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TECHNICAL NOTE
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LANDING-IMPACT CHARACTERISTICS OF LOAD-ALLEVIATING STRUTS ON A MODEL OF A WINGED SPACE VEHICLE

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LANDING-IMPACT CHARACTERISTICS OF LOAD-ALLEVIATING STRUTS ON A MODEL OF A WINGED SPACE VEHICLE

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SUMMARY

A brief experimental investigation was made of the landing-impact characteristics of a 1/9-scale dynamic model of a winged space vehicle. The landing tests were made by catapulting a free model onto a hard-surface runway and onto water. The model had a conical fuselage and a flat-plate wing with a basic delta planform and 75° sweepback of the leading edge. The use of yielding-metal shock absorbers and various landing-gear arrangements was investigated during landing impact.

The basic landing gear consisted of a dual rubber-tired nose wheel and twin main skids aft of the center of gravity near the wing tips. Landing motion and acceleration data were obtained over a range of landing attitudes, gross weights, and initial sinking speeds. Brief tests were made with an alternate nose-wheel location. An all-skid configuration also was briefly evaluated for hard-surface and water landings.

The landing gear employing yielding struts for impact-energy absorption during hard-surface landings resulted in accelerations of approximately $5\frac{1}{2}g$ near the nose gear over a range of landing parameters. Replacing the nose wheel and tire with a skid did not significantly change the accelerations. Landings in smooth water with rigid struts and adequate planing area at the nose skid resulted in a maximum landing acceleration of approximately 4g.

INTRODUCTION

The penalty for excess weight has been increased many fold in the transition from aircraft to spacecraft. With the elimination of aircraft type of take-off and the probability of infrequent landings of space vehicles, simplified landing-gear systems are feasible. In order to reduce weight and increase simplicity and reliability, the use of the energy-absorption properties of a yielding metal was considered as an alternate to conventional oleo systems for winged space vehicles.

An existing test technique has been adapted and a brief investigation made to obtain landing-impact data of special landing-gear systems on hard surface and on water. Impact accelerations and behavior were obtained with a free dynamic model representative of a winged space vehicle landing on a hard-surface runway at the monorail facility of the Langley Research Center. A skid and wheel landing gear (the type used for the X-15 airplane) was tested over a range of landing trims, gross weights,
and sinking speeds. An alternate nose-wheel gear location and an all- L
skid configuration were briefly investigated. A few smooth-water 9
landings also were made with an all-skid gear. 5
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DESCRIPTION OF THE MODEL

The general arrangement of the 1/9-scale dynamic model and details of the nose-wheel and shock-strut arrangement are shown in figures 1 and 2, respectively. Pertinent dimensions and characteristics are given in table I. Photographs of the model with various landing-gear configurations are shown in figure 3.

The model had a flat-plate wing with a basic delta planform (75° leading-edge sweepback) and was constructed of balsa and hardwood covered with a thin plastic-impregnated glass-cloth skin. The detachable conical fuselage was constructed of plastic-impregnated glass cloth. The launching brackets and landing-gear components were made of aluminum. The basic landing gear (fig. 3(a)) was a tricycle arrangement consisting of a pair of main-gear skids located behind the center of gravity near the wing tips and a nose wheel located well forward. The dual, corotating nose wheel had solid rubber tires mounted on aluminum rims (details in fig. 2). The nose wheel was attached to a spindle block by a compliable aluminum strut which incorporated the necessary wheel trail for stable castering characteristics. During impact the strut yielded in bending without impeding the rotation of the wheels (see fig. 4). The free-to-pitch main-gear skids were attached to rigid struts by similar compliable shock-absorbing elements (see fig. 3(a)). The free-stroke length provided for shock absorption was approximately 17 inches (full scale) for all struts. Strut lengths were such that with contact of all three gear components and with subsequent depression of the shock-absorbing elements the wing was at a negative angle of attack.

For the all-skid configuration (fig. 3(b)), a skid of the same size and planform as the main skids was substituted for the nose wheel. Water landings were made with the original nose skid and with a modified nose skid (fig. 3(c)) having twice the original planing-surface area and a 16° angle of incidence. Main-skid incidence for water landings was 2°. For water landings the yielding struts were removed and the skids rigidly mounted.

APPARATUS AND PROCEDURE

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The monorail facility of the Langley Research Center was used for the investigation. The launching apparatus and procedure are described in reference 1. The model is shown in figure 5(a) on the monorail launching carriage. The elevators were set for trimmed flight at the launching attitude and the model maintained approximately this attitude during free glide onto the runway. The model was landed on the runway surface shown in figure 5(b).

The hard landing surface (runway) was a plywood deck above the tank water level. Heavy wood-frame panels were covered with $\frac{1}{2}$-inch plywood and supported on adjustable steel tables mounted on the floor of the towing tank. The landing surface was 72 feet long. At the end of this run the model dropped off into the water where it was arrested by a barrier screen.

The range of parameters investigated with the basic main-skid—nose-wheel gear with shock struts during hard-surface landings included launching attitudes of 13° to 20°, gross weights of 5,000 to 7,000 pounds (full scale), and sinking speeds of $5\frac{1}{2}$ to 12 feet per second (full scale). The nose wheel on a rigid strut, the all-skid gear with shock struts, and the modified nose skid for water landings were briefly tested at one condition of launch attitude, gross weight, and sinking speed.

Normal accelerations were measured by accelerometers installed on the wing upper surface at the node lines for the first mode of vibration of the model (near the nose and main gear (fig. 1)), minimizing the input to the accelerometers due to structural vibrations. A 50g strain-gage-type accelerometer with a natural frequency of 625 cycles per second was used near the nose gear and a 20g unit with a natural frequency of 165 cycles per second near the main gear. Natural frequencies of the recording galvanometers were 100 and 150 cycles per second for the 50g unit and the 20g unit, respectively. A trailing cable, propelled along an overhead guide wire by a push-rod and rubber-band arrangement (fig. 5(b)), was used to transmit the accelerometer signals to an oscillograph recorder.

A motion-picture camera located at the side of the towing tank recorded general behavior and motion-time histories.

RESULTS AND DISCUSSION

A short motion-picture film supplement of typical hard-surface and water landings is available on loan. A request card and a description of the film will be found at the end of this paper, on the page immediately preceding the abstract page.

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Sequence photographs of typical landings of the model on the runway surface are shown in figure 6. The general behavior was very similar for all hard-surface landings and was characterized by approach at a high angle of attack, touchdown on the main gear, an angular rotation to nose-wheel impact, and the roll-out. Due to the extreme aft location of the main gear, initiating up-elevator deflection at touchdown had no apparent effect upon the rapid nose-down rotation.

A typical trim-acceleration time history during the significant portion of a hard-surface landing is plotted in figure 7. The main skids contacted initially at point A and the model then pivoted about the main skids with the attitude decreasing until contact of the nose wheel at point B. The nose-wheel impact produced a tail-down angular acceleration which resulted in a second main-gear impact at point C. The main-gear accelerations occurring before point C did not produce stresses in the main-gear struts sufficient to cause significant deformation. Large strut deformations (plastic yield) occurred at point B for the nose gear and at point C for the main gear.

The accelerations obtained at the three main points of the landing sequence for several landings with the main-skid—nose-wheel gear system are shown in figure 8 plotted against variation of launch attitude, gross weight, and initial sinking speed. Maximum acceleration measured near the main gear at initial main-gear contact (fig. 8(a)) was approximately 1g to 2g for all the conditions tested.

