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NASA Project Apollo Working Paper No. 1039

PROJECT APOLLO

LANDING CHARACTERISTICS

OF AN APOLLO-TYPE VEHICLE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Langley Air Force Base, Va.

December 29, 1961

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LANDING CHARACTERISTICS

OF AN APOLLO-TYPE VEHICLE

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SUMMARY

The knowledge of the dynamics of an Apollo-type vehicle landing at various speeds, attitudes and in different landing mediums was desired. Model tests were conducted on water, sand, and concrete.

On water, the best landing attitude was found to be a positive angle of impact with the center of gravity aft.

On sand, a negative angle of impact with the center of gravity aft is the optimum position; however, with the center of gravity forward and with a negative angle of impact, the model performed satisfactorily.

On concrete, a structurally similar model is necessary for accuracy but it is believed that a negative angle of impact is desirable.

INTRODUCTION

Due to insufficient information regarding the behavior of the Project Apollo Command Module at touchdown, a study of the landing dynamics of the vehicle was initiated. The tests reported herein were conducted simulating landing speeds of 10 feet per second through 50 feet per second horizontally and 30 feet per second vertically on water, sand, and concrete. Two $\frac{1}{10}$-dynamically-scaled models were used during the tests to determine the most desirable conditions of impact angle and velocity at which to land the capsule.

APPARATUS AND PROCEDURE

The tests were conducted with two $\frac{1}{10}$-scale models constructed of fiber glass and plastic. One model was used for the sand and water tests and the other for concrete tests. Pertinent dimensions and moments of inertia for the two models are listed in table I.

Figure 1 shows the test rig used during the model tests. The model was suspended by three mounting rods beneath the rig. The horizontal velocity was obtained by pulling the model and test apparatus back until the distance between the equilibrium position and the pullback position was sufficient to produce the desired velocity. When the test rig reached the bottom of its arc after its release a stop cable became taut and stopped the test rig, but permitted the model to move ahead at the desired horizontal velocity and angle of attack. The vertical velocity, which was held constant (30 feet per second) throughout the test program, was determined by the distance from the impact surface to the bottom of the model. Scale horizontal velocities from 10 feet per second through 50 feet per second were investigated with angles of impact varying from -30° to $+40^{\circ}$. The calm water tests were conducted in NASA Langley Research Center Tank No. 2, which has a water depth of 6 feet. The sand tests, using dry Standard Ottawa testing sand, and the concrete tests were conducted in the shop area of Tank No. 2.

Movies of the tests were made at 128 frames per second. The processed film was then examined to determine the angle of impact and the pitch angles.

RESULTS AND DISCUSSION

Results of the model tests are shown on plots with the center of gravity in both the forward and aft positions for water, sand, and concrete landing surfaces. These plots show the angle of impact versus the initial pitch angle.

Water Landings

Center of gravity aft.- Figure 2 shows the results of the tests with the center of gravity in the aft position. Data points that have been blacked solid indicate the tests during which the model turned over. Minimum pitch angles were experienced when the impact angle was on the order of 20° to 30°, regardless of the horizontal velocity. Figure 3 shows a photographic sequence of a 16° angle of impact at a horizontal velocity of 40 feet per second.

For horizontal velocities of 40 and 50 feet per second with angles of impact of $+5^{\circ}$ or less, the model had a tendency to leave the water, pitch bottom-forward and turnover. Figure 4 is a photographic sequence of a -15° angle of impact at a horizontal velocity of 40 feet per second.

Center of gravity forward.- Results of these tests are shown on figure 5. Half-solid points represent tests during which the model turned over or tumbled in pitch. Turnover points were recorded at negative angles of impact with horizontal velocities of 20 feet per second and 50 feet per second and at positive angles of impact with the horizontal velocity of 30 feet per second. At velocities of

10 feet per second and 40 feet per second, the model appeared to be nontumbling regardless of the attitude at impact. This landing position would not be desirable bacause of the ease with which the model turned over. This tumbling is caused by the following sequences of events: when the model pitches forward in a bottom-aftward direction, the followup wave caused by the initial impact strikes the model and this wave force together with the moment produced by the offset center of gravity being in the direction of rotation causes the model to tip over.

Sand Landings

Center of gravity aft.- Results of these tests are shown on figure 6. Turnover is represented by the solid points. With a negative angle of impact the model was found to be nontumbling throughout the entire speed range. The model would impact at a negative angle, pitch bottom-forward and then pitch bottom-aftward in a rocking motion. If the model impacted with a positive angle, the tendency was to pitch bottom-aftward and turnover.

Center of gravity forward.- The results for this parameter are shown in figure 7. The solid points again represent turnover. The two center-of-gravity locations, forward and aft, appeared to be similar for the sand tests. By comparison of figure 6 with figure 7, it can be seen that a slightly higher positive angle of impact can be tolerated with the center of gravity in the aft position. Figure 8 is a photographic sequence during which the model performed satisfactorily of -15° angle of impact at 40 feet per second with the center of gravity forward. Figure 9 shows a tumbling drop with an angle of impact of $+17^{\circ}$ at 40 feet per second with the center of gravity forward.

Concrete Landings

Results from the concrete tests were poor because the model was built with a high rigidity to withstand the impact. This high rigidity caused the model to bounce severely. The tests were limited for fear that the model would be damaged under a large number of tests; however, with the center of gravity forward nontumbling drops were obtained at -15° angle of impact with horizontal velocities of 20 and 10 feet per second and at -20° angle of impact with a horizontal velocity of 10 feet per second. With the center of gravity aft nontumbling drops were obtained at -8° and -11° angle of impact with a horizontal velocity of 20 feet per second and -15° angle of impact with a horizontal velocity of 10 feet per second.

