arm_swing return-status ;

: CLOSE
 npar
   ." A dive  is  considered  CLOSE  to the board  if the point of"
 margin
 ." entry is within 10 inches (25 cm)  from the edge of the spring-"
 margin
 ." board  or  if  the diver  contacts the board  during the aerial"
 margin
 ." maneuver. "
 npar
   ." A diver will enter close to the board if he fails to develop"
 margin
 ." sufficient horizontal, linear momentum. This is often due to a"
 margin
 ." backward lean at TAKE-OFF."
      return-status ;
```

```
: DIVE
 npar
  ." A DIVE is a performances where the entry is head first."
        return-status ;

: DIVING_ATTENTION
 npar
   ." DIVING POSTURE or DIVING ATTENTION is when the diver assumes"
 margin
 ." a standing position with good posture;  his musculature is firm"
 margin
 ." throughout.  His heels, insteps, lower legs,  knees, and thighs"
 margin
 ." should  be  placed  together.  The legs  should be extended and"
 margin
 ." locked.  Buttock  muscles  should  be  squeezed  together.  The"
 margin
 ." stomach muscles should be tightened towards the back-bone.  The"
 margin
 ." hands should be straight  in line with the wrists and forearms."
 margin
 ." The fingers  should be together with the thumbs slightly tucked"
 margin
 ." in.  The arms are kept at the side and  aligned with the center"
 margin
 ." of the diver's  body.  The shoulders should be parallel to  the"
 margin
 ." deck surface and in line with the entire front of the body. The"
 margin
 ." head and neck  should  be held vertical  with the eyes focusing"
 margin
 ." along a line that makes a 45 degree angle with the board."
 return-status ;

: DIVE_ENTRY
 npar
 ." The  STRETCH  position  is  the desired entry position for all"
 margin
 ." head-first entries. Firm body musculature is maintained in this"
 margin
 ." position.  As with the  REACH  position  the arms  are extended"
 margin
 ." above the diver's head. The hands grasp as described for a FLAT"
 margin
 ." HAND  ENTRY.  The arms are  stretched  and squeezed against the"
 margin
 ." diver's head. The eyes focus on the grasped hands. The angle of"
 margin
```

```
 ." entry should be just short of vertical."
  Gr_Continue Gr_Stretch return-status ;

: DIVING_POSTURE DIVING_ATTENTION ;

: EXTENSION
 npar
 ." After completing an aerial maneuver the diver must prepare for"
 margin
 ." entry.  The extension of the diver from either a TUCK or  PIKE"
 margin
 ." position is called the KICKOUT/EXTENSION.   In performing, the"
 margin
 ." KICKOUT/EXTENSION all action should be symmetric." return-status ;

: FAR
 npar
   ." An entry is considered  FAR  from the board if the point of"
 margin
 ." entry exceeds 30 inches (75 cm) away from the free edge of the"
 margin
 ." springboard.  "
 npar
   ." A  diver  will enter  far from  the board  if  he  develops"
 margin
 ." excessive horizontal linear momentum.  Usually this is attrib-"
 margin
 ." uted to the diver's lean at TAKE-OFF exceeding 5 to 10 degrees"
 margin
 ." forward of vertical."
 return-status ;

: FLAT_FEET
 npar
  ." For all jumps (foot-first entries), the  FLAT FEET  position"
 margin
 ." is to be maintained once the feet  have  entered  the water --"
 margin
 ." this stable configuration assist in keeping the entry vertical"
 margin
 ." The position  involves  extended legs being squeezed together."
 margin
 ." The  feet  are  dorsi-flexed,  as  they would be in a standing"
 margin
 ." position."   return-status ;

: FLAT_HAND_ENTRY
 npar
```

```
  ." A  FLAT HAND ENTRY  is performed  with the palms are turned"
margin
." outward and away from the diver. The diver's thumbs interlock."
margin
." The fingers of  the hand  performing the grasp  encompass  the"
margin
." middle of  the other hand.   This  hand position is  performed"
margin
." with extended arms and locked elbows."
return-status ;

: JUMP
npar
." A JUMP is a diving performances where the entry is feet first."
        return-status ;

: JUMP_ENTRY
npar
  ." DIVING  POSTURE  with  pointed  toes  is  the desired entry"
margin
." position for jumps. Once the diver's feet enter the water, the"
margin
." FLAT FOOT position should be assumed and maintained."
npar
  ." In preparing for a jump entry, the diver should extend to a"
margin
." LAYOUT position prior to attaining DIVING POSTURE."
DIVING_POSTURE  ;

: HURDLE
npar
  ." The  HURDLE  is performed after the initial APPROACH steps."
margin
." As the PRESS LEG extends, the HURDLE KNEE and arms are lifted,"
margin
." simultaneously.  Good  extension  in the  hurdle  position is"
margin
." desirable.   The  hurdle is landed on two feet;  a  final  ARM"
margin
." SWING is performed prior to the diver leaving  from the board."
margin
." The diver should maintain a visual contact with the end of the"
margin
." board  without  dropping  his head and shoulders forward.  The"
margin
." length of the hurdle jump should be less than the length of a"
margin
." normal walking stride."  Gr_Continue Gr_Hurdle return-status ;
```

```
: HURDLE_KNEE
npar
  ." The PRESS LEG is the jumping leg of the hurdle.  The  diver"
margin
." steps onto his press leg  and  extends it during  execution of"
margin
." the hurdle.  For right-handed people, the press leg usually is"
margin
." the left leg.   The other leg is called the  HURDLE LEG.   The"
margin
." hurdle knee is raised to form a 90 degree angle with the body;"
margin
." the plane of the  HURDLE KNEE is horizontal,  at waist height."
margin
." The lower part of the  HURDLE  leg may be tucked in such that"
margin
." the angle at the knee ranges between 45 to 90 degrees).   The"
margin
." toes should be pointed when executing the hurdle."
 return-status ;

: HURDLE_LEG HURDLE_KNEE ;

: KICKOUT EXTENSION ;

: LAYOUT
npar
  ." From  DIVING  POSTURE,  the arms are raised laterally upwards,"
margin
." with the elbows, wrists, hands, and fingers straight and in line,"
margin
." to shoulder height. The arms should be parallel with the standing"
margin
." surface." Gr_Continue Gr_Layout return-status ;

: LONG
npar
  ." An entry is considered LONG if the diver extends beyond the"
margin
." desired angle of entry.  The entry is forward of the vertical."
margin
." This  error  is  attributed to over rotating during the flight"
margin
." phase."
npar
  ." In competition a deviation of  20 degrees from the vertical"
margin
." results in a 3 to 4 point deduction in the diver's score."
```

```
return-status ;

: PIKE
npar
  ." In the PIKE position,  the  legs  are extended and toes are"
margin
." pointed.  The diver bends at the waist.   In assuming the PIKE"
margin
." position, the arms reach down towards the legs in front of his"
margin
." body  as the legs are raised.  The  positioning  of  the  arms"
margin
." varies;  the three accepted  PIKE  configurations are the OPEN"
margin
." PIKE, CLOSED PIKE, and SEMI-CLOSED PIKE   (refer to individual"
margin
." definition)." Gr_Continue Gr_Pike return-status ;

: OPEN_PIKE
npar
  ." This PIKE is performed with the diver bending at the waist;"
margin
." arms are extended laterally (as in the LAYOUT position);  legs"
margin
." are extended with pointed toes."
Gr_Continue Gr_Open_Pike return-status ;

: CLOSED_PIKE
npar
  ." This PIKE is performed with the hands  grasping  the back of"
margin
." the legs(near the knees).  Arms, with elbows remaining close to"
margin
." the body, as the arms pull the chest down towards the extended"
margin
." legs." Gr_Continue Gr_Closed_Pike  return-status ;

: SEMI-CLOSED_PIKE
npar
  ." This PIKE position has the diver reaching ( with extended"
margin
." arms) towards his pointed toes."
Gr_Continue Gr_Semi-closed_Pike  return-status ;



: PIKE_SAVE
npar
```

```
  ." A PIKE SAVE  can be performed  to align a diving entry."
margin
." Once the diver submerges below the surface  (waist level),"
margin
." he should pike ( bend at the waist ) and perform a forward"
margin
." roll. This action should help align his feet to a vertical"
margin
." entry position."  return-status ;

: PRESS_LEG  HURDLE_KNEE ;

: REACH
npar
  ." In this position, the diver is fully extended. His arms"
margin
." are straight with elbows locked  and reach above his head;"
margin
." his hips, knees, and ankles are fully extended.  The diver"
margin
." has a slight  forward lean  ( When performed properly, the"
margin
." be able to hold this  extended position for 3 to 5 seconds"
margin
." before falling forward).  Prior to the diver departing from"
margin
." the board (or throwing into his maneuver), the diver should"
margin
." attain the REACH position." Gr_Continue Gr_Take-Off return-status ;

: RIP_ENTRY
npar
  ." Instruct  the  diver  to maintain  firm body musculature"
margin
." throughout the performance.   After the diver impacts  the"
margin
." water, instruct  the athlete to pull his arms to his side."
margin
." The pull should be even and extend laterally." return-status ;

: SHORT
npar
  ." An entry is considered  SHORT  if the angle of entry is"
margin
." behind the vertical;  the  diver fails to reach a vertical"
margin
." entry position.This error is attributed to under-rotation."
npar
```

```
  ." In competition, a  deviation of  20  degrees  from  the"
margin
." vertical results in a 3 to 4 point deduction in the dive's"
margin
." score." return-status ;

: STRETCH DIVE_ENTRY ;

: TAKE-OFF
npar
  ." Prior  to  departing  from the board,  the diver should"
margin
." attain the REACH position.  In this position the diver has"
margin
." a slight forward lean and is fully extended (his arms reach"
margin
." above his head; his hips, knees, and ankles are extended)."
Gr_Continue Gr_Take-Off return-status ;

: TUCK
npar
  ." The TUCK position can be attained by drawing knees into"
margin
." the chest.  Simultaneously, the arms reach  laterally with"
margin
." the hand grasping the lower leg  (right hand on right leg,"
margin
." left hand on left leg).  The elbows shlould remain close to"
margin
." the  sides of the diver.  The  toes remain pointed with the"
margin
." heels brought  in towards the buttocks.   The  head  should"
margin
." remain in line with the body." Gr_Continue Gr_Tuck return-status ;

: TWIST
npar
  ." A twist at entry means  the  diver does  not  align his"
margin
." parallel  to the free edge  of the board  causing a 'cork-"
margin
." screw' entry.   This fault is  most  prevalent in twisting"
margin
." dives.  A dive is considered a failed dive if the twist at"
margin
." entry is greater than 1/8." return-status ;

only forth also definitions
```

```
: x-diction dictionary ;

