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DITCHING INVESTIGATION OF A 1/20-SCALE MODEL OF THE SPACE SHUTTLE ORBITER

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1975

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-2593		
4. Title and Subtitle Ditching Investigation of a 1/20-Scale Model of the Space Shuttle Orbiter		5. Report Date October 1975
		6. Performing Organization Code
7. Author(s) William L. Thomas		8. Performing Organization Report No.
		10. Work Unit No. 986-15-10-05
9. Performing Organization Name and Address Grumman Aerospace Corporation Bethpage, NY 11714		11. Contract or Grant No. NAS1-10635-20
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes Technical Film Supplement L-1176 is available on request. Final report.		

16. Abstract

An investigation was made to determine the ditching characteristics of the space shuttle orbiter. Tests were made with a 1/20-scale model in order to determine behavior patterns and accelerations imparted to the ditching vehicle. Ditchings were made with different configurations of weight and gear position. Also the effects of different water surface conditions were investigated.

The test results indicated that the favorable conditions for ditching usually involve a landing attitude of 12°. Smooth ditchings were always associated with the landing-gear retracted and never with the landing-gear extended. Higher landing mass, generally, resulted in higher acceleration values in both the longitudinal and normal directions. Surface waves tend to increase the pitch accelerations but at the same time tend to reduce the accelerations in the longitudinal and normal directions.

17. Key Words (Suggested by Author(s)) (STAR category underlined)	18. Distribution Statement
Ditching investigation Space Shuttle Orbiter	Unclassified - Unlimited Subject Category 16

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	47	$3.75

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SUMMARY

An investigation was made to determine the ditching characteristics of the space shuttle orbiter. Tests were made with a 1/20-scale model in order to determine behavior patterns and accelerations imparted to the ditching vehicle. Ditchings were made with different configurations of weight and gear position. Also, the effects of different water surface conditions were investigated.

The tests results indicated that the favorable conditions for ditching usually involve a landing attitude of 12°. Smooth ditchings were always associated with the landing-gear retracted and never with the landing-gear extended. Higher landing mass, generally, resulted in higher acceleration values both the longitudinal and normal directions. Surface waves tend to increase the pitch accelerations but at the same time tend to reduce the accelerations in the longitudinal and normal directions.

INTRODUCTION

Ditching investigations have been made by NASA for many different airplane designs. A compilation of data and a summary of the results of many of these studies are presented in reference 1. The most recent NASA ditching tests are reported in reference 2.

This report presents results of ditchings made in calm water and in rough water (sea states 2 and 4) by using a 1/20-scale model of the space shuttle orbiter. The model was tested at various landing attitudes, landing speeds and weights, and landing-gear positions. Impact accelerations were obtained and the dynamic behavior was recorded by motion-picture photography. The investigation was conducted in the Langley Impacting Structures Facility.

The 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 (Reference 3). Measurements and Calculations were made in U.S. Customary Units. Factors relating these two systems of units are given in Appendix A.

DESCRIPTION OF MODEL AND INSTRUMENTATION

A 1/20-scale model of the space shuttle orbiter (Figure 1) was used for the ditching investigation. Table I gives the scale relationships used to convert the model data to full-scale values and all values given herein have been converted to full scale. The model was made principally of fiber glass and balsa. Lead weights were used to alter mass configuration.

The model was constructed so that the lower fuselage surface of the model could be removed as a unit and replaced with a section that simulates bottom damage that is expected to occur in a ditching of the full-scale vehicle. This insert was made of balsa wood and contoured to simulate crushed thermal protection and fuselage bottom. See photograph, Figure 2. Pertinent physical properties of the model and full scale orbiter are given in Table II.

The landing gear was installed on the model with steel struts which had a necked-down scale-strength section to cause failure due to bending moment. The model failure bending moment was scaled to be equivalent to a full-scale drag-brace failure load in tension of 1.585×10^6 newtons (356,270 lbf) for the main gear and $.927 \times 10^6$ newtons (208,460 lbf) for the nose gear. A sketch showing the landing gear installation on the model is given in Figure 3.

The elevons were installed so that they could be held in position at approximately scale strength. In order to accomplish this installation, a calibrated string was fastened around each elevon fitting and a matching wing fitting so that scaled elevon ultimate hinge moments would cause the connection to break. Full-scale ultimate hinge moments of $.165 \times 10^6$ newton-meters ($.1213 \times 10^6$ ft. lbs.) for the inboard elevons and $.051 \times 10^6$ newton-meters ($.0373 \times 10^6$ ft. lbs.) for the outboard elevons were used. A similar arrangement for the body-flap where the full-scale ultimate hinge moment is $.254 \times 10^6$ newton-meters ($.1875 \times 10^6$ ft. lbs.) was utilized. Pertinent failure loads under test conditions are given in Table III.