CONCLUSIONS

As a result of the tests, the following recommendations are made:

1. On water, the best landing attitude is a high positive angle of impact with the center of gravity aft.

2. On sand, the best landing attitude is a negative angle of impact with the center of gravity aft. However, a negative angle of impact with the center of gravity forward is satisfactory.

3. For landings on concrete, a structurally similar model is needed to give accurate results; however, it is believed that a negative angle of impact is desirable for a hard surface landing.

	Sand & Water Impact Model	Concrete Impact Model
Weight	6.9 lb	6.85 lb
I_x Roll	.0353 slug-ft^2	.0262 slug-ft^2
I_y Pitch	.0393 slug-ft^2	.0317 slug-ft^2
I_z Yaw	.0379 slug-ft^2	.0251 slug-ft^2

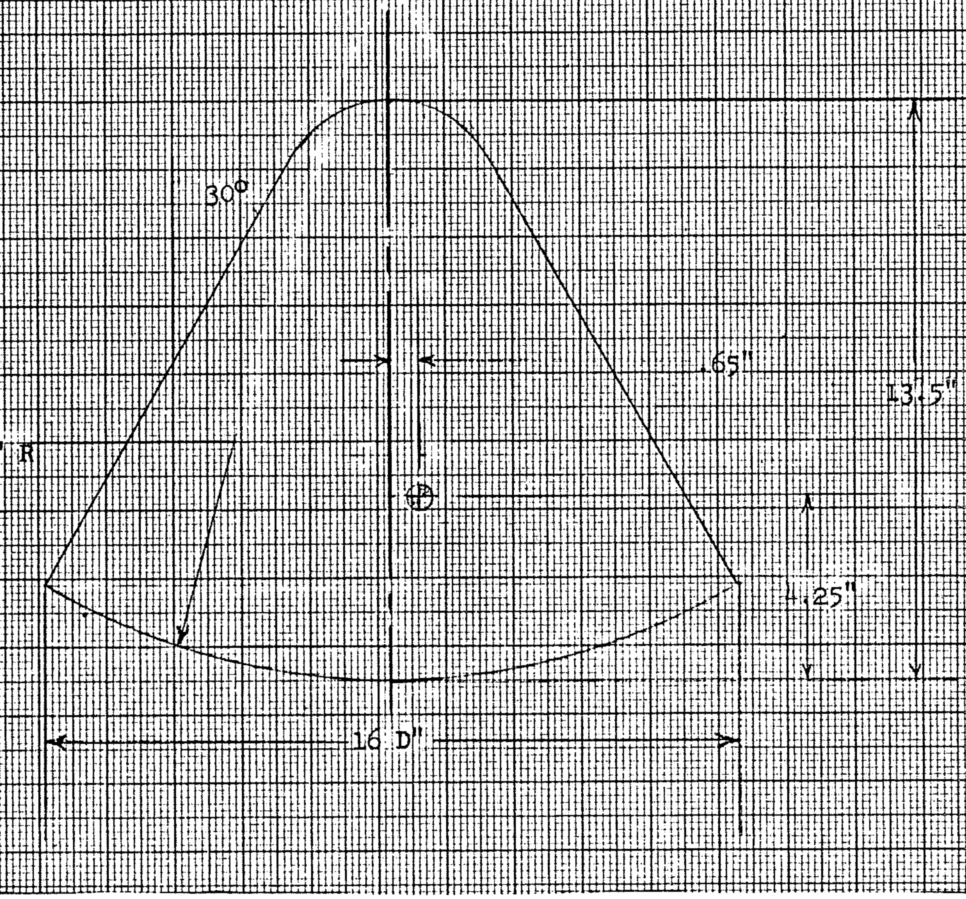

Table I.- Measured Values of $\frac{1}{10}$ Dynamic Models Used in Landing Tests.