Maximum acceleration measured near the nose gear at initial nose-gear impact (fig. 8(b)) was approximately $5\frac{1}{2}$g over a range of launch attitude from 13° to 20°, gross weights of 5,000 to 7,000 pounds (full scale), and initial sinking speeds from 5 to 12 feet per second (full scale). This was the maximum of all accelerations measured at either the main or nose gear. It would be expected that this acceleration would be constant within the range of attitude and sinking speed tested since the force required to cause yield of a given strut in the plastic range of the stress-strain curve is constant and adequate stroke was available. The expected decrease in accelerations with increase in gross weight is not evident within the accuracy of these data.

The accelerations measured at the main gear during the nose-wheel impact (point C on fig. 7) are shown in figure 8(c). The trends indicate an increase in acceleration with increase of launch attitude and initial sinking speed, and particularly so with increase in gross weight. It was subsequently determined that the main-gear shock struts deformed beyond the working stroke and bottomed in most of the landings at higher attitude, sinking speed, and gross weight. This resulted in a shortening of the shock-strut moment arm with accompanying increased force input and increased acceleration values. With sufficient free stroke for all conditions the acceleration values would probably be of the order of those obtained at initial main-gear impact (point A). Increasing the strut cross-sectional area in order to prevent bottoming would result in somewhat higher accelerations.

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Moving the nose-wheel gear aft approximately two-thirds of the distance to the center of gravity reduced maximum accelerations at the nose gear by slightly more than one-third, as seen in figure 8(b). During these landings the model exhibited a rocking tendency, pitching down about the nose wheel and lifting the main gear off the runway.

Maximum acceleration measured for the nose-skid gear, shown in figure 8(b), was approximately $8\frac{1}{2}$g. The moment arm between the bend point of the strut and the skid pivot (point of force input) was less than that of the wheel installation and resulted in a proportionate increase of the force required for yield. Correcting these data to an equivalent moment arm reduces acceleration values to approximately those obtained with the nose wheel.

Smooth-water landings with the all-skid gear used for hard-surface landings resulted in diving. Satisfactory landings were made with the modified nose skid having a planing area equal to twice that of the main skid. The accelerations obtained at the three main points of the landing sequence for several landings on water are shown in figure 9. The maximum accelerations at the main gear and the nose gear were approximately 2g and 4g, respectively. Motions in attitude and rise were relatively mild and highly damped.

A summary of the maximum accelerations experienced at the nose gear during landings of the various configurations is shown in figure 10. With the nose wheel mounted on a rigid strut at the forward position a maximum acceleration of about 40g was measured. The maximum acceleration for the wheel or skid (corrected to equivalent moment arm) with yield struts at the forward position was approximately $5\frac{1}{2}$g. Moving this gear aft reduced the acceleration to about $3\frac{1}{4}$g. Landings in smooth water resulted in maximum accelerations of approximately 4g.

CONCLUDING REMARKS

The landing gear employing yielding struts for impact energy absorption during hard-surface landings resulted in maximum accelerations of approximately $5\frac{1}{2}$g near the nose gear over a range of parameters. Replacing the wheel and tire with a skid did not significantly change the accelerations. Landings in smooth water with rigid struts and adequate planing area at the nose skid resulted in maximum landing acceleration of approximately 4g.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 2, 1960.

REFERENCE

1. Christopher, Kenneth W.: Effect of Shallow Water on the Hydrodynamic Characteristics of a Flat-Bottom Planing Surface. NACA TN 3642, 1956.

TABLE I.- PERTINENT CHARACTERISTICS AND DIMENSIONS OF THE VEHICLE

	1/9-scale model	Full scale
General:		
Gross weight, lb	6.8, 8.2, 9.6	5,000, 6,000, 7,000
Wing area, sq ft	3.28	266
Wing loading, lb/sq ft	2.1, 2.5, 2.9	18.8, 22.6, 26.3
Moment of inertia:		
Roll, slug-ft^2	0.034	2,000
Pitch, slug-ft^2	0.215	12,700
Yaw, slug-ft^2	0.235	13,900
Wing:		
Span, ft	1.59	14.325
Area, sq ft	3.28	266
Root chord, ft	3.33	30.0
Mean aerodynamic chord, ft	2.29	20.6
Fuselage:		
Length, ft	1.87	16.8
Diameter of base, ft	0.58	5.25
Main gear:		
Type	Skid	Skid
Number	2	2
Planform	Rectangular	Rectangular
Keel profile	Rounded nose	Rounded nose
Total length, ft	0.37	3.3
Beam, ft	0.05	0.45
Area, sq ft	0.019	1.5
Flat keel length, ft	0.29	2.6
Skid contact area, sq ft	0.016	1.3
Nose gear for -		
Hard-surface landings - wheel:		
Number	2	2
Diameter, ft	0.125	1.125
Width, ft	0.042	0.375
Tread, ft	0.083	0.75
Water landings - skid:		
Number	1	1
Planform	Rectangular (60° vee step)	Rectangular (60° vee step)
Length, ft	0.67	6
Beam, ft	0.062	0.56
Planing area, sq ft	0.040	3.2

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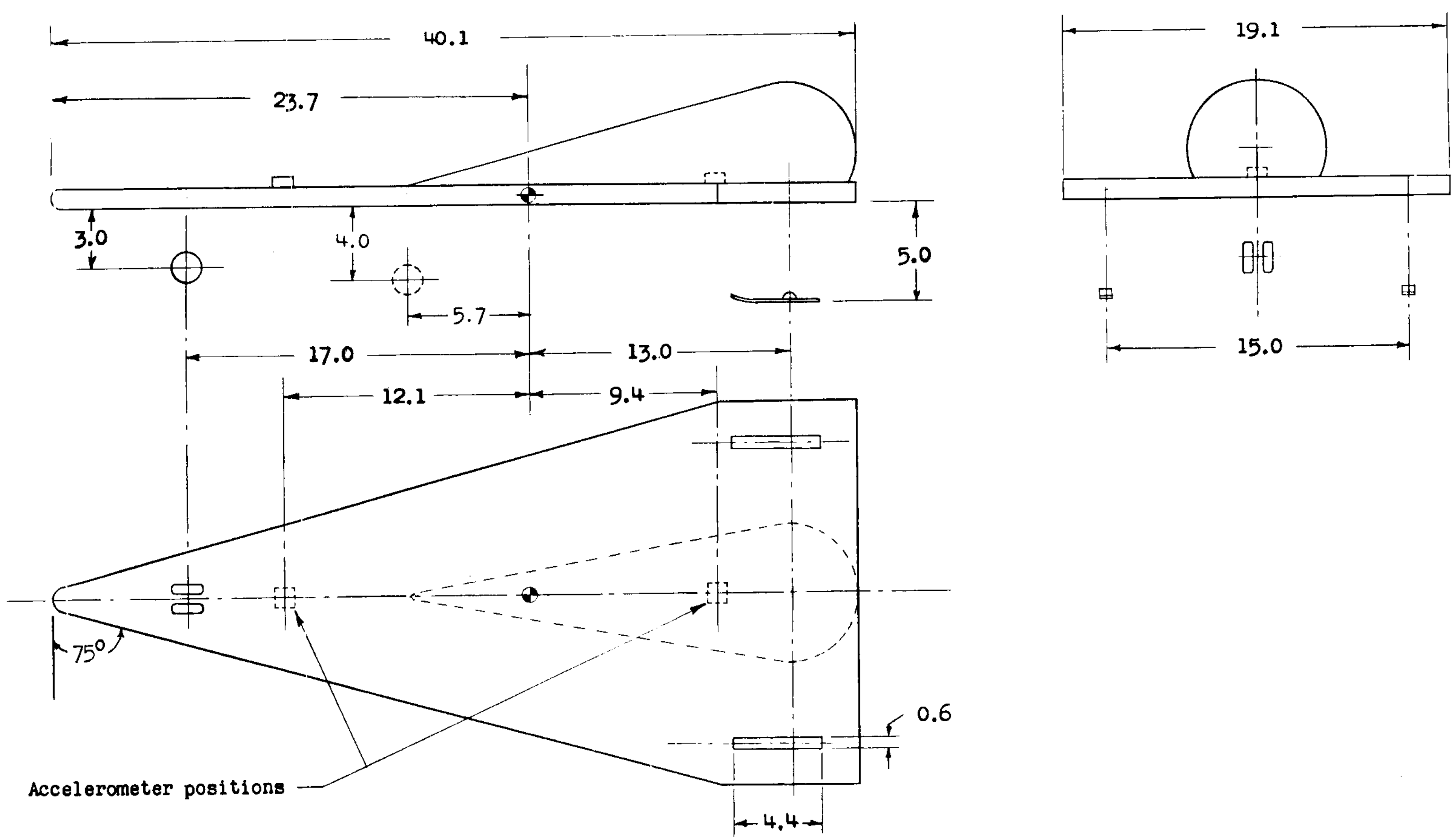