: D_Approach    2 ncr ." APPROACH: "   [ x-diction ] APPROACH    1 ;
: D_Hurdle      2 ncr ." HURDLE: "     [ x-diction ] HURDLE      1 ;
: D_Take-Off    2 ncr ." TAKE-OFF: "   [ x-diction ] TAKE-OFF    1 ;
: D_Stretch     2 ncr ." STRETCH: "    [ x-diction ] DIVE_ENTRY  1 ;
: D_Jump_Entry  2 ncr ." JUMP ENTRY: "[ x-diction ] JUMP_ENTRY  1 ;
: D_Tuck        2 ncr ." TUCK: "       [ x-diction ] TUCK        1 ;
: D_Layout      2 ncr ." LAYOUT: "     [ x-diction ] LAYOUT      1 ;
: D_Pike        2 ncr ." PIKE: "       [ x-diction ] PIKE        1 ;
: D_Open_Pike   2 ncr ." OPEN PIKE: "  [ x-diction ] OPEN_PIKE   1 ;
: D_Semi-Closed_Pike
      2 ncr ." SEMI-CLOSED PIKE:" [ x-diction ] SEMI-CLOSED_PIKE 1 ;
: D_Closed_Pike 2 ncr ." CLOSED PIKE:" [ x-diction ] CLOSED_PIKE 1 ;
: D_Pike_Save   2 ncr ." PIKE SAVE: " [ x-diction ] PIKE_SAVE   1 ;
: D_Rip_Entry   2 ncr ." RIP ENTRY: " [ x-diction ] RIP_ENTRY   1 ;
: D_Flat_Hand_Entry
      2 ncr ." FLAT HAND ENTRY: " [ x-diction ] FLAT_HAND_ENTRY 1 ;
: D_Flat_Feet   2 ncr ." FLAT FEET: " [ x-diction ] FLAT_FEET      1 ;
: D_Arm_Swing   2 ncr ." ARM PRESS:"  [ x-diction ] ARM_SWING      1 ;
: D_Diving_Posture
      2 ncr ." DIVING POSTURE:"   [ x-diction ] DIVING_POSTURE  1 ;
: D_Dive_Entry  2 ncr ." DIVE ENTRY:" [ x-diction ] DIVE_ENTRY     1 ;

only forth also definitions

: APPR-CONSISTENT
 npar
   ." The diver may need  to adjust the starting position for the"
 margin
 ." board contact phase.  Associating a counting sequence with the"
 margin
 ." approach through to the hurdle phase.  Consistency needs to be"
 margin
 ." developed,  ensure  that the athlete begins the approach  from"
 margin
 ." the same position  with the same foot  and  performs  the same"
 margin
 ."  number of steps each time." 1 ;


: EXTENSION_L/S
 npar
   ." Have the diver while maintaining firm musculature, practice"
 margin
 ." his extension.  The diver should perform the extension both on"
 margin
 ." the deck and in the water.  For dives, the aerial position may"
```

```
 margin
." be assumed on the board and the diver may roll ahead and extend"
 margin
." to the stretch position."  1 ;

: Restart
 npar
." To analyze another dive, type " dark ."  ANALYZE " light ." . " 1 ;

variable menu_entry        \ MENU SELECTION run word

: menu1 ( select an error)
   cls 3 ncr
  ." Select the most prevalent error (enter its corresponding #) "
   2 ncr ." 1. Entry is SHORT of vertical."
   2 ncr ." 2. Entry is LONG  of vertical."
   2 ncr ." 3. Entry is FAR from the board."
   2 ncr ." 4. Entry is CLOSE to the board."
   2 ncr ." 5. The AESTHETICS of the dive are poor."
   2 ncr ." 6. Diver TWISTS at entry."
   2 ncr ." 7. EXIT from program " 2 ncr
   keyin 2 ncr dup emit ascii 0 -  menu_entry ! ;

variable file1 variable file2 variable file3 variable file4
variable file5 variable file6 variable file7

"" short.rls      dup c@ 1+ here file1 ! ",
"" long.rls       dup c@ 1+ here file2 ! ",
"" far.rls        dup c@ 1+ here file3 ! ",
"" close.rls      dup c@ 1+ here file4 ! ",
"" aesthet.rls    dup c@ 1+ here file5 ! ",
"" twist.rls      dup c@ 1+ here file6 ! ",
"" dcheck.rls     dup c@ 1+ here file7 ! ",

: menu_check
   menu1 menu_entry @ 5 ndup
        1 - 0= if  file1 @ 1+ "load 5 ndrop else
        2 - 0= if  file2 @ 1+ "load 4 ndrop else
        3 - 0= if  file3 @ 1+ "load 3 ndrop else
        4 - 0= if  file4 @ 1+ "load 2 ndrop else
        5 - 0= if  file5 @ 1+ "load    drop else
        6 - 0= if  file6 @ 1+ "load         else
            file7 @ 1+ "load
            then then then then then then 2 ncr 1 ;
```

FILE NAME: BASIC.RLS

```
( BASIC:  Determines the type of Performance being analyzed )

  forget dummy

  : dummy ;


RULES

IF The jump/dive is performed in the LAYOUT position.*
THEN Analysis will focus on FORWARD LAYOUT JUMPS/DIVES.*
ANDTHENNOT The jump/dive is performed in the PIKE position.*
ANDTHENNOT The jump/dive is performed in the TUCK position.*
ANDTHENRUN menu_check
ANDTHENRUN continue1

IF The jump/dive is performed in the PIKE position.*
ANDIF The pike position is open (OPEN PIKE).*
ORIF The pike position is closed (CLOSED PIKE).*
ORIF The pike position is semi-closed (SEMI-CLOSED PIKE).*
THEN Analysis will focus on FORWARD PIKE JUMPS/DIVES.*
ANDTHENNOT The jump/dive is performed in the TUCK position.*
ANDTHENRUN menu_check
ANDTHENRUN continue1

IF The jump/dive is performed in the TUCK position.*
THEN Analysis will focus on FORWARD TUCK JUMPS/DIVES.*
ANDTHENRUN menu_check
ANDTHENRUN continue1

IFNOT Analysis will focus on FORWARD LAYOUT JUMPS/DIVES.*
IFNOT Analysis will focus on FORWARD PIKE JUMPS/DIVES.*
IFNOT Analysis will focus on FORWARD TUCK JUMPS/DIVES.*
THENHYP The scope of analysis is currently limited to forward
        layout/pike/tuck jumps/dives.*
ANDTHENRUN Restart

DONE
```

FILE NAME: SHORT.RLS

```
( #1 SHORT MODULE:  Diver under-rotates and enters short of vertical )


: SHORT_C
 npar
    ." An entry  that is short  results  from either  insufficient"
 margin
 ." angular momentum or a lack of height to complete the maneuver."
 margin
 ." The latter may result if the  entry point  is too far from the"
 margin
 ." board.  To correct  an entry  being short,  begin by reviewing"
 margin
 ." the fundamental components of the skill (approach, hurdle, and"
 margin
 ." take-off position); perhaps, start will a skill having a lower"
 margin
 ." degree of difficulty." 1 ;

: S1.ia
 npar
    ." To correct for  bent arms  during the arm swing, have diver"
 margin
 ." initiate his arm swing sooner.  The diver may need to increase"
 margin
  ." the height of his hurdle. Perhaps a narrower arm swing should"
 margin
 ." be used [The diver's arms should extend laterally down to  his"
 margin
 ." sides (adduct) rather than circling behind his body]. Then the"
 margin
 ." arm swing  should be continued, as normal, with straight arms."
 margin
 ."It may be necessary to decrease the depth of his swing." 1 ;


: S1a
 npar
   ." Review  the arm swing and reach positions.  The diver should"
 margin
 ." extend his legs, ankles and toes. On land, the diver should be"
 margin
 ." able to maintain the reach position  for 3 - 5 seconds  before"
 margin
." falling forward." 1 ;
```

```
: S2a
 npar
    ." The diver is concentrating  on completing the rotations and"
 margin
 ." has sacrificed the height of the aerial phase.  A  skill  with"
 margin
 ." fewer rotations  should be reviewed  with the athlete striving"
 margin
 ." to maximize the height he can attain." 1 ;

: S3a
 npar
    ." The athlete is concentrating on attaining height.  Emphasis"
 margin
 ." should be placed on performing a proper approach and hurdle to"
 margin
 ." take-off position with good extension."
 npar
    ." For advanced skills,  concentrate  on  improving the hurdle"
 margin
 ." while performing less difficult skills."
 npar
    ." At a novice level the hurdle may be improved by slowing its"
 margin
 ." execution and associating a counting sequence with each move-"
 margin
 ." ment pattern."
 npar
    ." Improved balance  and developing a kinesthetic awareness of"
 margin
 ." the skill may be achieved by performing the skill in shallow"
 margin
 ." water." 1 ;

: S4a
 npar
  ." Usually, this is attributed to a hurried approach."  1 ;

: S7/8.ia
 npar
    ." Angular momentum  may be  increased  by leaning  forward at"
 margin
 ." take-off.  During the board work phase, straight arms  should"
 margin
 ." be maintained, especially during the arm swing and when throw-"
 margin
 ." ing into the aerial maneuver."
 npar
```

```
   ." A tighter flight phase position  should  be  maintained  to"
margin
." maximize the speed of rotation.   Encourage the diver to main-"
margin
." tain firm body musculature throughout the skill."
npar
   ." The diver should increase his leg strength;  perhaps, a dry"
margin
." land program (weight training) should be started."
npar
   ." If balance and rhythm during board contact,  can  be  main-"
margin
." tained, then the fulcrum should be moved back." 1 ;

: S9/10.ia
npar
   ." The diver is already compensating for an entry that will be"
margin
." short of vertical.   The diver has made an error in the  board"
margin
." contact phase. Re-analyze the performance focus on  deviations"
margin
." in the approach, hurdle, and take-off phases." continuel DROP
 D_Approach DROP D_Hurdle DROP D_Take-Off DROP 1 ;


: S9a
npar
." The diver needs to develop a spot to begin his extension.   It"
margin
." may be helpful to call the diver out of his maneuver, until he"
margin
." develops a kinesthetic feel for the skill." 1 ;

: S9.a
npar
   ." The   diver  must  practise  his  vertical  decent  (Review"
margin
." standing fall-ins).  The  entry alignment  may be corrected by"
margin
." arching back and pressing arms ahead."
npar
   ." A  pike  save  will appear  to align  the  entry to  a near"
margin
." vertical position."  1 ;

: S10a
npar
```

```
   ." These performance errors may be caused by the KICKOUT being"
 margin
 ." too vigorous. Also, the entry position  may need to be located"
 margin
 ." closer to the board." 1 ;


