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by Lloyd J. Fisher and John O. Windham

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SUMMARY

An investigation was made of a 1/10-scale dynamically similar model of a winged missile to study its behavior when landed in the bare-fuselage condition in water and when landed with a hydro-ski landing gear. The model was free-launched into calm water from the monorail equipment located in the Langley impacting structures facility. Various landing attitudes, speeds, and configurations (ski and fuselage) were investigated. The behavior of the model was determined from visual observations and motion-picture records of the landings. Data are presented in tables and sequence photographs.

Because of the very high landing speed, the relatively large hydrodynamic pitching moment, and the low aerodynamic damping in pitch of the vehicle, it was difficult to get consistent controlled landings. The bare-fuselage landing behavior was extremely violent. The vehicle decelerated rapidly in a nose-down (nose-in-water) attitude, skipped, and turned either to the left or right near the end of a landing run. The severity of the behavior was such that the fuselage bottom would probably sustain appreciable damage – thus, rapid flooding and short flotation time are likely. The length of the landing run for a vehicle with a damaged bottom would be about 500 feet (150 meters). The hydro-ski landings also resulted in violent or inconsistent behavior at all test conditions except when the skis were located well forward of the center of gravity and set at a high angle of incidence. Relatively large hydro-skis were also required. In this case, the vehicle trimmed down, skipped slightly several times, and then ended the landing in a fairly smooth planing run of about 2000 to 3000 feet (600 to 900 meters). The fuselage bottom would probably sustain less damage with hydro-skis than in the unprotected bare-fuselage condition, and the flotation time should be increased.

INTRODUCTION

A dynamic model investigation was made several years ago to determine the landing characteristics during water recovery of a subsonic guided missile. The results from these tests are of current interest for possible application to landing characteristics of lifting-body spacecraft. The landing speeds for the missile are relatively high (150 to

170 knots, 77 to 87 m/s), being in the range of those under consideration for horizontal-landing lifting-body spacecraft. The subject investigation, therefore, affords some appropriate information in a speed range where little or no information is presently available. (Refs. 1 to 7 present hydro-ski landing results obtained in a speed range lower than that of the present investigation.)

The landings were made in calm water with the model both in the bare-fuselage condition and with hydro-ski landing gears. Since the prototype of the vehicle used in this investigation was not originally designed as a water-landing vehicle, its fuselage would probably be damaged in a water landing. Certain innovations in the model test program, which used an appreciably overstrength vehicle, were considered. For example, crumpled bottoms were used to simulate damage in the bare-fuselage condition but no damage was simulated when hydro-skis were used because of the assumed protection to the fuselage afforded by the hydro-skis.

The units used for the physical quantities in this paper are given both in the U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems are given in reference 8 and those used in the present investigation are presented in appendix A.

DESCRIPTION OF MODEL

A three-view drawing of the winged missile is given in figure 1. The scale relationships used herein are listed in table I. A 1/10-scale dynamically similar model of the vehicle having a wing span of 2.1 feet (0.64 meter) and a fuselage length of 3.2 feet (0.98 meter) was used in the investigation. Photographs of the model are shown in figure 2. The model was constructed principally of fiber glass impregnated with plastic. Internal ballast was used to obtain scale weight and pitching moment of inertia. The fuselage was constructed so that part of the bottom could be removed and replaced with a crumpled section (fig. 3) to simulate a damaged bottom. Two types of hydro-ski landing-gear configurations were investigated: a twin-ski arrangement, and a single-ski arrangement with wing-tip skis. Suitable sizes and locations of the hydro-skis (see table II and figs. 4 to 6) were determined from the model tests. Spray strips (fig. 7) were used in some of the undamaged-fuselage landing tests and in all the hydro-ski landing tests to decrease the suction forces on the aft fuselage bottom. Pertinent dimensions of the configurations tested are listed in table II.

APPARATUS AND PROCEDURE

Test Methods and Equipment

The model was launched by catapulting it from the monorail equipment located in the Langley impacting structures facility (fig. 8) so that it was free to glide onto the water at a predetermined landing attitude and speed. The model was attached to the launching carriage at the desired attitude with the control surfaces set so that the model did not yaw or change attitude appreciably in flight.

Test Conditions

The test conditions are presented in the following sections. All values given refer to the full-scale missile.

Mass.- The design gross mass of 9400 pounds (4300 kg) was used in the investigation.

Moment of inertia.- The moment of inertia about the Y-axis was 19 800 slug-ft^2 (26 800 kg-m^2).

Location of the center of gravity.- The center of gravity was located 4.8 inches (12 cm) below the fuselage reference line at 8 percent of the mean aerodynamic chord.

Landing attitude.- Landings were made at two attitudes: 17° (near lift-curve stall) and 10° (intermediate value between the stall attitude and three-wheel condition). The attitude was measured between the fuselage reference line and the smooth water surface.

Ailavators.- Tests were made with the ailavators set at either 0° or 10°, depending on the landing attitude.

Landing speed.- The landing speeds used in the investigation (150 to 170 knots, 77 to 87 m/s) are listed in tables III and IV. They are somewhat lower than the speeds computed from power-off lift curves furnished by the manufacturer. The lower speeds were used so that adequate control of the model flight could be obtained during the free glide onto the water.

Landing gear.- Some landing tests simulated landing without a landing gear. Landing tests were also made with either a single- or twin-hydro-ski landing gear installed. Various hydro-ski sizes, shapes, locations, and angles of incidence were investigated in preliminary tests made to select suitable skis. Those listed in table II and figures 4 to 6 are the ones for which results are presented.

Fuselage conditions.- The model was tested in the following fuselage conditions:

(a) Undamaged
(b) Crumpled bottom installed

} Bare

(c) Undamaged with single ski and wing-tip skis installed

(d) Undamaged with twin skis installed

Data Acquisition

The results of the investigation were obtained by visual observation and from motion-picture records of the model landings.

RESULTS AND DISCUSSION

A summary of the results of the investigation is presented in tables III and IV. The notations in the tables are defined as follows:

Nosed in	The model decelerated rapidly in a nose-down (nose-in-water) attitude.
Porpoised	The model undulated about the lateral axis with some part of the model always in contact with the water.
Ran smoothly	The model made no apparent oscillations about any axis and gradually settled into the water as the forward speed decreased.
Skipped	The model cleared or rebounded from the water.
Trimmed down	The model made a negative rotation about the lateral axis after contact with the water.
Turned	The model made a rotation about the vertical axis.

Sequence photographs of a typical landing are shown in figure 9 for the model with the crumpled bottom installed. Sequence photographs of a typical hydro-ski landing are shown in figure 10.

Motion-picture film supplement L-945 showing landing tests of the 1/10-scale model of the missile landing on water has been prepared and is available on loan. A request card form and a description of the film are included at the back of this paper.

Bare-Fuselage Landings

Undamaged.- In landings at the 17° and 10° attitudes, the model in the undamaged condition skipped violently, then made some smaller skips followed generally by a turn either to the left or right as the speed decreased, and a wing entered the water. The landing runs were about 700 feet (200 meters) long. (See table III.) The length of the runs was increased considerably by the addition of the spray strips (fig. 7) along the rear part of the fuselage bottom, which reduced the suction forces on the aft fuselage bottom. Even though the runs were longer, about 900 feet (270 meters), the behavior was similar to the runs without spray strips.

Damaged.- In landings with the crumpled bottom (fig. 3) installed, the model nosed in as it decelerated rapidly, skipped, and then turned either to the left or right near the end of the run of about 500 feet (150 meters). (See table III and fig. 9.) The damaged model behavior, though very severe, was less violent than that of the undamaged model.

It is considered that the crumpled-bottom condition closely approximates the damage expected in a full-scale bare-fuselage landing. Consequently, the behavior of the model should be the same as the full-scale vehicle. However, in an actual landing, holes would occur in the fuselage bottom, and rapid flooding and a short flotation time are to be expected.

Hydro-Ski Landings

The undamaged model behavior was improved considerably with the addition of a hydro-ski landing gear. In the preliminary tests, it was found that a low ski incidence angle (about 2°) and a location near the center of gravity usually resulted in long, fairly smooth runs; however, some violent, abrupt dives which terminated the run did occur. To correct this erratic behavior, the ski was moved well forward of the center of gravity and the ski incidence angle was increased to 10°. This resulted in shorter runs with the model planing partly on the skis and partly on the rearward end of the fuselage and the diving tendency being eliminated. (See table IV and fig. 10.) Since the hydro-skis should afford appreciable protection to the fuselage bottom, the fuselage bottom would probably sustain less damage than in a bare-fuselage landing and the flotation time should be increased.

The subject missile has no horizontal tail and consequently has low aerodynamic damping characteristics. Therefore, relatively large hydro-skis were required to provide sufficient stability. It has been observed in investigations of the application of hydro-ski landing gears to various airplanes that those airplanes with low aerodynamic damping in pitch have worse hydrodynamic stability characteristics than those with high aerodynamic damping. When low aerodynamic damping in pitch is combined with a relatively large hydrodynamic pitching moment, as in the present vehicle, an increased emphasis is placed on the hydrodynamic components to provide stability, as exemplified here by the size of the skis, their forward location, and their high angle of incidence.