Figure 1.- General arrangement of 1/9-scale dynamic model. All dimensions are in inches.

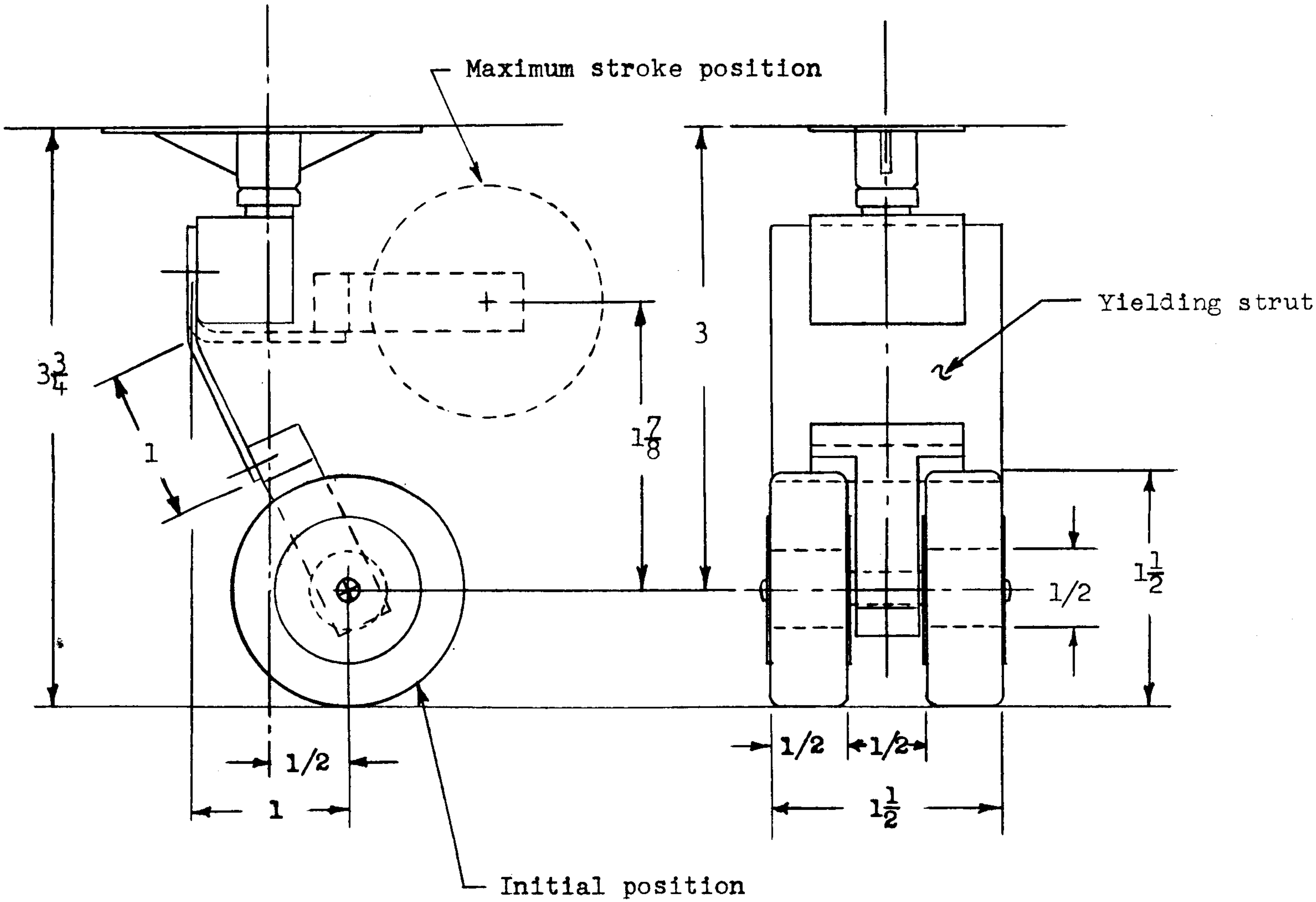
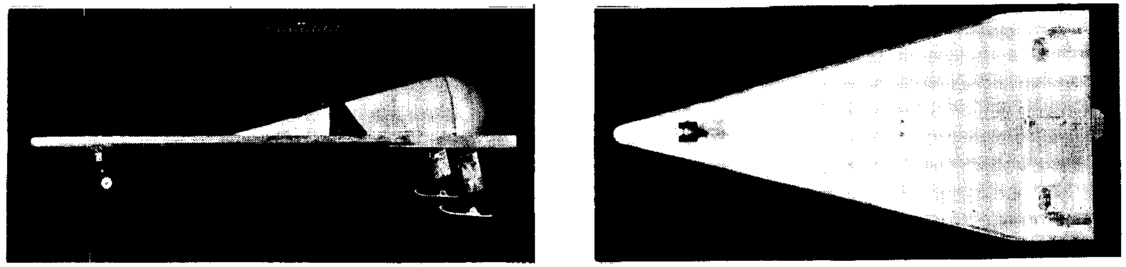
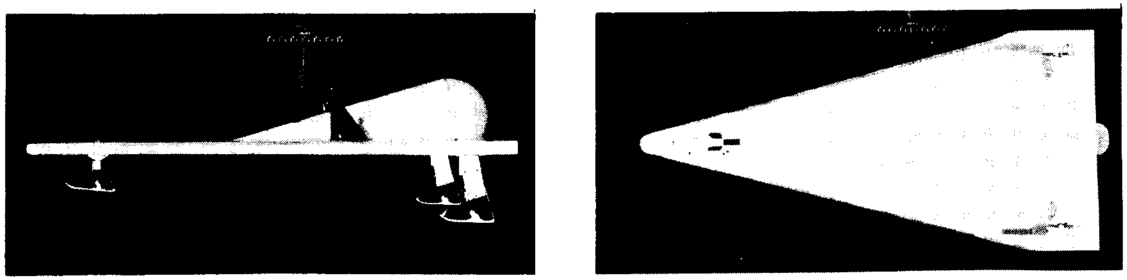