Normal and logitudinal accelerations were measured at the vehicle center-of-gravity (refer to Table II for location) with 2 piezoelectric accelerometers. The frequency response of these two accelerometers was flat from 2 Hz. to 5000 Hz with a maximum acceleration range of $\pm$ 100 g. Angular (pitch) accelerations were measured about the center-of-gravity with a matched pair of linear strain-gage accelerometers which exhibited a flat frequency response from D.C. to 250 Hz with a maximum acceleration range of $\pm$ 25 g. Acceleration output responses were recorded on magnetic tape. Time history plots of the recorded data were made using both an oscillograph and a Hewlett-Packard Analyzer (Model 5452B). All of the recorded data was analyzed initially unfiltered, however, a low pass filter (100-300 Hz) was utilized when necessary. The acceleration axis and the force directions are identified in Figure 4..

TEST CONDITIONS

Launch Conditions. - The ditching investigation was conducted by launching the model as a free body by means of a catapult. The catapult with the 1/20-scale model ready for launching is shown in Figure 5. The model left the launching carriage at scale speed and the predetermined landing attitude with the control surfaces set so that the attitude did not change appreciably during the brief free flight from catapult release to water contact. Prior to some test runs an upper wing surface spoiler was added in order to decrease the free flight period. The spoiler was positioned at F.S. 1250 and B.L. 250-370 with an angle to the wing surface of approximately 45°. For those test runs in which the spoiler was used see Table IV.

Landing Attitude. - Tests were made at an attitude of 16°, at an attitude of 12°, and at an attitude of 8°.

Landing Mass. - Tests were made with three mass configurations:

(1) 83.9×10^3 kg (185×10^3 lbm) - payload of 9×10^3 kg (20×10^3 lbm)

(2) 93×10^3 kg (205×10^3 lbm) - payload of 18×10^3 kg (40×10^3 lbm)

(3) 104.3×10^3 kg (230×10^3 lbm) - payload of 29.5×10^3 kg (65×10^3 lbm)

The minimum flight mass for the shuttle was not simulated due to mass limitations of the model.

Landing Speed. - Tests were made at various landing speeds from 53.5 m/sec (104 knots) to 104.4 m/sec (203 knots). The speed for each test run is shown in Table IV and was based on landing attitude and landing mass. The maximum velocity capability of the launch catapult was utilized in these tests.

Landing Gear. - Tests were made with landing gear retracted and with landing gear extended.

Body Flap Setting. - Except for one run, the tests were made with the body flap in the "up" position.

Elevon Angle Setting. - Elevon angle settings were positioned according to landing information supplied by NASA. In some instances the elevon position settings were changed to correct landing attitude or flight path (see Table IV).

Fuselage Bottom. - The balsa fuselage bottom insert (see Figure 2) which was supplied by NASA was used for all the test runs except those involving the lighter mass configuration. For these runs the bottom insert was removed.

Water Condition. - Ditching tests were made in both calm and rough water. Two rough water conditions were simulated:

(1) A sea state 4 with waves 2.1 meters (7 ft.) high and 55 meters (180 ft.) long, crest to crest.

(2) A sea state 2 with waves .6 meters (2 ft.) high and 7 meters (23 ft.) long, crest to crest.

All rough water ditchings were made into oncoming waves.

Sink Speeds. - Vertical sink speeds were varied by changing the launch to water contact height. Sink speeds from .2 m/sec (.7 ft/sec) to 2 m/sec (6.6 ft/sec) were made.

RESULTS AND DISCUSSION

A motion picture supplement (NASA film serial L-1176) is available on loan. The film (16 mm, 10 minutes, color, silent) shows comparative test landings of the 1/20-scale shuttle orbiter model.