Single ski.- In the single-ski landing tests, the model tended to veer off course; therefore, small wing-tip skis were added to remedy this trouble. The model usually trimmed down when it first contacted the water, skipped slightly, porpoised and then ended the landing in a fairly smooth planing run. Runs were about 2400 to 3800 feet (730 to 1160 meters) long, depending on landing speed and attitude. Indications were that the wing-tip skis would be needed if a single ski were used; however, automatic controls or adequate pilot technique could make the wing-tip skis unnecessary.

Twin skis.- In the twin-ski landing tests, the model usually trimmed down when it first contacted the water, skipped slightly several times, and then ended the landing in a fairly smooth planing run of about 2000 to 3000 feet (600 to 900 meters), depending on landing speed and attitude. Because of its better inherent lateral stability, the twin-ski configuration has some advantage over a single-ski configuration even though the overall behaviors were about the same.

Landing Speed

The model when landed at speeds computed from the lift curves furnished by the manufacturer (154 to 192 knots, 78 to 98 m/s) had excess lift, and satisfactory landing approaches could not be made. Preliminary tests showed that spoilers on the wing were not fully satisfactory in correcting the behavior; therefore, somewhat lower speeds (150 to 170 knots, 77 to 87 m/s) were used in this investigation. Landing at the desired attitudes could be accomplished at the lower speeds to permit a study of the effect of landing attitude. The variation in landing speed could be considered no more than that to be expected in full-scale operation caused by variation in head wind.

When undesirable motions occurred, the high landing speeds of the missile apparently contributed some to the violence of the motions but it was difficult to differentiate between speed effects and effects due to low aerodynamic damping in pitch or the high pitching moment of inertia.

CONCLUDING REMARKS

The results of an investigation of the bare-fuselage and the hydro-ski landing tests of a 1/10-scale dynamically similar model of a winged missile indicate that because of the very high landing speed, the relatively large hydrodynamic pitching moment, and the low aerodynamic damping in pitch of the vehicle, it was difficult to get consistent controlled landings. The bare-fuselage landing behavior was extremely violent. The vehicle decelerated rapidly in a nose-down (nose-in-water) attitude, skipped, and turned either to the left or right near the end of a landing run. The severity of the behavior was such that the fuselage bottom would probably sustain appreciable damage – thus, rapid flooding and short flotation times are likely. The length of the landing run for a vehicle with a damaged bottom would be about 500 feet (150 meters). The hydro-ski landings also resulted in violent and inconsistent behavior at all test conditions except when the skis were located well forward of the center of gravity and set at a high angle of incidence. Relatively large hydro-skis were required. Because of its better inherent lateral stability, a twin-hydro-ski landing gear has some advantage over a single-ski configuration. The vehicle would trim down, skip slightly several times, and then end the landing in a fairly smooth planing run of about 2000 to 3000 feet (600 to 900 meters). The fuselage bottom would probably sustain less damage with hydro-skis than in the bare-fuselage condition and the flotation time should be increased.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., December 9, 1966,
124-08-04-15-23.

APPENDIX A

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960. (See ref. 8.) Factors required for converting the U.S. Customary Units 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	ft^2	0.0929	$meters^2$ (m^2)
Force	lbf	4.4482	newtons (N)
Mass.	lbm	0.4536	kilograms (kg)
Moment of inertia . . .	slug-ft^2	1.3558	kilogram-$meters^2$ (kg-m^2)
Velocity	knots	0.5144	meters/second (m/s)

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

Prefixes to indicate multiples of units are as follows:

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

REFERENCES

1. Thompson, William C.: Rough-Water Ditching Investigation of a Model of a Jet Transport With the Landing Gear Extended and With Various Ditching Aids. NASA TN D-101, 1959.
2. Thompson, William C.: Preliminary Investigation of Land-Water Operation With a 1/10-Scale Model of a Jet Airplane Equipped With Hydro-Skis. NACA RM L58A22, 1958.
3. Hoffman, Edward L.; and Fisher, Lloyd J.: Model Investigation of the Effect of Mounting Hydro-Skis on Shock Absorbers. NACA RM L54L02, 1955.
4. Wadlin, Kenneth L.: Considerations Affecting Hydro-Ski Airplane Design. NACA RM L53I28b, 1953.
5. Fisher, Lloyd J.: Model Ditching Investigation of Three Airplanes Equipped With Hydro-Skis (Revised). NACA RM L53G24a, 1953.
6. Ramsen, John A.: The Effect of Rear Chine Strips on the Take-Off Characteristics of a High-Speed Airplane Fitted With NACA Hydro-Skis. NACA RM L9B10a, 1949.
7. Dawson, John R.; and Wadlin, Kenneth L.: Preliminary Tank Tests of NACA Hydro-Skis for High-Speed Airplanes. NACA RM L7I04, 1947.
8. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors. NASA SP-7012, 1964.

TABLE I.- SCALE RELATIONSHIPS

[λ = Scale of model]

Quantity	Full scale	Scale factor	Model
Length	l	λ	λl
Area	A	λ^2	$\lambda^2 A$
Force	F	λ^3	$\lambda^3 F$
Mass	M	λ^3	$\lambda^3 M$
Moment of inertia . . .	I	λ^5	$\lambda^5 I$
Velocity	V	$\sqrt{\lambda}$	$\sqrt{\lambda} V$

TABLE II.- PERTINENT DIMENSIONS OF THE MISSILE AND HYDRO-SKI LANDING GEAR

	Full-scale vehicle		1/10-scale model	
General:				
Mass (fuel expended, single tail)	9400 lbm	4300 kg	9.4 lbm	4.3 kg
Center-of-gravity location, percent M.A.C.	8	8	8	8
Pitching moment of inertia	19 800 slug-ft^2	26 800 kg-m^2	0.198 slug-ft^2	0.27 kg-m^2
Overall length	33.83 ft	10.31 m	3.38 ft	1.03 m
Wing:				
Span	21 ft	6.4 m	2.1 ft	0.64 m
Area	150 ft^2	13.9 m^2	1.5 ft^2	0.14 m^2
Aspect ratio	2.94	2.94	2.94	2.94
Dihedral	0°	0°	0°	0°
Incidence	0°	0°	0°	0°
Sweepback at 25 percent chord	40°	40°	40°	40°
Taper ratio	0.8	0.8	0.8	0.8
NACA airfoil section – perpendicular to 25-percent-chord line	64A009.5	64A009.5	64A009.5	64A009.5
Fuselage:				
Frontal area	17.4 ft^2	1.62 m^2	0.17 ft^2	0.016 m^2
Length	32.2 ft	9.81 m	3.2 ft	0.98 m
Horizontal tail	None	None	None	None
Vertical tail:				
Area (total)	27 ft^2	2.5 m^2	0.27 ft^2	0.025 m^2
Aspect ratio	3.2	3.2	3.2	3.2
Sweepback at 25 percent chord	40°	40°	40°	40°
NACA airfoil section – perpendicular to 25-percent-chord line	64A009.5	64A009.5	64A009.5	64A009.5
Control surfaces:				
Ailavator movement	±31.5°	±31.5°	±31.5°	±31.5°
Area of each ailavator	8.2 ft^2	0.76 m^2	0.082 ft^2	0.0076 m^2
Rudder movement	±18.5°	±18.5°	±18.5°	±18.5°
Area of rudder	2.2 ft^2	0.20 m^2	0.022 ft^2	0.002 m^2
Single hydro-ski:				
Length	6.6 ft	2.0 m	0.66 ft	0.2 m
Width	1.7 ft	0.52 m	0.17 ft	0.05 m
Length-beam ratio	4	4	4	4
Area	8.3 ft^2	0.77 m^2	0.083 ft^2	0.0077 m^2
Incidence angle	10°	10°	10°	10°
Ski loading (wing-tip skis excluded)	1130 lbf/ft^2	54.1 kN/m^2	113 lbf/ft^2	5.41 kN/m^2
Location (T.E. forward of c.g.)	2.5 ft	0.76 m	0.25 ft	0.08 m
Location (T.E. below fuselage reference line)	5.7 ft	1.7 m	0.57 ft	0.17 m
Wing-tip skis:				
Length	1.25 ft	0.38 m	0.125 ft	0.038 m
Width	0.62 ft	0.19 m	0.062 ft	0.019 m
Length-beam ratio	2	2	2	2
Area	0.84 ft^2	0.078 m^2	0.0084 ft^2	0.00078 m^2
Incidence angle	18°	18°	18°	18°
Location (T.E. aft of c.g.)	5.25 ft	1.60 m	0.525 ft	0.16 m
Location (T.E. below fuselage reference line)	4.8 ft	1.5 m	0.48 ft	0.15 m
Twin hydro-skis:				
Length	5.0 ft	1.5 m	0.5 ft	0.15 m
Width	1.25 ft	0.38 m	0.125 ft	0.038 m
Length-beam ratio	4	4	4	4
Area of one ski	4.7 ft^2	0.44 m^2	0.047 ft^2	0.004 m^2
Incidence angle	10°	10°	10°	10°
Ski loading	1000 lbf/ft^2	47.9 kN/m^2	100 lbf/ft	4.79 kN/m^2
Location (T.E. forward of c.g.)	2.1 ft	0.64 m	0.21 ft	0.06 m
Location (T.E. below fuselage reference line)	5.7 ft	1.7 m	0.57 ft	0.17 m

TABLE III.- SUMMARY OF RESULTS OF BARE-FUSELAGE LANDING TESTS

IN CALM WATER OF A 1/10-SCALE MODEL OF A WINGED MISSILE

[All values are full-scale]

Landing attitude, deg	Ailavator setting, deg	Landing speed		Length of run		Comments
		knots	m/s	ft	m	
Undamaged condition						
17	10	150	77	*650	200	Skipped violently, then made somewhat smaller skips, turned either left or right near end of run
		150	77	800	245	
		150	77	850	260	
10	0	160	82	*710	215	Skipped violently, then made somewhat smaller skips, turned either left or right near end of run
		160	82	950	290	
		160	82	940	285	
Crumpled bottom installed						
17	10	150	77	*500	150	Nosed in as it decelerated rapidly, skipped, turned either left or right near end of run
		150	77	*510	155	
		150	77	*490	150	
10	0	160	82	*520	160	Nosed in as it decelerated rapidly, skipped, turned either left or right near end of run
		160	82	*510	155	
		160	82	*490	150	

*Without spray strips.

