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WATER LANDING CHARACTERISTICS OF
A MODEL OF A WINGED REENTRY VEHICLE

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16. Abstract

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Results indicate that the maximum normal accelerations for configurations 1 and 2 when landing in calm water were approximately 8g and 6g, respectively, and the maximum longitudinal accelerations were approximately 5g and 3g, respectively. A small hydroflap was needed to obtain satisfactory calm-water landings with configuration 2, whereas configuration 1 gave good landings without a hydroflap.

All landings made in rough water resulted in unsatisfactory motions. For landings made in three different wave sizes, both configurations dived. The maximum normal accelerations for configurations 1 and 2 when landing in waves were -10.1g and -18.7g, respectively, and the maximum longitudinal accelerations for both configurations were approximately 13g.

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SUMMARY

Proposed manned space shuttle vehicles are expected to land on airport runways. In an emergency situation, however, the vehicle may be required to land on water. A 1/10-scale dynamic model of a winged reentry vehicle has been investigated to determine the water landing characteristics. Two configurations of the proposed vehicle were studied. Configuration 1 had a 30° negative dihedral of the stabilizer-elevon surface whereas configuration 2 had a 30° positive dihedral.

Results indicate that the maximum normal accelerations for configurations 1 and 2 when landing in calm water were approximately 8g and 6g, respectively, and the maximum longitudinal accelerations were approximately 5g and 3g, respectively. A small hydroflap was needed to obtain satisfactory calm-water landings with configuration 2, whereas configuration 1 gave good landings without a hydroflap.

All landings made in rough water resulted in unsatisfactory motions. For landings made in three different wave sizes, both configurations dived. The maximum normal accelerations for configurations 1 and 2 when landing in waves were -10.1g and -18.7g, respectively, and the maximum longitudinal accelerations for both configurations were approximately 13g.

INTRODUCTION

Proposed manned space shuttle vehicles are expected to land on airport runways; however, there is a possibility of emergency situations which would necessitate a water landing (or ditching) of the vehicle. In view of this possibility, an investigation was undertaken to explore the water landing behavior of a model of a winged-body reentry vehicle. The purpose of this paper is to present the results from that investigation.

In contrast with current manned spacecraft which land in a vertical (parachute) landing mode, the model of the present investigation was tested only in the horizontal (winged) landing mode in calm water and in rough water. The results from similar tests on other proposed manned spacecraft models are presented in references 1 and 2. The present model was tested with two different horizontal stabilizer configurations: one with a

30° negative dihedral angle (configuration 1) and the other with a 30° positive dihedral angle (configuration 2). The results are presented in terms of impact accelerations and behavior characteristics.

Units used for the physical quantities defined in this paper are given both in the International System of Units and in the U.S. Customary Units. Measurements and calculations were made in the U.S. Customary Units. Factors relating the two systems of units are presented in reference 3, and those used in the present investigation are presented in the appendix.

DESCRIPTION OF MODELS

The model used in the investigation was a 1/10-scale dynamic model of a proposed variable geometry nine-man spacecraft. The model was dynamically scaled according to Froude's law. Scale relationships between model and full-scale values are presented in table I, and the first item, geometric length, varies as the scale factor λ. Since both the model and the full-scale vehicle land in the same earth gravity field, the accelerations are the same for both model and full-scale vehicle. The model and the full-scale vehicle also land in the same fluid (water), thus mass density is also the same for both model and full-scale vehicle. With these three relationships fixed, other pertinent scale relationships follow from the laws of physics for dynamically scaled models.

Values for pertinent vehicle parameters are presented in table II for the full-scale vehicle and the 1/10-scale model. The model, shown schematically with full-scale dimensions in figures 1 and 2, was constructed of lightweight balsa wood between sections of thin plywood and was covered with a thin layer of fiber glass and plastic to make it watertight. The model was rigidly constructed and no attempt was made to scale any part of it elastically. The variable sweep wings were tested at a sweep angle of 0°. Elevons on the aft end of the horizontal stabilizers were preset for trim control and locked in place during each test. The model was tested in two configurations: one (designated configuration 1) had 30° negative dihedral stabilizers and the other (designated configuration 2) had 30° positive dihedral stabilizers. Photographs of the two configurations are presented in figures 3 and 4. Both configurations had essentially the same mass, moment-of-inertia, and body-size values, as given in table II.

Hydrotabs shown in figure 4 were employed on both configurations in an effort to keep the wing tips from contacting the water until late in the landing runout. The water landing behavior of configuration 2 was also evaluated with attached hydroflaps and, for four tests, with a fixed landing-gear system. Hydroflaps were used on the lower trailing edge of the vehicle producing lift which opposes suction forces produced by waterflow under the aft fuselage. Two different size aluminum hydroflaps were tested and details of the smaller one that proved the most satisfactory are shown in figure 5.

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The proposed design of a landing-gear system for this vehicle consisted of a nose wheel and skids mounted aft of the model center of gravity. For these tests, the landing gear had no shock absorbing capability. The small hydroflap and the fixed gear are shown in figures 4(b) and 4(c).

APPARATUS AND PROCEDURE

Water landings of the winged-reentry-vehicle configurations were accomplished at the Langley impacting structures facility by launching the model with a compressed air catapult. A photograph of the apparatus is given in figure 6. The model was underslung to a lightweight carriage which was propelled by the catapult to the desired velocity whereupon the model was released to impact the water in free flight. The velocity of the model was determined from two magnetic pickups which were spaced at a preset distance along the carriage rails. The landing characteristics of the model were evaluated from onboard accelerometers and from motion-picture coverage. Two strain-gage accelerometers, having the characteristics noted in table III, were mounted at the model center of gravity and oriented to measure the normal and longitudinal accelerations. Signals from these accelerometers were transmitted through a trailing cable to an oscillograph. A sketch showing the location of the accelerometers, acceleration axes, and model landing (pitch) attitude is presented in figure 7. Four motion-picture cameras were employed to record the dynamic behavior of the model. The cameras were placed to provide coverage of the side, front, and three-quarter rear views of the model.

Calm water was used for most of the tests; however, a brief rough-water investigation was also conducted. Three different size waves were used representative of sea states 1 to 3 which are normally generated by wind speeds from 0 to 15 knots. At full scale, wave A (sea state 1) had a random height from 0 to 64 cm (0 to 25 in.) and a length of 12 m (40 ft), wave B (sea state 2) was 64 cm (25 in.) high and 34 m (110 ft) long, and wave C (sea state 3) was 122 cm (48 in.) high and 30 m (100 ft) long. The model was landed normal to the wave front to simulate a worst-case approach.

Landings were made over a range of velocities consistent with model aerodynamics and the attitudes investigated. Model aerodynamics from unpublished data obtained in an investigation presented in reference 4 were used in determining the following table of model trim settings for the test velocities in the present investigation:

Horizontal velocity		Pitch attitude, deg	Elevon setting, deg
m/sec	ft/sec		
50	164	16	-6
55	180	12	0
59	194	8	6

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RESULTS AND DISCUSSION

A summary of all test conditions, together with the corresponding water-landing response of configurations 1 and 2, is presented in tables IV and V, where all values have been converted to full scale. The accelerations and dynamic motions of the configurations during the various water landing conditions are discussed separately in the sections which follow. All values are full scale.

Accelerations

For the purposes of this paper, accelerations are considered as positive when the forces producing the accelerations are in the direction of the positive axis (see fig. 7); also, a change of velocity is referred to as an acceleration even though the change may be a reduction in velocity.

Typical oscillograph records of normal and longitudinal accelerations for configurations 1 and 2 are shown in figure 8 for both landings in calm water and landings in waves. Data presented for configuration 2 were obtained using the smaller hydroflap which was found to give the best results in calm-water landings. Landings in calm water generally resulted in three or more distinct acceleration pulses (fig. 8) as the model porpoised slightly in and out of the water. For these tests, which were conducted with a nominal 12° pitch attitude and a horizontal velocity of 55 m/sec (179 ft/sec), the maximum accelerations for configuration 1 occurred upon the first impact and were 4.1g in the normal direction and 3.4g in the longitudinal direction (1g = 9.8 m/sec^2). Full-scale time is given to indicate the elapsed time between impacts. For the same test conditions, configuration 2 experienced a sustained (lasting approximately 0.4 sec) normal acceleration of about 4g during each impact with a short duration spike of 5.6g during the second impact and a maximum longitudinal acceleration of 2.4g which occurred during the initial impact.

High-frequency structural oscillations reflected in the accelerometer traces were faired typically as shown in figure 8(b). Acceleration data presented in tables IV and V were obtained from such fairings. The acceleration values shown in the tables are maximum values for each of the first three impacts.

Landing in waves with both configurations always resulted in an uncontrolled dive. Only one acceleration pulse was obtained for most of these landings as typified by the oscillograph record of figure 8(b) for landings on intermediate wave B. For the one instrumented run conducted in each wave condition, the maximum normal accelerations were -10.1g for configuration 1 and -18.7g for configuration 2, and the maximum longitudinal accelerations were 13.0g for configuration 1 and 13.9g for configuration 2. The duration of the acceleration pulse in both cases was approximately 0.6 sec.

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Figure 9 compares the acceleration values of configuration 1 and configuration 2 for landings in calm water. Both configurations were tested at similar landing conditions and the data presented are the maximum acceleration values for all three impacts of each test. Data points above the diagonal line indicate tests wherein accelerations for configuration 1 exceed the accelerations for configuration 2. The data indicate that, in general, configuration 1 experienced higher accelerations, both normal and longitudinal, than did configuration 2. The maximum normal accelerations measured on configuration 2 never exceeded 6g, whereas configuration 1 experienced accelerations to approximately 8g with one impact of one run as high as 10.5g. Similarly, the maximum longitudinal accelerations for configuration 2 never exceeded 3g whereas for configuration 1 these accelerations extended to over 4g.

Figure 10 shows the effect of pitch attitude on the maximum accelerations which occurred during calm-water landings for each of the configurations. In this figure, only the maximum value obtained during the entire run for each landing is plotted. With the exception of one run, maximum accelerations for configuration 1 exceed those for configuration 2. There is, however, no trend to define a relationship between the maximum acceleration and the vehicle pitch attitude.

Dynamic Motions

The analysis of the model dynamic motions during the water landings was derived from motion-picture coverage and the discussions which follow for the two configurations are accompanied by selected sequential photographs from that coverage.

