ENGINEERING FOR THE HUMAN BODY

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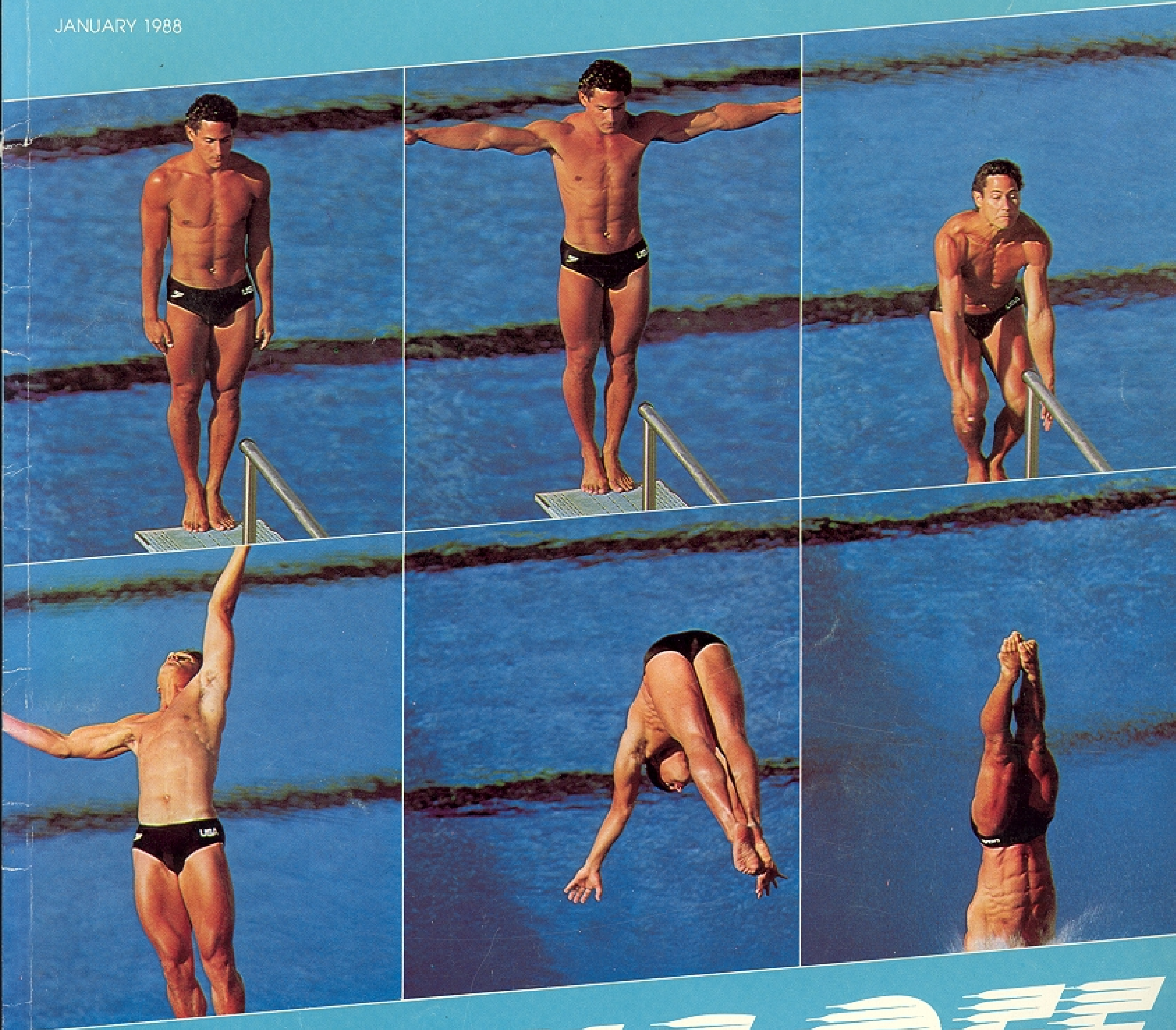

TAKING OFF

Taking Off: Greg Louganis' Diving Style

The linear and angular momentum that will take the diver to soaring heights must be produced during takeoff

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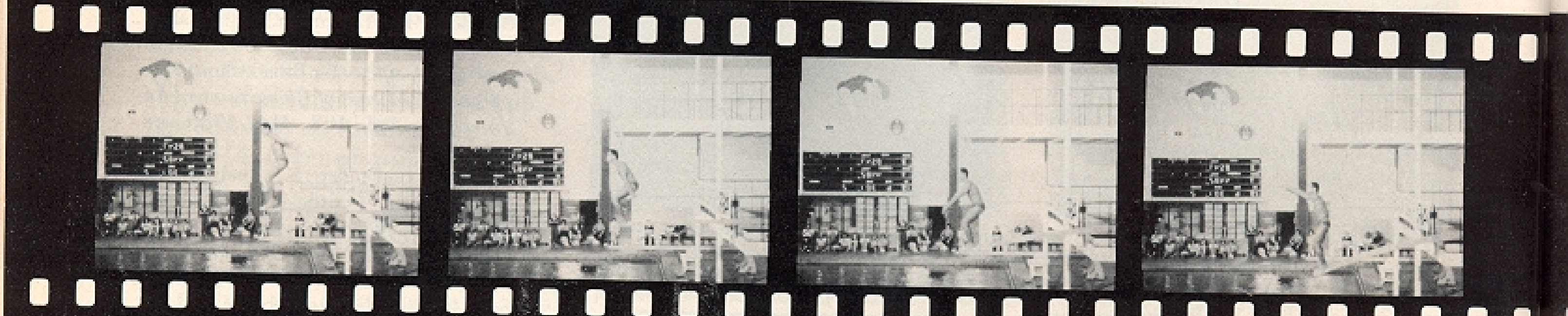
AN OLYMPIC SILVER medalist at the age of 16 (in the 10-meter platform), American diver Greg Louganis has gone on to win the National, Olympic, and World springboard and platform titles as well. His superiority in the sport is universally acknowledged despite serious challenges from American teammates and a strong contingent of divers from China. But, for some spectators, Louganis' performances are more than just fascinating entertainment. His dives—indeed all competitive dives—have proven a challenging subject for biomechanical investigation. So challenging, in fact, that the studies have already become specialized. Some researchers have focused on the biomechanics of water impact: how can a diver execute a so-called "rip" entry, in which there is minimal disturbance of the water surface [1]? Or, how might body positioning be related to acute and chronic neck, low back, shoulder, or hand injuries [2]? Others have been intrigued by the diver's flight and in particular by how four twists of the body can be accomplished in less than two seconds of free fall [3–7].