Results for all test conditions are presented in summary form in Tables IV and V. Typical time-history acceleration curves for ditchings are presented for the following test runs:

Figure 7	Test Run 6
Figure 8	Test Run 12
Figure 9	Test Run 15
Figure 10	Test Run 17
Figure 11	Test Run 20
Figure 12	Test Run 25
Figure 13	Test Run 30
Figure 14	Test Run 34
Figure 15	Test Run 37
Figure 16	Test Run 40
Figure 17	Test Run 41
Figure 18	Test Run 45
Figure 19	Test Run 48

Effect of Damage

When damage was simulated by using a contoured fuselage bottom insert typical ditching behavior was a fairly smooth run. Generally, the aft end of the fuselage would contact the water first causing the model to trim down to a near-level attitude and fly for a short distance before recontacting the water. The inboard elevons were normally failed on any kind of ditching while the outboard elevons were generally failed only in rough water ditchings or in ditchings that were not considered smooth. All of the smooth ditchings were with the landing-gear retracted. The total landing run for a smooth landing was approximately 4 to 6 fuselage lengths. In order to simulate a possible extreme damage condition, the simulated damage botton was removed. This exposed a smooth floor midway the model fuselage. Half inch square spoilers were added to the floor and test run 27 was conducted, see Table IV and V. A dive resulted. Other test runs with the simulated damage bottom removed (runs 62-66) but without the spoilers resulted in nose deep runs. This is not the expected full-scale damage condition but was an attempt to bracket possible damage conditions. The expected conditions is that using the simulated damage bottom. As stated above a fairly smooth runout is expected but considerable fuselage tearing and leaking or flooding will occur. Flotation time will be dependent on the integrity of the wing surfaces. If the wing remains relatively damage free the vehicle will float similar to the model in the photograph of Figure 6.

Landing Gear Extended

The gear down test runs proved to be the least desirable for a smooth ditching. On all of the 4 gear down runs (Tables IV and V, runs 28, 29, 59, and 60) the model dived and stopped abruptly with the nose completely submerged. The total landing run distance for the gear down runs was approximately 2 to 4 fuselage lengths. The landing-gear struts were either severed or bent aft enough to be considered failed.

Effect of Sea State

The maximum acceleration values encountered in rough water (sea state 4) ditchings when compared to calm water ditchings can be summarized as follows:

(1) For the normal direction - except for 8° landing attitude, the accelerations were 25% lower. For the 8° landing attitude, the accelerations were about the same.

(2) For the longitudinal direction - the accelerations were about 40% lower

(3) For the pitch accelerations - the recorded values were twice as high.

For the sea state 2 ditchings the acceleration comparison with calm water ditchings could be summarized as follows:

(1) Except for the 8° landing attitude, the maximum accelerations were about 25% lower. For the 8° landing attitude, the acceleration were about 40% higher.

(2) For the longitudinal direction - the maximum accelerations were about 40% lower.

(3) For the pitch accelerations - the recorded values were about 70% higher.

Effect of Vertical (Sink) Speed

The maximum acceleration values encountered during the high sink speed test runs when compared to calm water low sink speed runs can be summarized as follows:

(1) The normal accelerations were higher by about 20%.

(2) There was no appreciable difference in the longitudinal accelerations.

(3) The pitch accelerations were about twice as high.

Landing Mass

Another factor in ditching behavior is the landing mass of the vehicle. A higher landing mass results in a high landing speed. This results in higher maximum acceleration values in the longitudinal direction. A plot of maximum longitudinal acceleration for different landing attitudes vs landing mass is shown in Figure 20. The trend shown in Figure 20 is as expected that the higher the mass the higher the longitudinal acceleration.

In the normal axis, the acceleration values generally increase as the landing mass is increased. However, for the 8° landing attitude the opposite trend is noted. A plot of maximum normal accelerations vs landing mass is shown in Figure 21.

Figure 22 is a plot of pitch accelerations vs landing mass. Pitch accelerations appear to be nearly independent of landing mass. Acceleration values for the 3 plots are extrapolated to a landing mass of 70,000 kg (154,000 lbm) which is the minimum landing configuration for the present tests.

A typical calm water ditching in the full payload condition should result in a maximum longitudinal acceleration of about 6 g and a maximum vertical acceleration of about 9 g. The maximum angular acceleration would be about 2 rad/sec^2.

Landing Attitude

The most favorable landing attitude investigated appears to be the 12° landing attitude. Both the 16° and the 12° landing attitudes exhibit similar behavior and acceleration values for both calm water and a small wave condition. The 16° landing attitude has lower acceleration values when the water surface waves are large.

General Remarks

The results of the ditching investigation of a 1/20-scale space shuttle orbiter model indicate that the most favorable condition for a calm water ditching of those tested is a 12° landing attitude with the landing gear retracted. This attitude also seems to be preferred when a slight wave condition exists. High sink speeds tend to increase the pitch accelerations which will be detrimental to a smooth ditching. Higher landing mass, generally, will produce higher acceleration values in both the normal and longitudinal directions. A typical calm water ditching in a heavy mass configuration will result in a maximum longitudinal acceleration of about 6 g.

and a normal acceleration of 9 g. The maximum angular acceleration should be about 2 rad/sec^2.