Configuration 1 (negative-dihedral tail surfaces).- Figure 11 illustrates the behavior of configuration 1 landing on calm water at nominally 8°, 12°, and 16° pitch attitudes and at the horizontal velocities which correspond to those attitudes. The full-scale time between frames for landings at 8° and 12° pitch attitudes was 0.3 sec and the time between frames for the landing at 16° pitch attitude was 0.4 sec. Of these three landings, the one made at the 8° pitch attitude (fig. 11(a)) was the smoothest even though the landing velocity for that condition is the highest. Upon initial contact of the tail surfaces with the water (between photographs 2 and 3), the model trims down until the fuselage makes contact with the water (between photographs 6 and 7) resulting in the first impact. The model then skips off the water with the tail surfaces leaving the water last. The model contacts the water again (photograph 11) in a stable attitude and continues to porpoise slightly in and out of the water during the ensuing smooth runout. The landing made at 12° pitch attitude (fig. 11(b)) resulted in a small amount of spray over the nose (photograph 5) on first fuselage contact. The vehicle trims higher upon leaving the water than that which occurs at the 8° pitch attitude and on second fuselage contact (photographs 12 and 13) spray again comes over the nose; however, the model continues in a smooth runout. The landing made at the

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16° pitch attitude (fig. 11(c)) gave even greater porpoising action than that occurring at the 12° pitch attitude with slightly higher trim angle on emerging from the first impact. A slight roll to the right occurs as the model leaves the water (photographs 4 and 5) and on second contact the right elevon and stabilizer contact the water first which results in a left roll by the time the fuselage is wetted (photograph 9). The left roll is sufficient to cause the left wing tip to touch the water surface and spray can be seen coming from the left wing tip in photograph 10. The remaining runout is smooth. For most test conditions, noninstrumented as well as instrumented runs were made to determine the effect of the trailing instrument cable. The landing behavior was similar for both types of runs and is described in tables IV and V.

A summary of the landing behavior of configuration 1 for all tests is given in table IV. Note that at a pitch attitude of 16°, the model dived twice. These dives were attributed to a higher height of drop. In order to determine the effects of yaw and roll on landings in calm water, the model was tested with a preset 4° left yaw and with a 5° left roll. A slight dive occurred during a landing with 4° left yaw even though two runs at 5° left roll gave good landings; however, very good calm-water landings were obtained for configuration 1, especially for landings at the lower pitch attitudes.

As noted in table IV, all landings in waves with configuration 1 resulted in unsatisfactory motions. These landings were performed at a pitch attitude of 12° and landings were made on all three different wave sizes. Although the wave sizes used in the investigation were not considered large, the model dived during each test as illustrated in figure 12. The landings were typified by a nose-down pitching motion, generated when the tail surfaces contacted the water (wave), which resulted in a dive into a subsequent wave. The trailing edge of the model always contacted the water near the crest of a wave because the horizontal velocity was much higher than the sink velocity. No attempt was made to investigate the use of landing aids for landings in waves.

Configuration 2 (positive-dihedral tail surfaces).- Figure 13 depicts the calm-water landing behavior of configuration 2 (without hydroflap) at a nominal 12° pitch attitude. It is observed that the model initially contacts the water on the lower trailing edge of the fuselage and then trims down to strike the water in a flat attitude (photograph 4). Subsequently the model leaves the water, pitches up to a high uncontrollable attitude (photographs 6 to 9) such that the next impact occurs on the tail surface (photograph 10) which, in turn, induces a rapid pitch-down of the nose as the tail leaves the water (photograph 12). The next impact occurs at a negative trim and an undesirable dive ends the landing runout.

In view of the unsatisfactory landing behavior of configuration 2, without the hydroflap, several sizes of hydroflaps were installed on the lower trailing edge of the fuselage. The first hydroflap tested was a 51 cm (20 in.) square (full scale) aluminum tab canted down 30°. Figure 14 presents results from a calm-water landing with this hydroflap

design. The film sequence shows that when the tail with hydroflap contacts the water, the model pitches down until the fuselage contacts the water (photograph 6) and then skips free of the surface. However, as the model exits the water, the hydroflap is the last part of the vehicle to leave the surface, which imparts to the model a tail-up or nose-down moment to the extent that the subsequent impact occurs at a negative trim and results in a dive. Model behavior with a smaller hydroflap, having half the surface area of the first (see fig. 5), was next evaluated on configuration 2. Figure 15 presents the results of landings in calm water of the model at pitch attitudes of 8°, 12°, and 16° with the small hydroflap attached. The dynamic motions of the model are shown to be similar for all three attitudes in that the model contacts the water tail first, pitches down to a flat attitude for main fuselage contact and emerges from the water in a stable pitch attitude even though it rolls significantly to the right or left. (This roll action appeared to be random.) Hydrotabs installed on each wing tip leveled the wings and provided satisfactory impact and a stable runout. The hydrotabs on each wing used to simulate aileron control served their purpose well by leveling the wings in all cases for a smooth landing runout. These hydrotabs can be seen keeping the wings from digging into the water in photographs 9 to 11 of figure 15(a) and photographs 9 and 10 of figure 15(b). These results seemed to indicate that roll control would be needed to insure a satisfactory landing with configuration 2.

A typical sequence of photographs of configuration 2 landing in waves is shown in figure 16. Pitch attitude of the model was 12° and the wave was 122 cm (48 in.) high and 30 m (100 ft) long (wave C). The tail of the model hits against wave leading flank, trims down, and dives into the crest of the next wave. The run shown is typical of all landings in waves with configuration 2, with and without the small hydroflap attached, in that all landings were unsatisfactory.

In order to determine the effect of a deployed landing gear on the water landing of the model, several runs were made in calm water and in waves with the gear shown in figure 4 attached to configuration 2. The small hydroflap was also attached to the model to take advantage of its beneficial effects on the water landing of that configuration. A typical landing on calm water with the landing gear deployed is shown in figure 17. The figure shows that the model touches down on the rear skids and hydroflap and trims down with the skids never leaving the water. The nose wheel contacts the water (photograph 7) but fails to stop the negative pitch velocity (photograph 8) and a dive results (photographs 9 to 12). Similar results were obtained for landings in waves.

CONCLUDING REMARKS

An experimental investigation has been conducted to determine the water landing characteristics of a proposed winged reentry vehicle. Two configurations of a dynamically scaled model of the proposed vehicle were studied. Configuration 1 had a 30° nega-

tive dihedral of the stabilizer-elevon surface and configuration 2 had a 30° positive dihedral. With the exception of one run, the maximum normal accelerations for configurations 1 and 2 landing in calm water were approximately 8g and 6g, respectively, and maximum longitudinal accelerations were approximately 5g and 3g, respectively. A small hydroflap was needed to obtain satisfactory calm-water landings with configuration 2, whereas configuration 1 gave good landings without a hydroflap. All landings made in waves resulted in unsatisfactory motions. Both configurations dived in runs with three different wave sizes and maximum normal accelerations were -10.1g and -18.7g for configurations 1 and 2, respectively. Maximum longitudinal accelerations for both configurations landing in waves were approximately 13g.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 19, 1972.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

Factors required for converting the units for the measurements and calculations used herein to the International System of Units (SI) are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit (**)
Length	in.	0.0254	meters (m)
	ft	0.3048	meters (m)
Area	in^2	6.4516×10^{-4}	$meters^2$ (m^2)
Mass	slugs	14.5939	kilograms (kg)
Velocity	ft/sec	0.3048	meters/second (m/sec)
Linear acceleration . . .	ft/sec^2	0.3048	$meters/second^2$ (m/sec^2)
Force	lbf	4.448	newtons (N)
Moment of inertia	$slug\text{-}ft^2$	1.35582	$kilograms\text{-}meters^2$ ($kg\text{-}m^2$)

*Multiply value given in U.S. Customary Units by conversion factor to obtain equivalent value in SI Unit.

**Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
milli (m)	10^{-3}
centi (c)	10^{-2}
kilo (k)	10^{3}

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TABLE I.- SCALE RELATIONSHIPS

$[\lambda$, scale of model $= 1/10]$

Quantity	Full-scale value	Scale factor	Model
*Length	l	λ	λl
*Linear acceleration (gravity)	a	1	a
*Mass density	ρ	1	ρ
Area	A	λ^2	$\lambda^2 A$
Mass	m	λ^3	$\lambda^3 m$
Moment of inertia	I	λ^5	$\lambda^5 I$
Force	F	λ^3	$\lambda^3 F$
Speed	v	$\sqrt{\lambda}$	$\sqrt{\lambda}\, v$
Time	t	$\sqrt{\lambda}$	$\sqrt{\lambda}\, t$

*Scale factors which determine remaining scale relationships.

TABLE II.- PERTINENT PARAMETERS OF WINGED REENTRY VEHICLE

Parameter	1/10-scale model		Full-scale vehicle	
Mass (nominal)	6.80 kg	0.466 slug	6800 kg	466 slugs
Moment of inertia (nominal):				
I_{XX} (roll)	0.179 kg-m^2	0.132 slug-ft^2	17 900 kg-m^2	13 200 slug-ft^2
I_{YY} (pitch)	0.468 kg-m^2	0.345 slug-ft^2	46 800 kg-m^2	34 500 slug-ft^2
I_{ZZ} (yaw)	0.513 kg-m^2	0.378 slug-ft^2	51 200 kg-m^2	37 800 slug-ft^2
Body:				
Length	0.99 m	3.25 ft	9.9 m	32.5 ft
Span	1.01 m	3.32 ft	10.1 m	33.2 ft

TABLE III.- INSTRUMENTATION CHARACTERISTICS

Accelerometer orientation	Range, g units	Natural frequency, Hz	Damping percent of critical damping	Limiting flat frequency of other recording equipment, Hz
Normal (at vehicle center of gravity)	±25	465	0.52	120
Longitudinal (at vehicle center of gravity)	±25	467	.50	120

TABLE IV.- WATER LANDINGS OF CONFIGURATION 1. NOMINAL VEHICLE MASS 6800 kg (466 slugs)

[All values are full scale]