MORERULES

( Rule S1.i                      Arm Press )
IF The arms bend during the ARM SWING.*
ORIF The arms fail to extend to vertical during the REACH position.*
ORIFNOT The diver throws into his maneuver with extended arms.*
THEN The arm swing needs improving.*
ANDTHENRUN S1.ia

( Rule S1                        Take-off extension )
IF Diver over extends at TAKE-OFF (arms reach behind his head).*
ORIF Diver arches his back at TAKE-OFF.*
ORIF The diver's head is extended back at TAKE-OFF.*
ORIF The arm swing needs improving.*
ORIFNOT Diver has attained full extension (ankles, knees, hips)
     prior to TAKE-OFF.*
ORIF At maximum board depression the diver has a back lean
     (more than 10 degrees behind vertical) or arches.*
THEN The diver develops excessive backward lean.*
ANDTHENRUN S1a
ANDTHENRUN Continue1
ANDTHENRUN D_Take-Off

( Rule S2                          Take-off Extension )
IF Diver lacks height in the flight phase.*
ANDIF The skill involves multiple rotations.*
ANDIF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
ORIF Diver depresses the board with his upper body,
     rather pressing with his legs.*
THEN Diver develops too much forward lean at take-off.*
ANDTHENRUN S2a

( Rule S3                        hurdle )
IF Diver drives his HURDLE leg through causing a backward lean.*
ORIF The diver kicks his HURDLE leg out rather than stepping down.*
ORIFNOT The diver has achieved his average height or greater
     in his HURDLE.*
ORIF The final approach step is too long (exceeds twice the length
     of a normal walking step).*
ORIF Diver shortens the length of his HURDLE.*
```

```
THEN The diver develops excessive backward lean.*
ANDTHENRUN S3a
ANDTHENRUN Continuel
ANDTHENRUN D_Hurdle

( Rule S4                    approach )
IF Diver leans back or arches his back during the APPROACH.*
ORIF The final approach step is too long
     (exceeds twice the length of a normal walking step).*
THEN The diver develops excessive backward lean.*
ANDTHENRUN S4a
ANDTHENRUN D_Approach

( Rule S5                    Poor landing position )
IFNOT The diver develops excessive backward lean.*
ANDIFNOT Diver develops too much forward lean at take-off.*
ANDIFNOT The diver consistently land his HURDLE within 10 cm from
     the end of the board.*
THEN The diver must adjust his starting position of his approach.*

( Rule S6                   Approach consistency )
IFNOT The diver develops excessive backward lean.*
ANDIFNOT Diver develops too much forward lean at take-off.*
ANDIFNOT The APPROACH is smooth and controlled.*
ANDIFNOT The diver consistently land his HURDLE within 10 cm from
     the end of the board.*
THEN The diver must improve his approach.*
ANDTHENRUN APPR-CONSISTENT

( Rule S7/8.i                 Lack of Angular Momentum )
IF The diver fail to complete the required rotations of the skill.*
ANDIFNOT The diver develops excessive backward lean.*
THEN The diver fails to develop sufficient angular momentum
     at take-off.*

( Rule S7                    Aerial Position )
IF The diver fails to develop sufficient angular momentum
     at take-off.*
ANDIF The arm action is slow in throwing into the aerial maneuver.*
ORIF The throw into the aerial maneuver is late.*
ORIF The diver departs from the board with bent knees.*
THEN The diver does not fully develop his potential
     angular momentum.*

( Rule S8                    Aerial Position )
IF The diver fails to develop sufficient angular momentum
     at take-off.*
ANDIFNOT The jump/dive is performed in the LAYOUT position.*
```

```
ANDIF The aerial position is loose (diver fails to pike/tuck tightly.*
THEN Diver will retard his rotational speed.*

( Rule S9/10.i                     Closed Eyes )
IF Diver's eyes are closed during the aerial or KICKOUT.*
THEN Diver is unable to spot the water to time his extension.*

( Rule S9.i                       Dive extension/entry--saves)
IF The performance is a DIVE.*
ANDIF The diver performs a PIKE SAVE at entry.*
ORIF Diver opens his arms forward and away from the springboard
     during his EXTENSION.*
ORIF Diver raises his head during the flight phase.*
ORIF Diver's arms extend to the STRETCH position close to his body.*
ORIFNOT Diver is fully extended (Ankle, knee, hip)
     after the KICKOUT.*
ORIF Diver raises his head or aches his back at entry.*
ORIF The arms reach forward and away from the water
     in attaining the STRETCH position.*
ORIF If shoulders extend back when diver enters the water.*
THEN The diver anticipates entry will be short of vertical.*
ANDTHENRUN S9/10.ia

( Rule S9.ii                      Shallow entry )
IF The entry point is too far forward from the end of the board.*
ORIF The dive is shallow.*
THEN Diver may fear going deep into the water or over rotating
     onto his back.*

( Rule S9                         Dive extension/entry )
IF The performance is a DIVE.*
ANDIF The diver anticipates entry will be short of vertical.*
ORIF EXTENSION/KICKOUT is early.*
ORIF Diver extends to STRETCH position too quickly.*
ORIF Diver is unable to spot the water to time his extension.*
ORIF Diver may fear going deep into the water or over rotating
     onto his back.*
THEN Extension from the aerial maneuver or entry needs to be improved.*
ANDTHENRUN EXTENSION_L/S
ANDTHENRUN S9a
ANDTHENRUN S9.a
ANDTHENRUN D_Pike_Save
ANDTHENRUN continue1
ANDTHENRUN D_Stretch

( Rule S10.i                        Jump extension/entry--saves)
IFNOT The performance is a DIVE.*
ORIF The diver's head is extended back after the KICKOUT or at entry.*
```

```
ORIF Diver over extends and arches his back prior to entry.*
ORIFNOT Diver is fully extended (Ankle, knee, hip)
     after the KICKOUT.*
ORIF Diver extends his head back, during the flight phase.*
THEN The diver anticipates entry will be short of vertical.*
ANDTHENRUN S9/10.ia

( Rule S10                    Jump extension/entry )
IFNOT The performance is a DIVE.*
ANDIF The diver anticipates entry will be short of vertical.*
ORIF EXTENSION/KICKOUT is early.*
ORIF Arms are raised forward and up during the EXTENSION.*
ORIF The arms are extended to the REACH  position and remain there.*
ORIF Arms reach behind the vertical, rather than laterally
     to the vertical position in preparing for entry.*
ORIF Diver is unable to spot the water to time his extension.*
ORIF The diver arches upon entering the water.*
THEN Extension from the aerial maneuver or the entry needs
     to be improved.*
ANDTHENRUN EXTENSION_L/S
ANDTHENRUN S10a
ANDTHENRUN continue1
ANDTHENRUN D_Jump_Entry

( Rule S11                    Neg. Sub-hypotheses )
IFNOT The diver develops excessive backward lean.*
ANDIFNOT Diver develops too much forward lean at take-off.*
ANDIFNOT The diver must adjust his starting position of his approach.*
ANDIFNOT The diver must improve his approach.*
ANDIFNOT The diver does not fully develop his potential
     angular momentum.*
ANDIFNOT Diver will retard his rotational speed.*
ANDIFNOT Extension from the aerial maneuver or the entry needs
     to be improved.*
THEN Perhaps another facet of the dive requires correcting
     (Try #3 Entry is Far from the board).*
ANDTHENRUN SHORT_C

( Rule S12                    Option to continue )
IF You wish to analyze another aspect of this performance.*
THEN A different entry from the menu should be selected.*
ANDTHENRUN menu_check

( Rule S13                    Hypothesis )
IF The diver develops excessive backward lean.*
ORIF Diver develops too much forward lean at take-off.*
ORIF The diver must adjust his starting position of his approach.*
ORIF The diver must improve his approach.*
```

```
ORIF The diver does not fully develop his potential
     angular momentum.*
ORIF Diver will retard his rotational speed.*
ORIF Extension from the aerial maneuver or the entry needs
     to be improved.*
ORIF Perhaps another facet of the dive requires correcting
     (Try #3 Entry is Far from the board).*
ANDIFNOT A different entry from the menu should be selected.*
THENHYP Diver needs to increase his angular momentum.*
ANDTHENRUN SHORT_C
ANDTHENRUN Restart

DONE
```

FILE NAME: LONG.RLS

```
( # 2 LONG MODULE:  Diver over-rotates & enters long of vertical )

: EXTENSION_L
 npar
    ." Diver anticipates aerial maneuver and does not achieve full"
 margin
 ." extension prior to take-off.  Review  the skill  progressions"
 margin
 ." or practise a skill with a lower degree of difficulty to boost"
 margin
 ." the athlete's confidence. If possible have the athlete perform"
 margin
 ." isometrics of the skill." 1 ;

: L1a
 npar
    ." The diver is  anticipating his aerial maneuver and fails to"
 margin
 ." fully extend prior to take-off.   Increasing the length of the"
 margin
 ." step into the hurdle will decrease  forward lean  at take-off."
 npar
    ." For a dive, performing a  pike  save  will make  the entry"
 margin
 ." appear vertical.  Whereas, for a jump, the diver should arch"
 margin
 ." to make his entry appear vertical." 1 ;

: L2a
 npar
    ." The diver's height may be maximized  by reducing his forward"
margin
 ." lean during the board contact phase. Have the diver concentrate"
 margin
 ." on full leg extension during the hurdle and reach positions." 1 ;

: L3a
 npar ." Diver will also tend to enter FAR from the board." 1 ;

: L5a
 npar
    ." Angular momentum may be decreased at take-off by reducing the"
 margin
 ." amount of forward lean  at  take-off.  Have  the diver strive to"
 margin
 ." maximize the height of his flight phase.  The diver should reach"
```

```
margin
." and be fully extended prior to departure. "
npar
   ." By  delaying the entry into the aerial position or  extending"
margin
." to the entry position sooner will decrease the speed of rotation."
margin
." (Attaining a more open aerial position  in order to decrease the"
margin
." speed of rotation is undesirable). Firm body musculature must be"
margin
." maintained."
npar
  ." When assuming and  extending  from the  aerial position,  the"
margin
." arms should open laterally (abduct), in preparing for the entry."
  1 ;

: L7/8.ia
npar
   ." The diver is already  compensating for an  entry that will be"
margin
." long of vertical.   The  diver has made  an error  in the  board"
margin
." contact phase. Re-analyze the performance focusing on deviations"
margin
." in the approach, hurdle and take-off phases." continuel DROP
 D_Approach DROP D_Hurdle DROP D_Take-Off DROP 1 ;

: L7/8.iia EXTENSION_L/S DROP
npar
   ." Emphasize a controlled kickout to avoid over reaching which"
margin
." causes the back to arch.  To avoid going long, the kickout may"
margin
." have to be started sooner and be slowed down. Arms may have to"
margin
." to reach ahead of the body and up to stretch position." 1 ;