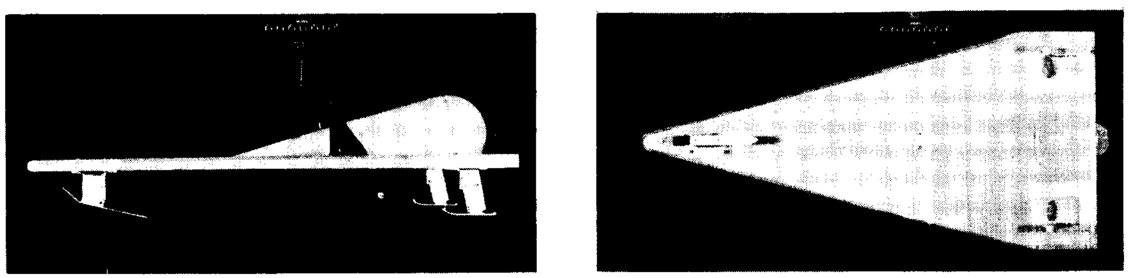
Figure 2.- Details of nose-wheel gear of model. All dimensions are in inches.



(a) Nose-wheel—main-skid gear, hard-surface landings.



(b) All-skid gear, hard-surface landings.



(c) All-skid gear, water landings. L-60-4318

Figure 3.- Photographs of model, showing landing-gear configurations.

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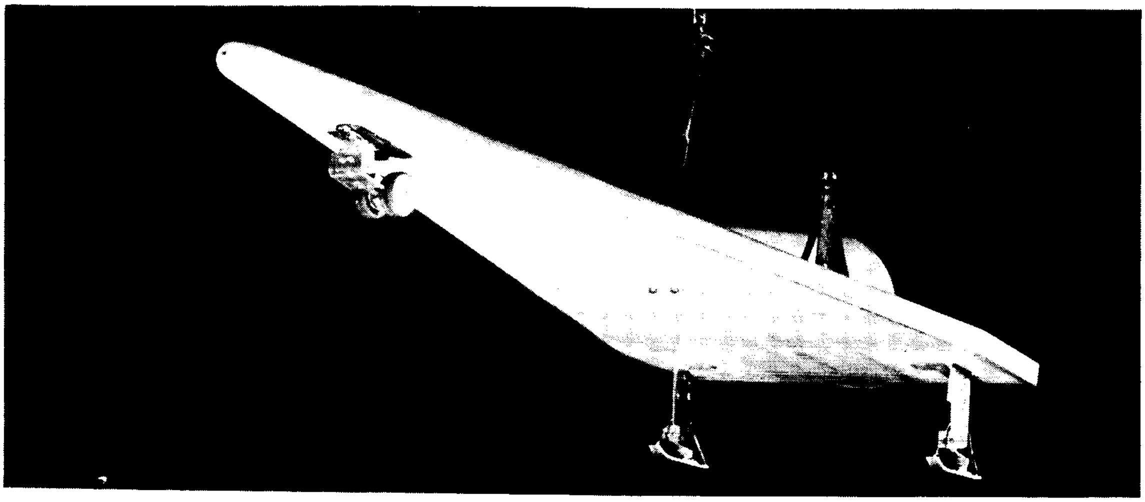

