THE USE OF FORCE PLATES FOR JUMPING RESEARCH

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The force plate is becoming a basic tool used in the study of jumping activities, for it provides a direct measure of one of the principal components responsible for a jump to occur - the force. Essentially the device is an electronic scale which measures the magnitude of the vertical and two horizontal forces, the torque about the vertical axis and the location of the resultant force acting on the platform.

Although there are a variety of ways that the force can be measured, the most prevalent means are by piezoelectric crystals and electric resistance strain gages. For those interested in the force plate design details and wide variety applications please refer to Ramey, 1975; International Society of Biomechanics (ISB), 1975-. The ISB has a formal force platform group that catalogues the world wide use of force plate designs and applications. Many of the platforms described by the force platform group are custom-made and incorporate a wide range of capabilities.

Figure 1 shows a commercially available piezoelectric type force plate made by Kistler Instruments, AG. It has a surface measuring approximately 400 mm x 600 mm and is capable of measuring forces up to 4,500 lbs. Typical force records for the support phase of the long jump are also shown.

Figure 2 shows the custom-made strain gage type force plate system of Mr. Howard Payne of the University of Birmingham, England. The transducer containing the strain gages is shown in the foreground. Figure 3 shows the arrangement at the test site where two of these approximately 3-foot square force plates can be used side by side.

A strain gage based force plate system is produced commercially by Advanced Mechanical Technology, Inc. (AMTI) having a surface measuring approximately 460 mm x 500 mm and capable of measuring forces up to 2400 lbs. Both the Kistler and AMTI systems can be supplied with the required signal conditioning and microprocessor control.

With the above mentioned equipment available it is easily possible to obtain accurate force-time curves for the support phase of jumping activities. What then becomes necessary is the extraction of relevant information from these records and, in this regard, one finds a variety of uses for these force records. The following briefly illustrates such uses:

Some Uses of Force Plates in Jumping Studies

- Provide a force time record of the activity.

- Compare force records made by the same jumper using variations of the technique.
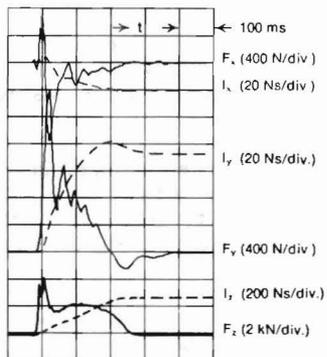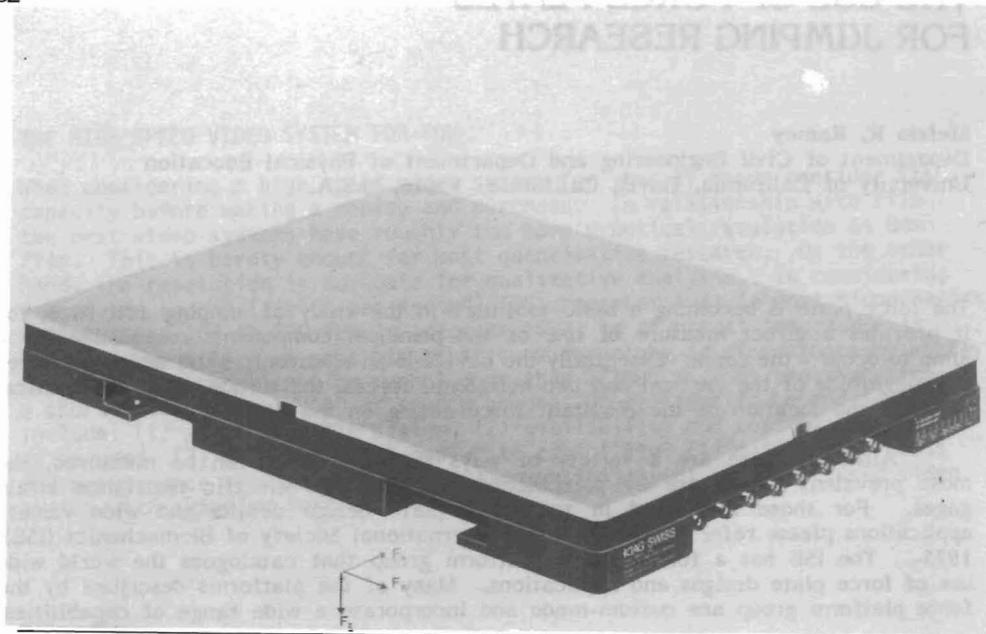
Kistler Instrumente AG