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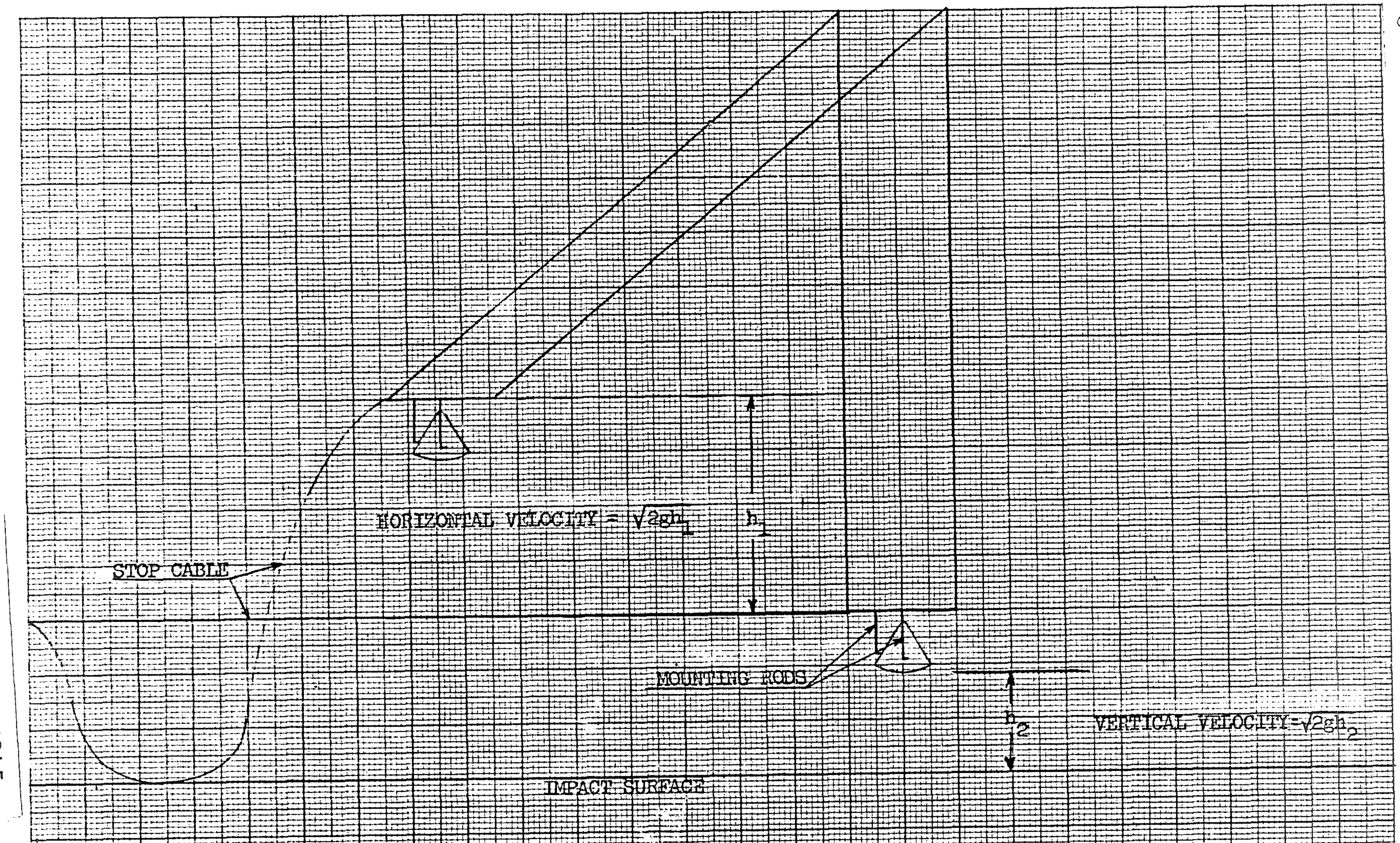


Figure 1.- Sketch of test rig used to obtain scale vertical and horizontal speeds.