TABLE IV.- SUMMARY OF HYDRO-SKI LANDING TESTS IN CALM WATER

OF A 1/10-SCALE MODEL OF A WINGED MISSILE

[All values are full-scale]

Landing attitude, deg	Ailavator setting, deg	Landing speed		Length of run		Comments
		knots	m/s	ft	m	
Single hydro-ski with wing-tip skis						
17	10	150	77	2450	750	Trimmed down, skipped slightly, porpoised, then made a fairly smooth planing run
		150	77	2370	720	
		150	77	2450	750	
10	0	170	87	3800	1160	Trimmed down, skipped several times, porpoised slightly, then made a fairly smooth planing run
		170	87	3650	1110	
		170	87	3410	1040	
Twin hydro-skis						
17	10	150	77	1900	580	Trimmed down, skipped slightly several times, then made a fairly smooth planing run
		150	77	2000	610	
		150	77	1900	580	
10	0	170	87	2900	880	Trimmed down, skipped, porpoised slightly, then made a fairly smooth planing run
		170	87	2900	880	
		170	87	2850	870	

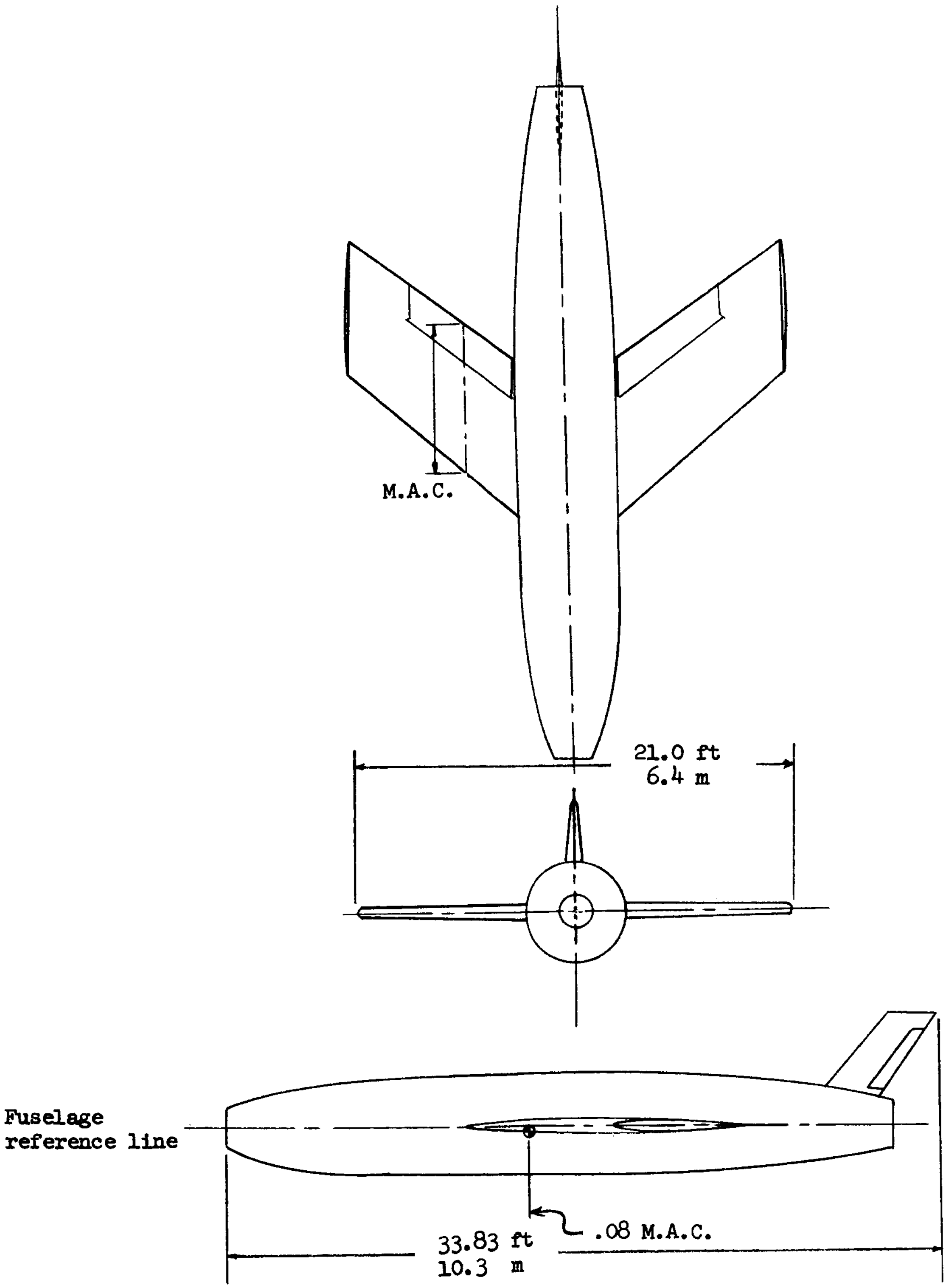
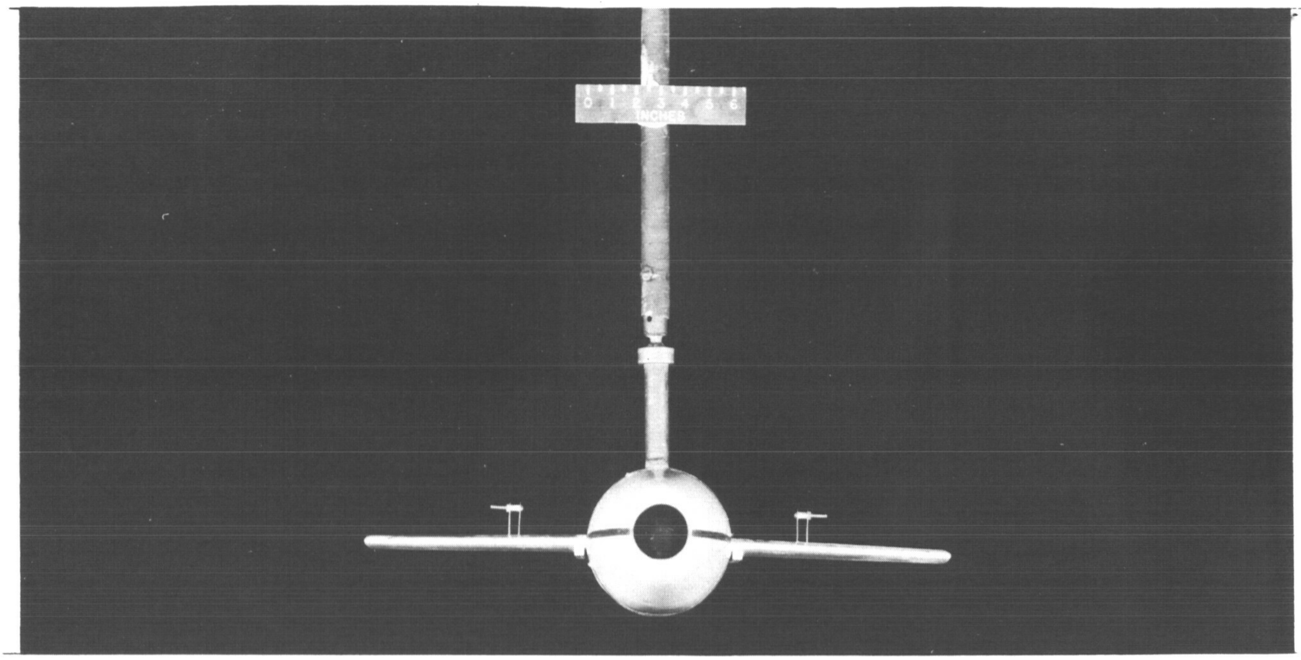
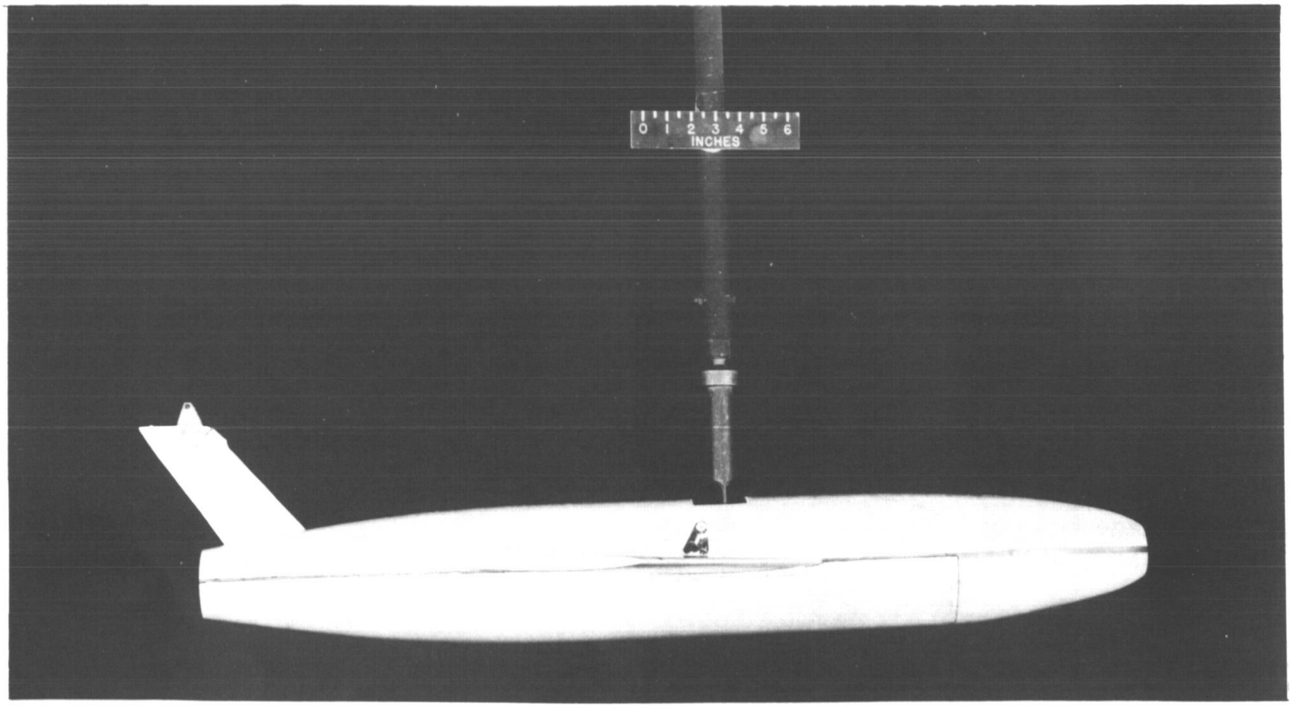