FIGURE 1

Piezoelectric Force Plate
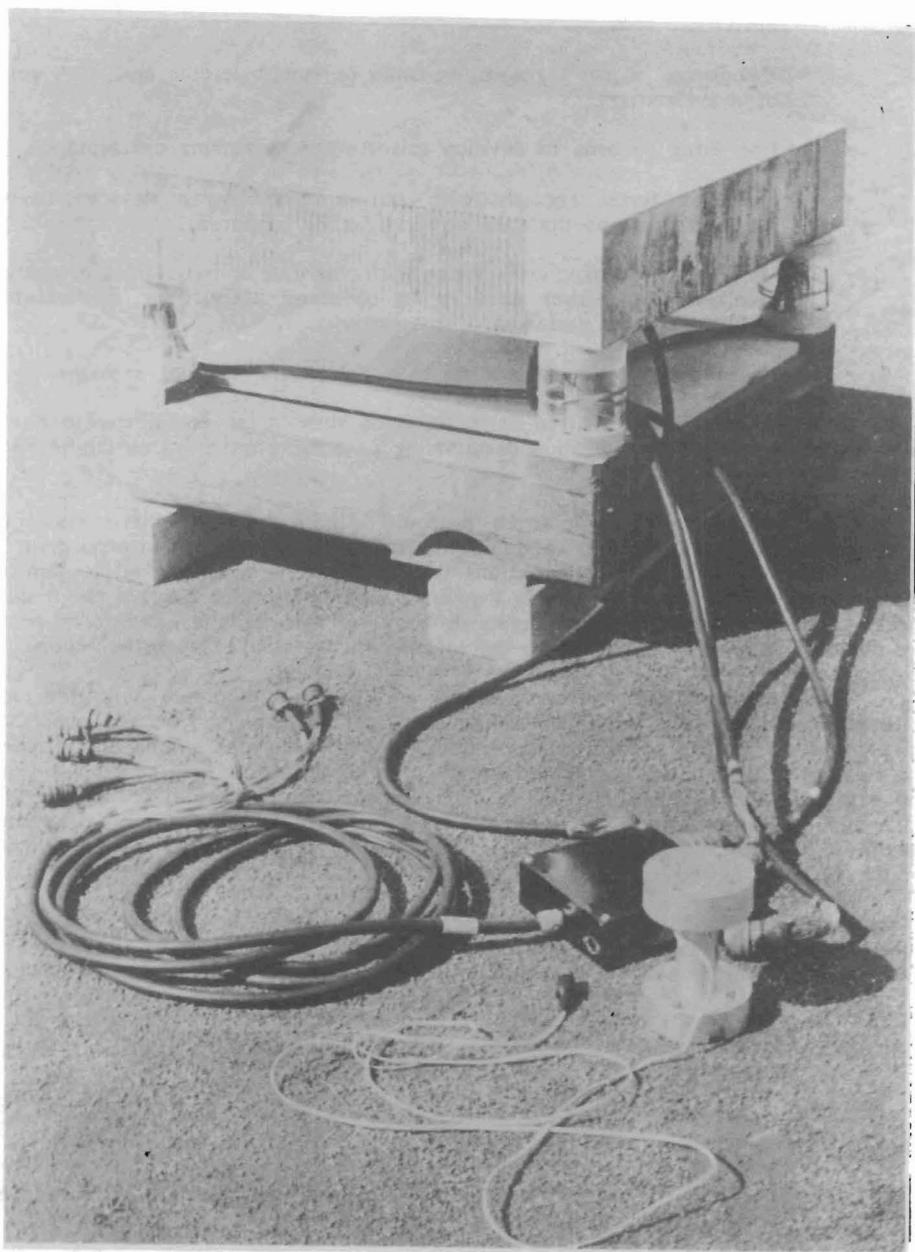
FIGURE 2

Strain Gage Force Plate

- Compare force records made by different jumpers but of the same activity.

- Use force records to calculate other pertinent parameters. (i.e. velocity of mass center).

- Use force records to develop criteria for measuring performance.