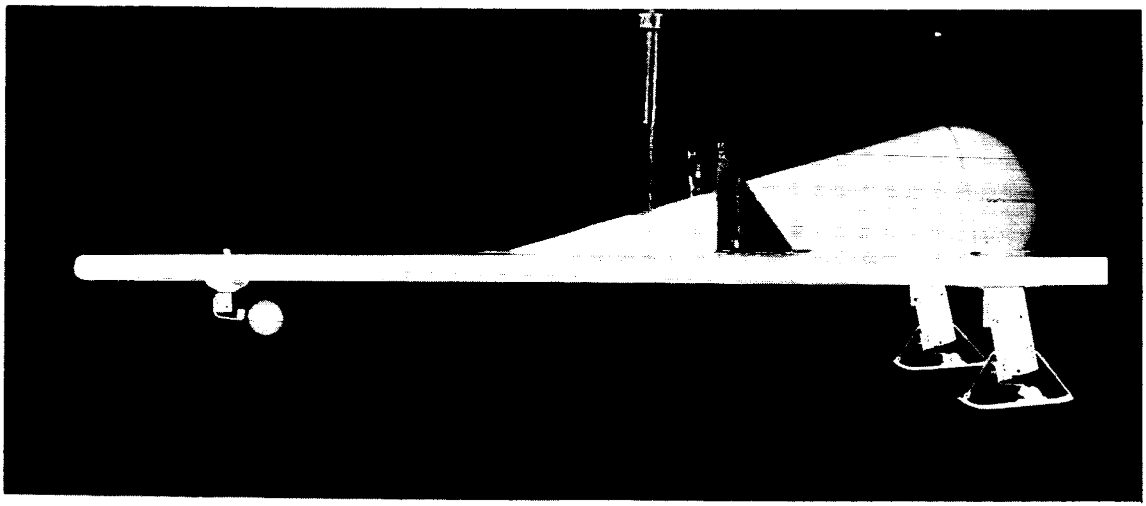

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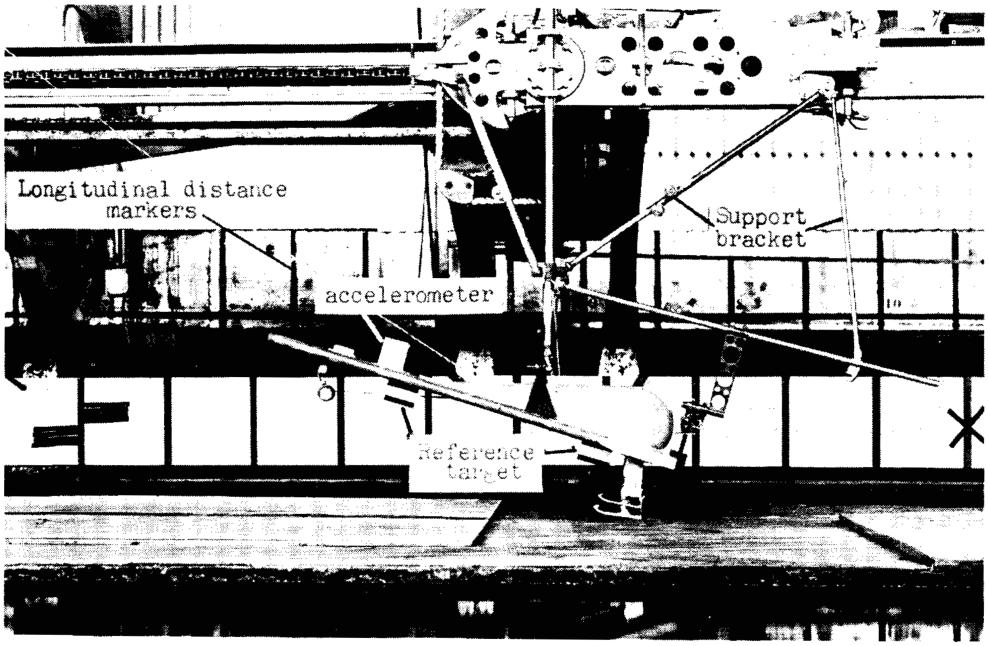
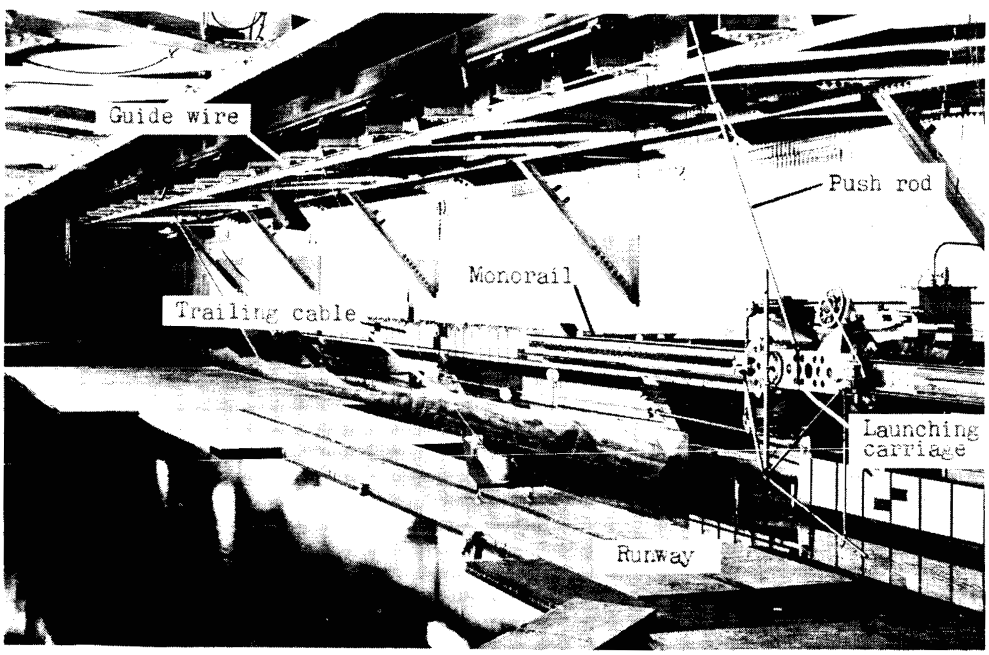
Figure 4.- Photograph of model after a landing, showing yielded shock struts.



(a) Launching carriage and model.



(b) General view of monorail and runway. L-60-4320

Figure 5.- Photograph of model on launching gear and landing on runway.

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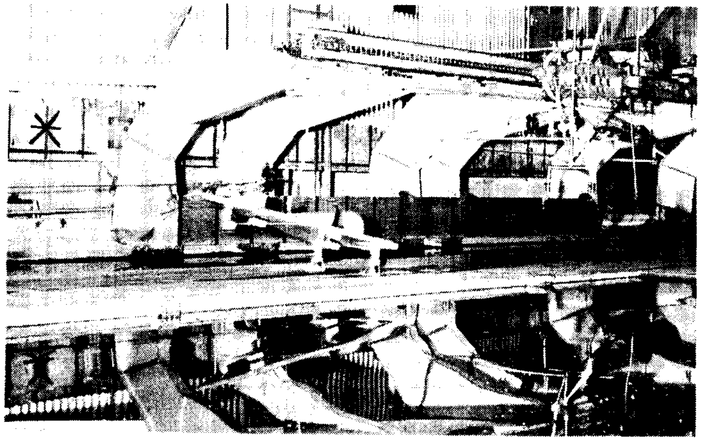

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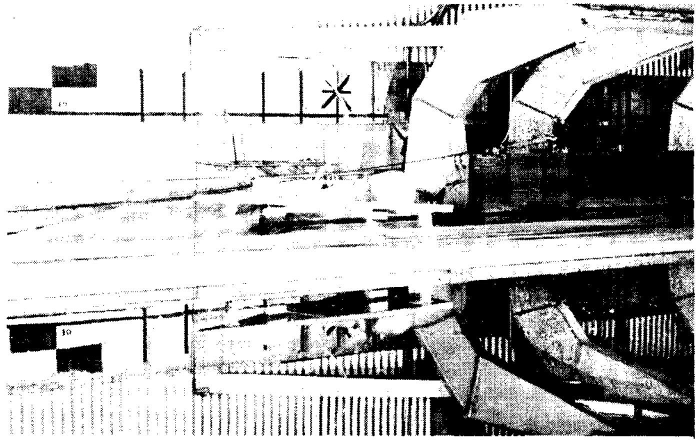

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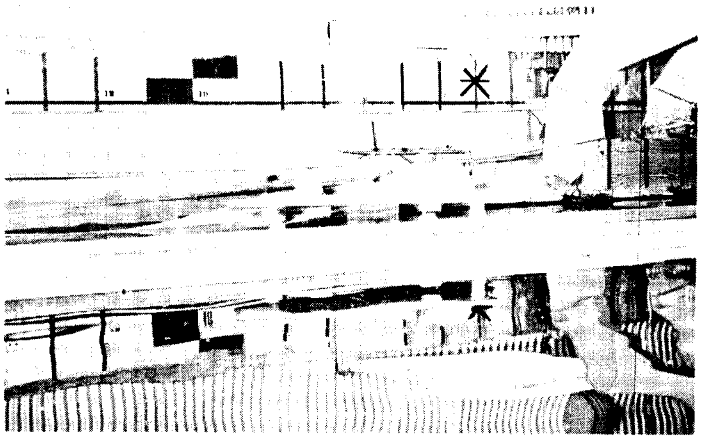

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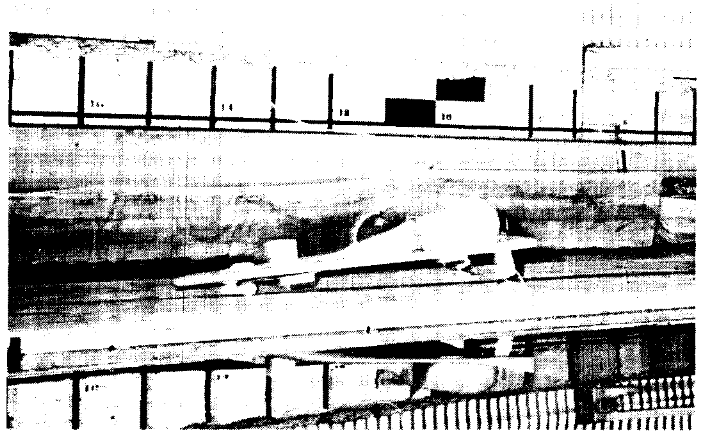

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Figure 6.- Sequence photographs during typical landing of model on hard surface with wheel-skid landing gear.