Our research [8–14] has been devoted primarily to the beginning of the performance, when the competitor is in contact with the diving surface and during which the initial linear and angular momentum conditions for the flight are established. Specifically, our interest has been in springboard and platform takeoffs of elite competitors,

Fig. 1 Springboard takeoff sequence (Δt = 0.069 seconds) of Louganis' reverse dive pike (known as dive 301B) performed in the preliminaries of National Sports Festival V. The judges awarded an average of 9.6 out of 10 for this dive.



including Louganis. In the following descriptions of dive takeoffs, we will use data from Louganis' performances as examples for the kinematic and kinetic variables discussed.

Springboard Dives

At U.S. National Sports Festival V, held in 1983 at the United States Air Force Academy in Colorado Springs, 3-meter springboard dives were filmed from the side with a stationary 16 mm Locam camera operating at 84.6 and 88.5 frames per second during the preliminary and final competitions, respectively. A detailed description of the procedures used to observe the athletes can be found in a previous publication by Miller and Munro [8]. Figures 1 and 2, showing takeoff sequences of Louganis' reverse dive pike (referred to as dive number 301B) and inward 2½ pike (referred to as dive number 405B), were taken directly from these research films.

For our purposes, takeoff was defined operationally as the final period of contact with the springboard. In the case of running dives, takeoff begins when the diver lands from the hurdle. For standing dives, the precise moment of initiation is more difficult to determine. Consequently, analysis commenced when the springboard showed a perceptible upward movement signifying that the diver was accelerating downward (called unweighting) after assuming the starting position.

The platform treats all competitors equally regardless of body size, muscular strength, or speed of movement. But the springboard is different. It can be adjusted to some extent to accommodate individual differences by changing the board's fulcrum position. The fulcrum position is chosen empirically, based on both the importance of attaining a high vertical velocity for the beginning of the flight and having sufficient time on the board to build up the angular momentum necessary to somersault the required number of times for the designated dive.

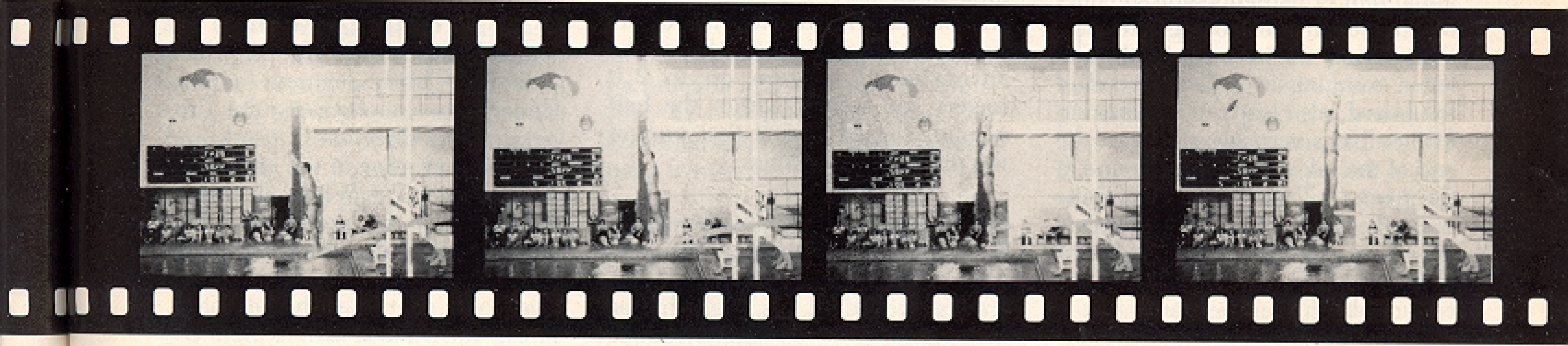
Gaining Height on a Springboard Dive. In order to gain adequate height for a given performance, the diver tries to maximize the downward velocity at the beginning of the takeoff; maximize the upward acceleration relative to the board as it is being depressed; and minimize the negative acceleration relative to the board during its recoil.

The downward velocity of the diver's center of gravity (CG) at the beginning of the takeoff differs dramatically between running and standing dives. This difference is ultimately reflected in the velocity attained at the beginning of the flight. In springboard dives from the forward and reverse groups that employ a running approach such as in Figure 1, downward velocity at the beginning of the takeoff depends chiefly upon the diver's hurdle height. For Louganis, these downward vertical velocities ranged from 4.0 to 4.5 meters per second (Table 1), among the largest calculated for the event's competitors. This implies that Louganis' hurdles were also among the highest of the competitors.

From a judging standpoint, dives from the back and inward groups, such as in Figure 2, begin when the diver's arms leave the starting position. This is immediately followed by upward movement of the total body so that the diver can "drop" and thereby achieve some downward momentum with which to initiate depression of the springboard. In the limited number of standing takeoffs analyzed for international caliber male divers [9, 12], the highest downward velocities attained ranged from 2.3 to 2.7 meters per second.

The second important factor in gaining height relates to actively pushing downward against the springboard as it is being depressed. At the beginning of springboard depression, as a result of ongoing hip, knee, and ankle flexion, the diver's center of gravity moves downward more than does the tip of the board. As depression continues, however, hip and then knee extension begin while the arms continue to swing through. By the time the board is at its lowest point, the diver is already moving upward. For example, Louganis' vertical velocities with the board at its lowest point ranged from 0.5 to 1.5 meters per second upward.