The recommended ditching procedure to follow based on the dynamic model investigation reported herein and on results shown in reference 1 is that the shuttle orbiter should be ditched in a medium nose up attitude of about 12° at as light a mass as possible and as slow a speed as is consistent with adequate aerodynamic control.

Summary of Results

The ditching tests of a 1/20-scale dynamic model of the space shuttle orbiter led to the following results:

(1) The most favorable landing attitude is 12° nose up for either calm water or the wave conditions tested. Wheels should be retracted.

(2) A maximum longitudinal acceleration of about 6 g, a maximum normal acceleration of about 9 g, and a maximum angular acceleration of about 2 rad/sec^2 will occur.

(3) A fairly smooth runout will occur.

(4) Considerable fuselage bottom damage is expected.

(5) Duration of Flotation is dependent on the integrity of the wing. If the wing remains relatively damage free, the vehicle will float for a reasonable length of time.

APPENDIX A

CONVERSION OF SI UNITS TO U.S. CUSTOMARY UNITS

Conversion factors for the units used herein are given in the following table:

Physical Quantity	SI Unit	Conversion Factor (*)	U.S. Customary Unit
Length	meters (m)	0.0254 0.3048	inches (in.) feet (ft.)
Mass	kilograms (kg)	0.454	pounds mass (lbm)
Force	newtons (N)	4.448	pounds force (lbf)
Moment	newton-meter	1.35582	pound-feet (lb-ft)
Moment of inertia	kilogram-meters^2 (kg-m^2)	1.35582	slug-feet^2 (slug-ft^2)
Velocity	meters/second (m/sec)	0.5144 0.3048	knots (kt) feet/second (ft/sec)

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

Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
kilo (k)	10^3

REFERENCES

1. Fisher, Lloyd J.; and Hoffman, Edward L.: Ditching Investigation of Dynamic Models and Effect of Design Parameters on Ditching Characteristics. NACA Rept. 1347, 1958. (Supersedes NACA TN 3946)

2. Thompson, William C.: Ditching Investigation of a 1/30 Scale Dynamic Model of a Heavy Jet Transport Airplane. NASA TM X-2445, 1972

3. Comm. on Metric Pract.: ASTM Metric Practice Guide. NBS Handbook 102, U.S. Dep. Com., March 10, 1967

TABLE I - SCALE RELATIONSHIPS
Froude Scaling
[λ=Scale of Model=1/20]

Quantity	Full-Scale Value	Scale Factor	Model Value
Length	L	λ	λL
Force	F	λ^3	$\lambda^3 F$
Moment	M	λ^4	$\lambda^4 M$
Moment of Inertia	I	λ^5	$\lambda^5 I$
Mass	m	λ^3	$\lambda^3 m$
Time	t	$\sqrt{\lambda}$	$\sqrt{\lambda} t$
Speed	V	$\sqrt{\lambda}$	$\sqrt{\lambda} V$
Linear Acceleration	a	1	a
Angular Acceleration	α	λ^{-1}	$\lambda^{-1}\alpha$

TABLE II - PERTINENT PHYSICAL PROPERTIES OF SHUTTLE ORBITER

Parameter	Full-Scale Orbiter		1/20-Scale Model	
Overall Length	37.2 meters	122.0 ft.	1.86 m	6.10 ft.
Wing Span	23.8 meters	78.0 ft.	1.19 m	3.90 ft.
Center-of-Gravity, X station/Z station ...	A 1109/374.8	-		
	B 1108.7/378.5	-		
Mass . . .	A 85,464 kg	188,247 lbm.	10.68 kg	23.53 lbm.
	B 103,200 kg	227,313 ltm.	12.90 kg	28.41 lbm.
Moments of Inertia =				
Yaw	A 8.214X10^{6}kgm^2	6.058X10^{6}slugft^2	2.567 kg-m^2	1.893 slug-ft^2
	B 9.126X10^{6}kgm^2	6.731X10^{6}slugft^2	2.851 kg-m^2	2.103 slug-ft^2
Pitch	A 7.952X10^{6}kgm^2	5.865X10^{6}slugft^2	2.485 kg-m^2	1.833 slug-ft^2
	B 8.887XD^{6}kgm^2	6.555X10^{6}slugft^2	2.777 kg-m^2	2.048 slug-ft^2
Roll	A 1.094X10^{6}kgm^2	0.807X10^{6}slugft^2	0.342 kg-m^2	0.252 slug-ft^2
	B 1.152X10^{6}kgm^2	0.850X10^{6}slugft^2	0.361 kg-m^2	0.266 slug-ft^2