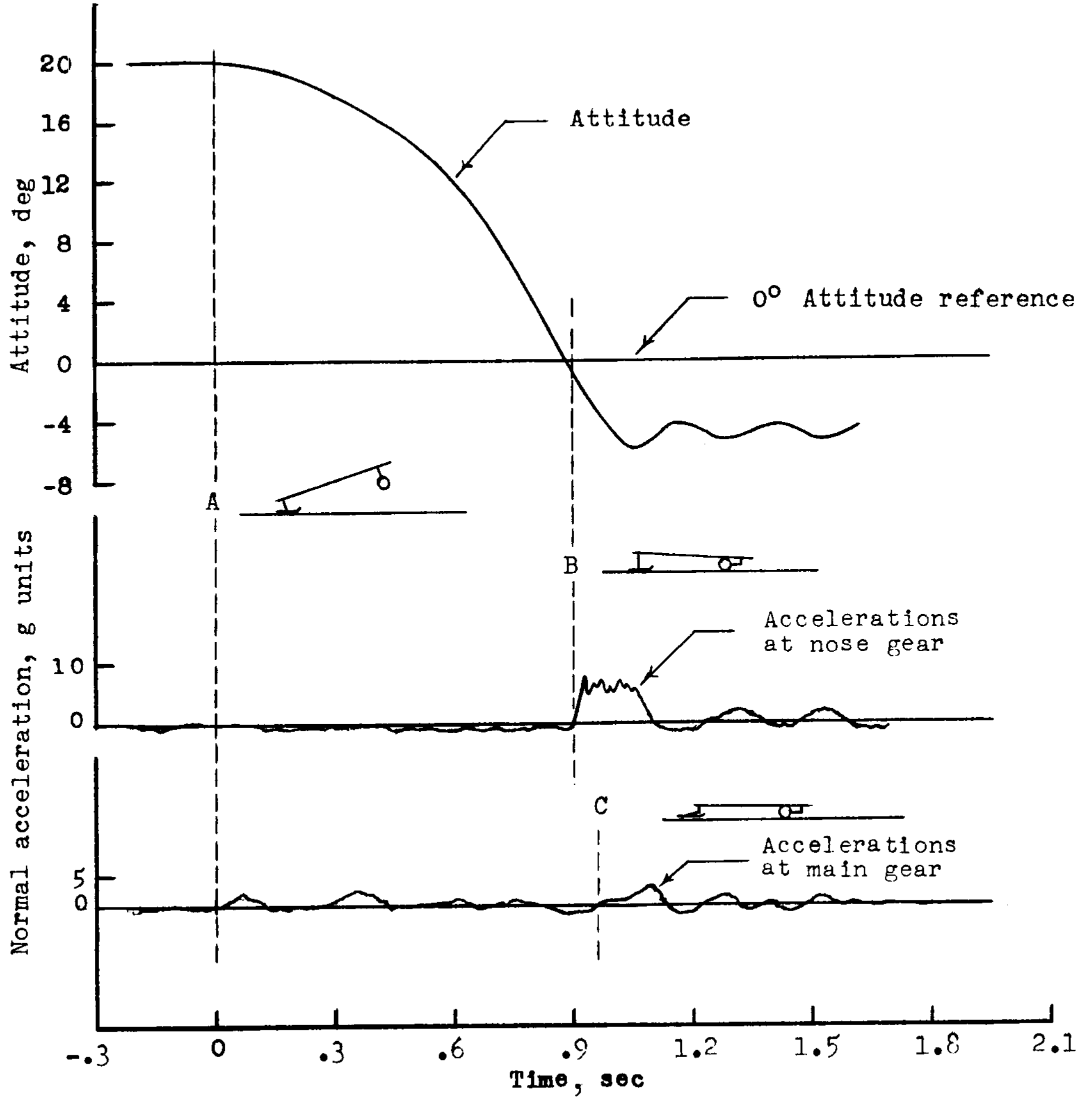
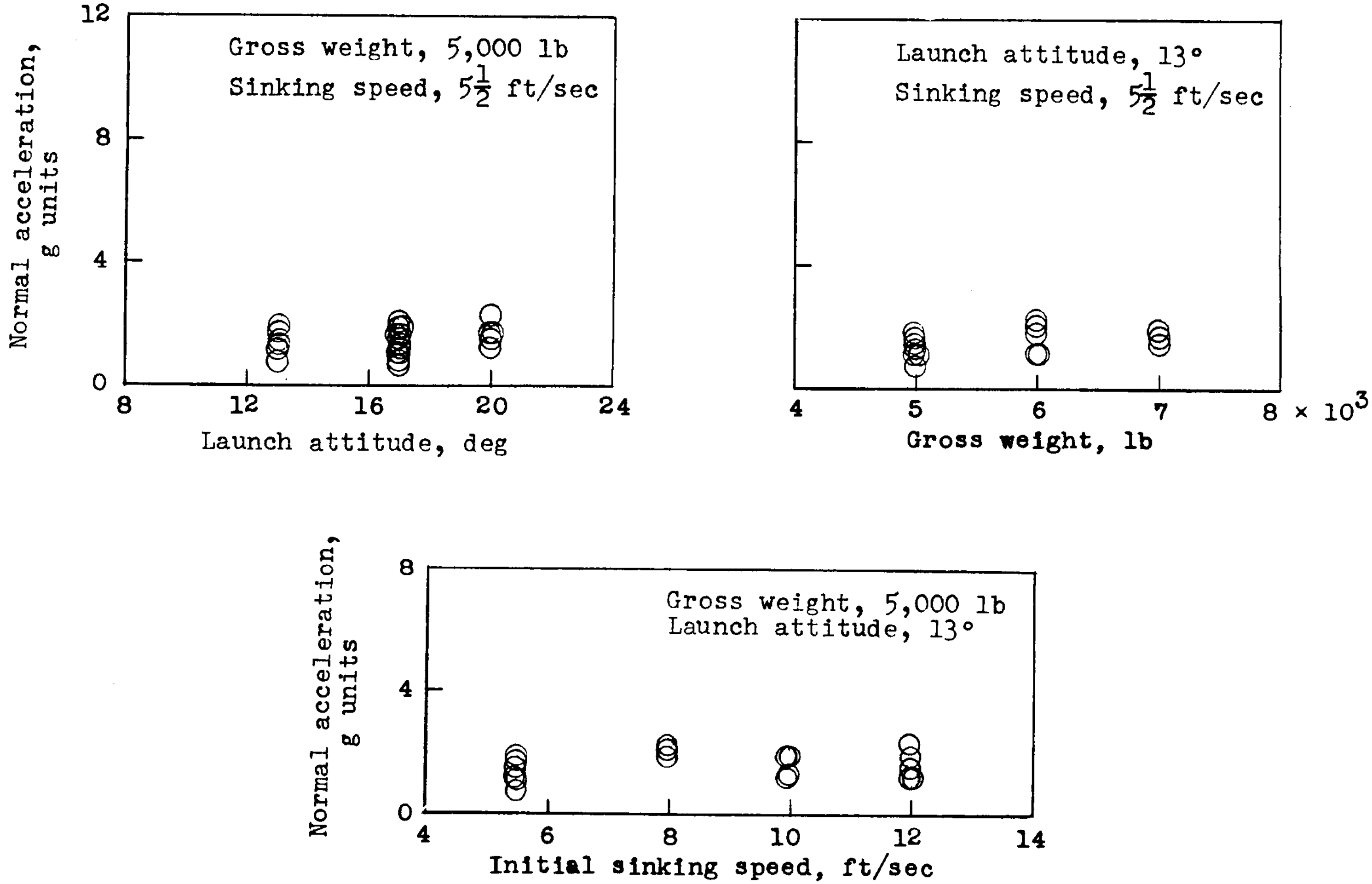
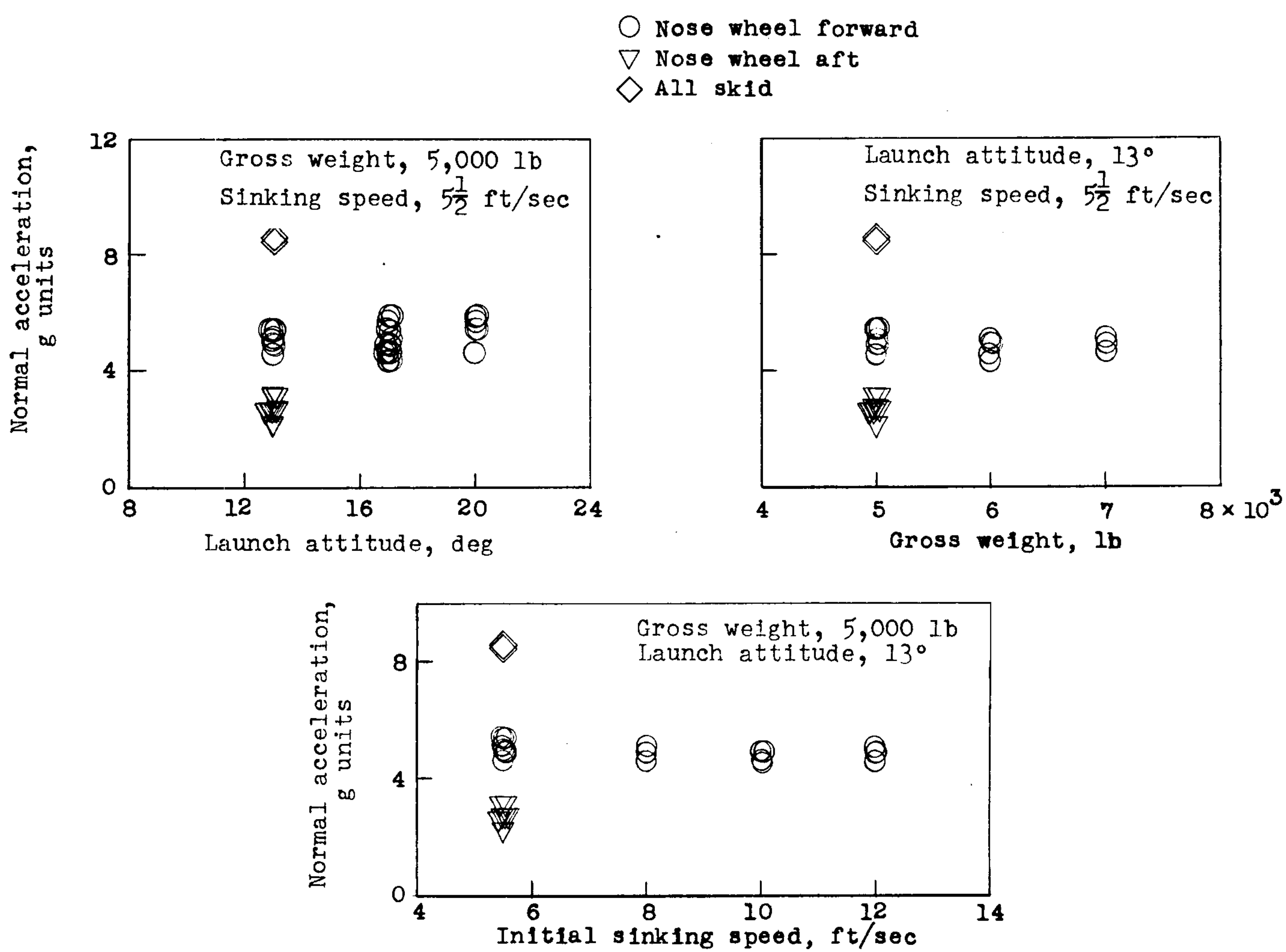