The fact that divers have consistently higher vertical velocity magnitudes at final contact than at touchdown [11] supports the contention that they are not simply passively "riding" the board but rather are introducing additional force to facilitate depression. Our research on running dives has indicated that elite divers accelerate upward with respect to the board during the first 50 to 60 percent of the springboard depression period, reflecting a downward pushing action against the board [8, 10]. This force is supplied primarily by the legs, particularly as they accelerate the large head-trunk mass upward. Because the period of time the center of gravity (CG) accelerates upward relative to the board includes the time during which the knees continue flexion and initiate extension, both eccentric and concentric contraction of the knee extensors may play a role in this important aspect of the takeoff. Contrary to popular belief, however, the arms do not ap-



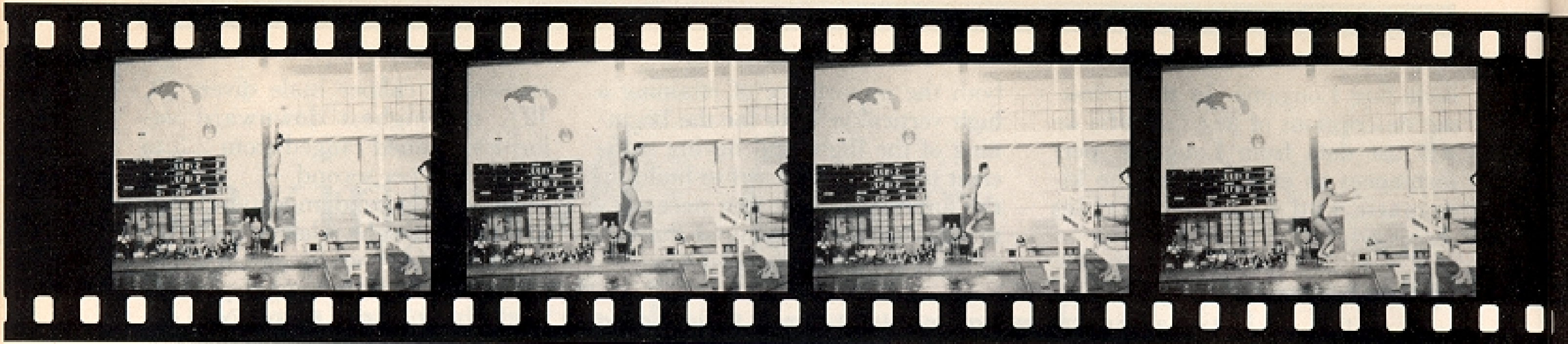


Fig. 2 Springboard takeoff sequence (Δt = 0.115 seconds) of Louganis' inward 2½ pike (known as dive 405B) performed in the finals of National Sports Festival V. The average judge's award for this dive, which had a degree of difficulty (DD) of 3.0, was 7.6 out of 10. Greg Louganis won a silver medal in the 10-meter platform at the 1976 Olympics, a gold medal at the 1978 World Championships, a gold medal in both 3-meter springboard and 10-meter platform in the 1982 World Championships, 1984 Olympics and 1986 World Championships. Sixty-nine percent of all Olympic gold medals in men's diving have gone to Americans [16].

pear to contribute significantly to the additional downward force exerted on the board.

The extent of springboard depression, then, is mainly a result of the diver's downward velocity at the beginning of the takeoff and subsequent upward acceleration relative to the board. For Louganis, the board tip deflected between 0.6 and 0.9 meters with the smaller magnitudes corresponding to standing dives and the higher ones to running dives (Table 1). In 1-meter springboard competitions held in national and intercollegiate meets, it was evident that Louganis is capable of submerging the tip of the 1-meter board in the water during the course of forward and reverse dive takeoffs.

The last important factor in gaining height is concerned with minimizing energy losses during recoil. Analysis of the data from the running takeoffs of elite divers indicates that, in general, springboard recoil for any given dive takes less time than does depression [8]. For Louganis, recoil averaged 44 percent of the 0.45 seconds required for his takeoffs. This differential between springboard depression and recoil times is attributed primarily to the diver's upward acceleration with respect to the board during the initial half of its depression in combination with some energy absorption during the recoil period. The latter, resulting in a faster recoil of the board, also leads to a reduction in the diver's vertical velocity at the end of the takeoff. At the extreme, a diver can "kill the bounce" by consciously permitting considerable knee and hip flexion as the board recoils. Although this is an effective energy absorption mechanism, it is certainly not a desirable one in the performance of a competitive dive. Thus, while some difference between springboard depression and recoil times is expected, excessively short recoil times probably indicate faulty takeoff mechanics, suggesting the diver is allowing the knees to flex too soon in anticipation of the somersault.

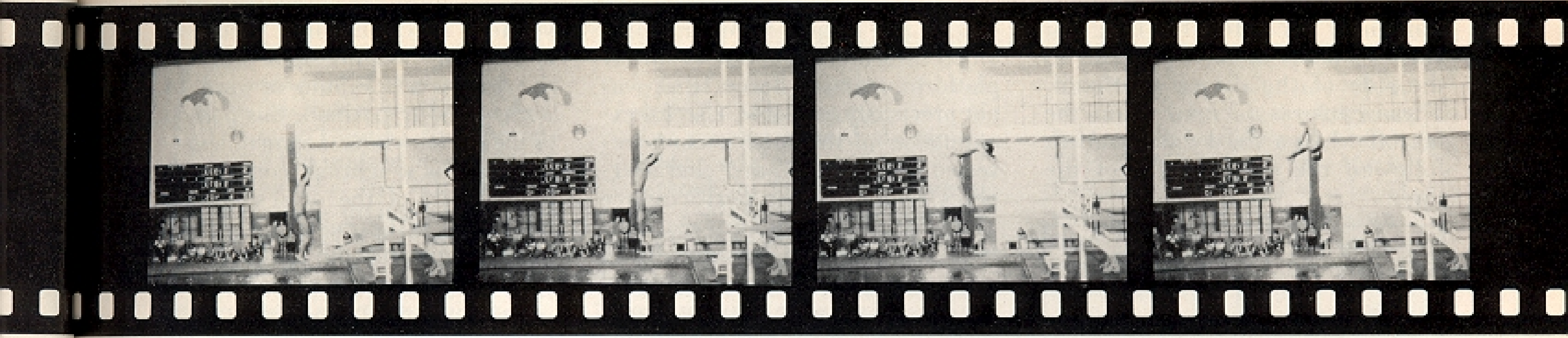
As a result of these three major factors—maximizing downward velocity, maximizing upward acceleration, and minimizing negative acceleration relative to the board during recoil—vertical velocities ranging from approximately 4.0 meters per second for standing dives to 6.0 meters per second for running dives have been recorded for elite male divers at their final instant of contact with the board preceding the flight. Within each group, dives involving more somersaults tend to have lower vertical velocities than the simple dives requiring only half somersaults. Louganis' velocity magnitudes have this pattern (Table 2). In general, however, for a given springboard dive, Louganis' higher vertical velocities at the end of the takeoff distinguished his performances from those of his fellow competitors at National Sports Festival V [11].