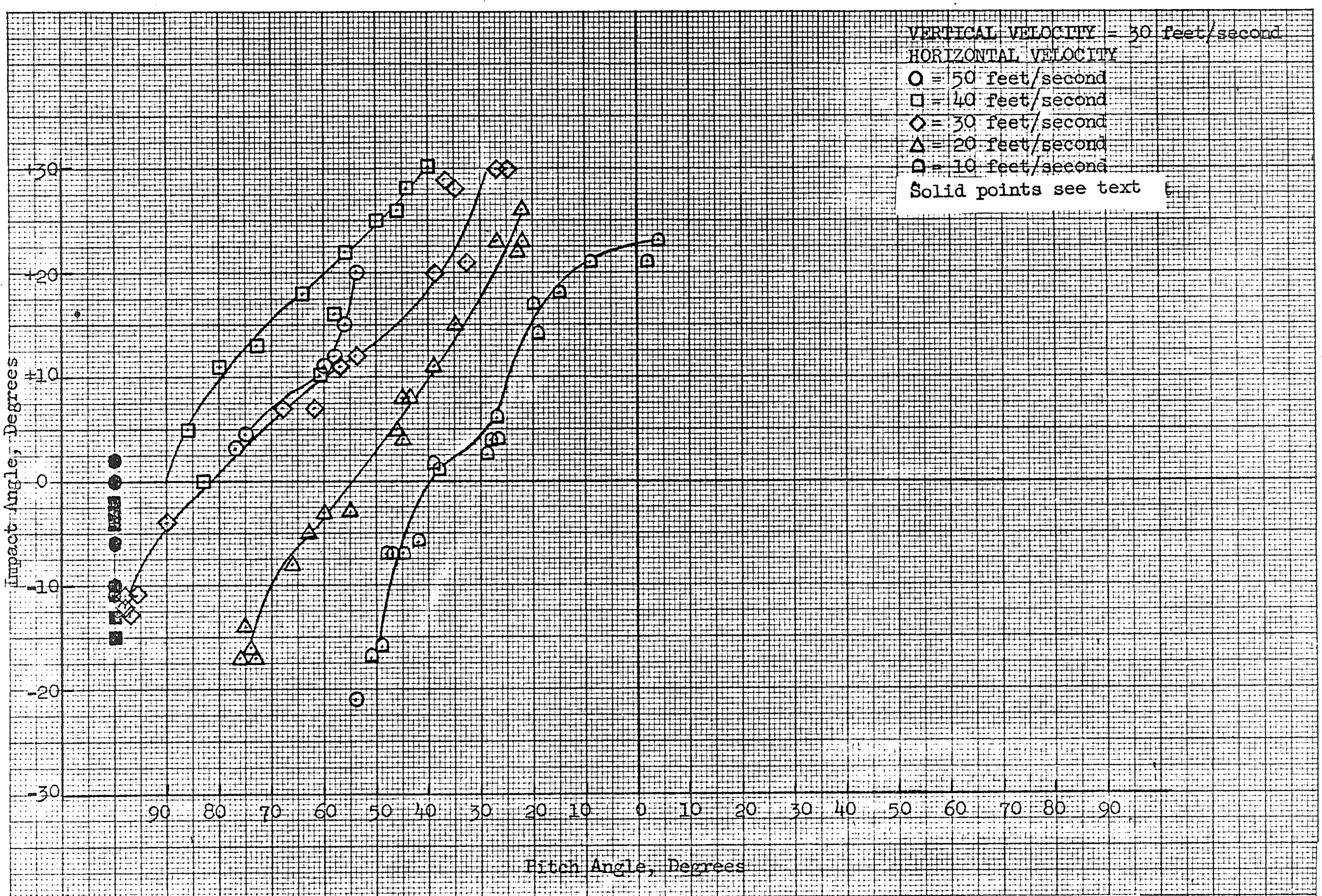
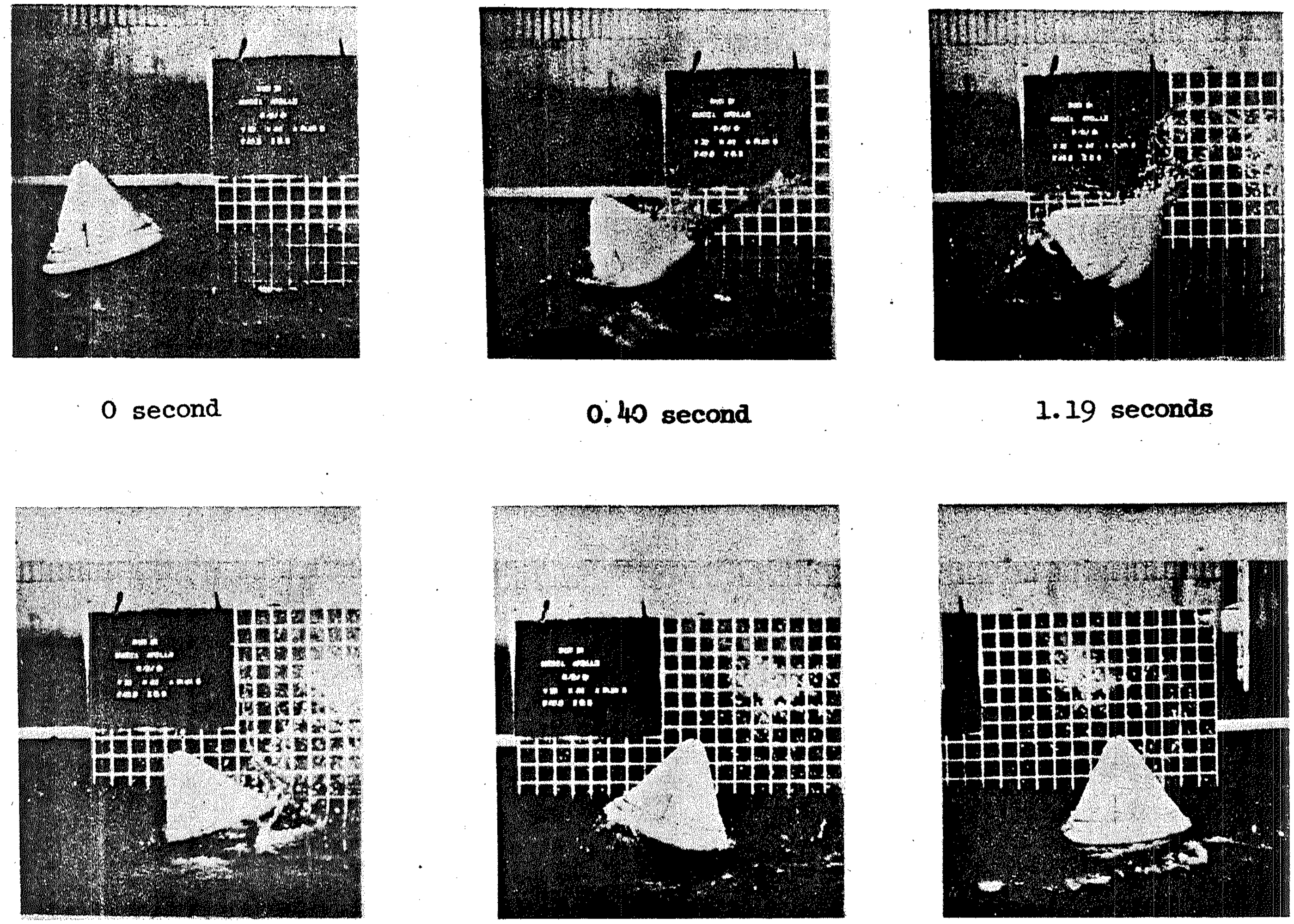


Figure 2.- Water impact with the center of gravity aft.