A Orbiter with 32K payload

B Orbiter with 65K payload

TABLE III- PERTINENT FAILURE LOADS UNDER TEST CONDITIONS

Parameter	Full-Scale Orbiter		1/20 Scale Model	
Main-Landing Gear Failure Load in Tension*	1.585X10^6 newtons	356,270 lbs.	8.691 newton-m	6.41 ft. lbs.
Nose-Landing Gear Failure Load in Tension*	0.927X10^6 newton	208,460 lbs.	2.66 newton-m	1.96 ft. lbs.
Inboard-Elevon Failure Hinge Moment	0.165X10^6 newt-m	.1213X10^6 ft.lbs.	1.028 newton-m	.7581 ft. lbs.
Outboard-Elevon Failure Hinge Moment	0.051X10^6 newt-m	.0373X10^6 ft.lbs.	0.316 newton-m	.2331 ft. lbs.
Body-Flap Failure Hinge Moment	0.254X10^6 newt-m	.1875X10^6 ft.lbs.	1.589 newton-m	1.172 ft. lbs.

*The model landing gear (main and nose) had equivalent scaled failure <u>bending moments</u> acting on their respective struts.

TABLE IV - SUMMARY OF RESULTS OF SHUTTLE MODEL DITCHING INVESTIGATION

(ALL VALUES ARE FULL SCALE)

Run No.	Landing Attitude	Elevon Setting	Landing Mass Thousands		Landing Speed		Sink Speed		Maximum Impact Accelerations		
									Normal	Longitudinal	Angular
	DEG	DEG	kg	lbm.	knots	m/sec	m/sec	ft/sec	g - units	g - units	Rad/Sec^2
1	16	4	93	205	104	53.5	NR	NR	NR	NR	NR
2	16	4	93	205	120	61.7	NR	NR	NR	NR	NR
3	12	4	93	205	135	69.4	NR	NR	NR	4.1	NR
4	12	3 1/2	93	205	140	72.0	1.2	4.0	8.3	4.5	+1.8
5	12	3 1/2	93	205	146	75.1	1.7	5.6	19.4	5.6	+2.0
6*	12	3 1/2	93	205	152	78.2	.7	2.3	6.0	5.3	+1.8
7	12	3 1/2	93	205	149	76.7	.7	2.3	5.5	4.1	+1.8
8	12	3 1/2	93	205	151	77.7	NR	NR	NR	NR	NR
9	12	3 1/2	93	205	169	87.0	NR	NR	11.6	-7.9	+1.6
10	12	3 1/2	93	205	152	78.2	.7	2.3	6.9	4.3	+1.4
11*	8	7	93	205	167	85.9	.5	1.6	7.3	6.1	+2.0
12	8	7	93	205	170	87.5	.7	2.3	6.9	6.6	+2.3
13	8	7	93	205	175	90.0	NR	NR	9.1	5.6	+1.9
14	16	1	93	205	135	69.4	1.0	3.3	5.1	3.8	+2.4
15	16	1	93	205	135	69.4	1.0	3.3	7.6	5.0	+2.5
16	16	1	93	205	135	69.4	1.0	3.3	7.3	4.7	-2.1
17	16	9 1/2	104.3	230	151	77.7	.5	1.6	10.6	5.8	+1.5
18	16	9 1/2	104.3	230	154	79.2	.4	1.3	7.2	5.7	+1.7
19*	16	9 1/2	104.3	230	154	79.2	.4	1.3	12.0	5.8	-1.5
20	12	11	104.3	230	166	85.5	.4	1.3	11.8	6.0	-2.2
21	12	11	104.3	230	166	85.5	.4	1.3	13.3	6.6	-1.7