Figure 7.- Acceleration-time history of typical landing. All values full scale.



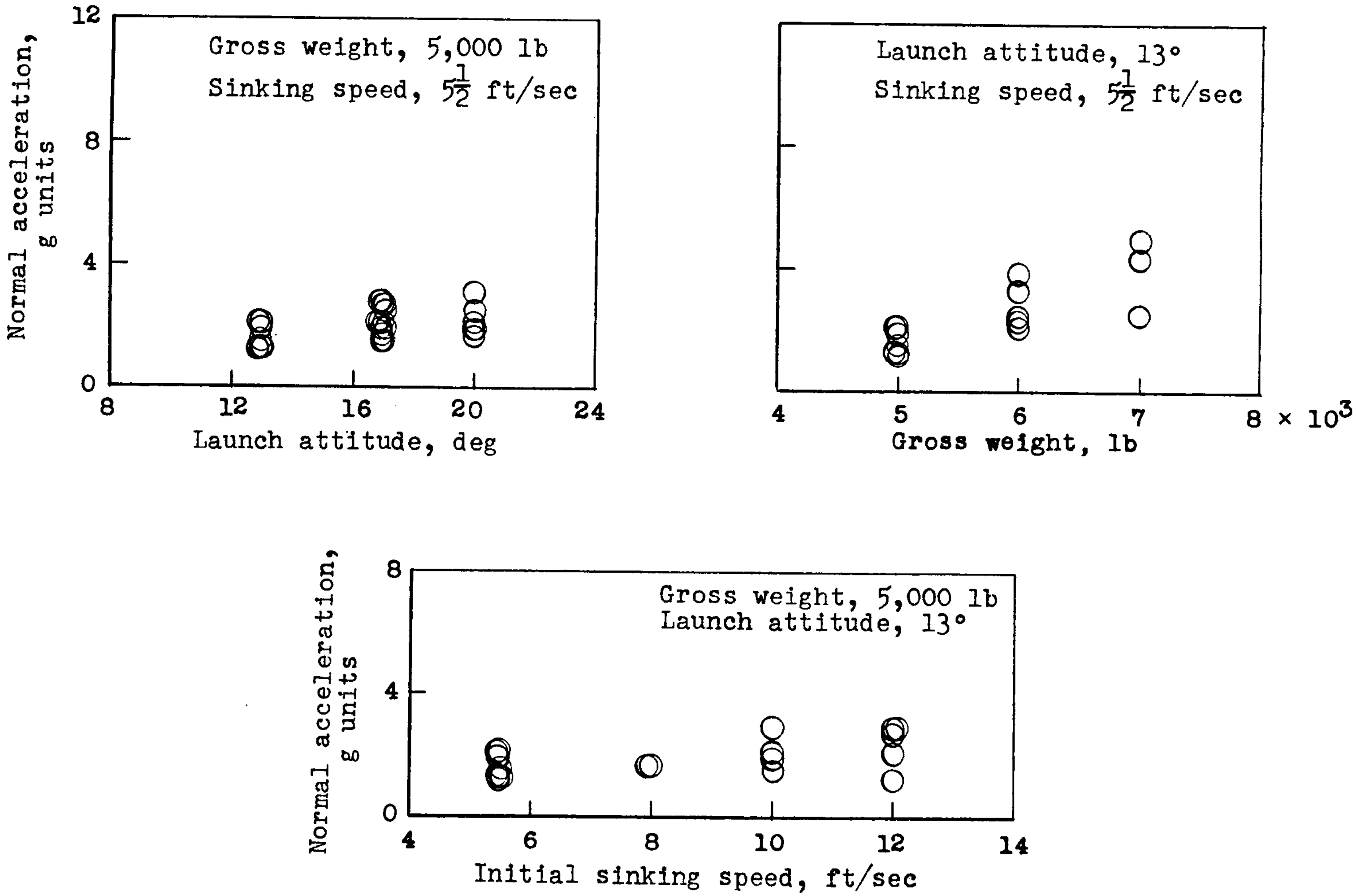
(a) Initial main-gear impact, point A.