Figure 1.- Three-view drawing of a winged missile. (Dimensions are full-scale.)

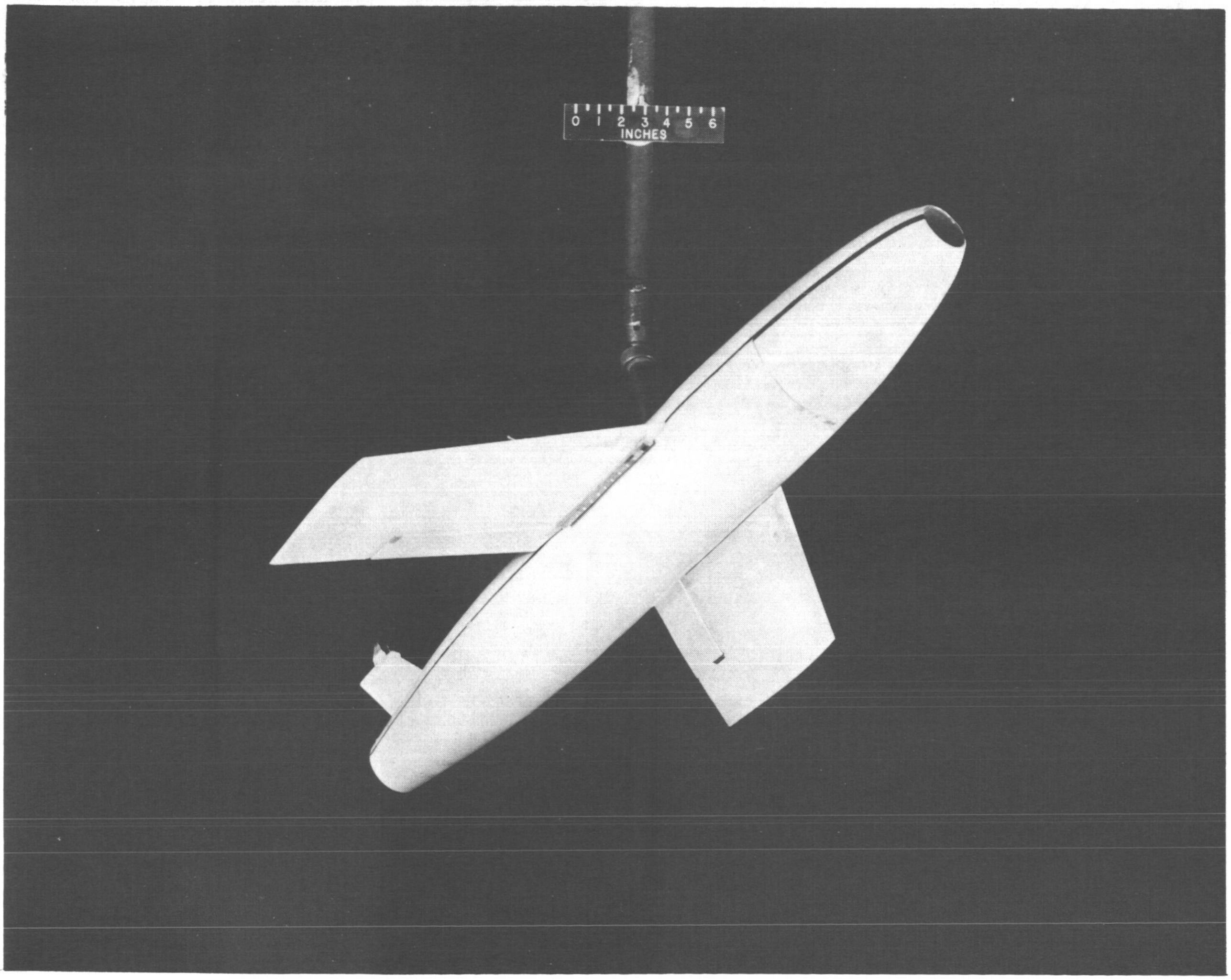


(a) Front view. L-88642



(b) Side view. L-88640

Figure 2.- 1/10-scale model of a winged missile.



(c) Three-quarter bottom view. L-88641

Figure 2.- Concluded.