- Combine force records with output from other devices to study interrelationships that are not individually apparent.

- Use force records in conjunction with cine data and equations of analytical mechanics to either analyze an observed activity or mathematically simulate a new variation of the activity.

- Use force records to provide feedback during training sessions.

In what follows we shall discuss some of these uses and illustrate how one must exercise care and have an understanding of basic physics to use these records successfully.

First consider a typical force record. Figure 4 shows the vertical force components obtained for a vertical jump test (as one might obtain in a Sargent Jump Test). These records are for situations where the subject was asked to jump with and without preliminary knee flexing ("double pumping"). Here observe the maximum forces to be about 3.7 times the jumper's body weight. Further, the force patterns are obviously different and we note the larger time associated with the second jump.

These straightforward observations are of value but only of a limited nature. When the force records are combined with cine data one obtains a greater appreciation of what is taking place. For example, Figure 5 shows synchronized cine frames of the running long jump that produced the force record shown. One can easily observe the relative interaction of the body's displacement and the associated forces. Here it is seen that the knee flexion of the supporting leg is relatively small when the maximum force is being generated in the thrust region. This fact has implications on the type of weight training that might be helpful for these athletes.

In a more quantitative vein, the force record can be used to calculate the take-off velocity associated with the jump. This, however, must be done with care. Here one uses the impulse-momentum equations of mechanics which shows

$$m(\mathbf{v} - \mathbf{v'}) = \int_{t_a}^{t_b} F(t)\,dt \tag{1}$$

where m is the mass of the jumper;

$\mathbf{v}$ is the velocity vector of the mass center at the end of the support phase (this is the take-off velocity);

$\mathbf{v'}$ is the velocity vector of the mass center at the beginning of the support phase;

$F(t)$ is the resultant force vector acting on the jumper at time t;

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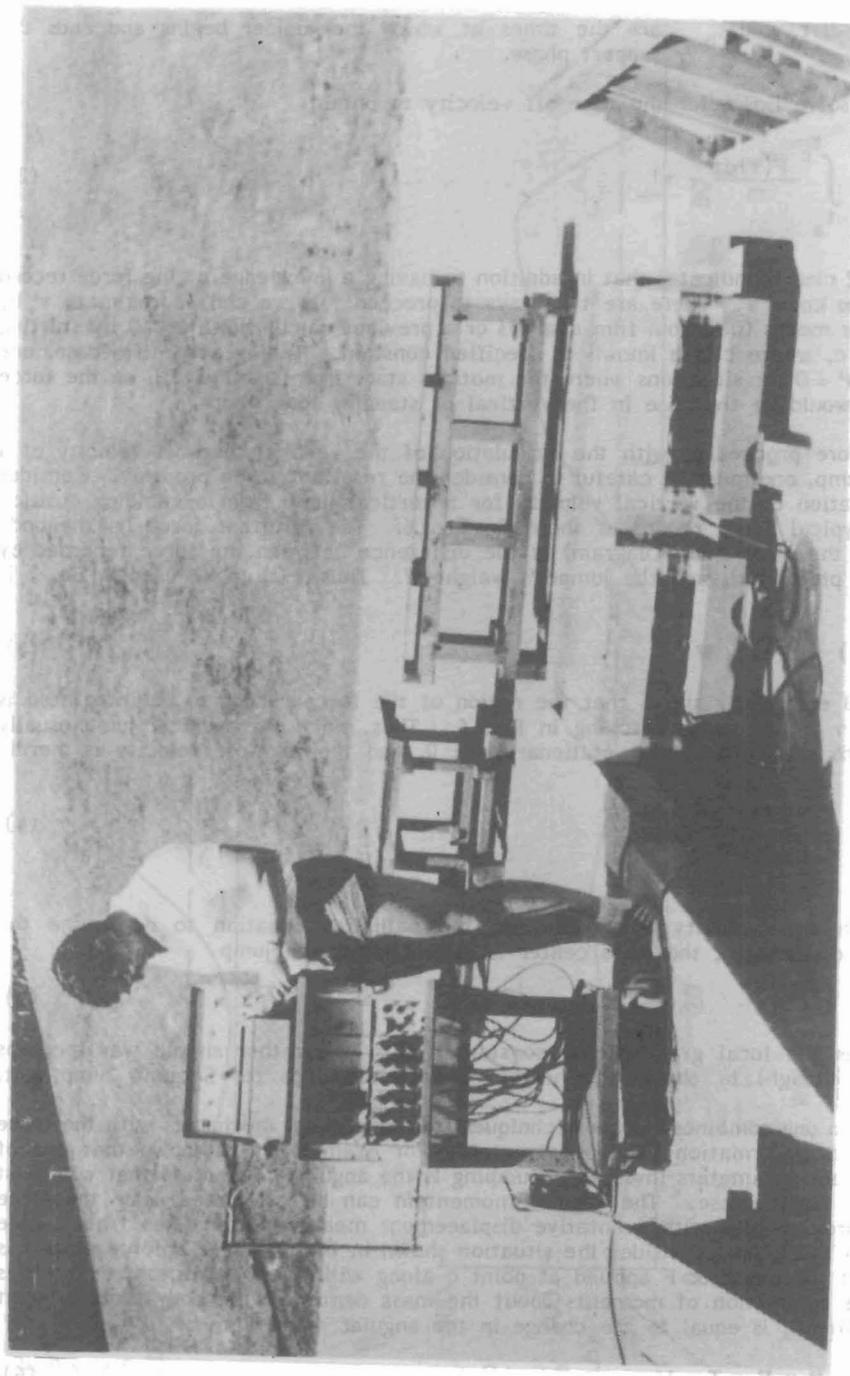
FIGURE 3