0 second

0.40 second

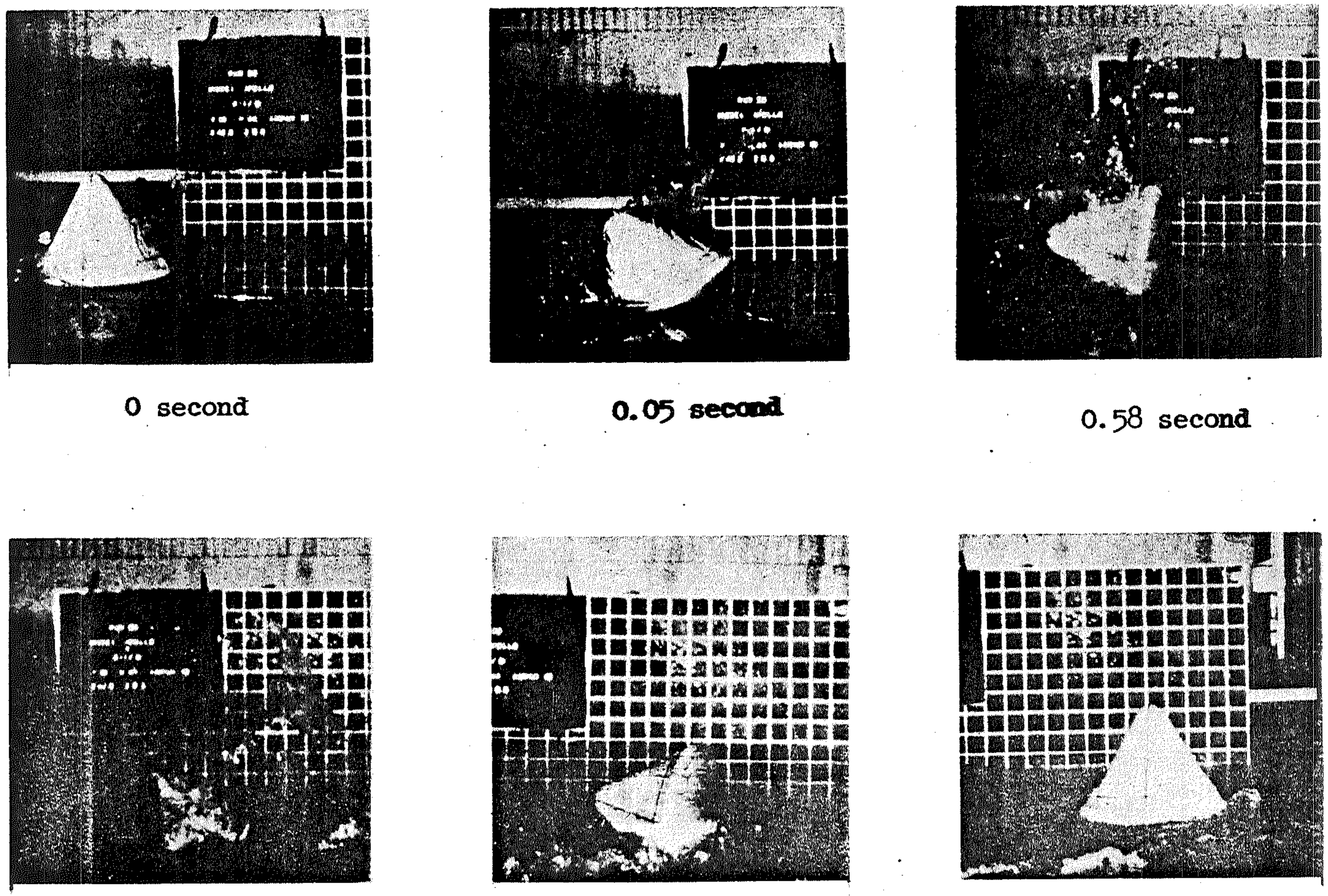
1.19 seconds

1.66 seconds

2.89 seconds

4.90 seconds

Figure 3.- Typical sequence photographs of model landing on water with a +16°. Time is full scale.



0 second

0.05 second

0.58 second

1.58 seconds

3.24 seconds

4.49 seconds

Figure 4.- Typical sequence photographs of model landing on water with a -15°.
Time is full scale.