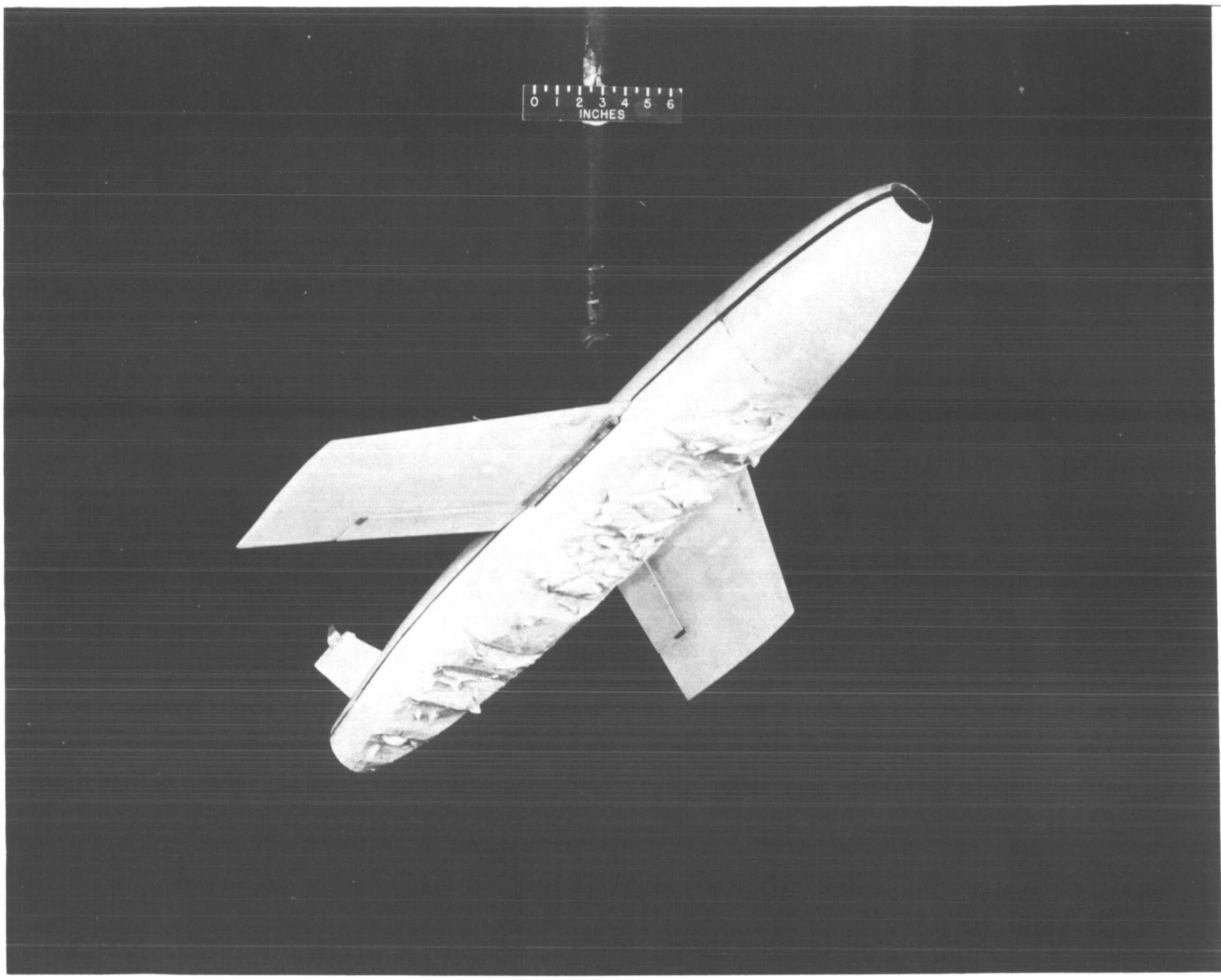
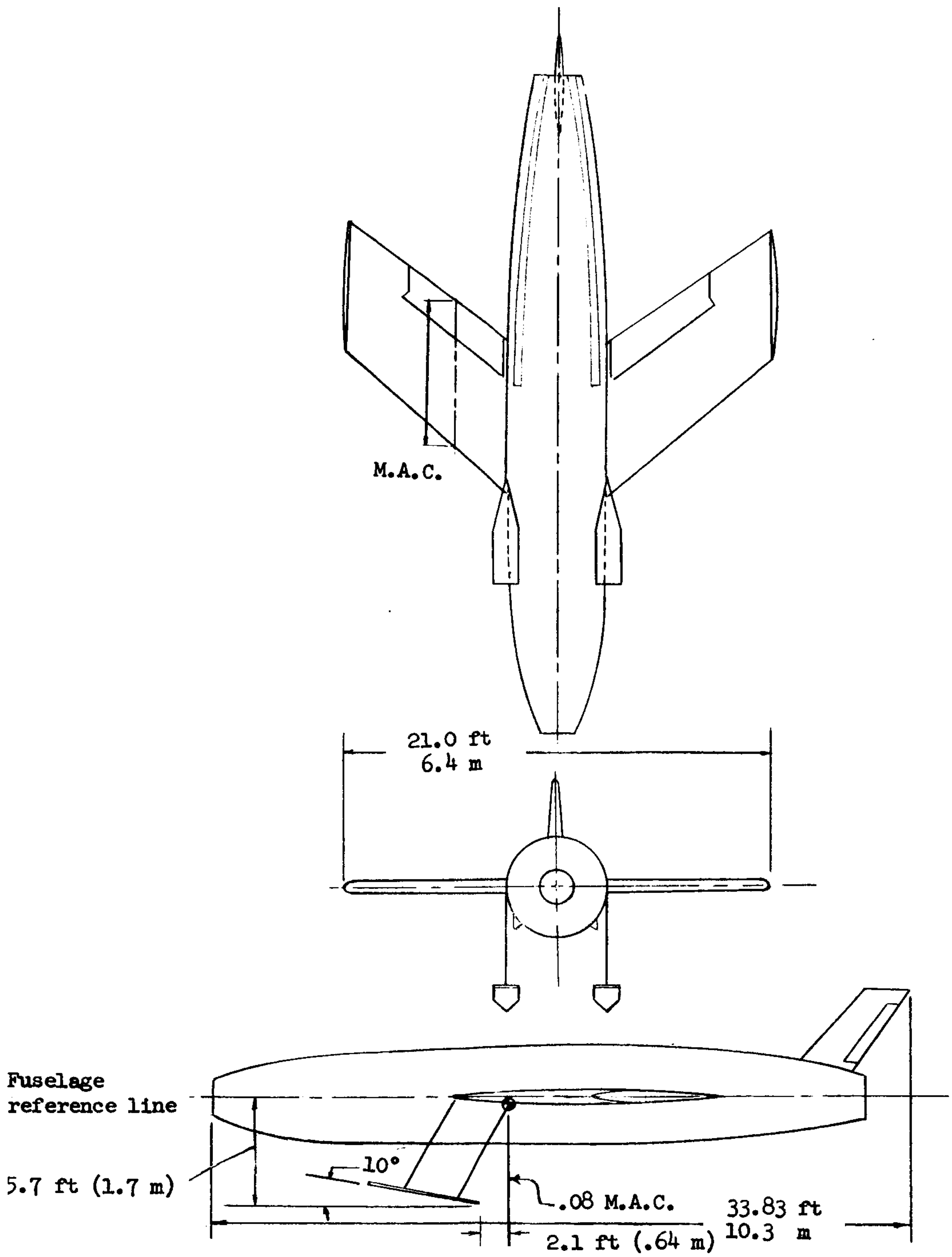
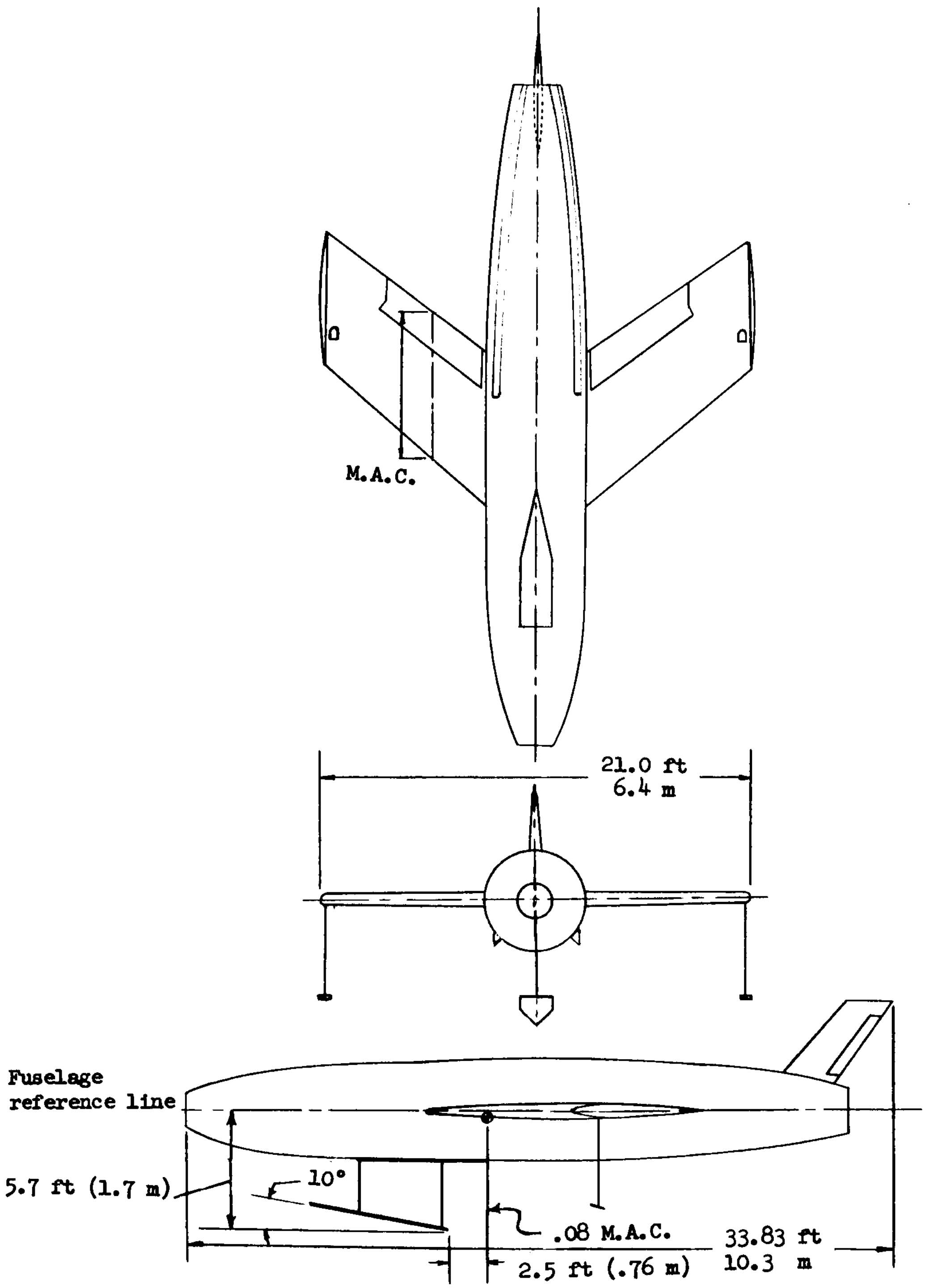


Figure 3.- 1/10-scale model with crumpled bottom installed. L-88637



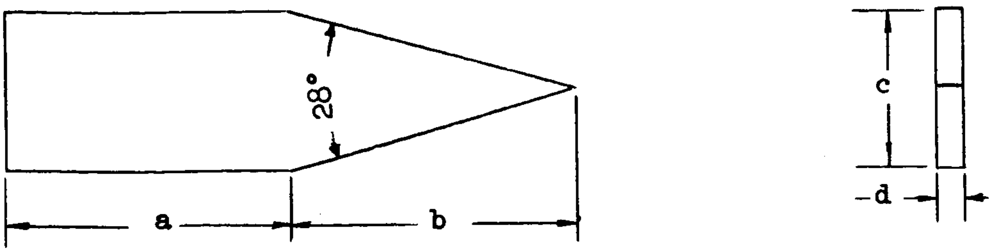
(a) Twin skis.