Force Plates at Test Facility

t_a and t_b are the times at which the jumper begins and ends the support phase.

One may solve Eq. 1 for the take off velocity to obtain

$$\mathbf{v} = \int_{t_a}^{t_b} \frac{F(t)dt}{m} + \mathbf{v'} \tag{2}$$

Equation 2 clearly indicates that in addition to having a knowledge of the force record we need to know $\mathbf{v'}$. There are two ways to proceed: 1) we can approximate $\mathbf{v'}$ by some other means (i.e. from film analysis or a previous calculation); or, 2) by starting with $\mathbf{v'} = c$, where c is a known or specified constant. Taking a specific case, one can take $\mathbf{v'} = 0$ for situations where the motions start from a stand still on the force plate, as would be the case in the vertical or standing long jumps.

Before proceeding with the calculation of the vertical take-off velocity of a vertical jump, one must be careful to consider the resultant force properly. Consider the calculation of the vertical velocity for a vertical jump from a standing position using a typical force record as shown in Fig. 6. The resultant force on the body (shown in the Free Body Diagram) is the difference between the force recorded by the force plate, $f(t)$, and the jumper's weight $\mathbf{W}$. Thus, $F(t)$ to be used in Eq. 2 is given as

$$F(t) = f(t) - \mathbf{W} \tag{3}$$

Equation 3 essentially shows that the region of the force record to be integrated is that shown by the cross hatching in Fig. 6. Thus, since the vertical jump usually begins with the mass center stationary, $\mathbf{v'} = 0$, and the take-off velocity is merely

$$\mathbf{v} = \int_{t_a}^{t_n} \frac{F(t)\ dt}{m} \tag{4}$$

With this velocity one could use the ballistics equation to determine the maximum distance, h, the mass center is raised during the jump

$$h = v^2/2g \tag{5}$$

where g is the local gravitational constant. This is a rather simple way (perhaps expensive though) to obtain the height of vertical jumps for Sargent Jump test.

When one combines further techniques from analytical mechanics with the force record other information can be extracted. For example, it is known that one of the important parameters involved in jumping is the angular momentum that will exist during the flight phase. The angular momentum can be calculated using the force plate records coupled with quantative displacement measurements taken from a cine analysis of the jump. Consider the situation shown in Fig. 7 where a force plate has a resultant force vector F applied at point q along with a resultant torque $\mathbf{T}$. It is known the summation of moments about the mass center of the body system, point p in the figure, is equal to the change in the angular momentum or