MORERULES

( Rule  L1                        take-off extension )
IFNOT Diver has attained full extension (ankles, knees, hips)
     prior to TAKE-OFF.*
ORIF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
```

```
ORIF Diver's arms are extended ahead of vertical during the REACH
     position prior to TAKE-OFF.*
ORIF Diver lifts his feet back causing him to leave the board early.*
ORIF During board contact, the diver pikes or leans forward.*
ORIF During board contact, the diver presses the board with his
     trunk rather than his legs.*
THEN Diver develops too much forward lean.*
ANDTHENRUN L1a
ANDTHENRUN Continue1
ANDTHENRUN D_Take-Off

( Rule  L2                      hurdle )
IF During the HURDLE, the diver pikes at the waist.*
ORIF The length of the HURDLE is too long
     (exceeds the length of a walking step).*
ORIF The diver's head or shoulders are ahead of the vertical
     during the HURDLE.*
ORIF Knee drive into the HURDLE is weak or poor
     (The HURDLE KNEE is lower than the waist).*
ORIF Arms fail to extend to vertical, during the HURDLE.*
THEN Diver needs to improve the height attained
     during his HURDLE.*
ANDTHENRUN L2a
ANDTHENRUN Continue1
ANDTHENRUN D_Hurdle

( Rule  L3                        Approach )
IF Diver leans forward during his APPROACH.*
ORIF The final APPROACH step is too short
     (less than the length of a normal walking step).*
ORIF During the APPROACH, diver's shoulders drop forward.*
ORIF Diver drops his head forward to spot the end of the board.*
ORIFNOT The APPROACH is smooth and controlled.*
THEN Diver develops too much forward lean.*
ANDTHENRUN L3a
ANDTHENRUN continue1
ANDTHENRUN D_Approach

( Rule  L4.i                     Attaining Pike Position )
IF The pike position is semi-closed (SEMI-CLOSED PIKE).*
ORIF The pike position is open (OPEN PIKE).*
ANDIF The arms reach too far ahead when piking;
     arms reach past the legs.*
THEN The PIKE position is poorly attained.*

( Rule  L4                       Attaining Pike Position )
IF The jump/dive is performed in PIKE position.*
ORIF Knees are bent while in the PIKE position.*
```

```
THEN The PIKE position is poorly attained.*

( Rule  L5                      Attaining Aerial Position )
IF The head remains tucked or buried during the KICKOUT.*
ORIF Diver enters aerial position before the arms have attained
     a REACH position.*
ORIF The PIKE position is attained early (Diver should depart in
     the REACH position for skills with less than two rotations).*
ORIF The PIKE position is poorly attained.*
THEN By improving his entry into the aerial position,
     the diver will reduce his angular momentum.*
ANDTHENRUN L5a

( Rule  L6                      Over-rotation )
IF Diver over rotates--completes more than the required number
     of rotations.*
THEN The diver needs to enter the aerial later and/or
     prepare for entry sooner.*
ANDTHENRUN L5a


( Rule  L7/8.i                      Eyes Closed )
IF Diver's eyes are closed during the aerial or KICKOUT.*
THEN Diver is unable to spot the water to time his extension.*

( Rule  L7.i                        Dive Extension/Entry -- Saves )
IF The performance is a DIVE.*
ANDIF The diver performs a PIKE SAVE at entry.*
ORIFNOT The diver is fully extended (hips, knees, ankles)
     prior to entry.*
ORIF Arms extend in front of the diver, rather than being vertical
     after KICKOUT.*
ORIF The diver's legs bend at entry.*
ORIF Diver tucks head in at entry.*
THEN The diver anticipates his entry will be long of vertical.*
ANDTHENRUN L7/8.ia


( Rule  L7.ii                       Dive Extension )
IF The performance is a DIVE.*
ANDIF KICKOUT is late (Diver has past vertical before extending).*
ORIF Arms are brought forward to the STRETCH position
     (ie. narrow return).*
ORIF The diver over extends during the KICKOUT.
(This causes the lower body to over rotate and the legs to bend)*
ORIF The lower back arches after KICKOUT.*
ORIFNOT The diver is fully extended (hips, knees, ankles)
     after KICKOUT.*
```

```
ORIF Diver is unable to spot the water to time his extension.*
THEN Diver's extension from the aerial maneuver needs improving.*
ANDTHENRUN L7/8.iia

( Rule  L7.iii                  Dive entry )
IF The performance is a DIVE.*
ORIFNOT The diver is fully extended (hips, knees, ankles)
     prior to entry.*
ORIF The diver's shoulders are not extended during entry.*
ORIF Arms are forward of body after EXTENSION.*
ORIF The hands reach down and back towards the board at entry
     (early PIKE SAVE).*
ORIF Diver arches his lower back near entry.*
ORIF The entry point is too close to the end of the board.*
THEN The entry requires improving.*
ANDTHENRUN D_Stretch
ANDTHENRUN Continue1
ANDTHENRUN D_Pike_Save

( Rule L8.i                    Jump Extension/Entry - saves )
IFNOT The performance is a DIVE.*
ANDIF Diver's head is extended back after the KICKOUT.*
ORIF Diver over extends and arches his back.*
ORIFNOT Diver is fully extended (Ankle, knees, hips)
     after the KICKOUT.*
THEN The diver is anticpating that his entry will be long of vertical.*
ANDTHENRUN L7/8.ia

( Rule  L8.ii                  Jump [foot first] Extension )
IFNOT The performance is a DIVE.*
ANDIF Diver's head is forward after KICKOUT.*
ORIF KICKOUT is late.*
ORIF The head is thrown forward and down during the EXTENSION.*
ORIFNOT The diver is fully extended (hips, knees, ankles)
     after KICKOUT.*
ORIF Diver is unable to spot the water to time his extension.*
THEN Diver's extension from the aerial maneuver needs improving.*
ANDTHENRUN L7/8.iia

( Rule  L8.iii                  Jump entry )
IFNOT The performance is a DIVE.*
ORIF In preparing for entry the arms are brought to DIVING POSTURE
     ahead of the body, rather than extending laterally to LAYOUT
     then to DIVING ATTENTION.*
ORIFNOT Diver is fully extened (ankles, knees, hips) prior to entry.*
ORIF The arms remain extended ahead of the vertical during entry.*
ORIF The diver fails to assume FLAT FEET upon entering the water.*
THEN The entry requires improving.*
```

```
ANDTHENRUN D_Jump_Entry

( Rule L9                        Extension/Entry )
IF The diver is anticpating that his entry will be long of vertical.*
ORIF Diver's extension from the aerial maneuver needs improving.*
ORIF The entry requires improving.*
THEN Dive mechanics must be improved.*

( Rule  L11                      Neg. Hypotheses )
IFNOT Diver develops too much forward lean.*
ANDIFNOT Diver needs to improve the height attained
     during his HURDLE.*
ANDIFNOT By improving his entry into the aerial position,
     the diver will reduce his rate of rotation.*
ANDIFNOT Diver's extension from the aerial maneuver needs improving.*
ANDIFNOT The diver needs to enter the aerial later and/or
     prepare for entry sooner.*
ANDIFNOT Dive mechanics must be improved.*
THEN Perhaps there is another factor causing the entry to be long.
     (Try #4  Entry too close to the board).*
ANDTHENRUN L5a

( Rule  L12                      Option to continue )
IF You wish to analyze another feature of this performance.*
THEN A different entry should be selected from the menu.*
ANDTHENRUN menu_check

( Rule  L13                      Hypothesis )
IF Diver develops too much forward lean.*
ORIF Diver needs to improve the height attained
     during his HURDLE.*
ORIF By improving his entry into the aerial position,
     the diver will reduce his rate of rotation.*
ORIF Diver's extension from the aerial maneuver needs improving.*
ORIF The diver needs to enter the aerial later and/or
     prepare for entry sooner.*
ORIF Dive mechanics must be improved.*
ORIF Perhaps there is another factor causing the entry to be long.
     (Try #4 Entry too close to the board).*
ANDIFNOT A different entry should be selected from the menu.*
THENHYP Diver needs to control the development of angular momentum.*
ANDTHENRUN L5a
ANDTHENRUN Restart

DONE
```

FILE NAME: FAR.RLS

```
( #3 FAR MODULE: Entry is too far from the board--exceed 30 inches)

: Far_C
 npar
    ." An entry that is far from the board will tend to have  a lot"
 margin
 ." of wash (excessive splash).   The diver must strive to increase"
 margin
 ." the height of the dive. The last step into the hurdle should be"
 margin
 ." lengthened and the hurdle should be shortened.   Have the diver"
  margin
 ." select his entry point  close to the  springboard.  The  diver-"
 margin
 ." springboard  interaction  may be improved  by moving the fulcum"
 margin
 ." ahead (this stiffens the board); although, a stiffer board will"
margin
 ." be easier to perform on,  to become proficient  at  springboard"
 margin
 ." diving skills a flexible board should be used." continuel DROP
 D_Pike_Save DROP 1 ;

: F2.ia
 npar
    ." Review the 3 or 4 step approach and hurdle sequence.  Look"
 margin
 ." for deviations in the approach phase."  D_Approach DROP 1 ;

: F2a
 npar
    ." Propperly executed board work  requires that the diver be"
 margin
 ." in phase with the board. Active extension with the press leg"
 margin
 ." along with a good knee drive  into the hurdle  will  improve"
 margin
 ." the performance." 1 ;


: F3a
 npar
    ." The   diver must strive  to maximize his height by concen-"
 margin
 ." trating on attaining  full extension  during  the  hurdle and"
 margin
```

```
." reach positions.  Also  the  last stride of the hurdle may be"
margin
." lengthened."
npar
   ." An  early  departure  may indicate  that the  board contact"
margin
." phase needs improving; have the athlete initiate his arm swing"
margin
." and his leg extension sooner." 1 ;

: F4a
npar
   ." The diver must keep his body erect and not pike (or bend at"
margin
." the waist), until he throws into the maneuver.  The diver must"
margin
." attain the reach position  prior to entering the aerial phase."
margin
." Have the athlete concentrate on maximizing his height." 1 ;

MORERULES
( Rule F1.i                      consistent approach )
IFNOT The APPROACH is smooth and controlled.*
ORIFNOT The diver consistently lands his HURDLE within 10 cm from
     the end of the board.*
THEN Diver must concentrate on perfecting his approach.*
ANDTHENRUN APPR-CONSISTENT

( Rule  F1                       approach )
IF Diver leans forward during his APPROACH.*
ORIF During the APPROACH, diver's shoulders drop forward.*
ORIF Diver drops his head forward to spot the end of the board.*
ORIF Diver must concentrate on perfecting his approach.*
THEN The approach needs improving.*
ANDTHENRUN D_Approach