Horizontal velocity		Height above calm water to lowest point on model at time of release		Landing attitude, deg			Elevon setting, deg	Water condition	Runout from point of launch		Maximum accelerations, g units		Description of landing behavior
m/sec	ft/sec	cm	in.	Pitch	Roll	Yaw			m	ft	Normal	Longitudinal	
								Calm-water landings					
58.5	192	26.9	10.6	8	0	0	+6	Calm	300	1000	Not instrumented		Very good landing – smooth
58.5	192	41.1	16.2	8.2	0	0	+6		300	1000	Not instrumented		Very good landing – quite smooth
58.8	193	41.1	16.2	8.2	0	0	+6		300	1000	4.3, 6.6, 5.8	4.5, 2.6, 1.8	Very good landing – quite smooth
58.8	193	41.1	16.2	8.2	0	0	+6		300	1000	3.6, 6.2, 5.5	4.0, 2.6, 1.7	Very good landing – quite smooth
53.0	174	44.5	17.5	12	0	0	0		300	1000	Not instrumented		Very good landing
53.0	174	44.5	17.5	12	0	0	0		300	1000			Very good landing
53.9	177	47.8	18.8	11.3	0	0	0		270	900			Good landing – slight spray over nose on second impact
54.6	179	73.2	28.8	12	0	0	0		340	1100			Good landing – slight spray over nose on second impact
54.6	179	38.1	15.0	12	0	0	0		270	900	4.2, 7.1, 2.6	3.8, 2.1, 0.9	Good landing – slight spray over nose on second impact
55.2	181	38.1	15.0	12	0	0	0		270	900	4.1, 4.1, 3.0	3.4, 2.0, 1.0	Good landing
50.6	166	82.6	32.5	16	0	0	-6		180	600	Not instrumented		Model dived – probably due to excessive sink velocity
50.6	166	82.6	32.5	16	0	0	-6		180	600			Slight dive after large left roll and slight left yaw maneuver
50.0	164	31.8	12.5	16	0	0	-6		270	900			Very good landing
52.7	173	35.1	13.8	16	0	0	-6		270	900	7.0, 5.0, 2.5	3.7, 1.7, 0.9	Very good landing
52.4	172	35.1	13.8	16	0	0	-6		240	800	7.0, 7.7, 10.5	3.9, 2.1, 1.2	Good landing
53.3	175	26.9	10.6	11.3	5 Left	0	0		300	1000	Not instrumented		Very good landing
53.6	176	26.9	10.6	11.3	5 Left	0	0		300	1000			Good landing
53.9	177	44.5	17.5	11.5	0	4 Left	0		240	800			Good landing – slight dive with spray over nose during runout
54.2	178	47.8	18.8	11.5	0	4 Left	0		300	1000			Good landing – spray over nose during runout
								Landings in waves					
54.9	180	50.8	20.0	12	0	0	0	Wave A			Not instrumented		Model dived
55.2	181	66.5	26.2	12	0	0	0	Wave B					Model dived
54.9	180	85.9	33.8	12	0	0	0	Wave C					Model dived
54.9	180	53.8	21.2	12	0	0	0	Wave A			No record	13.0	Model dived
54.9	180	53.8	21.2	12	0	0	0	Wave B			-10.1	11.7	Model dived
54.6	179	102	40.0	12	0	0	0	Wave C			6.8	10.5	Model dived

Wave A – Random height 0 to 64 cm (0 to 25 in.), length 12 m (40 ft).

Wave B – Height 64 cm (25 in.), length 34 m (110 ft).

Wave C – Height 122 cm (48 in.), length 30 m (100 ft).

TABLE V.- WATER LANDINGS OF CONFIGURATION 2. NOMINAL VEHICLE MASS 6800 kg (466 slugs)

[All values are full scale]

Horizontal velocity		Height above calm water to lowest point on model at time of release		Landing attitude, deg			Elevon setting, deg	Water condition	Runout from point of launch		Maximum accelerations, g units		Description of configuration variation	Description of landing behavior
m/sec	ft/sec	cm	in.	Pitch	Roll	Yaw			m	ft	Normal	Longitudinal		
													Calm-water landings	
54.6	179	28	11	12	0	0	0	Calm	240	800	Not instrumented		Model (no hydroflap)	Poor landing – model dived
54.6	179	28	11	12	0	0	0		240	800				Poor landing – model dived
54.6	179	28	11	12	0	0	0		210	700				Poor landing – model dived
50.6	166	30	12	16	0	0	-6		240	800				Poor landing – model dived
50.9	167	30	12	16	0	0	-6		170	550				Poor landing – model dived
50.9	167	25	10	16	0	0	-6						Hydroflap, 51 cm (20 in.) square, 30° down	Model dived – early in landing – hydroflap too large
57.3	188	30	12	8	0	0	6		440	1450			Hydroflap, 25 cm (10 in.) wide, 51 cm (20 in.) long	Good landing
56.4	185	23	9	8	0	0	6		305	1000	4.3, 3.7, 5.0	2.4, 1.9, 1.3		Very good landing – smooth
58.2	191	23	9	8	0	0	6		305	1000	3.2, 3.8, 3.3	2.6, 2.0, 1.5		Very good landing – smooth
54.6	179	28	11	12	0	0	0		370	1200	Not instrumented			Good landing – hydrotabs kept wings from digging in
54.2	178	28	11	12	0	0	0		370	1200	Not instrumented			Good landing – hydrotabs kept wings from digging in
53.9	177	25	10	12	0	0	0		305	1000	4.1, 5.6, 4.4	2.4, 1.5, 1.3		Very good landing
54.6	179	28	11	12	0	0	0		305	1000	4.5, 5.3	2.5, 1.8		Very good landing
*53.9	177	89	35	12	0	0	0		240	800	9.5, 12.1, 4.5	2.9, 1.5, 3.9		Poor landing – spray over nose – rolled left, wing dug in
51.2	168	25	10	16	0	0	-6		340	1100	Not instrumented			Very good landing
50.9	167	25	10	16	0	0	-6		340	1100	Not instrumented			Very good landing
51.5	169	25	10	16	0	0	-6		270	900	4.9, 3.2, 4.4	2.6, 1.5, 1.1		Good landing
51.8	170	25	10	16	0	0	-6		305	1000	3.9, 3.9, 3.9	2.4, 1.5, 1.3		Good landing
54.9	180	20	8	12	5 Left	0	0		370	1200	Not instrumented			Good landing – hydrotabs kept wings from digging in
54.9	180	25	10	12	0	4 Left	0		240	800				Model dived
54.2	178	25	10	12	0	4 Left	0		370	1200				Fair run – wings almost dug in
53.6	176	23	9	12	0	0	0				-12.2	No record	Hydroflap and landing gear deployed	Model dived
54.6	179	23	9	12	0	0	0				-9.8	No record	Hydroflap and landing gear deployed	Model dived
													Landings in waves	
55.2	181	91	36	12	0	0	0	Wave C	<120	<400	Not instrumented		Model (no hydroflap)	Model dived
54.9	180	66	26	12	0	0	0	Wave B	90	300				Model dived
54.9	180	66	26	12	0	0	0	Wave A	90	300				Model dived
53.6	176	53	21	12	0	0	0	Wave A			-14.2	13.1	Hydroflap, 25 cm (10 in.) wide, 51 cm (20 in.) long	Model dived
53.9	177	53	21	12	0	0	0	Wave B			-18.5	13.9		Model dived
54.2	178	89	35	12	0	0	0	Wave C			12.9, -18.7	No record		Model dived
55.2	181	91	36	12	0	0	0	Wave C	150	500	Not instrumented·			Model dived
55.2	181	91	36	12	0	0	0	Wave C	<120	<400	Not instrumented			Model dived
53.6	176	56	22	12	0	0	0	Wave A				7.8	Hydroflap and landing gear deployed	Model dived
54.2	178	86	34	12	0	0	0	Wave C			11.1, -6.0	3.2, 4.7	Hydroflap and landing gear deployed	Model dived

Wave A – Random height 0 to 64 cm (0 to 25 in.), length 12 m (40 ft)

Wave B – Height 64 cm (25 in.), length 34 m (110 ft)

Wave C – Height 122 cm (48 in.), length 30 m (100 ft)

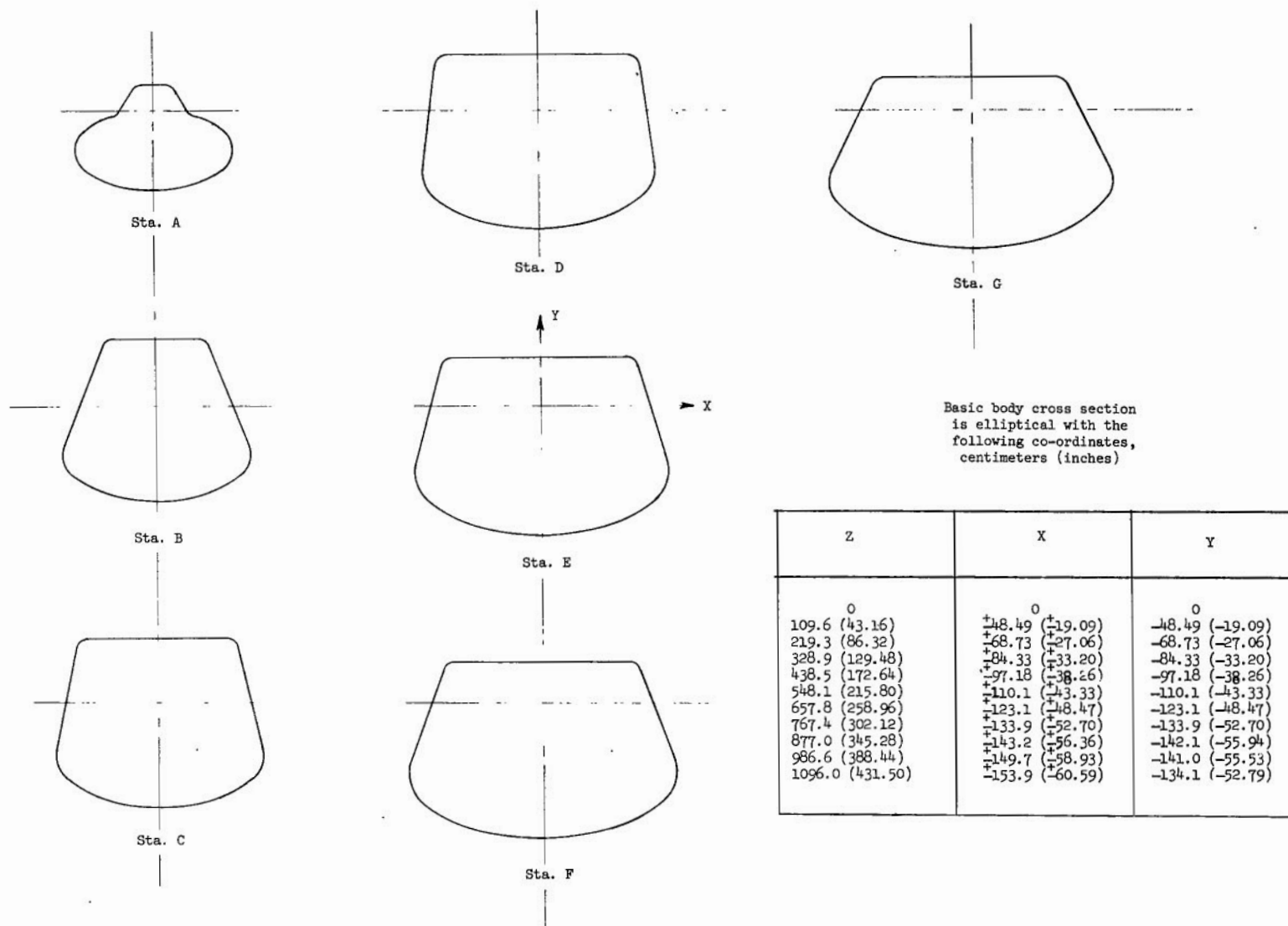*Not used for comparison purposes because of higher release height.