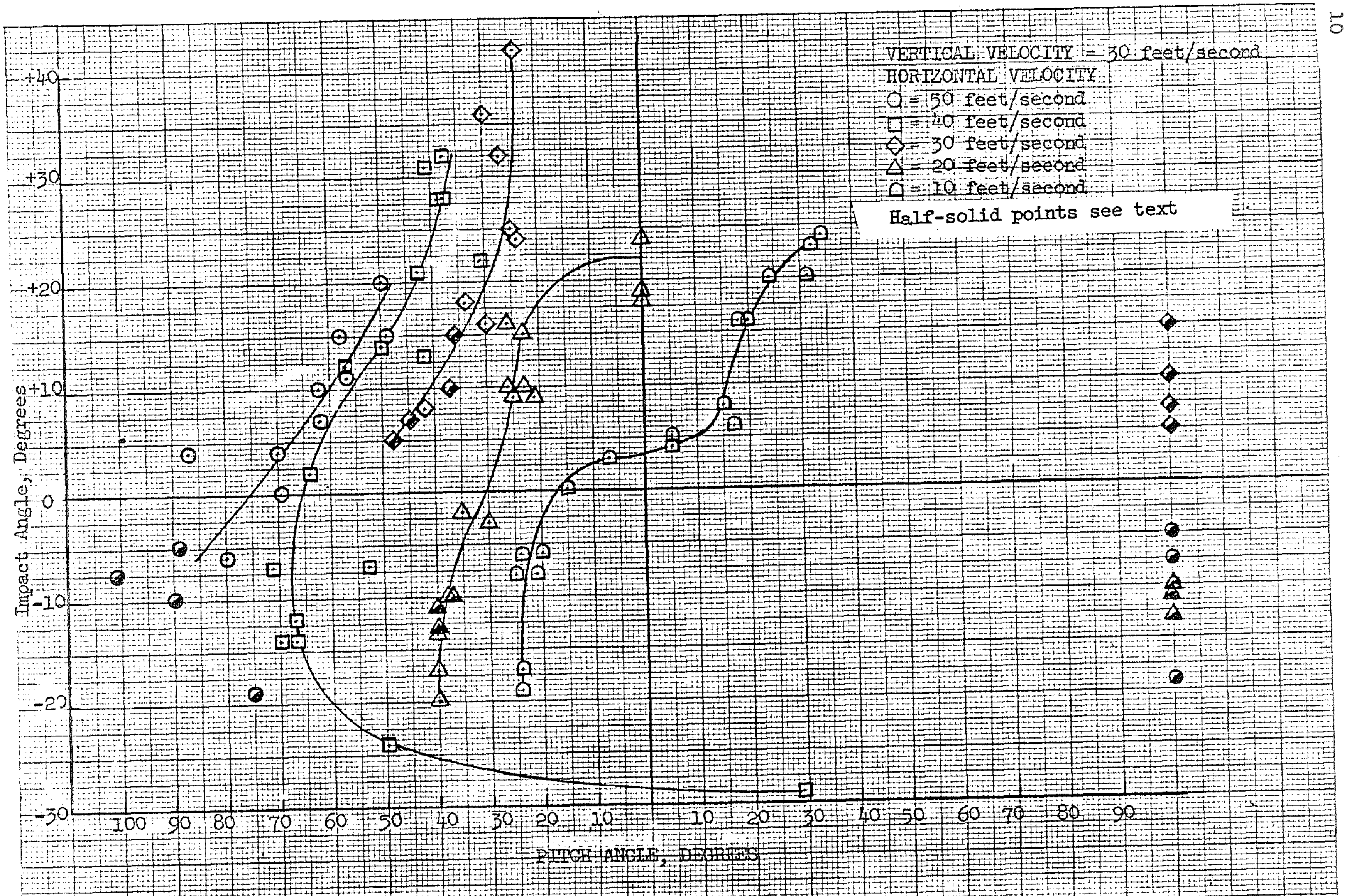


Figure 5.- Water impact with the center of gravity forward.

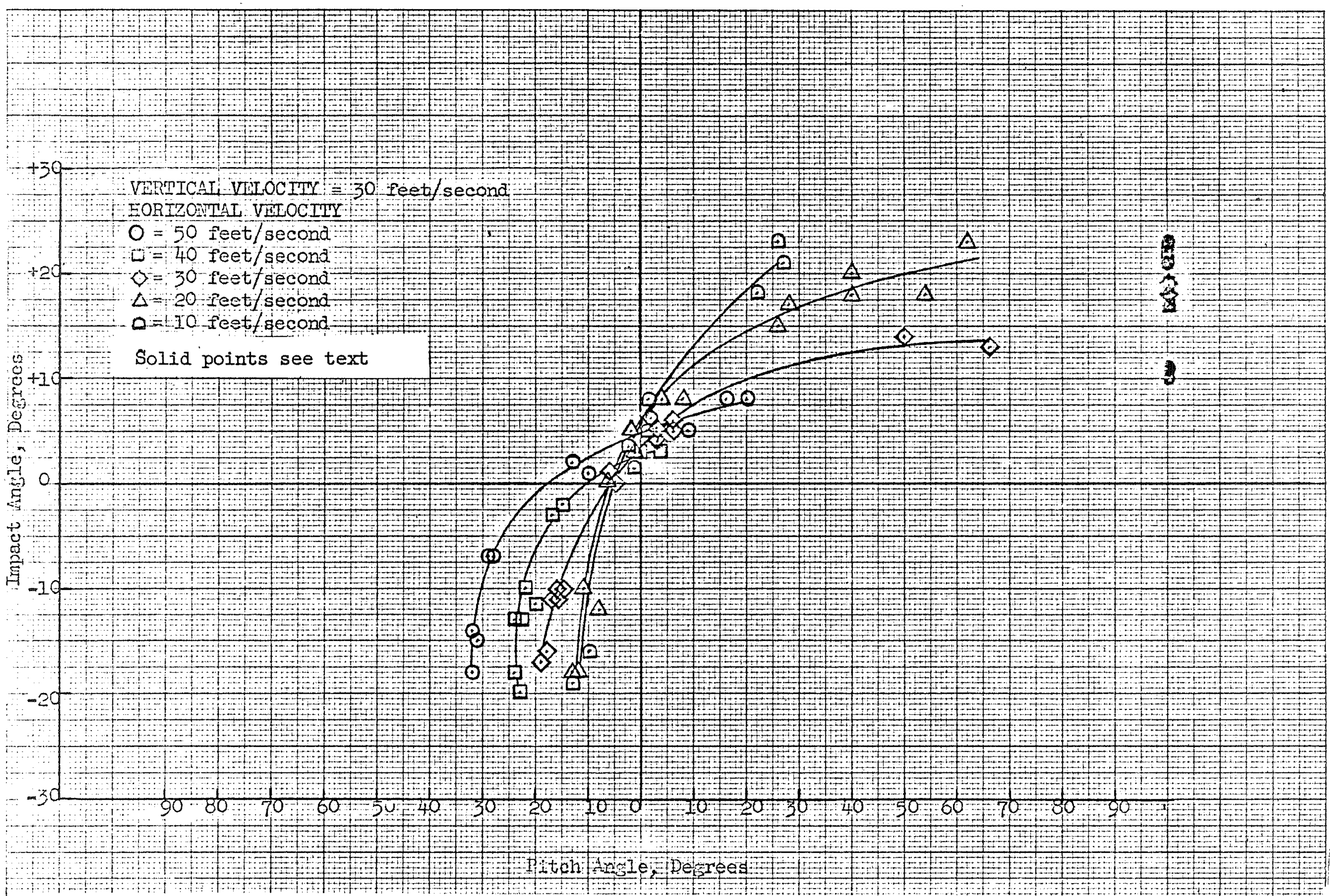


Figure 6.- Sand impact with the center of gravity aft.