Run No.	Landing Attitude DEG	Elevon Setting DEG	Landing Mass Thousands kg	Landing Mass Thousands lbm.	Landing Speed knots	Landing Speed m/sec	Sink Speed m/sec	Sink Speed ft/sec	Maximum Impact Accelerations: Normal g - units	Maximum Impact Accelerations: Longitudinal g - units	Maximum Impact Accelerations: Angular Rad/Sec^2
22*	12	11	104.3	230	169	87.0	.4	1.3	6.4	6.0	+2.1
23	12	11	104.3	230	167	85.9	.2	.8	9.4	6.0	+2.1
24*	8	11 1/2	104.3	230	182	93.6	.3	1.0	4.9	7.4	+2.5
25	8	11 1/2	104.3	230	191	98.3	.3	1.0	7.9	7.5	+2.6
26	8	11 1/2	104.3	230	177	91.2	.3	1.0	4.9	6.6	+2.7
27	12	4	83.9	185	135	69.4	.4	1.3	4.1	4.0	+1.0
28*	12	11	104.3	230	163	83.8	.4	1.3	11.7	2.7	+2.0
29*	8	11	104.3	230	183	94.1	1.1	3.6	NR	8.7	+1.6
30	16	8 1/2	104.3	230	151	77.7	1.0	3.3	13.5	4.6	-1.5
31	16	8 1/2	104.3	230	151	77.7	1.2	4.0	14.0	4.9	-1.7
32*	16	8 1/2	104.3	230	151	77.7	1.3	4.3	12.1	4.9	-1.7
33	12	11	104.3	230	164	84.4	1.0	3.3	11.0	6.0	-2.1
34	12	12	104.3	230	169	87.0	1.4	4.6	13.5	6.8	+3.3
35*	12	14	104.3	230	164	84.4	1.0	3.3	5.4	5.8	+4.1
36	8	15	104.3	230	176	90.5	1.8	5.9	8.6	7.7	+2.7
37*	8	15	104.3	230	180	92.6	2.0	6.6	10.8	7.9	+3.9
38	8	15	104.3	230	180	92.6	NR	NR	NR	NR	NR
39	16	9 1/2	104.3	230	153	78.7	1.2	4.0	7.8	NR	+5.6
40	16	9 1/2	104.3	230	153	78.7	1.2	4.0	13.1	5.9	+5.6
41*	16	9 1/2	104.3	230	152	78.2	1.5	4.9	4.4	4.3	+2.6
42	16	9 1/2	104.3	230	153	78.7	1.5	4.9	6.8	4.1	-3.0

Run No.	Landing Attitude DEG	Elevon Setting DEG	Landing Mass Thousands		Landing Speed		Sink Speed		Maximum Impact Accelerations		
			kg	lbm.	knots	m/sec	m/sec	ft/sec	Normal g - units	Longitudinal g - units	Angular Rad/Sec^2
43	16	9 1/2	104.3	230	154	79.2	1.5	4.9	NR	NR	+6.0
44*	12	12	104.3	230	165	84.9	1.1	3.6	9.3	4.8	-5.4
45	12	12	104.3	230	166	85.5	1.3	4.3	10.2	4.0	-6.0
46	12	12	104.3	230	165	84.9	1.7	5.6	8.5	5.5	-5.8
47*	8	14	104.3	230	165	84.9	1.0	3.3	6.6	4.0	+3.9
48	8	14	104.3	230	166	85.5	1.3	4.3	9.3	6.4	+6.0
49	8	14	104.3	230	165	84.9	1.1	3.6	7.1	4.0	-3.0
50*	8	14	104.3	230	181	93.1	1.0	3.3	7.8	3.8	+5.2
51	12	12	104.3	230	163	83.8	.8	2.6	8.2	3.7	-2.8
52	12	12	104.3	230	166	85.2	.8	2.6	5.8	4.7	-3.5
53*	12	12	104.3	230	164	84.4	.9	3.0	8.1	3.6	+3.5
54*	16	9 1/2	104.3	230	154	79.1	.9	3.0	9.2	4.4	-2.3
55	16	9 1/2	104.3	230	154	79.1	.8	2.6	6.2	4.7	+3.5
56	16	9 1/2	104.3	230	154	79.2	.7	2.3	8.2	3.8	-2.5
57	16	9 1/2	104.3	230	154	79.1	.6	2.0	10.6	5.8	+2.8
58	16	9	104.3	230	155	79.5	.8	2.6	7.5	5.5	+4.2
59*	16	9	104.3	230	154	79.1	.4	1.3	2.4	3.7	+3.2
60	16	9	104.3	230	155	79.5	.4	1.3	5.3	4.6	-2.6
61	12	11	104.3	230	167	86.0	.3	1.0	7.3	6.8	+3.8
62	12	4	83.9	185	159	81.9	-	-	6.7	-10.2	-3.2
63	12	7	83.9	185	159	81.9	.3	1.0	4.6	2.0	+2.0

Run No.	Landing Attitude DEG	Elevon Setting DEG	Landing Mass Thousands kg	lbm.	Landing Speed knots	m/sec	Sink Speed m/sec	ft/sec	Maximum Impact Accelerations Normal g - units	Longitudinal g - units	Angular Rad/Sec^2
64	12	7	83.9	185	153	78.5	.2	.7	5.7	3.0	+1.4
65	16	4	83.9	185	139	71.7	.4	1.3	6.7	2.8	+2.0
66	16	4	83.9	185	139	71.6	.6	2.0	5.5	2.6	+4.8
67*	8	7	104.3	230	203	104.4	.5	1.6	5.9	6.6	+3.8

NOTES:

(1) NR - Not Recorded

(2) *Runs shown in film supplement (NASA film serial L-1176).