A comparison of downward velocity magnitudes at the beginning of the takeoff with those at the end of takeoff indicates that divers such as Louganis effectively use the springboard to gain up to 2.0 meters per second within the half second elapsed during that part of the diving performance.

Generating Angular Momentum. Since the diver's angular momentum with respect to his center of gravity (called H_g) is negligible at the beginning of the takeoff (about 1 to 2 kg m²/s) and remains constant during the flight, the necessary H_g for executing the required number of somersaults must be generated during the takeoff. Throughout the major portion of springboard depression, as the diver's trunk rotates backward with respect to his hips, and his arms swing upward, all dives are characterized by an H_g consistent with reverse and back somersaulting rotation. By the point of maximum depression of a multiple somersault dive, however, the direction of H_g is in the direction of the dive to be executed. For Louganis, the absolute magnitude of H_g was between 5 and 11 kg m²/s at the point of maximum springboard depression. It is during recoil, however, that the major buildup in H_g occurs [9].

Although they differ in approach and body orientation with respect to the water, dives from the back and reverse groups employ a similar coordination of body segment actions. Both groups involve a full arm swing and continuous upward reach into the initiation of the flight (Figure 1). The direction of trunk rotation and arm swing are thus consistent with that of the angular momentum required for the dive and the focus at the end of the takeoff in these dives is an upward reach with the arms.

By contrast, dives from the forward and inward groups, which also share body segment actions similar to one another, require a reversal in the direction of trunk and arm rotation prior to the end of recoil (Figure 2). While the diver seeks to drive the hips upward, the head, arms, and trunk must rotate forward and downward before the diver loses contact with the board. Thus, the speed with which the



arms can be swung upward and then reversed becomes an important factor in multiple somersaulting dives in these groups. Louganis is able to maintain a reasonably straight arm swing in this process (Figure 2). However, less skilled divers often have to resort to a bent arm swing to reduce the moment of inertia with respect to the shoulders, allowing them to complete the required arm motion in the limited time available. Because Louganis spends longer on the board in the takeoff than less skilled divers, he also has the advantage of additional time to adequately perform the arm swing.

As angular momentum is generated during recoil of the springboard, it is the remote angular momentum of the body segments that accounts for almost 80 percent of the total. By contrast, the local contributions are notably small, representing 20 percent or less with most of that coming from the trunk with its large mass and moment of inertia. A full 80 to 90 percent of the total local angular momentum is accounted for by the trunk, with its large mass and moment of inertia [9]. In multiple somersaulting dives, the arms are responsible for 30 to 35 percent of the final H_g, which emphasizes the importance of a fast and reasonably straight arm swing.

Thus, in springboard diving, the role of the arms seems more important in the production of angular momentum than in depression of the springboard. This suggests that, if a choice must be made, the diver would benefit more from using his arms to generate angular momentum than to use them to try to depress the board. This finding may possibly explain why the timing of the arm swing was observed to be different for the North American and Chinese divers [14].

The Chinese, who are currently among the best divers in the world, have a reputation for being able to spin very rapidly. While one might attribute this at least partially to their smaller statures and associated smaller moments of inertia, there also appears to be a major difference in the position of their arms at initial contact with the board following the hurdle. Whereas North American divers tend to be completing the downswing of the arms when they contact the board, the Chinese appear to land with their hands slightly ahead of their hips because they have eliminated the pause with the arms upstretched at the top of the hurdle. Thus, while their arms may sacrifice some of the contribution to depressing the board, they can begin to generate angular momentum in the direction of the somersault earlier and perhaps produce larger angular momentum magnitudes as a result. This hypothesis remains to be tested experimentally.

The final angular momentum also appears to reveal insights into springboard diving. By the time Louganis completed his takeoffs at National Sports Festival V, his angular momentum with respect to his center of gravity (H_g) had reached magnitudes ranging from 16 to 19 kg m²/s for his forward (dive number 101A), reverse (dive number 301B) and inward (dive number 401B) dives to between 66 and 70 kg m²/s for his back 2½ (dive number 205B) and forward 3½ (dive number 107B) respectively [10].

Because angular momentum is a function of mass, mass distribution, and segment angular velocities, angular momentum magnitudes cannot be compared directly among divers whose physical characteristics may differ. It therefore seems logical to also report angular momentum values in relation to the magnitude required for a particular diver to perform a forward dive straight (dive number 101A). In Louganis' case, this would indicate that he had to generate approximately four times more angular momentum to perform a forward 3½ pike than to perform a forward dive straight.

Platform Dives

At the 1986 World Aquatics Championships in Madrid, both platform reaction force and motion data were collected during the preliminaries and finals of the 10-meter platform competition. The project, initiated and funded by the Medical Commission of the International Olympic Committee, was organized and carried out under the leadership of Richard C. Nelson of the Exercise and Sport Science Department at Pennsylvania State University with the cooperation of corporate sponsors, meet organizers, and an international team of sports biomechanics researchers.

A 60- by 90-centimeter Kistler force plate, installed on the end of the center of the 10-meter platform, sensed the forces exerted by the divers against it. The force plate was isolated from the surrounding structure by a minimum distance of one centimeter and its surface, like the surface of the diving platform, was covered with one centimeter of a tartan-like material. Ewald Hennig of the department of *Sportwissenschaft* of the University of Konstanz in West Germany, who was responsible for the collection of the force data, developed the software that processed the platform's output voltages, which were reflections of the three orthogonal components of the platform reaction. The voltages were sampled at 500 Hz per channel for a period of two seconds by an analog-to-digital converter in an Apple IIe microcomputer equipped with a Transwarp accelerator card (Applied Engineering, Carrollton, Texas).

The dives were simultaneously recorded by Ikegami video cameras at the front and to the side of the diving platform. These cameras focused upon the takeoff while a third video camera followed the entire flight of the diver.