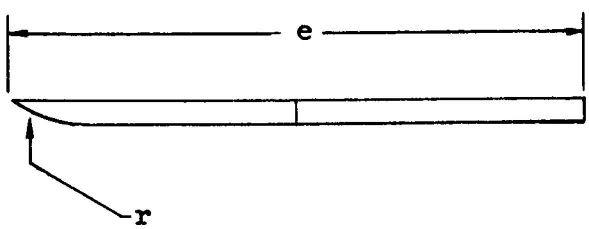
Figure 4.- Three-view drawing of a winged missile with hydro-ski landing gear. (Dimensions are full-scale.)



(b) Single ski with wing-tip skis.

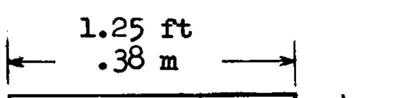
Figure 4.- Concluded.

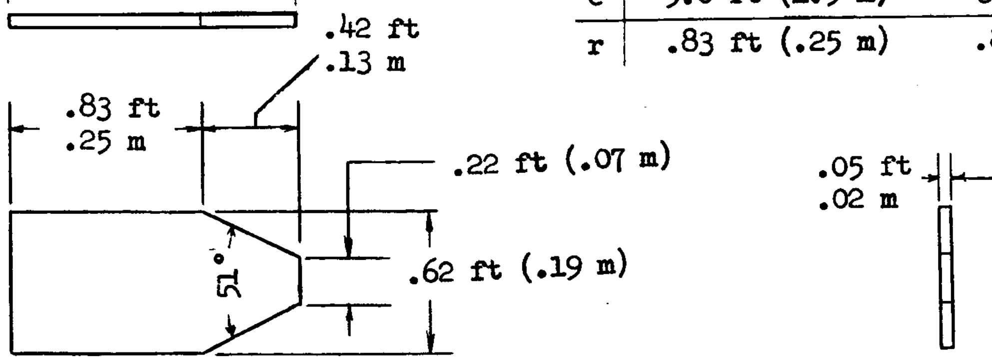




MAIN SKI

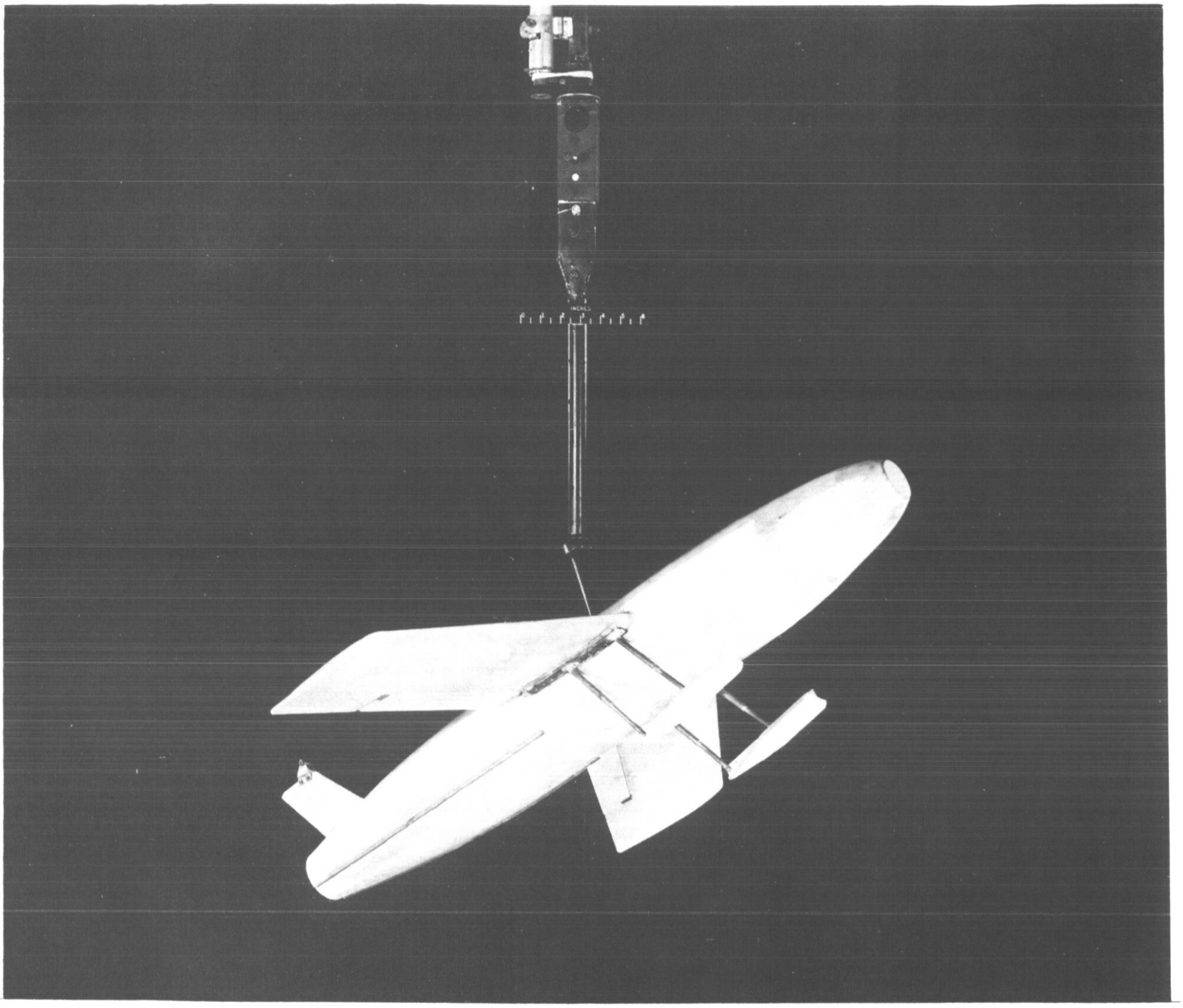
	Twin skis	Single ski
a	2.5 ft (.76 m)	3.3 ft (1.0 m)
b	2.5 ft (.76 m)	3.3 ft (1.0 m)
c	1.3 ft (.40 m)	1.7 ft (.52 m)
d	.21 ft (.06 m)	.21 ft (.06 m)
e	5.0 ft (1.5 m)	6.6 ft (2.0 m)
r	.83 ft (.25 m)	.83 ft (.25 m)