Wing Tip Chord,
centimeters (inches)

X_w	Y_w (upper)	Y_w (lower)
0	0	0
1.1 (.415)	3.17 -1.2	-2.2 (-.86)
2.1 (.81)	4.27 1.68	-2.79 (-1.10)
4.2 (1.66)	6.05 (2.33)	-3.35 (-1.32)
5.4 (2.14)	7.47 (2.94)	-3.66 (-1.44)
8.2 (3.24)	8.66 3.4	-3.63 (-1.43)
12.2 (4.81)	10.4 4.10	-3.12 (-1.03)
16.4 (6.47)	11.8 (4.56)	-2.5 (-.97)
24.7 (9.71)	13.4 5.27	-1.2 (-.46)
32.89 (12.95)	13.7 5.303	.1 (.04)
41.13 (16.19)	13.2 5.20	1.5 (.58)
49.31 (19.42)	11.8 (4.66)	2.5 (.97)
57.56 (22.66)	9.65 (3.80)	2.64 (1.04)
65.79 (25.90)	6.78 (2.67)	2.5 (.97)
73.99 (29.13)	3.71 (1.47)	1.5 (.58)
78.00 (30.71)	2.13 (.84)	.89 (.35)
82.20 (32.37)	0	0

Wing Root Chord,
centimeters (inches)

X_w	Y_w (upper)	Y_w (lower)
0	0	0
1.3 (.50)	3.84 (1.5)	-2.74 -1.08
2.5 (1.00)	5.28 (2.08)	-3.43 (-1.35)
5.0 (2.00)	7.49 (2.95)	-4.17 (-1.64)
7.59 (2.99)	9.1 (3.59)	-4.52 (-1.78)
10.1 (3.98)	10.6 (4.18)	-4.47 (-1.76)
15.2 (5.98)	12.9 5.08	-3.84 (-1.51)
20.2 (7.97)	14.6 5.74	-3.05 (-1.20)
30.3 (11.95)	16.5 (6.49)	-1.4 (-.56)
40.49 (15.35)	16.8 (6.61)	.10 (.04)
50.60 (19.35)	16.7 (6.57)	1.8 (.71)
60.71 (23.90)	14.6 (5.74)	3.05 (1.20)
70.84 (27.69)	11.8 (4.66)	3.75 (1.48)
80.95 (31.87)	8.38 (3.30)	3.05 (1.20)
91.08 (35.86)	4.55 (1.79)	1.8 (.71)
96.14 (37.85)	2.64 (1.04)	1.1 (.42)
101.2 (39.84)	0	0

Figure 1.- General arrangement of 1/10-scale variable geometry reentry vehicle model (configuration 1). Dimensions are given first in meters and parenthetically in inches (except as otherwise noted). All values are full scale.

Sta. A

Sta. D

Sta. G

Sta. B

Sta. E

Sta. C

Sta. F

Basic body cross section
is elliptical with the
following co-ordinates,
centimeters (inches)

Z	X	Y
0	0	0
109.6 (43.16)	±48.49 (±19.09)	−48.49 (−19.09)
219.3 (86.32)	±68.73 (±27.06)	−68.73 (−27.06)
328.9 (129.48)	±84.33 (±33.20)	−84.33 (−33.20)
438.5 (172.64)	±97.18 (±38.26)	−97.18 (−38.26)
548.1 (215.80)	±110.1 (±43.33)	−110.1 (−43.33)
657.8 (258.96)	±123.1 (±48.47)	−123.1 (−48.47)
767.4 (302.12)	±133.9 (±52.70)	−133.9 (−52.70)
877.0 (345.28)	±143.2 (±56.36)	−142.1 (−55.94)
986.6 (388.44)	±149.7 (±58.93)	−141.0 (−55.53)
1096.0 (431.50)	±153.9 (±60.59)	−134.1 (−52.79)

Figure 2.- Body cross sections at stations shown in figure 1. All dimensions are full scale.
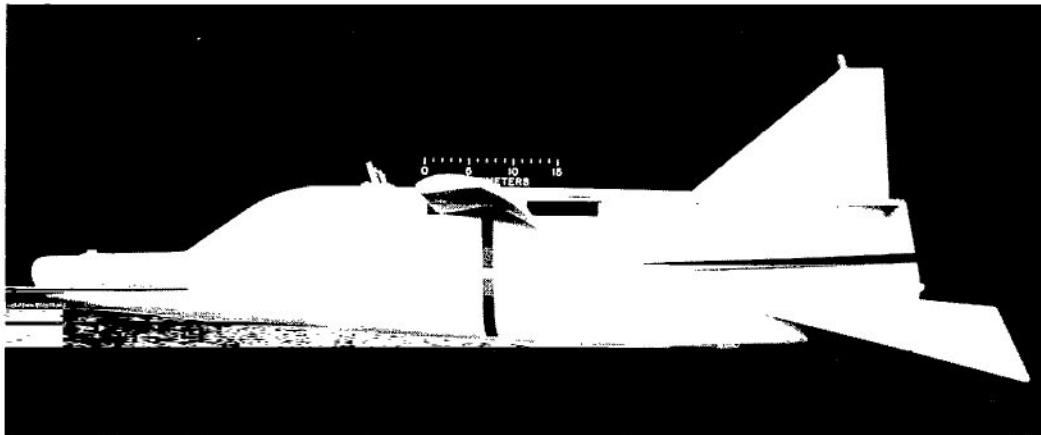
(a) Side view.
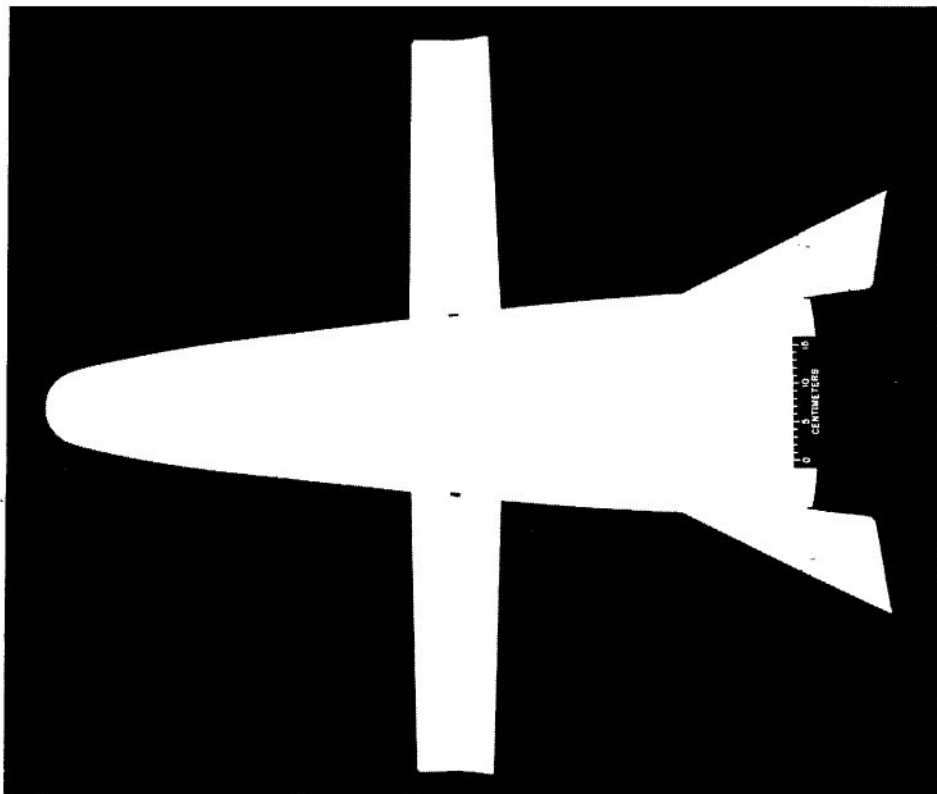
(b) Bottom view.

Figure 3.- Photographs of configuration 1 (negative dihedral tail).
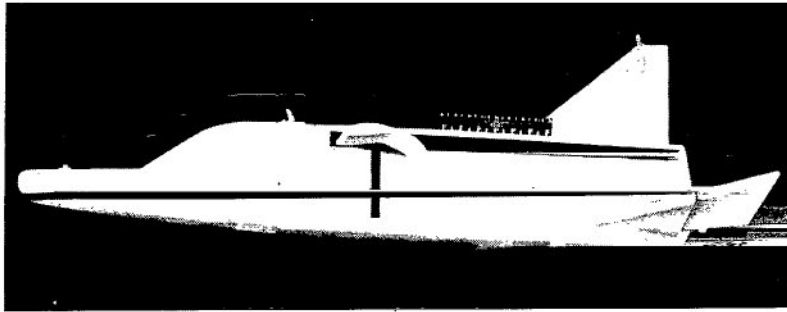
(a) Bare model side view.

(b) Side view of model showing landing gear
extended, hydrotab, and hydroflap.
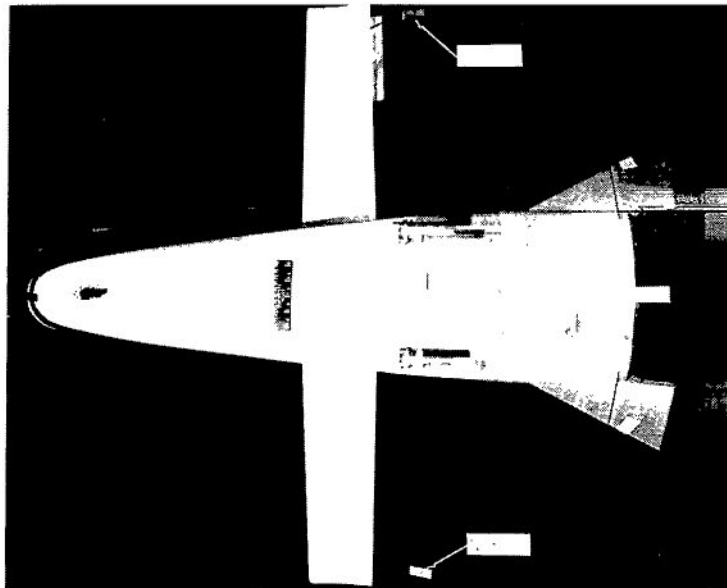
L-72-2438
(c) Bottom view.

Figure 4.- Photographs of configuration 2 (positive dihedral tail).