Figure 8.- Normal accelerations obtained during hard-surface landings for various launch attitudes, gross weights, and initial sinking speeds. All values full scale.



(b) Initial nose-gear impact, point B.

Figure 8.- Continued.



(c) Secondary main-gear impact following initial nose-gear impact, point C.

Figure 8.- Concluded.

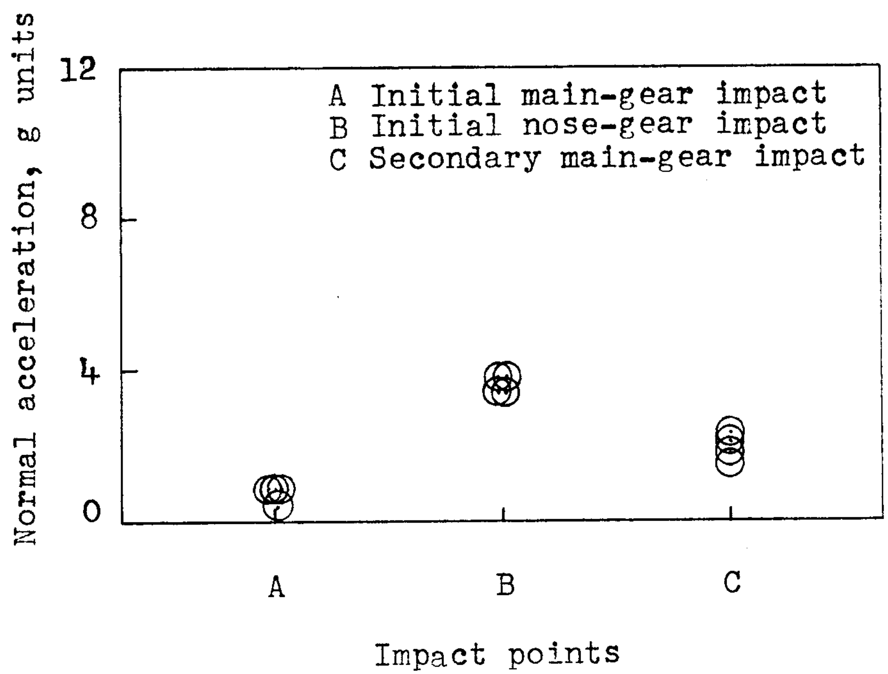


Figure 9.- Normal accelerations obtained during smooth-water landings. Gross weight, 5,000 lb; launch attitude, 17°; sinking speed, 6 ft/sec. All values full scale.

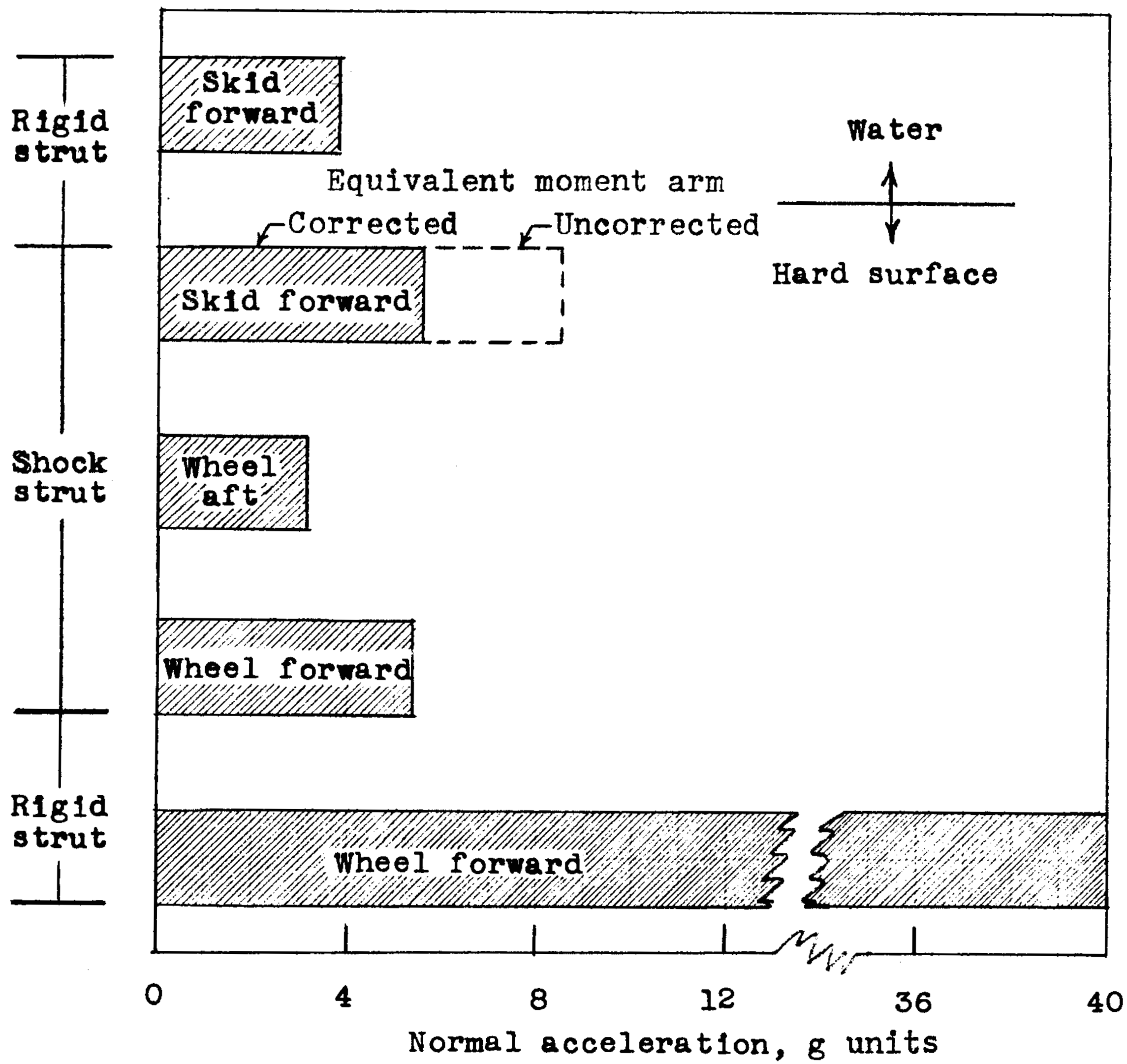


Figure 10.- Summary chart of maximum landing accelerations at nose gear for various landing-gear configurations on hard surface and water.