( Rule F2.i                     poor approach causing a poor hurdle )
IF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
ORIF During the HURDLE, the diver pikes at the waist.*
ORIF The final APPROACH step is too short
     (less than the length of a walking step).*
ORIF The length of the HURDLE is too long
     (exceeds the length of a walking step).*
THEN Poor balance or forward lean initiated in the approach has affected
     the hurdle mechanics.*
ANDTHENRUN F2.ia
```

```
( Rule  F2                        hurdle )
IFNOT The PRESS LEG is extended to begin the HURDLE phase.*
ORIF Knee drive into the HURDLE is weak or poor
     (The HURDLE KNEE is lower than the waist).*
ORIF Arms fail to extend to vertical, during the HURDLE.*
ORIF Poor balance or forward lean initiated in the approach has affected
     the hurdle mechanics.*
THEN Diver's hurdle needs improving.*
ANDTHENRUN F2a
ANDTHENRUN D_Hurdle

( Rule  F3                        take-off extension )
IF Diver departs from the board with bent knees.*
ORIF Diver's arms are extended ahead of vertical during the REACH
     position prior to TAKE-OFF.*
ORIFNOT Diver has attained full extension (ankles, knees, hips)
     prior to TAKE-OFF.*
THEN Diver anticipates aerial maneuver and does not achieve
     full extension at TAKE-OFF.*
ANDTHENRUN F3a
ANDTHENRUN continue1
ANDTHENRUN D_Take-Off

( Rule  F4                        excessive forward lean )
IF Diver lacks height in the flight phase.*
ANDIF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
THEN The diver has developed excessive forward lean.*
ANDTHENRUN F4a

( Rule  F5                         Neg. Sub-hypotheses )
IFNOT The approach needs improving.*
ANDIFNOT Diver's hurdle needs improving.*
ANDIFNOT Diver anticipates aerial maneuver and does not achieve
     full extension at TAKE-OFF.*
ANDIFNOT The diver has developed excessive forward lean.*
THEN Perhaps another aspect of the dive needs improving.
     (Try #1 Entry is short of vertical).*
ANDTHENRUN FAR_C

( Rule  F6                        Option to continue )
IF You wish to analyze another facet of this performance.*
THEN A different entry should be chosen from the menu.*
ANDTHENRUN menu_check

( Rule  F7                        Hypothesis )
IF The approach needs improving.*
ORIF Diver's hurdle needs improving.*
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```
ORIF Diver anticipates aerial maneuver and does not achieve
     full extension at TAKE-OFF.*
ORIF The diver has developed excessive forward lean.*
ORIF Perhaps another aspect of the dive needs improving.
     (Try #1 Entry is short of vertical).*
ANDIFNOT A different entry should be chosen from the menu.*
THENHYP Diver develops excessive horizontal momentum and needs
     to attain a more vertical position at TAKE-OFF.*
ANDTHENRUN Far_C
ANDTHENRUN Restart

DONE
```

FILE NAME: CLOSE.RLS

```
( #4 CLOSE:  Entry is too near to the board - within 18 inches )

: Close-Psych
 npar
    ." Some coaches believe this error should be corrected early,"
 margin
 ." since  the diver  will soon  develop  compensating techniques"
 margin
 ." that may be difficutl to correct."  1 ;

: CLOSE_C
 npar
    ." Insufficient horizontal momentum causes the diver to enter"
 margin
 ." too close to the board."
 npar
    ." A gross performance error, (such as:  missing  a  step or"
 margin
 ." incorrect starting position of the approach)  may be a cause"
 margin
 ." of the entry being  too close  to the board.  Have the diver"
 margin
 ." master his approach and hurdle."
 npar
    ." A backward lean developed  during the board contact  will"
 margin
 ." also cause a dive to be too close to the board.   To correct"
 margin
 ." for such an error have the diver increase  the tempo of  the"
 margin
 ." apporach and decrease the length of the step into the hurdle"
 margin
 ." which will increase the length of the hurdle and the lean at"
 margin
 ." take-off."
 npar
    ." Have the diver select a point of entry farther away from the"
 margin
 ." end of the springboard."  continue1 DROP Close-Psych DROP
 npar
    ." The diver may not fully  understand the dive and be lifting"
 margin
 ." his feet pre-maturally from the board. Review basic skills and"
 margin
 ." progressions of the dive to promote kinesthetic awareness and"
 margin
```

```
 ." an understanding of the skill. If this fails perhaps the skill"
 margin
 ." is too difficult for the diver and a lower level skill  should"
 margin
 ." be reviewed."  1 ;

: C1a
 npar
    ." The athlete is concentrating on attaining height.  Have the"
 margin
 ." diver perform a similar skill with lower degree of difficulty,"
 margin
 ." concentrating on his approach  and take-off phase.  The  tempo"
 margin
 ." of the approach should be smooth and controlled, ensure correct"
 margin
 ." placement of the press leg." 1 ;

: C3.ia
 npar
    ." The diver should begin his active push on the board sooner."
 margin
 ." Instruct the athlete to begin his leg extension at the instant"
 margin
 ." of board contact." 1 ;

: C3.iia
 npar
    ." An error in the  approach or the hurdle phase has probably"
 margin
 ." caused this poor position.  Re-analyze these phases, look for"
 margin
 ." deviation from ideal performance."
        D_Approach DROP D_Hurdle DROP 1 ;


 MORERULES

( Rule C1                         approach )
IFNOT The APPROACH is smooth and controlled.*
ORIF The final approach step is too long
     (exceeds twice the length of a normal walking step).*
ORIF The HURDLE is short and the diver has a backward lean.*
THEN Diver's approach needs improving.*
ANDTHENRUN C1a
ANDTHENRUN Continue1
ANDTHENRUN D_Approach
```

```
( Rule C2                     hurdle )
IF Diver drives his HURDLE leg through causing a backward lean.*
ORIF Diver shortens the length of his HURDLE.*
ORIF Diver kicks HURDLE leg out rather than stepping down to
     complete his HURDLE.*
ORIF The diver arches his back while performing the HURDLE.*
THEN The hurdle phase requires improving.*
ANDTHENRUN C1a
ANDTHENRUN continue1
ANDTHENRUN D_Hurdle

( Rule C3.i                   Early departure    )
IF The leg press during board contact is late
     (begins during board recoil).*
ORIF The arm throw into the dive is early.*
THEN The diver departs early from the board.*
ANDTHENRUN C3.ia

( Rule C3.ii                  previous error in approach/hurdle )
IF At maximum board depression the diver has a back lean
     (more than 10 degrees behind vertical) or arches.*
THEN The diver has already developed too much forward lean.*
ANDTHENRUN  C3.iia

( Rule C3                     take-off extension )
IF Diver over-extends at TAKE-OFF (arms reach behind his head).*
ORIF Diver arches his back at TAKE-OFF.*
ORIF Diver's head is extended back at TAKE-OFF.*
ORIF The diver departs early from the board.*
ORIF The diver has already developed too much forward lean.*
THEN The diver develops excessive backward lean.*
ANDTHENRUN D_Take-Off

( Rule C4                     Inconsistency in Approach )
IFNOT The diver consistently land his HURDLE within 10 cm from
     the end of the board.*
ANDIFNOT Diver's approach needs improving.*
ANDIFNOT The hurdle phase requires improving.*
ANDIFNOT The diver develops excessive backward lean.*
THEN The diver must correct his approach.*
ANDTHENRUN APPR-CONSISTENT

( Rule C5                     Neg. sub-hypotheses )
IFNOT Diver's approach needs improving.*
ANDIFNOT The hurdle phase requires improving.*
ANDIFNOT The diver develops excessive backward lean.*
ANDIFNOT The diver must correct his approach.*
THEN Perhaps another facet of the dive needs to be improved.
```

```
     (Try #2 Entry is long of vertical).*
ANDTHENRUN CLOSE_C
ANDTHENRUN continue1

( Rule C6                    Option to continue )
IF You wish to analyze another facet of the performance.*
THEN A different entry from the menu should be chosen.*
ANDTHENRUN menu_check

( Rule C7                    Hypothesis)
IF Diver's approach needs improving.*
ORIF The hurdle phase requires improving.*
ORIF The diver develops excessive backward lean.*
ORIF The diver must correct his approach.*
ORIF Perhaps another facet of the dive needs to be improved.
     (Try #2 Entry is long of vertical).*
ANDIFNOT A different entry from the menu should be chosen.*
THENHYP Diver does not develop sufficient horizontal momentum.*
ANDTHENRUN Close-Psych
ANDTHENRUN Restart

DONE
```

FILE NAME: AESTHET.RLS

```
( #5 AESTHETICS MODULE:  Dive performance mechanics are not pleasing )

: A1.ia
 npar
    ." Review basic body positions.   Physical  manipulation  and"
 margin
 ." verbal cues may be used to correct body positions. Performing"
 margin
 ." these skills before a mirror may be helpful." 1 ;

: A1a
 npar
    ." The diver needs to develop consistency in the approach. By"
 margin
 ." adding a counting sequence to the approach a smooth, rhythmic"
 margin
 ." approach may be developed." 1 ;

: A2.ia
 npar
    ." The arm swing should be quicker and initiated sooner.   If"
 margin
 ." arms continue to bend,  then  a narrower  arm swing should be"
 margin
 ." used; that is,  the diver should bring his  arms laterally to"
 margin
 ." his sides (adduct) rather than circling behind his body. Then"
 margin
 ." the arm swing should be continued as normal with arms remain-"
 margin
 ." ing straight.   Perhaps, the  depth  of  the  swing should be"
 margin
 ." reduced." 1 ;

: A2.iia
 npar
    ." An aesthetically pleasing performance involves good posture"
 margin
 ." throughout the skill.   The  body  should  be  represented  by"
 margin
 ." straight lines; therefore, the diver should strive to be erect"
 margin
 ." and maintain firm body musculature." D_Hurdle DROP 1 ;

: A2a
 npar
```

```
   ." The diver  needs to develop a  kinesthetic awareness of his"
 margin
 ." skill.  Review the basic body positions  (DIVING POSTURE  and"
 margin
 ." HURDLE); physical manipulation and verbal cues may be used to"
 margin
 ." correct body positions." 1 ;

: A3a
 npar
   ." The diver needs to develop strength in his press leg; have"
 margin
 ." the athlete practise  jumping off his press leg  while in the"
 margin
 ." hurdle position.   He should land simultaneously on both feet"
 margin
 ." on a bench.  Ensure the diver fully extends his press leg."
 npar
  ." The  height of the flight phase  can be enhanced by keeping"
 margin
 ." the arm swing synchronized with  the springboard motion.   At"
 margin
." take-off,  the diver should ensure good extension with minimum"
 margin
 ." forward lean."  1 ;