18
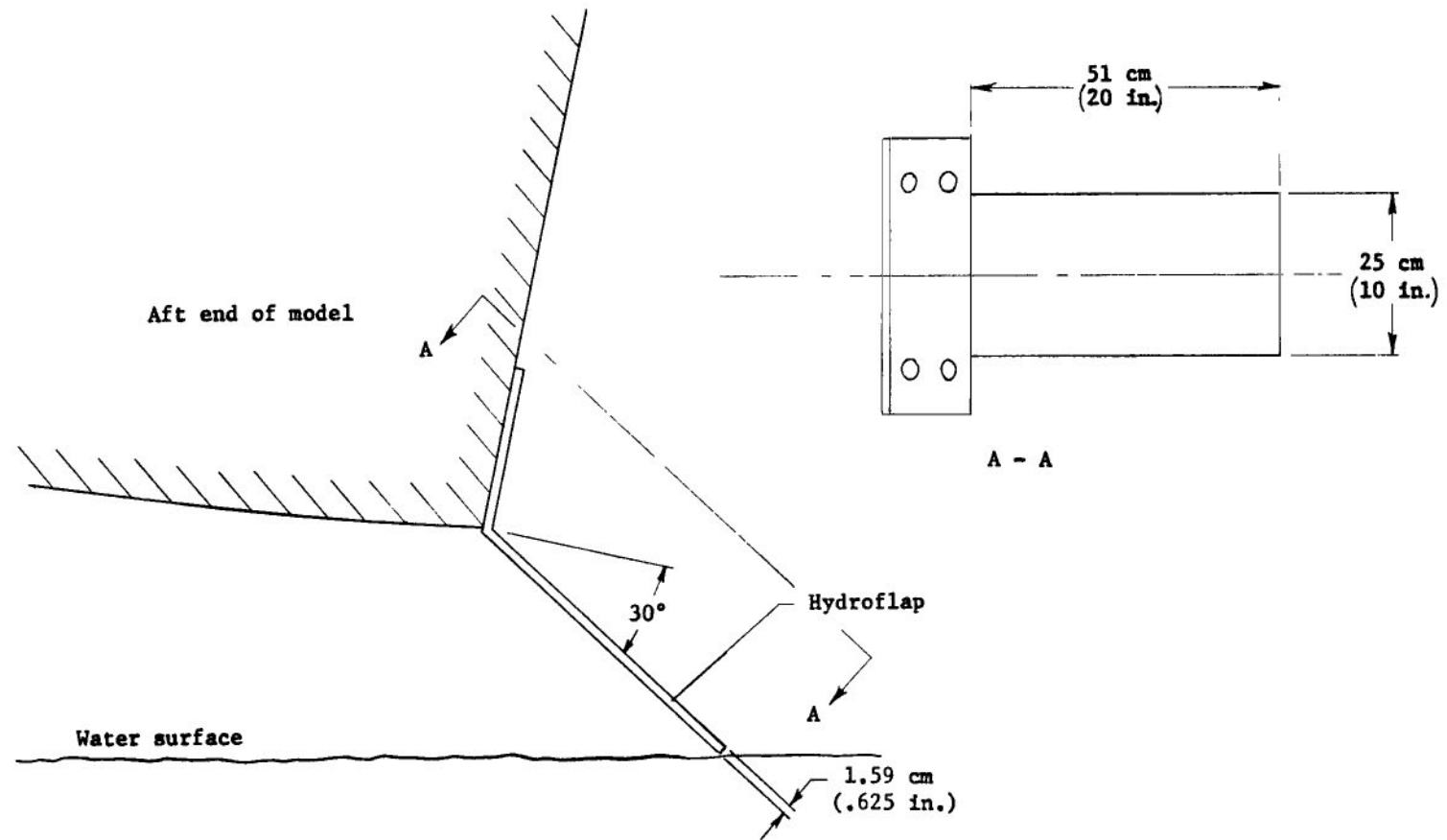
Figure 5.- Sketch of hydroflap used on configuration 2. All values are full scale.
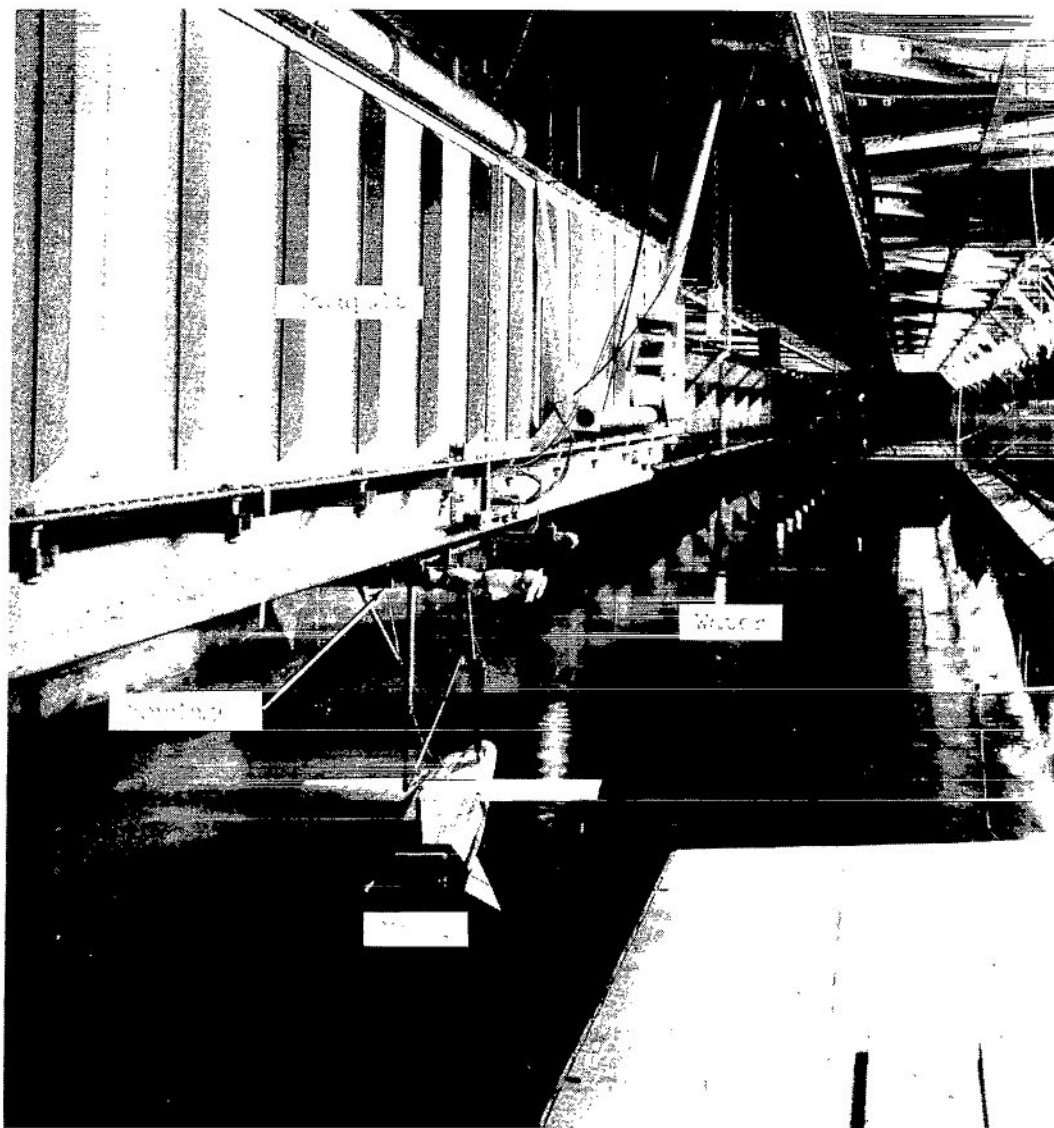
L-69-2444.1

Figure 6.- Photograph of test apparatus for horizontal water landings.
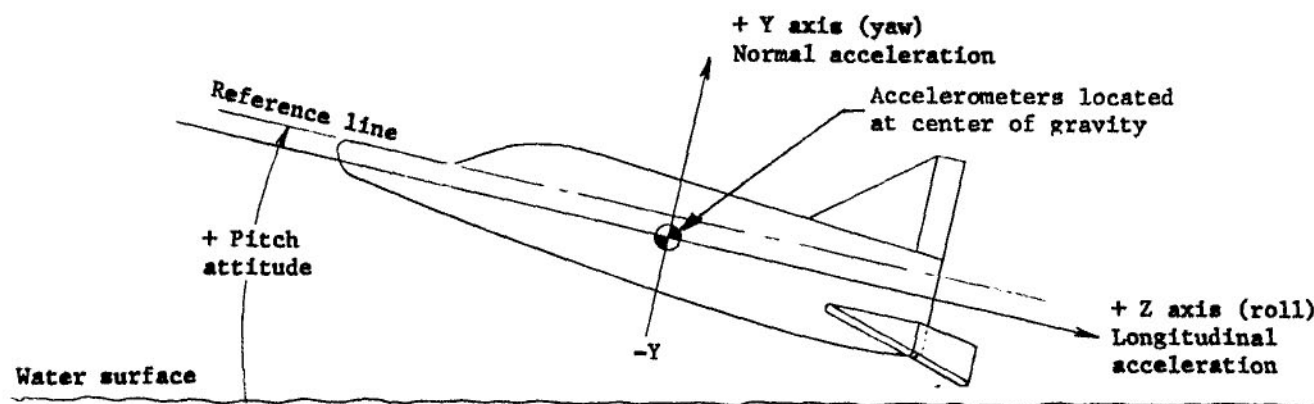
Figure 7.- Sketch identifying acceleration axes and pitch attitude.

INITIAL TAIL CONTACT
1ST IMPACT
2D IMPACT
3D IMPACT

NORMAL ACCELERATION

4.1 g
4.1 g
3.0 g

LONGITUDINAL ACCELERATION

3.4 g
2.0 g
1.0 g

TIME 0   .2 SEC   .4 SEC   .6 SEC   .8 SEC   2.2 SEC   2.4 SEC   2.6 SEC   3.6 SEC   3.8 SEC   4.0 SEC   4.2 SEC

CONFIGURATION 1

1ST IMPACT   NORMAL ACCELERATION   2D IMPACT   3D IMPACT

INITIAL CONTACT OCCURS
PRIOR TO TIME 0

4.1 g
5.6 g
4.4 g

LONGITUDINAL ACCELERATION

2.4 g
1.5 g
1.3 g

TIME 0   .2 SEC   .4 SEC   2.0 SEC   2.2 SEC   2.4 SEC   3.4 SEC   3.6 SEC   3.8 SEC

CONFIGURATION 2

(a) Landings in calm water.

Figure 8.- Typical oscillograph records of accelerations during water landings of configurations 1 and 2. Horizontal velocity, 55 m/sec (179 ft/sec); pitch attitude, 12°; roll and yaw, 0°. All values are full scale.