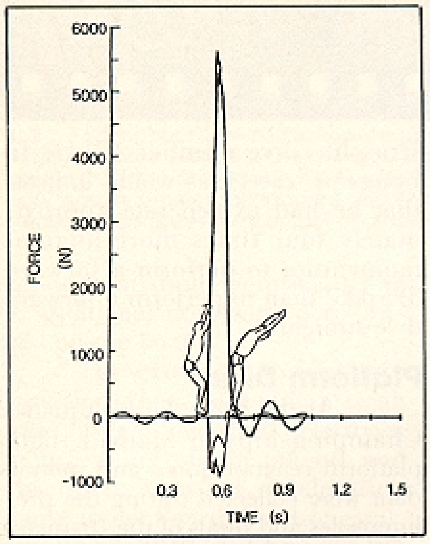


Fig. 3 Vertical and horizontal 'braking' platform reaction force-time histories for Louganis' forward 3½ (dive 107B) with records from the preliminaries and finals superimposed. The negative deflection indicates the horizontal component with the smaller of the two deflections being elicited during the preliminary round. Louganis' initial and final contact positions during the preliminary round are also indicated for this running dive.

The project in Madrid provided information about 10-meter platform reaction forces that was not previously available. Careful examination of the force records revealed several interesting characteristics related to the performance (Table 3). While platform reactions from the four non-twisting diving groups (Figures 3 to 6) displayed features that were diving group specific, each diver was able to duplicate an individual pattern for a given dive with a high degree of accuracy. This reproducibility is evident in Figure 4, in which vertical and horizontal platform reaction force patterns elicited by Louganis for the same dive in the preliminary and final competitions are superimposed.

Standing Dives from the Platform. The platform vertical reaction force histories of takeoffs from inward, back, and reverse groups of dives can be conveniently divided into six sections.

Initially, the force is constant, reflecting a reaction to body weight as the competitor briefly maintains a standing starting position prior to diving.

Then, in most cases, the vertical reaction force increases above body weight, signifying that the diver is accelerating upward. In terms of body position, this portion of the curve, which is sometimes referred to as weighting, corresponds to the start of the diver's upward movement as he raises his heels or lifts his arms, or both, at the beginning of the takeoff.

Subsequently, the vertical reaction falls below body weight indicating a period of negative vertical acceleration associated with a slowing of the diver's upward movement and the initiation of downward movement as knee and hip flexion begin.

A final period of weighting or positive acceleration in the curve is unmistakable as the force again exceeds body weight, rises steeply to a maximum value, and then falls rapidly. During this period, the diver completes the downward movement and moves rapidly up-

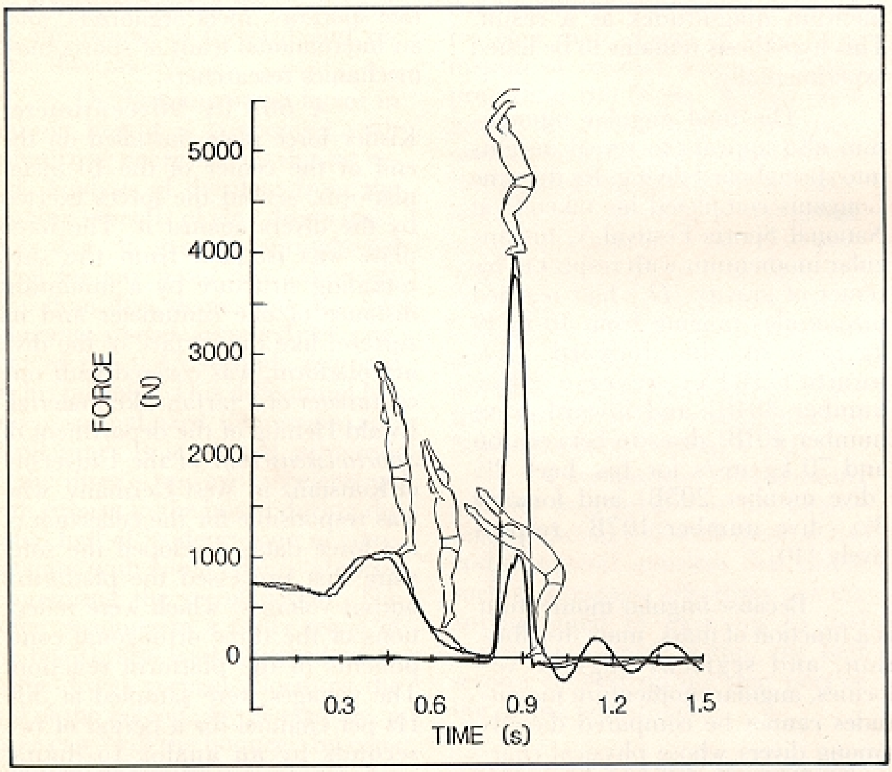


Fig. 4 Vertical and horizontal 'propulsive' platform reaction force patterns for Louganis' inward 3½ tuck (dive 407C) with records from the preliminaries and finals superimposed. The second and third body outlines, located on the vertical force curve, show Louganis' highest and lowest body positions, respectively. A very slight offset of about 18 newtons evident in the zero of the horizontal force record before and after the takeoff suggests that the force plate may not have been mounted completely level.

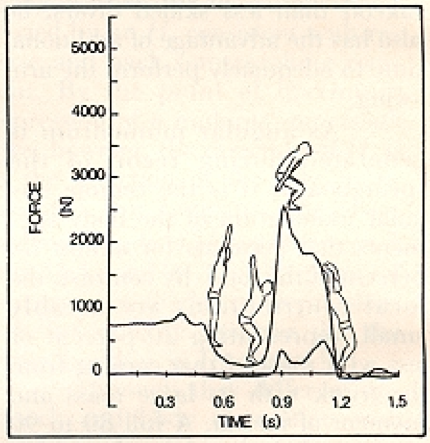


Fig. 5 Vertical and horizontal 'propulsive' platform reaction force-time histories for Louganis' reverse 3½ tuck (dive 307C) performed in the finals. The first and third body outlines indicate his highest and lowest body positions, respectively.

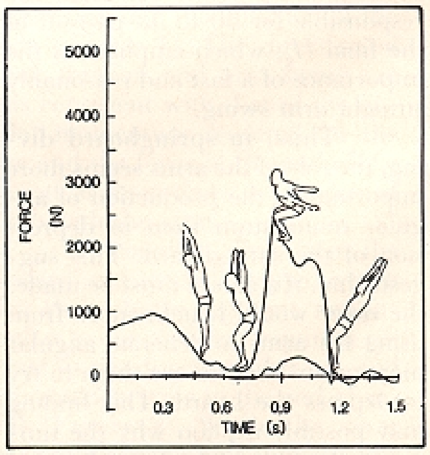


Fig. 6 Vertical and horizontal 'propulsive' platform reaction force patterns for Louganis' back 3½ tuck (dive 207C) performed in the preliminaries. The first and third body outlines show his highest and lowest body positions, respectively.