: A4a
 npar
   ." The amount of angular momentum  can be  controlled  by the"
 margin
 ." forward lean at take-off.   During the board work phase,  the"
 margin
 ." arms should remain extended, especially, in the arm swing and"
 margin
 ." when throwing  into the aerial maneuver."
 npar
   ." By tightening the aerial position,  the  speed of  rotation"
 margin
 ." can be increased." 1 ;

: A5a
 npar
   ." Diver may need to increase the height of the flight phase."
 A3a DROP 1 ;

: A6a
 npar
   ." A  closed  pike  position shows strength and agility.   When"
```

```
margin
." performing a skill in  pike position, a  closed  pike  position"
margin
." should be selected." 1 ;

: A7.a              ( excessive angular momentum )
npar
   ." Deviation in the aerial position  may be  to compensate for"
 margin
." developing excessive forward lean at take-off.  Excessive for-"
margin
." ward lean at  take-off  tends  to decrease  the height  of the"
margin
." performance,  increase  the developed  angular  momentum,  and"
margin
." increase the distance travelled away from the board." 1 ;

: A7.b            ( insufficient angular momentum )
npar
   ." Deviation  in the aerial position may be  to compensate for"
margin
." the lack of sufficient forward lean at take-off.  Insufficient"
margin
." forward lean  at take-off  tends to increase the height of the"
margin
." performance,  decrease the  developed  angular  momentum,  and"
margin
." decrease the distance traveled away from the board." 1 ;

: A7.c
npar
   ." The diver needs to develop a  kinesthetic  awareness of the"
margin
." aerial body position. Physical manipulation or verbal cues may"
margin
." assist  in correcting the body positions.  Often poor perform-"
margin
." ance during the flight phase may be caused by anticipating the"
margin
." aerial maneuver.  Practise isometrics of entering and extend-"
margin
." ing from the position.   Also  practise a skill  with a lower"
margin
." degree of difficulty with emphasis on proper aerial position." 1 ;

: A7a
npar
   ." Aesthetically  pleasing  aerial maneuvers require firm body"
```

```
margin
." musculature.  Legs  should be  squeezed  together  throughout"
margin
." the maneuver. Symmetrical  motion  is desirable  in attaining"
margin
." the position and during the extension.  Straight lines in the"
margin
." body position should be evident."
cr  margin
." (To review the desired mechanics of either the TUCK, PIKE,  or"
margin
." LAYOUT refer to its definition)." 1 ;

: A9a
npar
   ." Practise drills  to align the entry to a vertical position."
margin
." The diver needs to develop a rip entry." cr D_Rip_Entry DROP 1 ;

: A10a
npar
   ." The diver has too much horizontal velocity at entry; either"
margin
." his point of entry needs to be moved away from the board or he"
margin
." should concentrate on achieving more height in the dive.   To"
margin
." increase his height, good extension at  take-off is necessary;"
margin
." also, the last step into his  hurdle should be  lengthened and"
margin
." the hurdle, itself, should be shortened."
npar
   ." The amount of splash may be reduced if the diver performs a"
margin
." pike save at entry." continuel DROP D_Pike_Save DROP 1 ;

: AESTHETICS_C
npar
  ." Grace and poise is combined with athletic ability and skill."
margin
." Throughout a diving performance,  control is exercised and the"
margin
." diver  maintains firm body musculature.  The  body  positions"
margin
." used in executing a skill  should  be traceable using straight"
margin
." lines." 1 ;
```

```
MORERULES

( Rule A1.i                        body posture )
IFNOT During the APPROACH, HURDLE through to TAKE-OFF, diver has
     good posture (DIVING POSTURE).*
ORIF During APPROACH, diver drops his head forward to spot the end
     of the springboard.*
ORIFNOT The diver maintains firm body musculature throughout
     the performance.*
THEN Diver needs to improve his basic body posture.*
ANDTHENRUN A1.ia

( Rule A1                          approach )
IFNOT The APPROACH is smooth and controlled.*
ORIFNOT The diver consistently lands his HURDLE within 10 cm from
     the end of the board.*
ORIF Diver needs to improve his basic body posture.*
THEN The approach needs improving.*
ANDTHENRUN A1a

( Rule A2.i                         arm swing )
IF The arms bend during the ARM SWING.*
ORIF The arms are bent during the REACH position.*
ORIFNOT The diver throws into his maneuver with straight arms.*
THEN The arm swing should be initiated sooner.*
ANDTHENRUN A2.ia

( Rule A2.ii                        hurdle )
IFNOT The diver has arms extended in the HURDLE position.*
ORIFNOT The diver has toes pointed throughout the HURDLE.*
ORIF The diver pikes (bends at the waist) during the HURDLE.*
THEN The hurdle deviates from the recommended form.*
ANDTHENRUN A2.iia

( Rule A2                           approach/hurdle )
IF The approach needs improving.*
ORIF The arm swing should be initiated sooner.*
ORIFNOT During the APPROACH, the diver has straight arms.*
ORIF The hurdle deviates from the recommended form.*
ORIFNOT The diver maintains firm body musculature throughout the skill.*
THEN The diver needs to enhance his presentation.*
ANDTHENRUN A2a

( Rule A3                          height )
IF Diver lacks height, during the flight phase.*
THEN Diver needs to improve his board work.*
ANDTHENRUN A3a
```

```
( Rule A4                      rotation )
IF Diver rate of rotation is slow.*
THEN The diver should either increase his angular momentum at
     take-off or improve his flexibility to attain tighter aerial
     positions.*
ANDTHENRUN A4a

( Rule A5                         Extension )
IFNOT KICKOUT from the aerial position is symmetric.*
ORIFNOT KICKOUT is smooth and controlled.*
THEN Diver needs to improve his extension from the aerial position.*
ANDTHENRUN A5a

( Rule A6                          Desired Pike Position )
IF The jump/dive is performed in the PIKE position.*
ANDIF The skill involves multiple rotations.*
ANDIF The pike position is open (OPEN PIKE).*
ORIF The pike position is semi-closed (SEMI-CLOSED PIKE).*
THEN Dive aesthetics may be improved if the athlete performs
     the skill in the CLOSED PIKE position.*
ANDTHENRUN A6a

( Rule A7.ia                       Layout aerial position )
IF The jump/dive is performed in the LAYOUT position.*
ANDIF IF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
ANDIF The LAYOUT position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.a
ANDTHENRUN A2a
ANDTHENRUN continue1
ANDTHENRUN D_Layout

( Rule A7.ib                       Layout aerial position )
IF The jump/dive is performed in the LAYOUT position.*
ANDIF At maximum board depression the diver has a back lean
     (more than 10 degrees behind vertical) or arches.*
ANDIF The LAYOUT position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.b
ANDTHENRUN A2a
ANDTHENRUN continue1
ANDTHENRUN D_Layout

( Rule A7.ic                       Layout aerial position )
IF The jump/dive is performed in the LAYOUT position.*
ANDIF The LAYOUT position has some deviation form ideal performance.*
THEN The diver needs to perfect the aerial position.*
```

```
ANDTHENRUN A7.c
ANDTHENRUN continuel
ANDTHENRUN D_Layout

( Rule A7.iia                          Tuck aerial position )
IF The jump/dive is performed in the TUCK position.*
ANDIF IF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
ANDIF The TUCK position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.a
ANDTHENRUN A2a
ANDTHENRUN continuel
ANDTHENRUN D_Tuck

( Rule A7.iib                          Tuck aerial position )
IF The jump/dive is performed in the TUCK position.*
ANDIF At maximum board depression the diver has a back lean
     (more than 10 degrees behind vertical) or arches.*
ANDIF The TUCK position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.b
ANDTHENRUN A2a
ANDTHENRUN continuel
ANDTHENRUN D_Tuck

( Rule A7.iic                          Tuck aerial position )
IF The jump/dive is performed in the TUCK position.*
ANDIF The TUCK position has some deviation form ideal performance.*
THEN The diver needs to perfect the aerial position.*
ANDTHENRUN A7.c
ANDTHENRUN continuel
ANDTHENRUN D_Tuck

( Rule A7.iiia                         Pike aerial positions )
IF The jump/dive is performed in the PIKE position.*
ANDIF IF At maximum board depression the diver is leaning forward
     (more than 10 degrees ahead of vertical) or pikes.*
ANDIF The PIKE position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.a
ANDTHENRUN A2a
ANDTHENRUN continuel
ANDTHENRUN D_Pike

( Rule A7.iiib                         Pike aerial positions )
IF The jump/dive is performed in the PIKE position.*
ANDIF At maximum board depression the diver has a back lean
```

```
    (more than 10 degrees behind vertical) or arches.*
ANDIF The PIKE position has some deviation form ideal performance.*
THEN The diver may be compensating for poor board work.*
ANDTHENRUN A7.b
ANDTHENRUN A2a
ANDTHENRUN continue1
ANDTHENRUN D_Pike

( Rule A7.iiic                     Pike aerial positions )
IF The jump/dive is performed in the PIKE position.*
THEN The diver needs to perfect the aerial position.*
ANDTHENRUN A7.c
ANDTHENRUN continue1
ANDTHENRUN D_Pike

( Rule A7                          Deviations in aerial position )
IF The diver may be compensating for poor board work.*
ORIF The diver needs to perfect the aerial position.*
ORIF Diver's legs or feet are apart in the aerial maneuver.*
ORIF The feet are flat (not pointed) during the aerial maneuver.*
ORIF Musculature is relaxed either when entering, during or when
    extending from the aerial maneuver.*
THEN Aerial mechanics need improving.*
ANDTHENRUN A7a

( Rule A8                          Twist/extension )
IF A TWIST occurs at entry.*
ORIFNOT Shoulders and hips are aligned when preparing for entry.*
THEN Dive analysis should focus on errors associated with a twist
    at entry (Select #6).*

( Rule A9                          Entry )
IF Excessive splash at entry.*
ANDIFNOT Diver moves forward during the entry causing splash
    (ie. excessive wash).*
THEN Diver needs to improve his entry position and master a
    rip entry.*
ANDTHENRUN A9a

( Rule A10                         Entry )
IF Excessive splash at entry.*
ANDIF  Diver moves forward during the entry causing splash
    (ie. excessive wash).*
THEN Dive analysis should focus on errors associated with entry
    being LONG of vertical (Select #2).*
ANDTHENRUN A10a

( Rule A11                      Neg. Sub-hypotheses )
```

```
IFNOT The diver needs to enhance his presentation.*
ANDIFNOT Diver needs to improve his board work.*
ANDIFNOT The diver should either increase his angular momentum at
     take-off or improve his flexibility to attain tighter aerial
     positions.*
ANDIFNOT Diver needs to improve his extension from the aerial position.*
ANDIFNOT Dive aesthetics may be improved if the athlete performs the
     skill in the CLOSED PIKE position.*
ANDIFNOT Aerial mechanics need improving.*
ANDIFNOT Dive analysis should focus on errors associated with a twist
     at entry (Select #6).*
ANDIFNOT Diver needs to improve his entry position and master a
     rip entry.*
ANDIFNOT Dive analysis should focus on errors associated with entry
     being LONG of vertical (Select #2).*
THEN Perhaps, the dive can be improved aesthetically by correcting
     another facet of the dive.*
ANDTHENRUN AESTHETICS_C