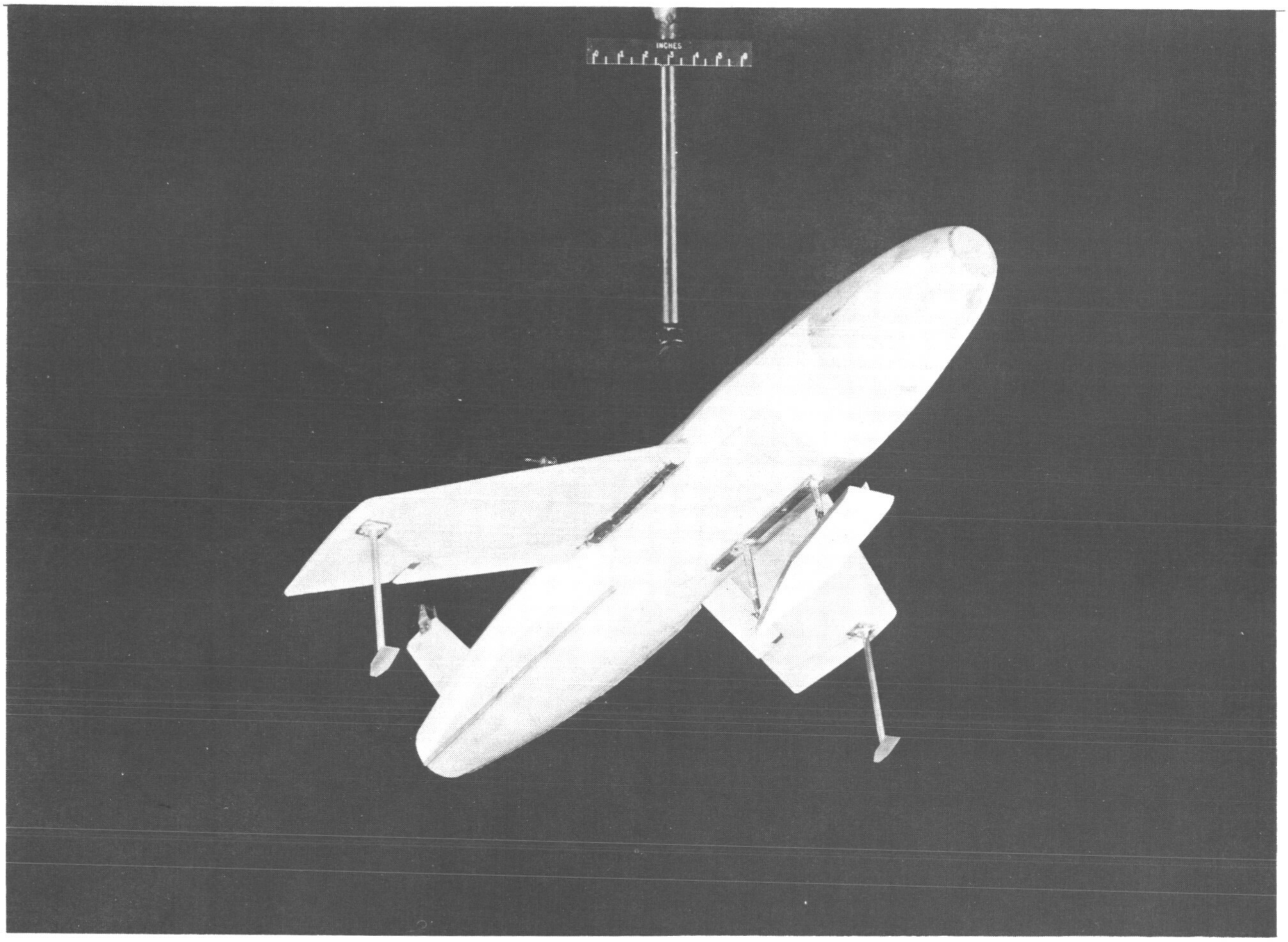
WING–TIP SKI

Figure 5.- Details of hydro-skis and wing-tip skis. (Dimensions are full-scale.)



(a) Twin skis. L-95254

Figure 6.- 1/10-scale model with hydro-ski landing gear.



(b) Single ski with wing-tip skis. L-94892

Figure 6.- Concluded.

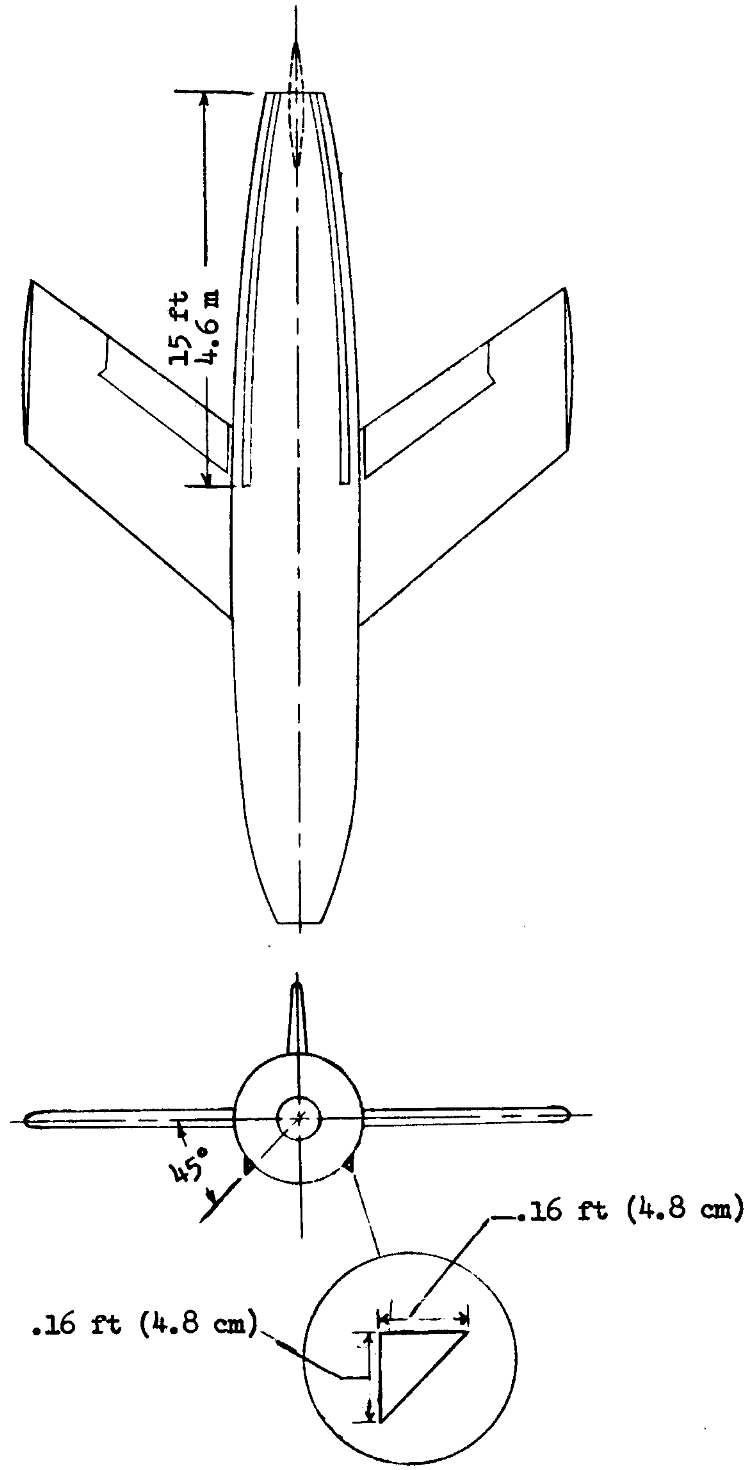


Figure 7.- Details of spray strips used in model tests. (Dimensions are full-scale.)

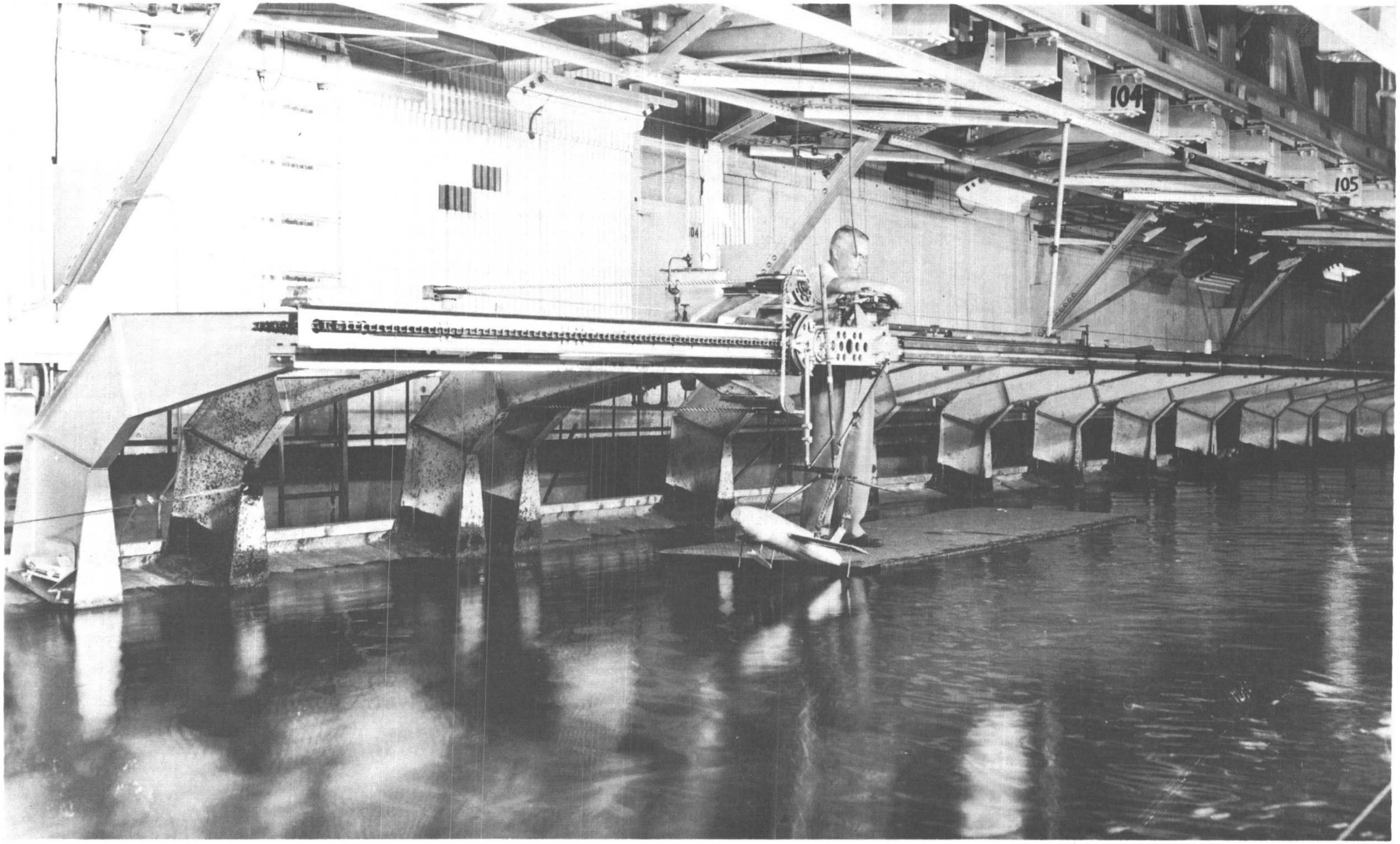
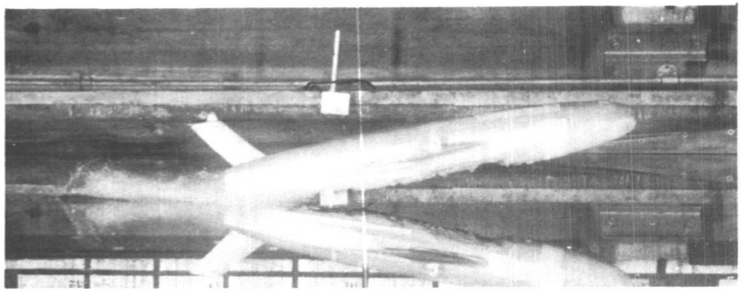
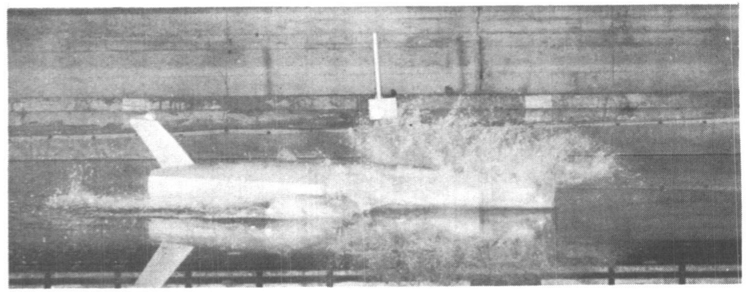