−10.1 g

NORMAL ACCELERATION

INITIAL
CONTACT
OCCURS
PRIOR TO
TIME 0

LONGITUDINAL ACCELERATION

11.7 g

TIME 0   .2 SEC   .4 SEC

CONFIGURATION 1

−18.5 g

NORMAL ACCELERATION

INITIAL
CONTACT
OCCURS
PRIOR TO
TIME 0

LONGITUDINAL ACCELERATION

13.9 g

TIME 0   .2 SEC   .4 SEC
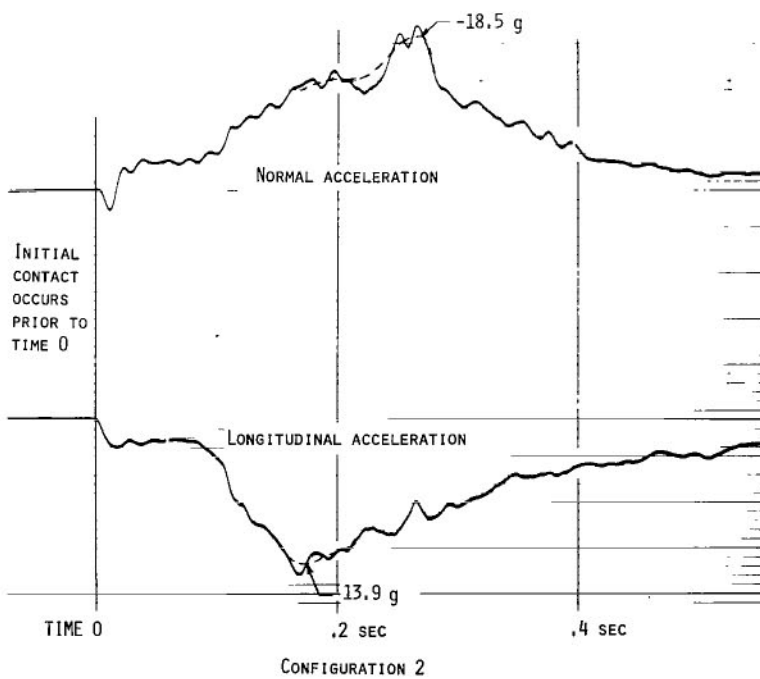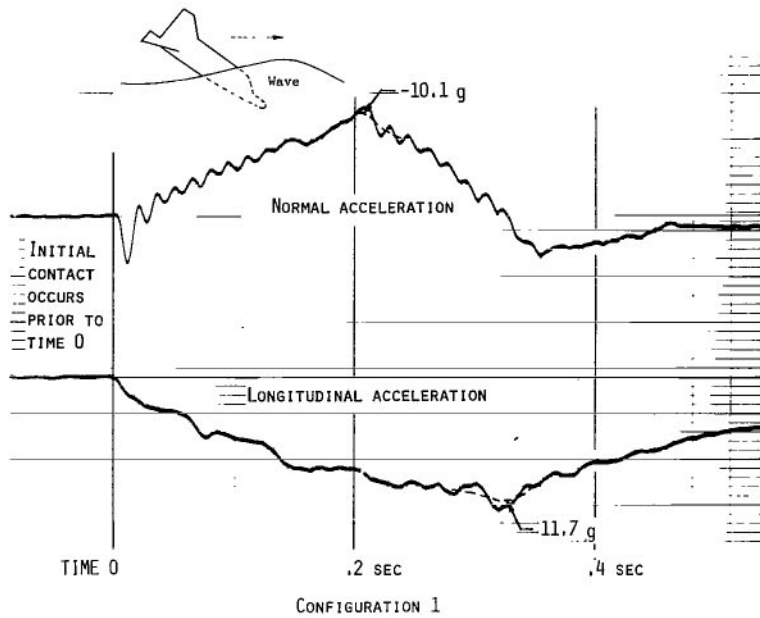
CONFIGURATION 2

(b) Landings in waves 64 cm (25 in.) high and 34 m (110 ft) long.

Figure 8.- Concluded.

23
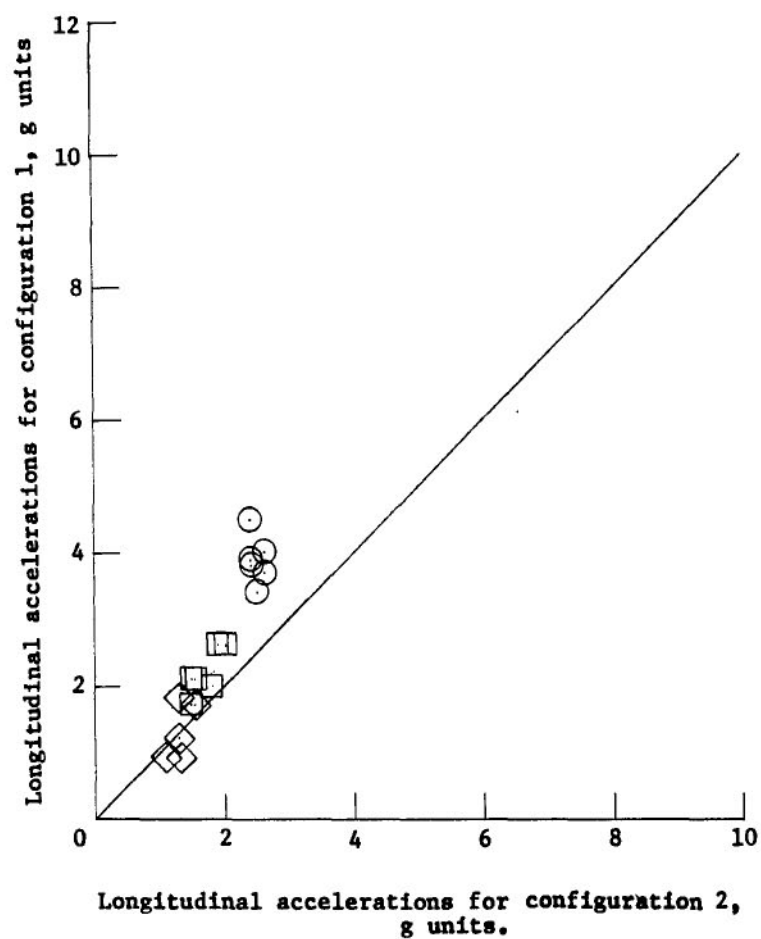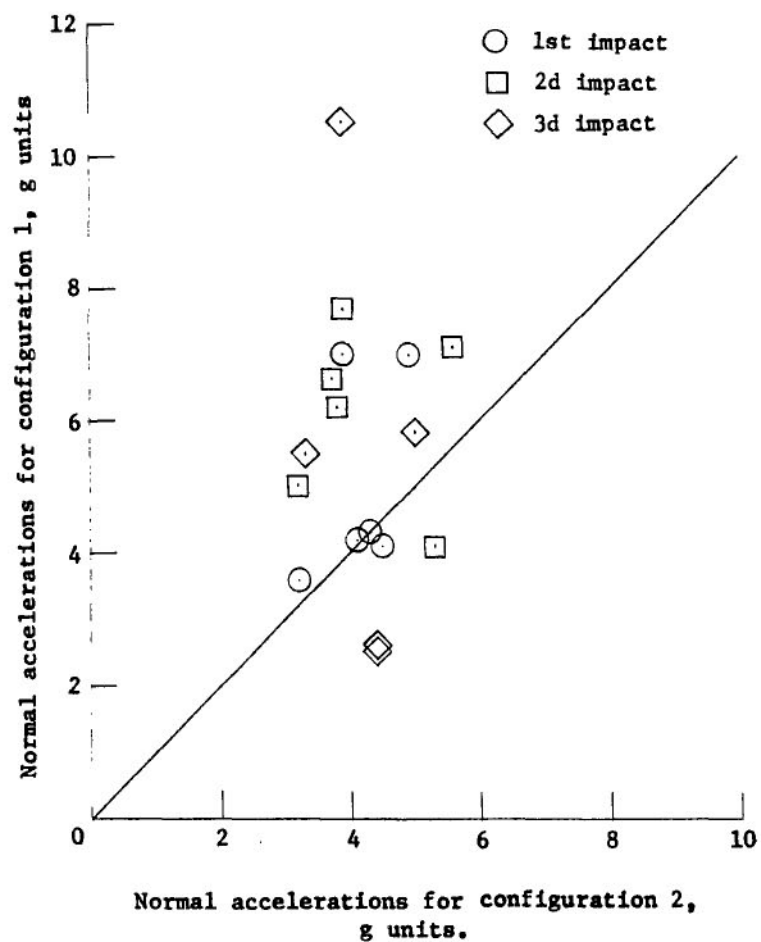
Figure 9.- Comparison of acceleration values of configurations 1 and 2 for landings in calm water.
All values are full scale.
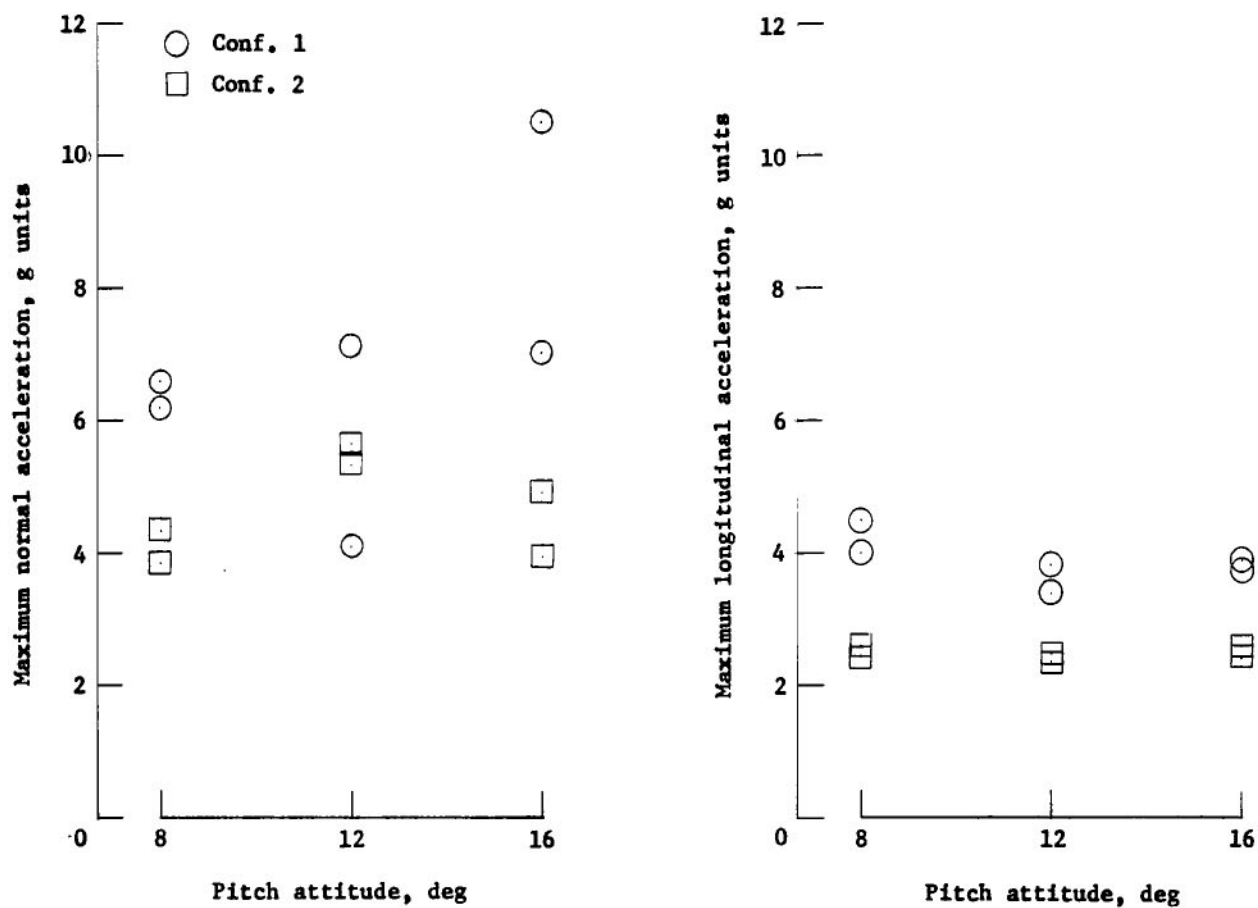
Figure 10.- Comparison of maximum accelerations of configurations 1 and 2 for landings in calm water plotted to show effect of pitch attitude. All values are full scale.
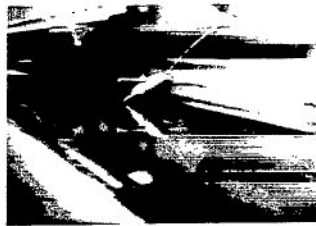
1   2   3