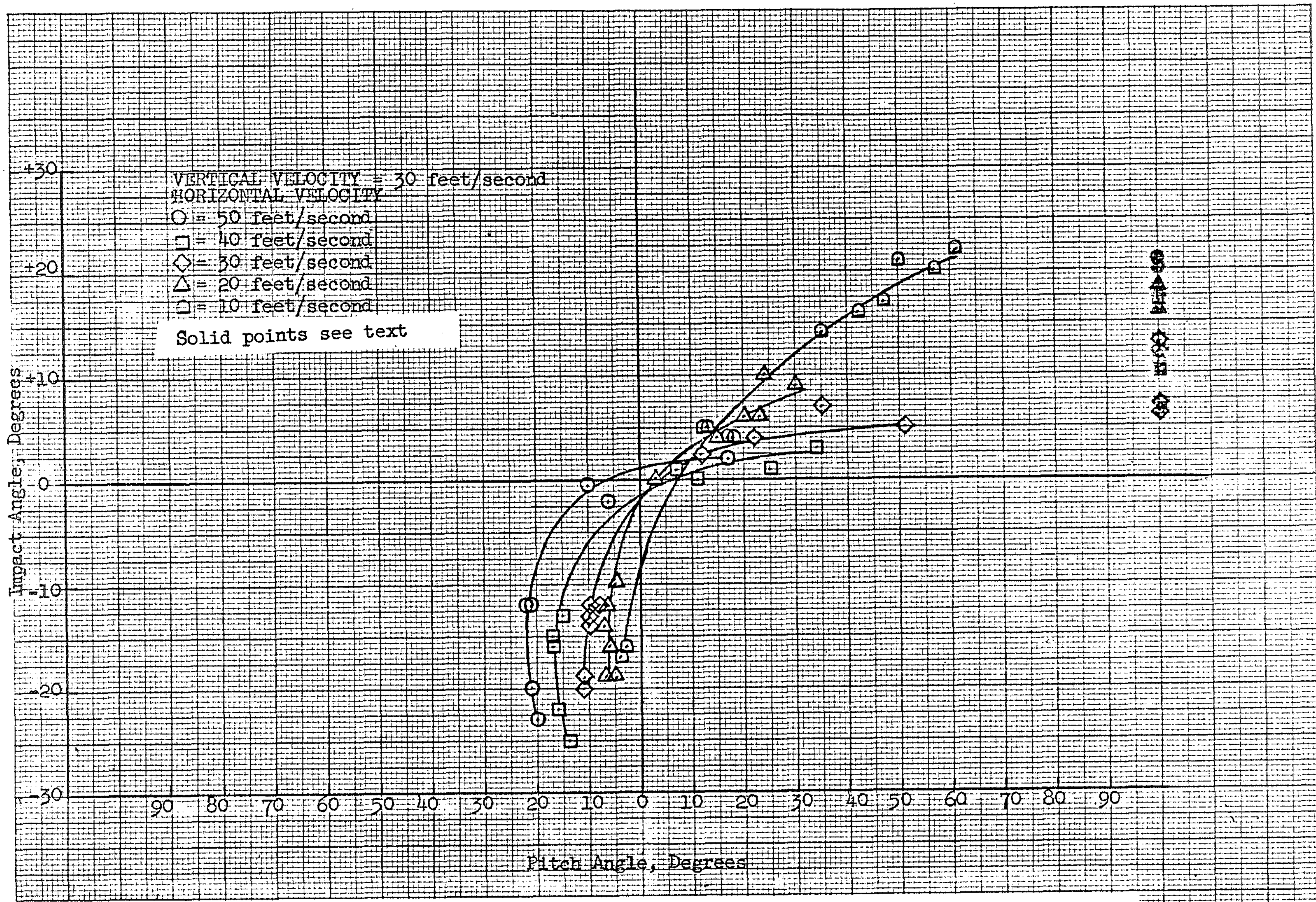


Figure 7.- Sand impact with the center of gravity forward.

