# A NEW MODEL OF THE SPRINGBOARD IN DIVING

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This paper presents a model which describes the vertical, horizontal and rotational movement of a diving springboard. Model parameters were determined from experimental data. The springboard model was used in conjunction with a diver model to simulate a diving takeoff. Diving performance of an elite female diver was recorded at 200 Hz and was digitised to obtain kinematic data used to drive the simulation. There was good agreement in terms of linear and angular takeoff conditions between the performance and the simulation. It is concluded that the proposed model is an improved representation of the springboard as a simple mass-spring system. This model will be used in conjunction with a diver model to investigate takeoff techniques and optimise diving performance.

**KEY WORDS:** springboard, diving, model.

**INTRODUCTION:** During a springboard diving takeoff, the springboard is depressed and then recoils along a curvilinear path, projecting the diver upwards and forwards into the flight. Modelling the springboard alone to reflect its extreme complexity requires extensive computation (Kooi & Kuipers, 1994). In order to incorporate the springboard into a diver/ springboard system, a simpler model with reasonable accuracy is preferred. Although a single degree of freedom (DOF) 'bar model' has been proposed (Kooi & Kuipers, 1994), a linear mass-spring model (Sprigings, Stiling & Watson, 1989) is generally accepted. The mass-spring model represents only the vertical behaviour of the springboard and thus the vertical reaction force acting on the diver. It should be noted that the springboard deflects in a curvilinear path, providing also a horizontal reaction force which plays an important role in the generation of angular momentum and board clearance (Miller et al., 1990). In addition, the springboard rotates as it defects which influences the divers' orientation. The purpose of this study was to develop a model which represented the vertical, horizontal and rotational behaviour of the springboard for subsequent use in a diver/springboard model to investigate takeoff techniques and optimise diving performance.

**METHOD:** The springboard was modelled as a 0.3 m rod with three DOF: vertical (z), horizontal (x) and rotational ( ) movement (Figure 1).

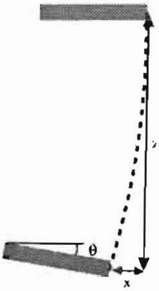


Figure 1: The springboard modelled as a rod with three DOF.

The vertical behaviour of the springboard was modelled as a linear mass-spring system with no damping (Sprigings et al, 1989). The moment of inertia was calculated using the equation for an uniform rod. Vertical stiffness and effective mass were obtained using the dynamic method described in Miller and Jones (1999). The vertical stiffness was allowed to vary depending on foot position such that the further away from the board tip, the stiffer the board. It was assumed that the mass centre of the body was 0.15 m from the toes and that there would be no more than 0.15 m variation from the position where the toes were right at the board tip. In the study by Sprigings et al. (1990), a nearly linear relation between the stiffness and the position of applied load (PAL) was observed when the PAL is close to the board tip. At the fulcrum number of 7.5, the stiffness with PAL at 0.2 m and 0.3 m were approximately 7000 N/m and 8000 N/m respectively. The slope could therefore be calculated as:

$$m = \frac{8000-7000}{0.3-0.2} = 10000$$

Let the distance between the board tip and the toes be d, the equation of vertical stiffness could be expressed as:

$$k = 10000\,(d + 0.15) + c \qquad (1)$$

where c = constant, which could be determined once k was known for d = 0.
The horizontal movement was constrained by a geometrical function relating the vertical and the horizontal deflections. Once the vertical springboard parameters have been determined, the horizontal displacement, velocity and acceleration can be computed from the geometrical function and its derivatives. Similarly, the board angle was expressed as a function of the vertical board tip deflection.
A high speed video camera operating at 200 Hz was used to record an elite female diver performing 18 dives in the forward and reverse groups from a one-metre springboard. Ten body landmarks (wrist, elbow, shoulder, hip, knee, ankle, heel, ball, toes and the centre of the head) of the diver and the tip of the springboard in line with the foot during the contact phase were digitised. The board angle was calculated as the angle between the horizontal and a line fitted through heel, ball and board tip. The springboard position at touchdown was taken as the reference point with no deflection. The board angle and the horizontal deflection were regressed against the vertical deflection respectively.
After all parameters were determined, the model was incorporated into a diver/springboard system to simulate the takeoff of a forward two and one-half somersault pike (105B) from a one-metre springboard. The diver model was a eight-segment linked model driven by joint angle time histories calculated from digitised data. To evaluate the springboard model, the takeoff conditions of the performance and the simulation were compared