$$M_p = R \times F + T = \dot{H} \tag{6}$$
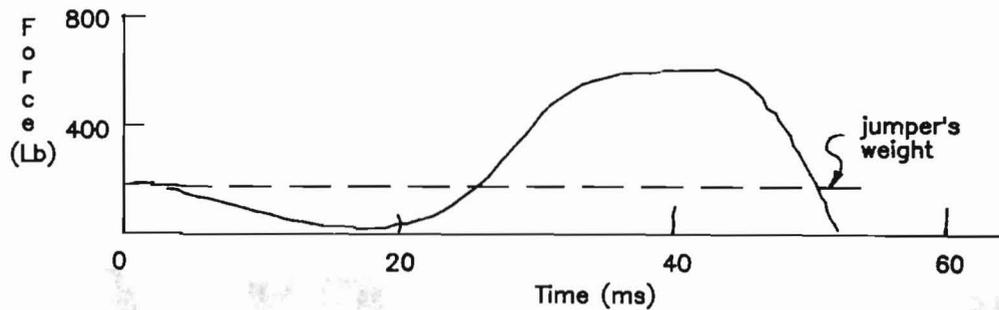
(a) Without preliminary knee flexing
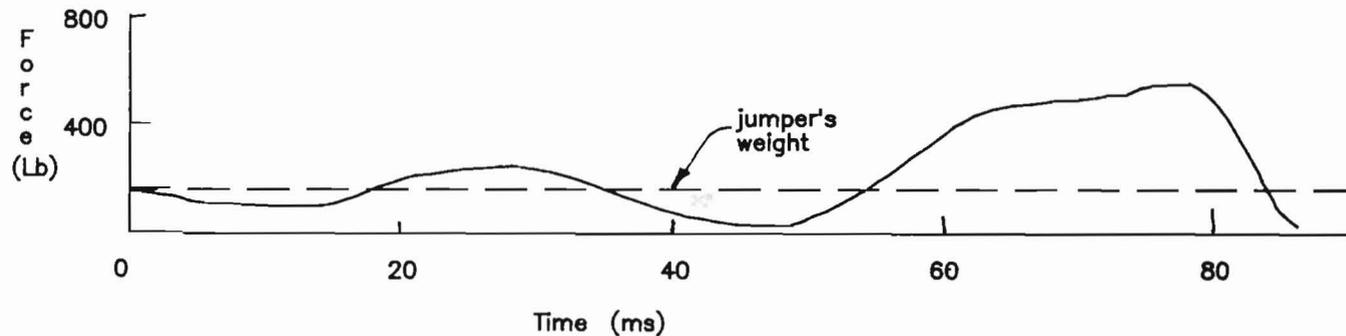
(b) With preliminary knee flexing