( Rule A12                    option to-continue )
IF You wish to analyze another aspect of the performance.*
THEN You should select a different entry from the menu.*
ANDTHENRUN menu_check

( Rule A13                    hypothesis )
IF The diver needs to enhance his presentation.*
ORIF Diver needs to improve his board work.*
ORIF The diver should either increase his angular momentum at
     take-off or improve his flexibility to attain tighter aerial
     positions.*
ORIF Diver needs to improve his extension from the aerial position.*
ORIF Dive aesthetics may be improved if the athlete performs the
     skill in the CLOSED PIKE position.*
ORIF Aerial mechanics need improving.*
ORIF Dive analysis should focus on errors associated with a twist
     at entry (Select #6).*
ORIF Diver needs to improve his entry position and master a
     rip entry.*
ORIF Dive analysis should focus on errors associated with entry
     being LONG of vertical (Select #2).*
ORIF Perhaps, the dive can be improved aesthetically by correcting
     another facet of the dive.*
ANDIFNOT You should select a different entry from the menu.*
THENHYP By improving the fundamentals, the dive will improve
     aesthetically. Also have the athlete increase his strength
     and flexibility.*
ANDTHENRUN AESTHETICS_C
ANDTHENRUN Restart
```

DONE

FILE NAME: TWIST.RLS

```
( #6 TWIST MODULE:  Diver twists at Entry )

: T1a
 npar
    ." All board work actions should be symmetrical.   A twist at"
 margin
 ." entry results  if the diver's  actions  are asymmetric.   The"
 margin
 ." diver needs  good extension in his  reach  position to ensure"
 margin
 ." that his body is aligned at  take-off.   If possible have the"
 margin
 ." athlete practice  isometrics  of the skill  concentrating  on"
 margin
 ." symmetrical movement and maintaining firm musculature."
   D_Take-Off DROP 1 ;

: T2a
 npar
    ." The diver's actions need to be symmetrical to avoid twist-"
 margin
 ." ing.   The  throw into  and  the  extension/kickout from the"
 margin
 ." aerial maneuver must be even and symmetric."  1 ;

: T3a
 npar
   ." To reinforce  symmetric  action of the  extension have the"
 margin
 ." athlete perform isometrics of the skill on land or in shallow"
 margin
 ." water. Arms should extend  laterally  to the  entry  position"
 margin
 ." (especially for dives)." 1 ;

: T5a
 npar
    ." Instruct  the  diver  to  maintain  firm  body musculature"
 margin
 ." throughout the entry.   Often, the  twist  at entry is due to"
 margin
 ." over-reaching with one arm.  Have the athlete change his hand"
 margin
 ." grasp (switch the hand doing the grasping)."  D_Flat_Hand_Entry
 DROP  continue1  npar
    ." An asymmetric action during the entry will cause a twist."
```

```
 margin
 ." Have the athlete learn a rip entry where both arms pull down"
 margin  ." evenly to his sides."  D_Rip_Entry 1 ;

: TWIST_C
 npar
   ." Performing board work  off the center of the springboard"
 margin
 ." can initiate a twist. Also, a twist at entry may be caused"
 margin
 ." by  asymmetric action  on the board,  during entry into or"
 margin
 ." extension from the aerial maneuver.   The diver's actions"
 margin
 ." must be  symmetircal  and  it  is  desireable  that  firm"
 margin
 ." musculature be maintained throughout the skill."
 npar
   ." To reinforce  symmetric  action of the  extension have the"
 margin
 ." athlete perform isometrics of the skill on land or in shallow"
 margin  ." water."  1 ;

MORERULES

( Rule T1                      Take-off )
IFNOT Diver's hips and shoulders are aligned and feet are parallel
     to each other at TAKE-OFF.*
ORIFNOT Diver lands his HURDLE in the center of the diving board.*
ORIFNOT ARM SWING is even and symmetrical.*
THEN The take-off requires improving.*
ANDTHENRUN T1a

( Rule T2                      Aerial )
IFNOT When entering and performing aerial maneuver, diver's
     actions are symmetric.*
THEN The aerial maneuver skills require improving.*
ANDTHENRUN T2a

( Rule T3                      Extension/Kickout )
IFNOT Shoulders and hips are aligned when preparing for entry.*
ANDIFNOT During the KICKOUT, legs extend together (symmetrical,
     even EXTENSION).*
ORIFNOT KICKOUT from the aerial position is symmetric.*
THEN Improve the kickout of the dive/jump.*
ANDTHENRUN T3a

( Rule T4                      Entry )
```

```
IFNOT Head is aligned rather than looking over one's shoulder.*
THEN Diver needs to focus on hands during his entry.*
ANDTHENRUN D_Stretch

( Rule T5                          Musculature/Double-Hand Entry )
IF Aerial maneuver is symmetric.*
ANDIF Shoulders and hips are aligned while preparing for entry.*
ANDIF KICKOUT from the aerial position is symmetric.*
ANDIF  During the KICKOUT, legs extend together (symmetrical,
     even EXTENSION).*
ANDIF Head is aligned rather than looking over one's shoulder.*
THEN An asymmetric action at entry or a loose body position
     may cause a twist at entry.*
ANDTHENRUN T5a
ANDTHENRUN D_Rip_Entry

( Rule T6                          Neg. sub-hypotheses )
IFNOT The take-off requires improving.*
ANDIFNOT The aerial maneuver skills require improving.*
ANDIFNOT Improve the kickout of the dive/jump.*
ANDIFNOT Diver needs to focus on hands during his entry.*
ANDIFNOT An asymmetric action at entry or a loose body position
     may cause a twist at entry.*
THEN Another facet of the dive may also require improving
     ( Try #5 Dive is poor aesthetically ).*
ANDTHENRUN TWIST_C

( Rule T7                          Option to continue )
IF You wish to continue analyzing this performance.*
THEN You should select another entry from the menu.*
ANDTHENRUN menu_check

( Rule T8                          Hypothesis )
IF The take-off requires improving.*
ORIF The aerial maneuver skills require improving.*
ORIF Improve the kickout of the dive/jump.*
ORIF Diver needs to focus on hands during his entry.*
ORIF An asymmetric action at entry or a loose body position
     may cause a twist at entry.*
ORIF Another facet of the dive may also require improving
     ( Try #5 Dive is poor aesthetically ).*
ANDIFNOT You should select another entry from the menu.*
THENHYP A twist at entry may be eliminated by ensuring symmetric
     maneuvers during the skill performance. Firm musculature
     should be maintained throughout the skill.*
ANDTHENRUN Restart

DONE
```

FILE NAME: DCHECK.RLS

```
( DOUBLE CHECK MODULE: Confirms Intent to Exit             )


MORERULES


IFNOT You wish to EXIT from the program.*
THEN You should enter a number between 1 - 6.*
ANDTHENRUN menu_check


IFNOT You should enter a number between 1 - 6.*
THENHYP Program terminated at your request.*
ANDTHENRUN Restart

DONE
```

Appendix I

EVALUATING THE KNOWLEDGE BASED EXPERT SYSTEM SPRINGBOARD DIVING SKILL ANALYSIS PROGRAM

The evaluation of the Knowledge Based Expert System application to Springboard Diving Skill Analysis was completed to verify the accuracy of the knowledge base and the acceptance of the system by the intended user group. The procedure for this validation involved the analyses of forward, non-twisting dives which had been video-taped during typical practice sessions. The questionnaire, contained on the following pages, was used to record their responses. The first page provided background information on the user. With the aid of a video play-back unit, the users were asked to assess each performance; their analysis was recorded on the third page of the questionnaire. Then, the same performances were analyzed using the knowledge based expert system. Afterwards, the users were asked to complete the portion of the questionnaire evaluating various aspects of the operation of the program. The results of the questionnaire are summarized in Section 3.4: Validation of the Knowledge Based Expert System.

EVALUATION

KNOWLEDGE BASED EXPERT SYSTEM APPLICATION
TO SPRINGBOARD DIVING PERFORMANCE ANALYSIS

NAME:______________________________ DATE:____________

BACKGROUND INFORMATION

1. Have you ever uses an EXPERT SYSTEM? __________________
____
____

2. What type of Computers have you worked with:
    ___ Commodore-64
    ___ Apple
    ___ Atari ST
    ___ OTHERS: _____________
    ____
    ___ IBM or Compatible
    ___ MacIntosh
    ___ Amiga

3. What type of work have you done on computer?
    ___ Programming
    ___ Spread Sheets
    ___ Games
    ___ Word Processing
    ___ Graphic Packages
    ___ Other: ___________
    ____

4. Diving Experience/Knowledge
    ___ Recreation Coach
    ___ Competitive Coach
    ___ Other: _____________
    ___ Recreation Participant
    ___ Competitive Diver

CERTIFICATION: ___ CADA Instructor I
___ CADA Instructor II
___ OTHER: __________________
____

EXPERIENCE: # Hours Spent Coaching (indicate if Recreational/ Competitive) ______________________________
____
____

KNOWLEDGE BASED EXPERT SYSTEM CRITIQUE:

1. Were the Program Instructions comprehensive?
2. How could the user interface be enhanced? (Graphics, menus, data entry, response time, etc.)
3. Was each question easy to understand?
4. Were the questions asked in a logical order?
5. Were the questions relevant?
6. Were the program decisions and advice appropriate?

GENERAL COMMENTS:

KNOWLEDGE BASE VALIDATION: DIVE PERFORMANCE ANALYSIS

DIVE # ____ DIVE ______________________ Est. Score ______

MAJOR ERROR(S) IN PERFORMANCE:

____	Entry SHORT of Vertical	____	Entry FAR from the board
____	Entry LONG of Vertical	____	Entry CLOSE to the board
____	Diver TWISTS at Entry	____	OTHER: ______________
____	AESTHETICALLY incorrect		______________

CONTRIBUTING FACTORS OF IDENTIFIED ERROR(S): ______________

DIVE # ____ DIVE ______________________ Est. Score ______

MAJOR ERROR(S) IN PERFORMANCE:

____	Entry SHORT of Vertical	____	Entry FAR from the board
____	Entry LONG of Vertical	____	Entry CLOSE to the board
____	Diver TWISTS at Entry	____	OTHER: ______________
____	AESTHETICALLY incorrect		______________

CONTRIBUTING FACTORS OF IDENTIFIED ERROR(S): ______________

DIVE # ____ DIVE ______________________ Est. Score ______

MAJOR ERROR(S) IN PERFORMANCE:

____	Entry SHORT of Vertical	____	Entry FAR from the board
____	Entry LONG of Vertical	____	Entry CLOSE to the board
____	Diver TWISTS at Entry	____	OTHER: ______________
____	AESTHETICALLY incorrect		______________

CONTRIBUTING FACTORS OF IDENTIFIED ERROR(S): ______________

Appendix J

SAMPLE PROGRAM OPERATION
of the Knowledge Base Expert System for Analyzing Springboard Diving Performances

A sample session using the knowledge based expert system for springboard skill analysis is presented. The performance being analyzed was a forward, tuck dive. The gross performance errors included a twist at entry with the entry being far from the board; the diver exhibited poor form during execution of the dive.

The following run-time operation examines the poor entry position and the twist at entry. The user responses are indicated in italics.

During the initial loading of the Springboard Diving Knowledge Based Expert System, the following informational screens were presented.

<==>

Knowledge-Based Expert System Application

for

SPRINGBOARD DIVING SKILL ANALYSIS

© 1989 University of Saskatchewan
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<==>

This software package was developed in the Department of Mechanical Engineering at the University of Saskatchewan. The program is to be used with a modified version of the MVP EXPERT-2 TOOLKIT.

Financial assistance was received from SASK SPORT BURSARY and SPORT CANADA GRANT.

The intent of the program is to explore the applications of Knowledge-based expert system to coaching. This program assists in analyzing springboard diving skill performances.

The program determines the cause of fundamental error(s) and