4   5   6
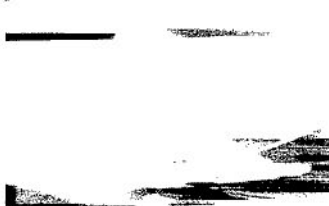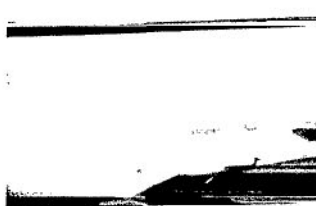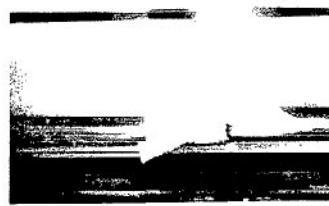
7   8   9

10   11   12
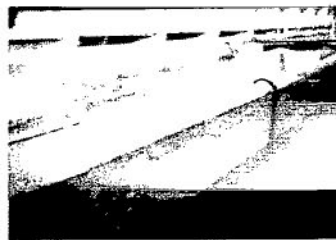
13   14   L-72-2439
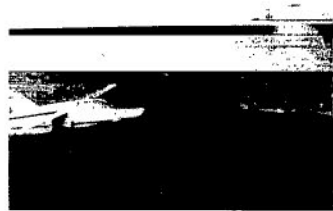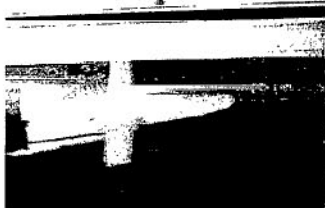
(a) Pitch attitude, 8°; horizontal velocity, 58.8 m/sec (193 ft/sec);
time between frames 0.3 sec.

Figure 11.- Typical sequence photographs of configuration 1 landings in calm water.
All values are full scale.
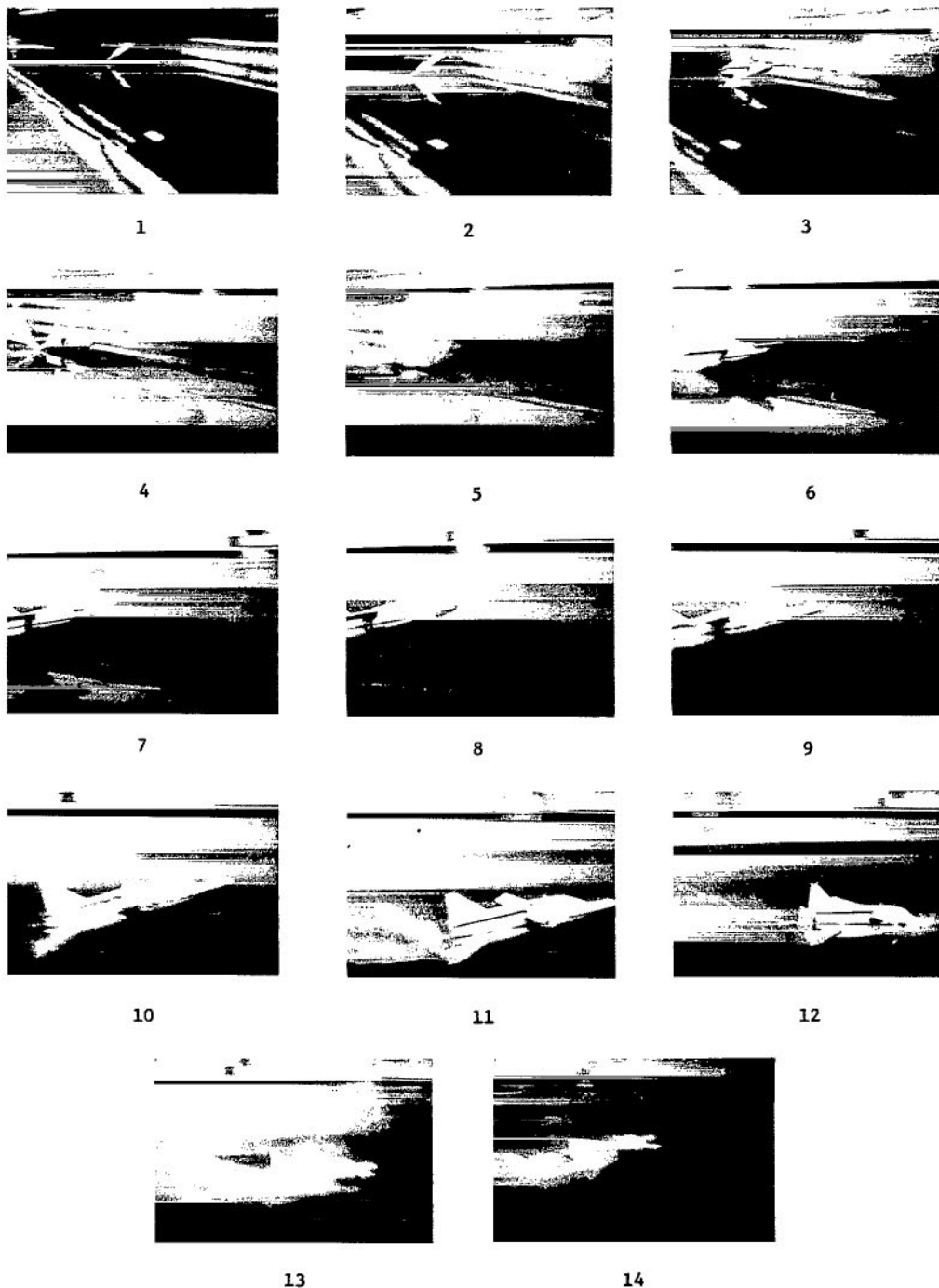
L-72-2440

(b) Pitch attitude, 12°; horizontal velocity, 53.0 m/sec (174 ft/sec); time between frames, 0.3 sec.

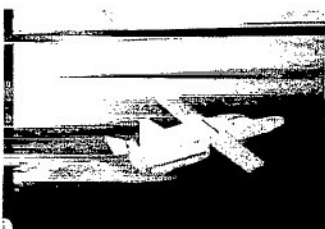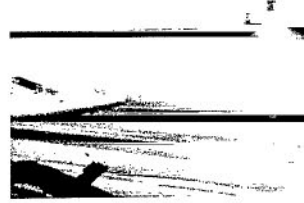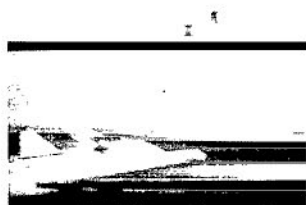Figure 11.- Continued.

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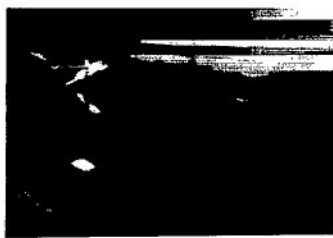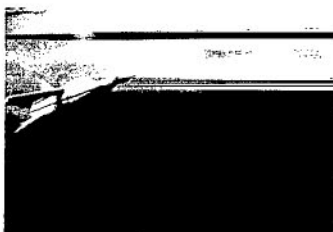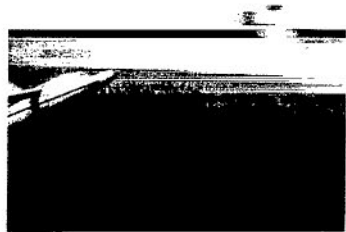
7

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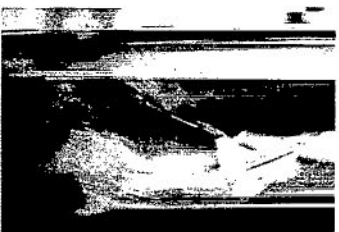
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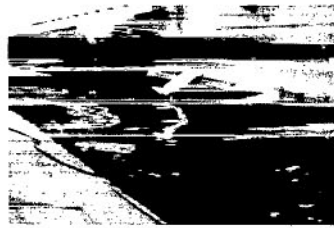
L-72-2441

(c) Pitch attitude, 16°; horizontal velocity, 50.6 m/sec (166 ft/sec);
time between frames, 0.4 sec.