FIGURE 4

Force History for Vertical Jumps

(a) VERTICAL FORCE-TIME CURVE
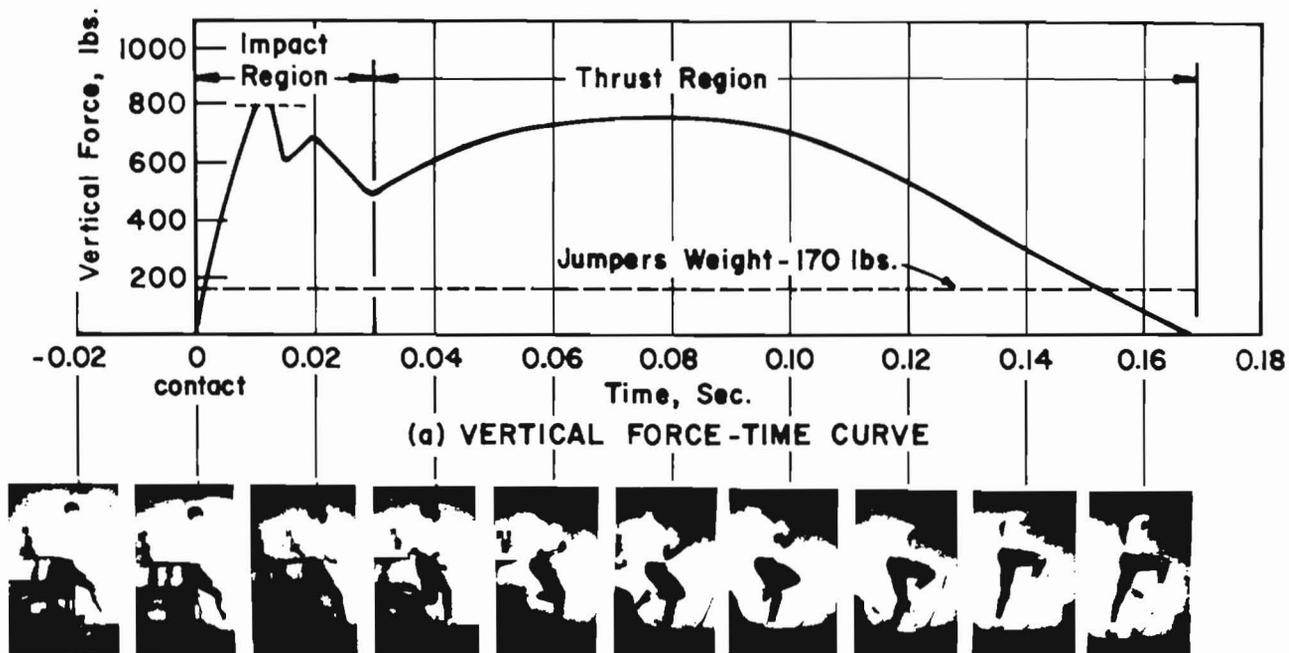
FIGURE 5

Force Plate and Cine Records
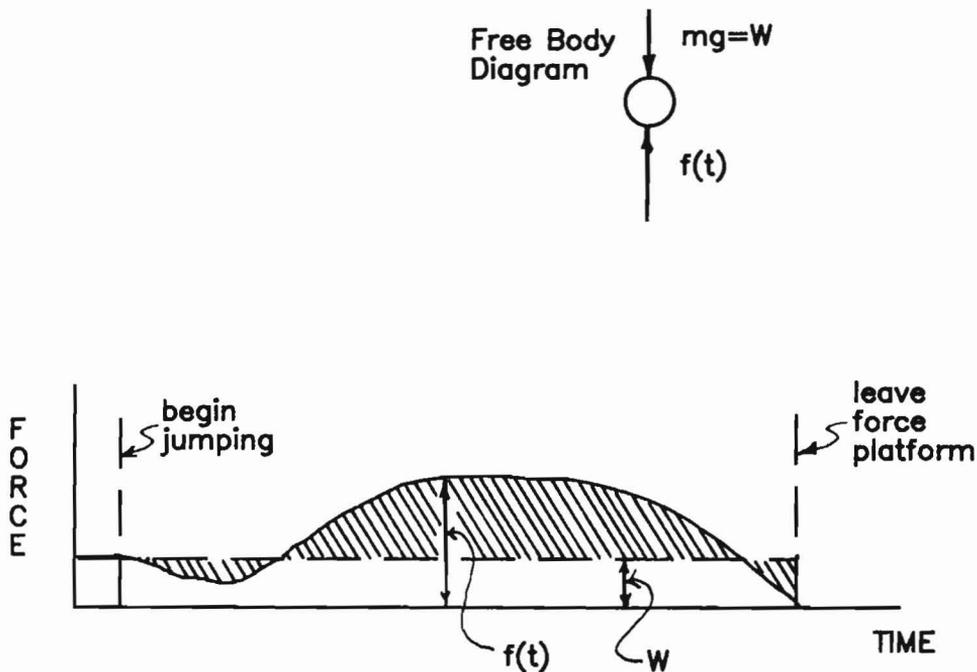
FIGURE 6

Area Used in Vertical Jump
Velocity Calculation

Here F and **T** are obtained from force plate while **R**, the position vector from the system mass center to the point q, is obtained from the cine analysis. $\dot{\text{H}}$ is the time derivative of the angular momentum while the jumper is on the force plate. In a fashion similar to that which was done in the equation for the take-off velocity, we may integrate Eq. 6 to obtain

$$H_{to} = \int_{t_a}^{t_b} (R \times F + T)dt + H'$$

(7)

where H_{to} is the angular momentum at take-off (end of the support phase) and **H'** is the angular momentum at the beginning of the support phase.

The drawback in using Eq. 7 however is that one must not only use a cine analysis to define the vector **R** but also must use a cine analysis to calculate **H'**. This latter calculation requires the determination of velocities from the film data, which for complex maneuvers, must be done carefully. For motions in which the initial angular momentum is small compared to the changes taking place during the support phase, **H'** may be neglected in order to provide a reasonable estimate of H_{to}. This may be the case in long and triple jump studies. In other cases **H'** cannot be ignored (an example would be in studies of back somersaulting during floor exercises in gymnastics).