**RESULTS:** At a fulcrum number of 7.5, the calculated vertical spring stiffness was 5446 N/m and the effective board mass was 8.87 kg. These values are comparable to those reported in the literature for a Maxiflex B springboard. The moment of inertia of the springboard about a transverse axis was 0.0665 kgm2. Substituting k = 5446 N/m and d = 0 in equation (1), the constant c was calculated as 3946N/m. The equation for variable stiffness is therefore:

$$k = 10000\,(d + 0.15) + 3946 \qquad (2)$$

Figure 2 shows the regression of x against z for a forward one and one-half somersault pike (103B). The regression suggests that a quadratic function fits the data as closely as a cubic function since the cubic term contributes less than 1 mm to the horizontal deflection. The quadratic function was:

$$x = -0.187z^2 + 0.002z - 0.0026$$

It was believed that a simpler function $x = az^2$ would be adequate to represent the relationship between x and z. When x was plotted against $z^2$ using all the experimental data points (Figure 3), the new function relating the horizontal and vertical deflections was:

$$x = -0.194z^2 \qquad (3)$$

The regression of  against z suggests that a linear function is adequate to represent the board angle-vertical deflection relationship (Figure 4):

$$\theta = -28.599z \qquad (4)$$

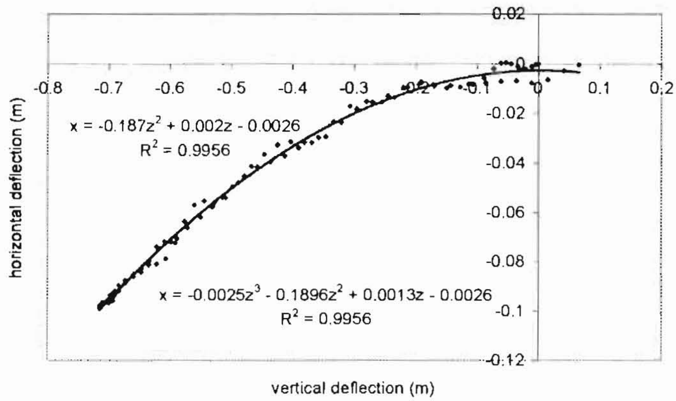


Figure 2: Quadratic and cubic fits to the springboard movement during the contact phase of a forward one and one-half somersault pike (103B).

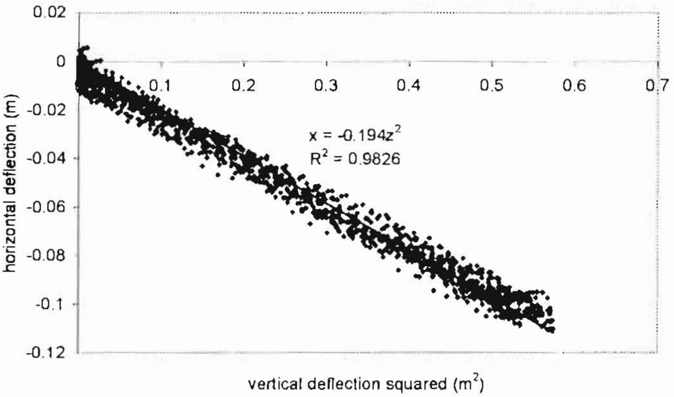


Figure 3: Linear regression of the horizontal deflection and the vertical deflection square using all experimental data points.

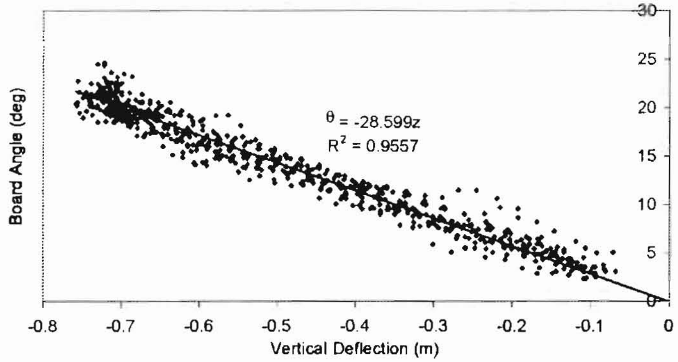


Figure 4. Linear regression of the board angle and the vertical deflection using all experimental data points.

Table 1 compares the takeoff conditions between the simulation model and the performance. It can be seen that there is good agreement in the takeoff time, maximum board depression, the diver's mass centre (CM) velocities, angular momentum and orientation. The average percentage difference was 2.2%.

**Table 1 Takeoff Conditions of Forward Two and One-half Somersault Pike (105B).**

| Variable | Performance | Simulation |
|---|---|---|
| Takeoff time | 0.435 s | 0.435 s |
| Maximum board depression | -0.73 m | -0.73 m |
| CM horizontal velocity | 1.33 m/s | 1.34 m/s |
| CM vertical velocity | 4.39 m/s | 4.62 m/s |
| Angular momentum | 58.91 $kgm^2$ | 59.08 $kgm^2$ |
| Trunk angle | 14° | 21° |

**DISCUSSION:** This paper presents a method to model the springboard with vertical, horizontal and rotational movement. From experimental data, it was shown that a quadratic function was adequate to relate the horizontal deflection to the vertical deflection, whereas a linear function was sufficient to describe the board angle-vertical deflection relationship. When the model was used with an angle driven diver model, there was good agreement between the simulation and the performance in terms of both linear and angular momentum. This suggests that the springboard model captures the physical characteristics of the springboard. This model, which allows horizontal board tip movement and rotation in addition to vertical movement, is an improved representation of the springboard as a simple mass-spring system.

**CONCLUSION:** This paper presents a model which describes the vertical, horizontal and rotational movement of a springboard. This model will be used in a diver/springboard system to investigate diving takeoff techniques and optimise performance.

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