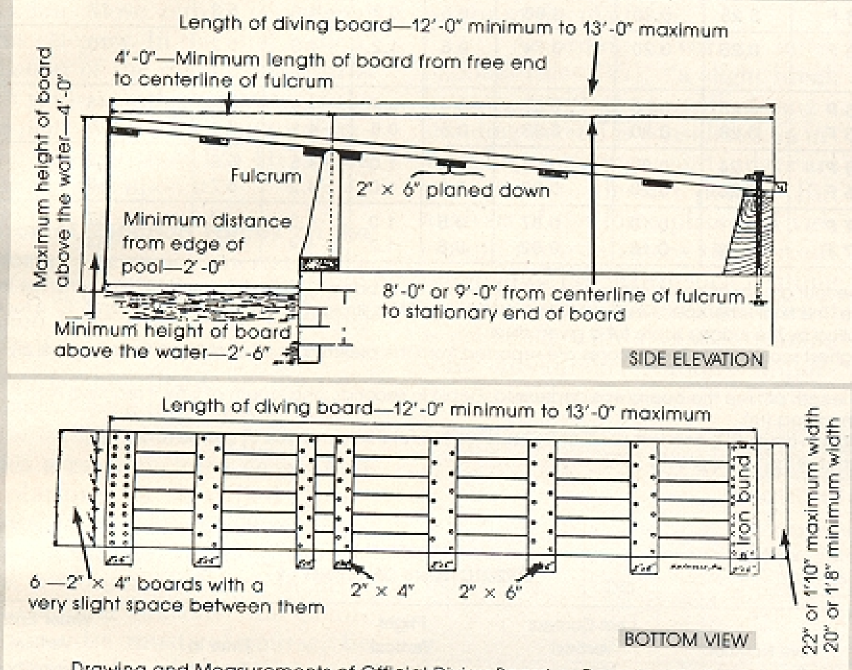
From Aircraft Wings to Diving Boards

Since 1904 when diving was first included in the modern Olympic Games, the springboard has undergone major improvements. In 1922, the 3.7-meter-long diving board, with one third of the board's length hanging over the fulcrum, sloped upward from 2.0 to 3.2 degrees. These conditions made a running approach in forward and reverse dives necessary in order to safely clear the board's end. Today, the 4.9-meter-long board is mounted completely level and has an adjustable fulcrum. While the term 'running approach' is still retained in the official diving rules, this approach now resembles more of a slow, controlled walk than a self-preservation run.

In terms of construction, the competitive springboard has evolved through three major stages. In the 1920s and for more than 25 years thereafter, it was a heavy wooden plank of white ash or Oregon pine covered with cocoa matting. Competitions of the day reflected the limitations imposed by this type of equipment with the most difficult dives involving only 1½ somersaults [17]. In 1948, Norman Buck of Seattle revolutionized the industry when he designed an I-beam type of board constructed from over 300 interlocking pieces of war surplus square aluminum tubing originally used in B-17 aircraft. In 1951, as a result of the widespread adoption of the "Buckboard," the NCAA removed the stipulation that boards used in their competitions had to be made of wood. By 1959, however, the "Buckboard" was supplanted by the "Duraflex," a one-piece aluminum extrusion-type springboard which was also a spin-off of the aircraft industry [14].

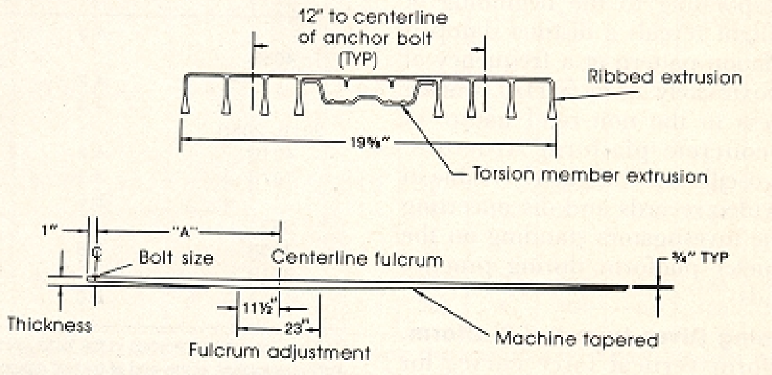
The original "Duraflex" board, manufactured by Arcadia Air Products of Sparks, Nevada, was machine-tapered from fulcrum to tip. In 1969, a second taper from the fulcrum back to the anchor was added. This model, termed the Maxi-Flex, is "constructed of a basic ribbed one-piece extrusion, heat treated for a minimum yield strength of 50,000 psi of aluminum alloy #6070-T6 . . . [with] a torsion box extrusion, anchor end extrusion, and tip end cap extrusion riveted to the basic section" [18]. In 1979, the Maxi-Flex Model B, which incorporated perforations into the tip, was marketed. While the "Duraflex" has retained basically the same design since its inception, improved aluminum alloys have been used in its construction providing greater strength and lighter weight. The board has been reduced in weight from 140 to 128 pounds. "Duraflex" springboards have been used exclusively in all major national, international, world, and Olympic competitions since 1959 and will be employed in the 1988 Olympics in Seoul, South Korea.

As a result of these changes in springboard construction, divers have been able to attain significantly greater vertical velocities at the end of the takeoff so that standards for water depth beneath the board have had to be correspondingly increased. It is difficult to envisage the time when a depth of 2.14 meters beneath a one-meter board was considered sufficient. Today's competitive standards require water depths of at least 3.50 meters for a 1-meter board and 3.80 meters for a 3-meter board.



Drawing and Measurements of Official Diving Board as Described in the Rules

The competitive springboard as specified in 1922 [17].



The Duraflex 'Maxiflex' board currently used in national and international competition [18].