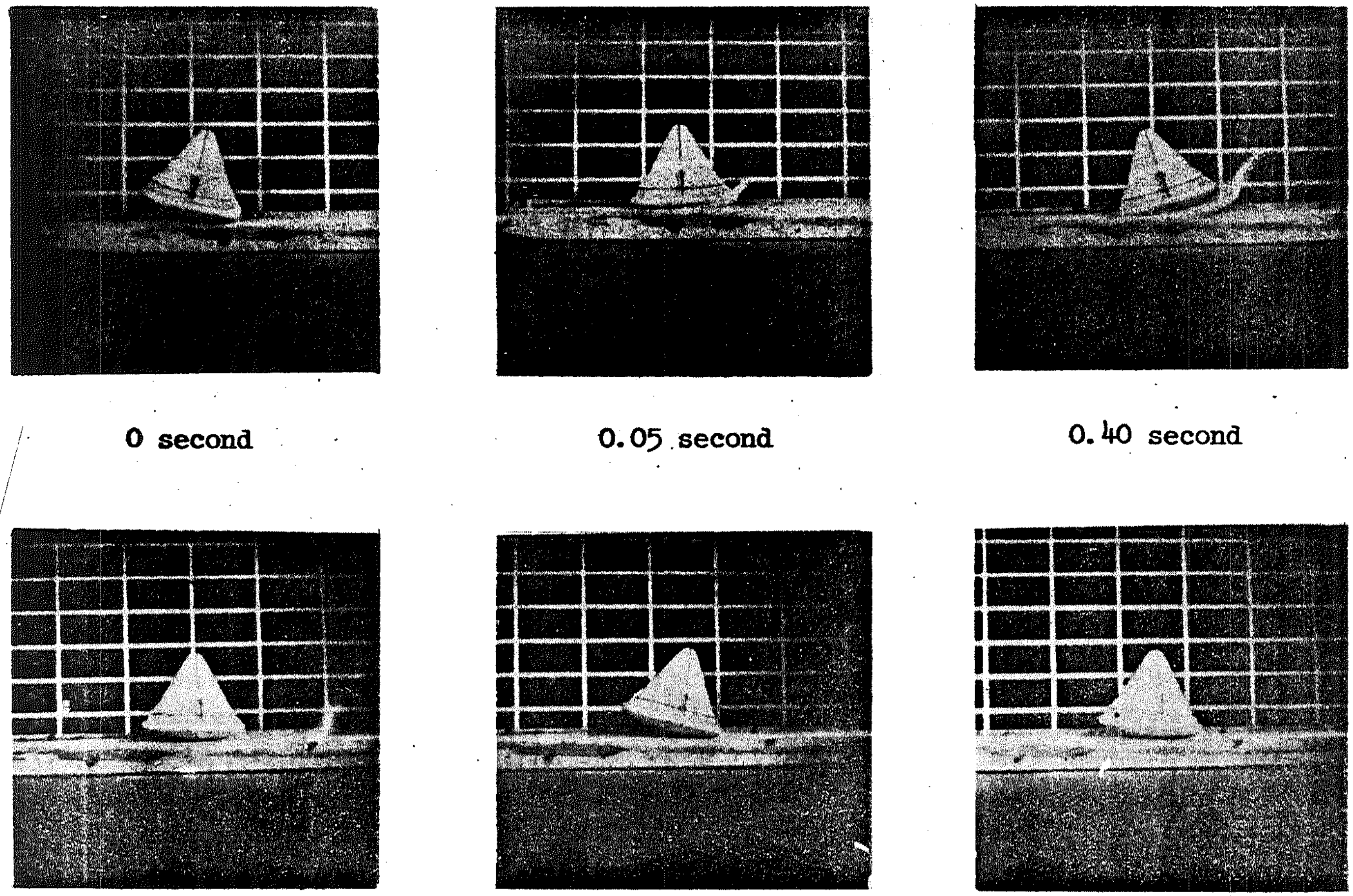
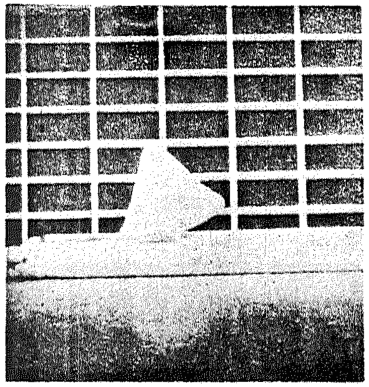
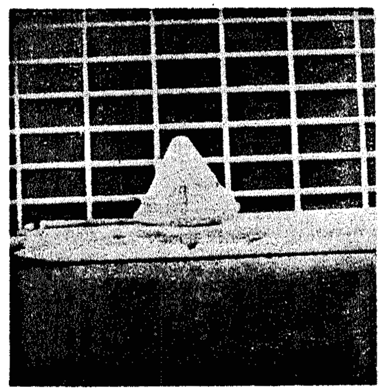


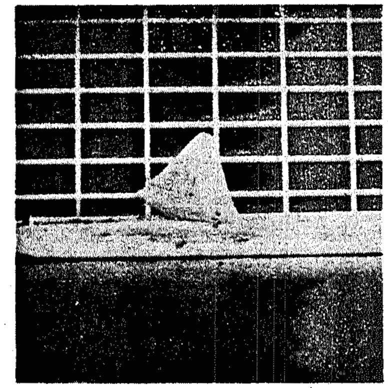
Figure 8.- Typical sequence photographs of model landing on sand with -15°. Time is full scale.



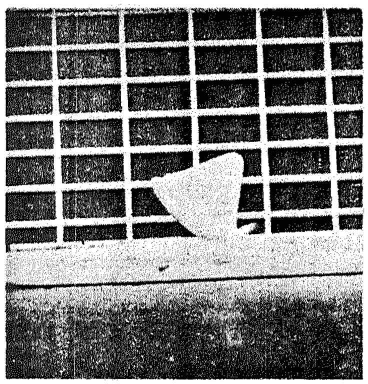
0 second



0.08 second

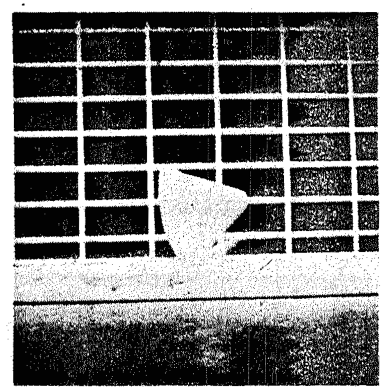


0.16 second



0.29 second

0.50 second



0.71 second

Figure 9.- Typical sequence photographs of model landing on sand with a +17°. Time is full scale.