So far the discussion has not explicitly addressed the problem of whether the jumper is using one or two feet during the support phase. If the situation is such that there is a two-footed support, as in Sargent Jump tests, and we are only interested in the movement of the mass center of the system, then all but Eqs. 6 and 7 can be used. If the support is on one leg then all of the previous discussion is valid. If, however, one wants information associated with the individual forces on each foot during the two-legged support phase, as might be needed in a study of the transfer of forces from one leg to the other, one must use two force plates. This is necessitated by the fact that the single force plate merely gives the magnitude, direction, and location of the resultant force applied to the device. The resultant does not necessarily lie under the contact point of the feet for the two legged stance as it must when support is from one leg.

One particularly interesting way to integrate the ideas presented above is to use a simulated jump as a means to determine the effect of altering the forces in a reasonable way. This technique could be used to develop a training strategy to be used to improve performance. Thus, the situation could proceed as follows:

1. Collect force plate and cine data for the jump.

2. Calculate performance parameters such as impulse, take-off velocity, change in angular momentum, etc.

3. Modify the force curves in some manner that seems reasonable, making small perturbations.

4. Again calculate the performance parameters.

5. Assuming that 4. produces a desired change in performance, begin to teach, train, strengthen, etc. the performer so that subsequent force histories collected during training sessions approximate the modified ones.
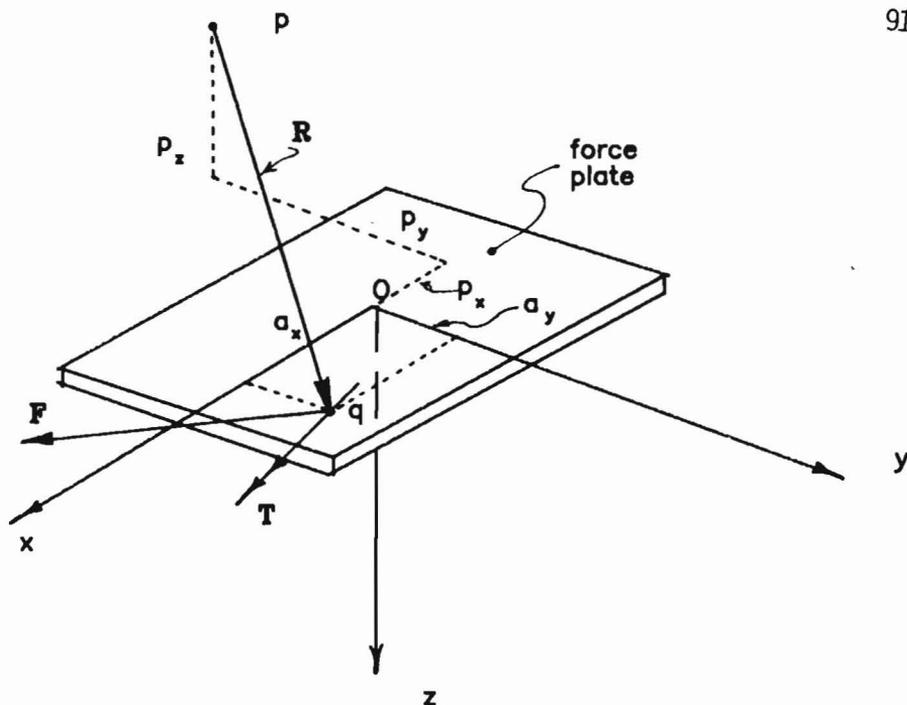
FIGURE 7

Forces and Torques on Force Platform

6.   Periodically calculate the relevant performance parameters to evaluate the progress toward the goal.

Here it is assumed that the primary goal is to produce a longer or higher jump. This suggested procedure is not unlike the way athletes and other jumping performers are presently instructed. However, with this approach additional quantitative parameters would be available to help the coach and performer evaluate intermediate progress.

REFERENCES

- International Society of Biomechanics (ISB) (1975-), Force Platform Group Newsletters, Dr. Barry D. Wilson, Dept. of Human Movement Studies, University of Queensland, St. Lucia, Brisbane, Australia 4067.

- Ramey, M.R. (1975), "Force Plate Designs and Applications", Exercise and Sport Sciences Reviews, Vol. 3, pp. 303-319.