TABLE I
GREG LOUGANIS' SPRINGBOARD TAKOFFS RUNNING DIVES NATIONAL SPORTS FESTIVAL V [8, 9]

Dive			Average Score (Out of ten) (3)	Springboard			Velocity (5)				Angular Momentum (wrt CG) kgm²/s (6)
Name	No. (1)	DD (2)		Depr. (s) (4)	Rec. (s) (4)	Defl. (meters) (4)	Horiz.		Vert.		
							TD m/s	LC m/s	TD m/s	LC m/s	
Forward Dive Straight	101A	1.6	9.5 P 8.3 F	0.25 0.25	0.21 0.20	0.89 0.86	0.5 0.5	0.8 0.8	−4.4 −4.0	6.0 5.3	−18 −17
Forward 3½ Pike	107B	3.1	8.3 F	0.25	0.20	0.74	0.6	1.2	−4.5	5.2	−70
Reverse Dive Pike	301B	1.9	9.6 P 9.3 F	0.25 0.28	0.20 0.20	0.87 0.93	0.4 0.5	0.9 0.8	−4.4 −4.1	5.9 6.1	15 19
Reverse 1½ Straight	303A	2.6	8.9 P 9.5 F	0.24 0.26	0.20 0.20	0.84 0.89	0.5 0.5	1.0 1.0	−4.5 −4.3	5.5 5.7	52 50
Reverse 2½ Pike	305B	3.0	7.7 P 7.7 F	0.27 0.26	0.19 0.18	0.87 0.92	0.5 0.6	1.0 1.2	−4.3 −4.4	5.8 5.8	57 54

(1) The first digit of the dive number indicates one of the four groups of non-twisting dives: "1" is forward; "2" is back; "3" is reverse; and "4" is inward. The third digit indicates the number of half somersaults in a dive. The final letter specifies the position of the dive: "A" is straight or layout; "B" is pike; and "C" is tuck.
(2) In a competition, degree of difficulty (DD) is multiplied by the judge's score for a given dive.
(3) The average score awarded by the judges. The highest score is ten. Some scores are reported from the preliminary (P) and some from the final (F) competition.
(4) The springboard responses measured include the length of time the board was depressed (Depr.) in seconds ; the length of time it recoiled (Rec.) in seconds, and the distance it was deflected (Defl.) in meters (m).
(5) Horizontal (Horiz.) and vertical (Vert.) velocities at touch-down (TD) and last contact (LC) refer to the total body center of gravity (CG).
(6) Angular momentum is reported with respect to (wrt) the center of gravity (CG).

ward as a result of hip, knee, and ankle extension. As evident in Figures 4, 5, and 6, there is a close temporal correspondence between the diver's lowest body position and the peak of the vertical force curve, suggesting that eccentric contraction of the lower extremity extensor musculature may be playing an important role in force production.

While theoretically, there is also a final period of negative acceleration as the force curve drops from body weight to zero, from a practical standpoint, this period is so brief that it can be disregarded.

And finally, analysis of the terminal portion of the force history corresponding to the beginning of the flight reveals a distinct damped oscillation pattern at a frequency of approximately 4 to 5 Hz, bearing witness to the non-rigid nature of the concrete platform structure. This oscillation was clearly visible in the video records and disconcerting to the investigators standing on the 10-meter platform during practice rounds.

Running Dives from the Platform. Platform vertical force curves for running dives from the forward group (Figure 3) consist of only three major sections. During the first section, oscillation of the diving platform is evident as a result of the

TABLE II
PREDICTIONS OF FLIGHT (1)

Dive Number (Louganis) (2)	Last Contact Vertical Velocity (m/s)	Flight Vertical Height (m) (3)	Time in the Air (s)	Water Entry Vertical Velocity (m/s)
10-Meter Platform				
407C	1.4	0.10	1.58	−14.1
403B	2.4	0.29	1.69	−14.2
307C				
	2.6	0.34	1.72	−14.2
107B				
	2.8	0.40	1.74	−14.3
301B	3.0	0.46	1.77	−14.3
113B				
207C	3.2	0.52	1.79	−14.4
201B	3.8	0.74	1.87	−14.5
3-Meter Springboard				
	4.0	0.82	1.29	−8.7
405B				
	4.2	0.90	1.32	−8.7
	4.4	0.99	1.35	−8.8
201B, 205B				
401B	4.6	1.10	1.38	−8.9
107B	5.2	1.38	1.47	−9.3
	5.6	1.60	1.54	−9.5
303A				
305B	5.8	1.71	1.57	−9.6
301B				
101A	6.0	1.83	1.60	−9.7

(1) The flight characteristics in the table are predicted based on the 3-meter springboard and 10-meter platform vertical velocities at the end of takeoff assuming negligible air resistance.
(2) The first digit of the dive numbers indicates one of the four groups of non-twisting dives: 1—forward; 2—back; 3—reverse; and 4—inward. The third digit indicates the number of half somersaults in a dive. The final letter specifies the position of the dive: A is straight (or layout), B is pike, and C is tuck. If the second numeral is a 0, the dive is non-flying. If it is a 1, the dive is flying.
(3) Above starting height.

approach run. Then, the vertical force rises sharply to a peak and subsequently falls back to zero, indicating the period of the diver's contact with the platform during the takeoff. While, theoretically, only the portion of the curve greater than body weight designates positive acceleration of the diver's center of gravity, because of the rapid rise and decay of the curve, the entire deflection above zero is considered in this category. In the final section, oscillation of the diving platform is again present with oscillation of the force plate (which has a natural frequency greater than 125 Hz) being superimposed upon it.

Horizontal Reaction Forces on the Platform. The major interest in the horizontal (forward and backward) reaction force component is during the final upward acceleration of the diver preceding flight. In the convention adopted for displaying these platform force histories, positive indicates a reaction force away from the platform, a so-called "propulsive" force, while negative designates a horizontal reaction into the tower, a "braking" force. In dives with standing takeoffs, the dominant impulse must, of course, be away from the platform or propulsive. Such a direction is consistent with generating angular momentum for dives from the reverse and inward groups but antithetical to this objective for backward and forward rotating dives.

While a running approach is employed in both springboard and platform competitions, there is a distinct difference in the way in which it is performed. In the case of the platform, the run is much faster and the hurdle is long and low since there is little advantage to achieving a large downward velocity at contact with the end of the concrete platform. The major objective of the run, and the reason it is, for all practical purposes, limited to dives from the forward group, is to provide conditions for eliciting a horizontal braking force consistent with producing forward somersaulting angular momentum.