Figure 11.- Concluded.
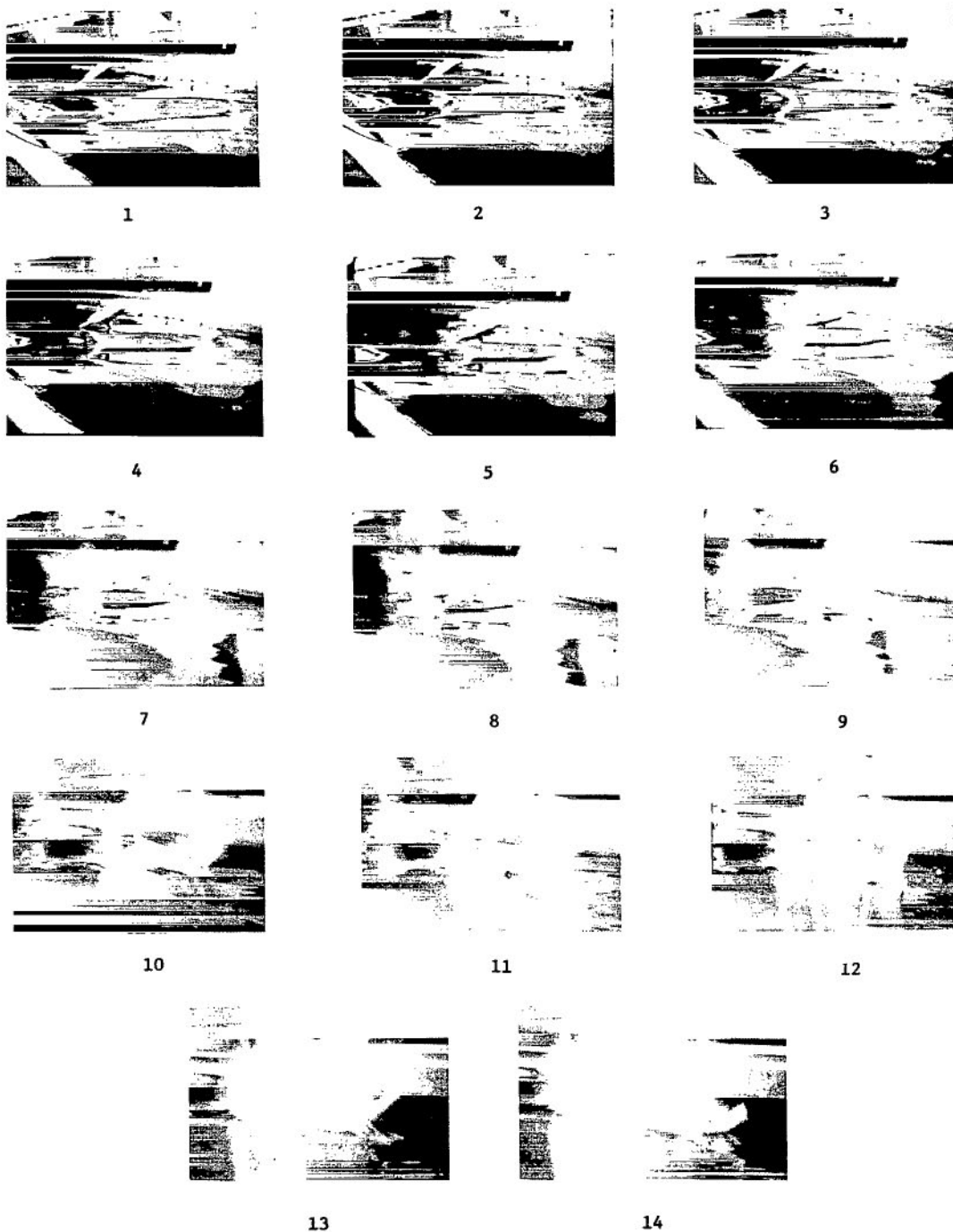
Figure 12.- Typical sequence photographs of configuration 1 landing in waves 64 cm (25 in.) high and 34 m (110 ft) long. Pitch attitude, 12°; horizontal velocity, 55.2 m/sec (181 ft/sec); time between frames, 0.1 sec. All values are full scale.
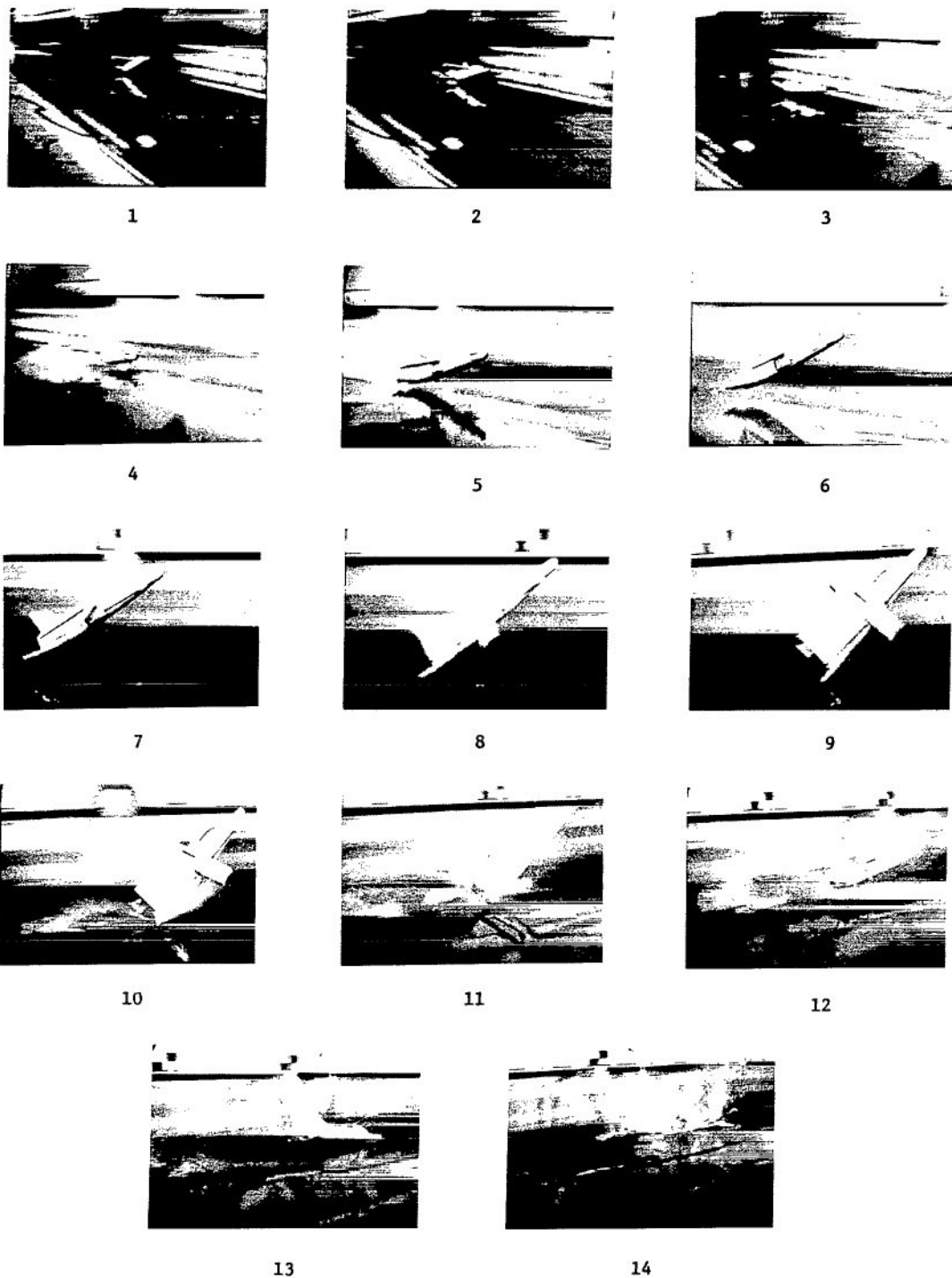
L-72-2443

Figure 13.- Typical sequence photographs of configuration 2 landing in calm water with no hydroflap on trailing edge (bare configuration). Pitch attitude, 12°; horizontal velocity, 54.6 m/sec (179 ft/sec); time between frames, 0.3 sec. All values are full scale.
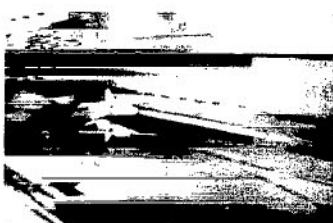
L-72-2444

Figure 14.- Typical sequence photographs of configuration 2 landing in calm water with 51 cm (20 in.) square hydroflap on trailing edge. Pitch attitude, 16°; horizontal velocity, 50.9 m/sec (167 ft/sec); time between frames, 0.2. All values are full scale.
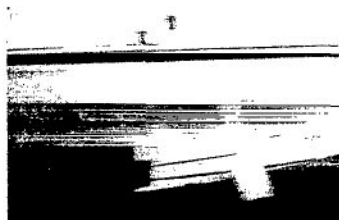
L-72-2445

(a) Pitch attitude, 8°; horizontal velocity, 57.3 m/sec (188 ft/sec);
time between frames, 0.3 sec.

Figure 15.- Typical sequence photographs of configuration 2 landing in calm water
with 25 cm (10 in.) × 50 cm (20 in.) hydroflap on trailing edge. All values are
full scale.

1

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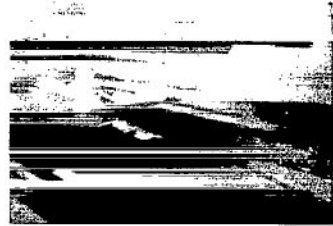
7

8
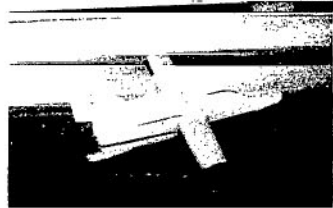
9

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11

12

L-72-2446

(b) Pitch attitude, 12°; horizontal velocity, 54.6 m/sec (179 ft/sec); time between frames, 0.3 sec.

Figure 15.- Continued.

L-72-2447

(c) Pitch attitude, 16°; horizontal velocity, 50.9 m/sec (167 ft/sec); time between frames, 0.3 sec.
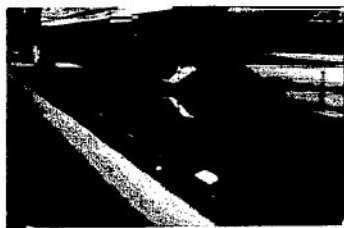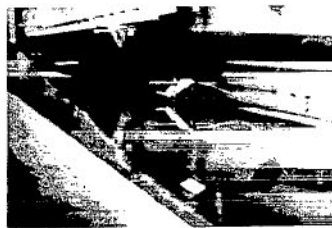
Figure 15.- Concluded.

Figure 16.- Typical sequence photographs of configuration 2 landing in waves 122 cm (48 in.) high and 30 m (100 ft) long. Pitch attitude, 12°; horizontal velocity, 55.2 m/sec (181 ft/sec); time between frames, 0.1 sec. All values are full scale.

L-72-2449

Figure 17.- Typical sequence photographs of configuration 2 with landing gear deployed landing in calm water. Pitch attitude, 12°; horizontal velocity, 54.6 m/sec (179 ft/sec); time between frames, 0.1 sec. All values are full scale.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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