```
provides advice which may serve as a guideline for dircting skill
development.   The developers accept no liability regarding the
information presented during program use.
          <==========================================>


             EXPERT-2  for FORTHMACS  ---  1987

     The program requires your response to various questions.  Based on
your response an appropriate cause of the performance error will be
identified.


     As prompted by the program, your response will be a single key
stroke -- either an indicated number or letter. To continue program
operation, press the <RETURN> key after your response.


     INPUT IDENTIFICATION:

     Y=yes    -- verifies the statement to be true
     N=no     -- verifies the statement to be false
     W=why    -- interrogates the system's rational
     T=trace -- reviews program rational[NOT FUNCTIONAL!]
     Q=quit   -- allows you to exit from the program
     X=change response -- permits altering previous input
     D=definition   -- provides explanation of the words
                       displayed in UPPER CASE of the program text
    EXPERT-2 ©1983 by NIMBLE.  EXPERT-2 is NOT released as a
     public domain program for wholesale duplication and distribution

     Type ANALYZE to begin
          <==========================================>
```

The session is initiated by determining the type of performance to be analyzed; these rules are found in the file BASIC.RLS. The resulting run operators from this module allow the user to direct the focus of subsequent questioning by selecting the observed performance fault. In this example, the poor entry position is examined first; the associated rules are contained in the file: FAR.RLS. Once a contributing cause of the requested performance error has been determined the user is provided the opportunity to examine another facet of the dive. Then, the user is prompted to identify a second performance error. In this example, the twist at entry was analyzed; the related rules of this module are contained in the file, TWIST.RLS.

PROGRAM OPERATION

```
ANALYZE <return>

Do you want the ‘trace’ feature? (y=yes,n=no: )
N <return>
NO

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
The jump/dive is performed in LAYOUT position.

N <return>
NO

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
The jump/dive is performed in PIKE position.

N <return>
NO

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
The jump/dive is performed in TUCK position.

Y <return>
YES

 I deduce
ANALYSIS WILL FOCUS ON FORWARD TUCK JUMP/DIVES.


                    . . . PRESS ANY KEY TO CONTINUE
```

```
   Select the most prevalent error (enter its corresponding #)

           1. Entry is SHORT of vertical.

           2. Entry is LONG of vertical.

           3. Entry is FAR from the board.

           4. Entry is CLOSE to the board.

           5. Dive is poor aesthetically.

           6. Diver TWISTS at entry.

           7. EXIT from program


3 <return>


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
Diver leans forward during APPROACH.

n <return>
NO


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
During the APPROACH, diver's shoulders drop forward.

n <return>
NO


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
Diver drops his head to spot the end of the board.

n <return>
NO


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
The APPROACH is smooth and controlled.
```

y <return>
YES

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
(x=change previous answers)
The diver consistently lands his HURDLE within 10 cm from
the end of the board.

y <return>
YES

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
(x=change previous answers)
The PRESS LEG is extended to begin the HURDLE phase.

y <return>
YES

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
(x=change previous answers)
Knee drive into the HURDLE is weak or poor (The HURDLE KNEE
is lower than the waist).

y <return>
YES

I deduce

Diver's hurdle needs improving.

Propperly executed board work requires that the diver be in phase with the board. Active extension with the press leg along with a good knee drive into the hurdle will improve the performance.

HURDLE:

The HURDLE is performed after the initial APPROACH steps. As the PRESS LEG extends, the HURDLE KNEE and arms are lifted, simulataneously. Good extension in the hurdle position is desireable. The hurdle is landed on two feet; a final ARM SWING is performed prior to the diver leaving the board The diver should maintain visual contact with the end of the board without dropping his head and shoulders forward. The length of the hurdle jump should be less than the length of a

```
normal walking stride.

   Press any key to view illustration of the skill.

           (An illustration of ideal hurdle position is presented).

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
You wish to analyze another facet of this performance.

y <return>
YES

I deduce

A different entry should be selected from the menu.


   Select the most prevalent error (enter its corresponding #)

          1. Entry is SHORT of vertical.

          2. Entry is LONG of vertical.

          3. Entry is FAR from the board.

          4. Entry is CLOSE to the board.

          5. Dive is poor aesthetically.

          6. Diver TWISTS at entry.

          7. EXIT from program


6 <return>

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
Diver's hips and shoulders are aligned and feet are parallel
   to each other at TAKE-OFF.

y <return>
YES


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
Diver lands his HURDLE in the center of the diving board.
```

```
y <return>
YES


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
ARM SWING is even and symmetrical.

y <return>
YES


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
When entering and performing aerial maneuver , diver;s
    actions are symmetric.

y <return>
YES


Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
Shoulders and hips are aligned when preparing for entry.

n <return>
NO

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
During the KICKOUT, legs extend together (symmetrical,
    even EXTENSION)

N <return>
NO

I deduce

Improve the kickout of the dive/jump.

   To  reinforce  symmetric  action of the extension have the
athlete perform isometrics of the skill on land or in shallow
water.   Arms  should extend  laterally to the entry position
(especially for dives).

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
                        (x=change previous answers)
You wish to continue analyzing this performance.
```

```
n <return>
NO

I conclude

A  twist  at entry may be eliminated  by  ensuring  symmetric
maneuvers during the skill performance.    Firm,  musculature
should be maintained throughout the skill.


To analyze another dive, type ANALYZE.
```

Appendix K

EXTENSIONS TO EXPERT-2 TOOLKIT

Forth[16] is an extensible, structured language where commands are named and defined. These commands are called *words.* Since the programmer selects the name of words to be defined, their name often reflects the function of the routine being defined. Programs are then, created as a combination of defined words. The concept of vocabularies[17] enables a given word to have more than one definition. That is, a given word may be assigned a definition in one vocabulary and a different definition in another vocabulary. Through specifying the vocabulary which means adding the vocabulary to the search order prior to defining or implementing a word ensures the proper definition is evoked.

The modification to the Expert-2 Toolkit, called *Definitions* employed the vocabulary concept. This feature provides the user the opportunity to have terminology defined or the definitions of ideal performances presented during program operation. Hence modifying the Expert-2 Toolkit was necessary. Firstly, the format for the question was adjusted to include the definition feature, as follows:

---

[16] The dialect of Forth which has been used is FORTHMACS.

[17] According to the Forth 83 Standard a vocabulary is an ordered list of word definitions [Forth Standards Team, 1983]

Is this statement TRUE? (y=yes,n=no,w=why,d=definitions,q=quit)
(x=change previous answers)

Secondly, the selection of 'd' was programmed to prompt the user to enter the the word(s) to be defined and then toggles the vocabulary search order to include the dictionary vocabulary. Upon entering the word, the word is then interpreted (executed). Lastly, after execution of the entered word, control is returned to the current questioning of the knowledge based expert system.

The dictionary vocabulary consists of words used to print definitions or explanations of desired mechanics associated with its name. Often these words incorporate other words that provide an illustration of the skill to provide a clearer definition. Each word terminates by restoring the vocabulary search order.

The source code necessary to implement this feature follows:

I. Modifications to Expert-2

To maintain program continuity modifications conformed with the syntax employed in Expert-2 Toolkit.

```
: diction?  ( char ---  tf)
    dup 68 = swap 100 = or
    dup if space boldon ." Definitions: " boldoff then ;

variable word-store 40 allot

: x-dictionary ( --- )
    2ncr 10 spaces dark ." Enter the word you wish to define;"
    light 2ncr 15 spaces
    ." separate double words with an underscore"
    cr word-store 40 expect word-store span @
    also  dictionary eval ;

 : ask ( fact^ --- tf )
    begin getfact t1 keyquit dup trace?
```

```
    if drop tracethen false else dup oops?
    if drop oopsthen false else dup diction?
    if drop x-dictionary false else dup why?
    if drop tellwhy false else yes? cr
     if @ remembertrue true
     else space boldon ." No" boldoff cr @
      rememberfalse  false
     then true
    then then  then  then
 until ;
```

II. Creating Dictionary Vocabulary

The complete source code of the dictionary vocabulary used in the Springboard Diving Skill Analysis Knowledge Based Expert System program is contained in Appendix H.

```
vocabulary dictionary         \ creates the vocabulary dictionary

also dictionary definitions   \ includes the dictionary
                              \ vocabulary in the search order
                              \ and subsequently defined words
                              \ will be placed in this list.

 : return-status              \ returns the vocabulary search
     previous also ;          \ order to its former status

 : EXAMPLE
   ." A typical example of the words in the dictionary "
 cr ." vocabulary would contain a word whose definition "
 cr ." prints an explanation of itself to the terminal."
 return-status ;
          \ sample word in the dictionary vocabulary

 : x-diction                \ toggles the dictionary vocabulary
      dictionary  ;         \ into the search order; used for
                            \ run-operator words for Expert 2

only forth also definitions   \ returns the vocabulary search
                              \ order to its usual status
```

REFERENCES

Bradlely, Mitch. *Forthmacs User's Guide.* Mountain View, California: Bradley Forthware.

Brodie, Leo. (1987). *Starting Forth.* Englewoeed Cliffs, New Jersey: Prentice-Hall, Inc.

Forth Standards Team. (1983). *Forth-83 Standard.* Mountain View, California: Mountain View Press.