Looking at the Platform Force Record. During the initial unweighting phase of the takeoff, and particularly during the performance of dives from the inward group, a number of divers actually left the platform surface as a result of their upward momentum. This was reflected in the data, which show that a distinct initial peak in the vertical force curve during weighting was followed by a straight horizontal line coincident with zero on the horizontal and vertical force scales and subsequently, in some instances, by the presence of a sharp impact peak designating the diver's return to the platform.

According to current international rules [15], "a slight break in contact with the board" during a standing takeoff is considered an involuntary movement and judges are permitted to deduct points. But analysis of the force plate and videotape records raises the serious question of just when such a lifting of the feet is inadvertent and when it is deliberate with a view to gaining some advantage. Another important consideration is one of safety. During this non-contact period, many of the divers move even closer to the edge, risking the possibility of missing a firm contact with the platform. Because of the brief time interval involved and the height of the platform above pool deck, it is highly unlikely that this movement can be perceived by those judging the competition.

Forward and Inward Dives on the Platform. As indicated in the discussion on springboard dives, forward and inward somersaulting dives are executed as the result of similar coordinated body segment actions. In the case of platform dives, the preliminary upswing of the arms is omitted and divers begin the takeoff with their arms already over their heads. Consequently, the final upward acceleration portion of the vertical reaction force history consists of an impulse of short dura-

TABLE III
LOUGANIS' PLATFORM TAKEOFFS
REACTION FORCE-VS-TIME (1)

Dive				Platform Max. Force (BW) (4)		Vertical Acceleration Periods					
						Positive		Negative		Positive	
Name	No. (2)	DD (3)	Average Score (out of 10)	Vert.	Horiz.	t (s)	Δv (m/s) (5)	t (s)	Δv (m/s)	t (s)	Δv (m/s)
Flying Forward 1½ pike	113B	1.8	7.4 P	8.5	−1.1	—	—	—	—	.124	4.9
			8.9 F	9.1	−1.8	—	—	—	—	.118	4.9
Forward 3½ pike	107B	3.0	7.5 P	7.5	−1.1	—	—	—	—	.125	4.5
			8.9 F	7.9	−1.8	—	—	—	—	.118	4.5
Back dive pike	201B	1.8	7.9 P	3.2	0.5	.271	.6	.400	−2.1	.337	5.3
			9.1 F	3.5	0.5	—	—	.388	−2.3	.331	5.4
Back 3½ tuck	207C	3.3	8.7 F	3.4	0.4	.361	.7	.423	−2.5	.363	5.0
Reverse dive pike	301B	1.9	8.3 P	3.2	0.4	.159	.2	.383	−2.0	.341	4.8
			8.6 F	3.3	0.5	—	—	.349	−2.0	.349	5.1
Reverse 3½ tuck	307C	3.4	8.6 F	3.5	0.6	.153	.2	.347	−2.2	.341	4.5
Inward 1½ pike	403B	2.0	8.9 P	6.1	1.1	.297	.7	.309	−1.9	.134	3.6
			8.7 F	6.0	1.2	.304	.6	.337	−2.0	.130	3.5
Inward 3½ tuck	407C	3.2	7.8 P	5.2	1.4	.271	.6	.287	−2.1	.124	2.8
			7.1 F	5.5	1.4	.285	.6	.304	−2.0	.125	2.8

(1) This table is selected platform reaction force-time characteristics of Louganis' takeoffs in the preliminaries (P) and finals (F) of the 1986 World Diving Championships.
(2) See Table 1, Note 1 for an explanation of dive numbers.
(3) See Table 1, Note 2 for an explanation of dive degree of difficulty (DD).
(4) The numeral in the table refers to the force expressed as the number of diver's body weights (BW).
(5) ΔV is change in velocity

tion characterized by a high force peak. For Louganis, the maximum vertical force ranged from 7.5 to 9.1 times his body weight for the dives from the forward group and 5.2 to 6.1 times his body weight for the dives from the inward group (Table 3). While the two groups of dives in general have similar configurations in their reaction force histories, force patterns presented in Figures 3 and 4 clearly differentiate between the running approaches of dives from the forward group and the standing starts of dives from the inward group.

Although Louganis' vertical reaction force patterns were similar in his preliminary and final trials both for his forward 3½ (dive number 107B, Figure 3) and his forward flying 1½ (dive number 113B), a distinct difference was evident in the horizontal component. In both cases in the finals, the braking component was clearly larger than the braking force in the preliminary trials. This facilitated the buildup of greater forward somersaulting angular momentum magnitudes. The result was reflected in scores of 8.9 in the final compared with only 7.4 and 7.5 in the preliminary trials.

Back and Reverse Dives on the Platform. The similarity in the patterns of motion of back and reverse dives is reflected in the similarity of platform reaction forces. The complete arm swing used in the springboard takeoffs is retained in platform takeoffs and is consistent with the direction of angular momentum required in both cases. The maximum vertical reaction force in dives from the back and reverse groups is small in comparison with those attained from the inward groups, all three of which use standing starts. However, the resultant upward force of the back and reverse dives lasts longer (Table 2).

Because the propulsive horizontal force characteristic of standing dive takeoffs promotes reverse somersaulting and impedes back somersaulting angular momentum, differences in the horizontal force patterns and body positions would be expected between the back and reverse groups. The intricacies of such differences and how they change with respect to dives of increasing degree of difficulty are the subject of ongoing investigation.

Implications for Flight

Table 2 provides a comparative summary of springboard and platform flight characteristics assuming negligible air resistance. On the basis of Louganis' performances, there is a clear distinction between the ranges of vertical velocities attained at the end of springboard and platform takeoffs. As a result, the diver achieves considerably less height in the flight above the diving surface in platform competition. Consequently, despite the 7-meter difference in starting height, flight times from the 10-meter platform do not exceed those from the 3-meter board by as great a margin as might be expected. Nevertheless, entry velocities of between 50 and 52 kilometers per hour characteristic of platform dives give the spectator and researcher a new appreciation of the skill required by athletes in this sport.

What does all this mean for the flight of the dive, which is the major focus of attention of spectators and judges alike? It is during the flight that the diver must capitalize on the linear and angular momentum produced during the takeoff. While the angular momentum cannot be changed during flight, the speed of the spin can be adjusted by changing the moment of inertia through alterations in body position. The diver therefore aims not only to complete the required rotations, but to finish them as high above the water as possible, allowing a long eye-pleasing drop prior to entry. Vertical takeoff velocities and their associated flight times are thus key to a successful performance. ■

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