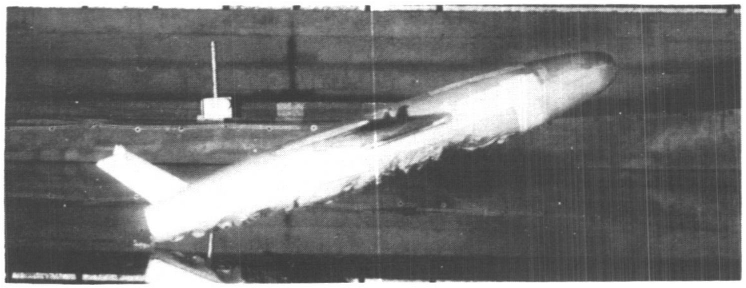
Figure 8.- Photograph of monorail with model attached to launching carriage. L-94891



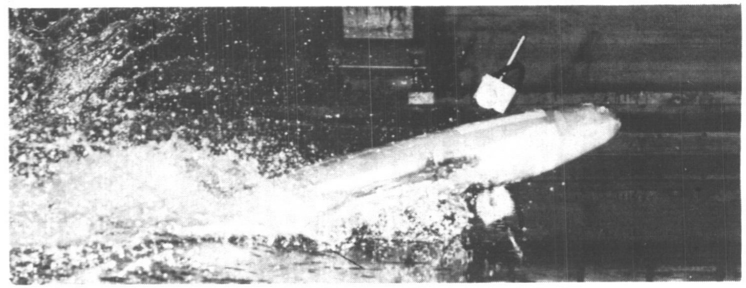
Near contact



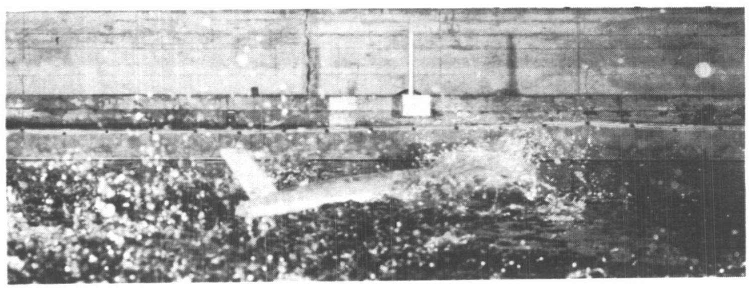
100 ft (30 m)



240 ft (70 m)



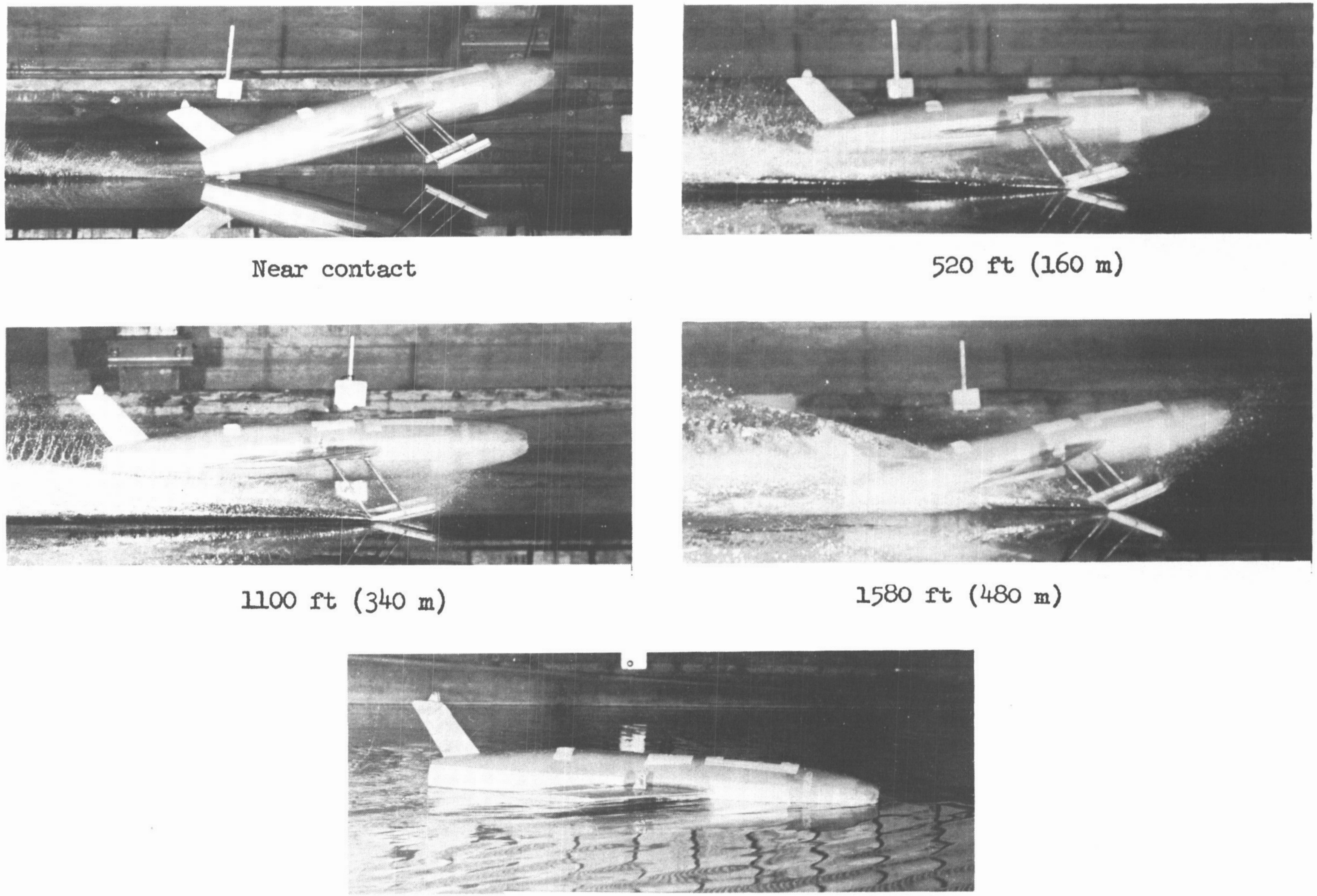
370 ft (110 m)



490 ft (150 m)

L-67-919

Figure 9.- Sequence photographs of model landing at the 17° landing attitude with ailavators up 10° and at a landing speed of 150 knots (77 m/s). Crumpled bottom is installed. Distances after contact are indicated and all values are full-scale.



Near contact

520 ft (160 m)

1100 ft (340 m)

1580 ft (480 m)

1920 ft (590 m)

L-67-920

Figure 10.- Sequence photographs of model landing at the 17° landing attitude with ailavators up 10° and landing speed of 150 knots (77 m/s). Undamaged fuselage condition with twin-hydro-ski landing gear installed. Distances after contact are indicated and all values are full-scale.

A motion-picture film supplement L-945 is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 6 min, black and white, silent) shows free-body dynamic model landing tests made with a 1/10-scale model of a missile landing in calm water.

Requests for the film should be addressed to:

Chief, Photographic Division
NASA Langley Research Center
Langley Station
Hampton, Va. 23365

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NASA Langley Research Center
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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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