(3) Wing Spoilers on: Runs 24 to 45 and Runs 63 to 67

(4) Runs 9 and 62: Orbiter stalled after launch and hit tail first

TABLE V - SUMMARY OF VISUAL OBSERVATIONS MADE DURING SHUTTLE MODEL DITCHING INVESTIGATION

Run No.	Landing Attitude Deg.	Landing Gear Position	Body Flap Position Deg.	Water Surface	Run Distance, Fuselage Lengths	Chronological Behavior of Model (c)
1	16	Up	-11.7	Calm	4	w-h
2	16				4	w-h-i
3	12				4	w-h-i
4	12				4	w-h-i
5	12				4	w-h-i
6	12				4	w-h-i
7	12				5	w-h-i-o
8	12				-	x
9	12				-	s
10	12				5.5	w-h-i
11	8				5.5	w-h-i
12	8				6	w-h-i
13	8				5	r-h-i
14	16				5	w-h-i
15	16				5	w-h-i
16	16				4	w-h-i
17	16				5.5	w-h-i
18	16				5.5	w-h-i
19	16				5.5	w-h-i
20	12				6	w-h-i
21	12				5.5	w-h-i

TABLE V - Continued

Run No.	Landing Attitude Deg.	Landing Gear Position	Body Flap Position Deg.	Water Surface	Run Distance, Fuselage Lengths	Chronological Behavior of Model (c)
22	12	Up	-11.7	Calm	5.5	w-h-i
23	12				5.5	w-h-i
24	8				5.5	w-h-i
25	8				6.5	r-h-i-o
26	8				5	w-h-i
27	12				2	d-i-o
28	12	Down			3.5	d-g-i
29	8	Down			2	d-g-i
30	16	Up			4.5	w-h-i
31	16				4	w-h-i
32	16				5.5	w-h-i
33	12				5.5	w-h-i
34	12				6	w-h-i
35	12				6	w-h-i
36	8				5.5	w-h-i
37	8				7.5	r-h-i-o
38	8				-	x
39	16				7	w-h-i
40	16				7	w-h-i
41	16			waves (a)	4	e-i
42	16			waves (a)	3	e-i

TABLE V - Continued

Run No.	Landing Attitude Deg.	Landing Gear Position	Body Flap Position Deg.	Water Surface	Run Distance Fuselage Lengths	Chronological Behavior of Model (c)
43	16	Up	-11.7	Waves (a)	4	e
44	12				7	e-i-o
45	12				5.5	r-d
46	12				7	m-i-o
47	8				8	m-i-o
48	8			Waves (b)	5.5	w-h-i
49	8				7.5	w-h-i-o
50	8				8.5	w-h-i-o
51	12				7.5	w-h-i-o
52	12				7.5	w-h-i-o
53	12				8.5	w-h-i
54	16				6	w-h-i-o
55	16				4	e-i-o
56	16				2	d-i
57	16		+6.	Calm	5	w-h-i
58	16		-11.7		5	w-h-i
59	16	Down			3.5	d-g-i-o
60	16	MG Down			2	d-g-i-o
61	12	Up			6	w-h-i
62	12	Up			-	s
63	12	Up			5	w-h-i-o

TABLE V - Continued

Run No.	Landing Attitude Deg.	Landing Gear Position	Body Flap Position Deg.	Water Surface	Run Distance, Fuselage Lengths	Chronological Behavior of Model (c)
64	12	Up	-11.7	Calm	4	n
65	16	↓	↓	↓	5	n-i
66	16	↓	↓	↓	4.5	n-i
67	8	↓	↓	↓	9	l-h-i

a. Waves 2.1m (7 ft.) high x 55 m (180 ft.) long, crest to crest

b. Waves .6m (2 ft.) high x 7m (23 ft.) long, crest to crest

c. In this column, the letters indicate the following motions:

- w - Trimmed Down - the attitude of the model decreased after contact with water.
- h - Ran Smoothly - the model made a very stable run.
- i - Inboard Elevon (s) hinge moment failure (s)
- o - Outboard Elevon (s) hinge moment failure (s)
- x - Instrumentation cable severed during launch of model
- s - The model stalled after launch and hit tail first
- r - The right wing of the model contacted the water first
- l - The left wing of the model contacted the water first
- d - dived - The model stopped abruptly with the nose of the model submerged
- g - Landing Gear (s) structural failure (s)
- e - The nose of the model ploughed through the wave crests
- m - The model skipped over the wave crests
- n - Nosed In - the nose of the model submerged momentarily

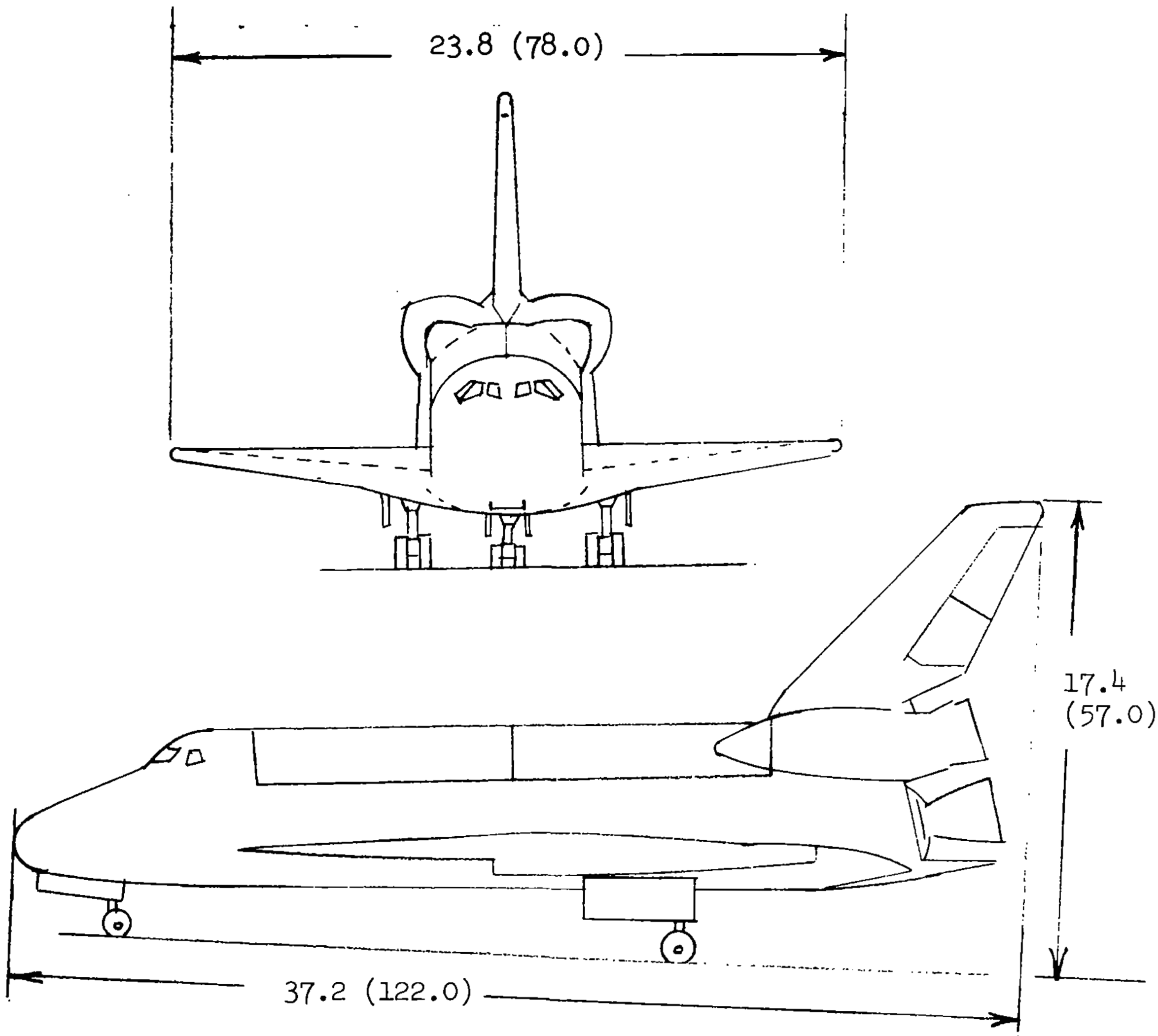

Figure 1 - General Arrangement of Shuttle Orbiter. Dimensions are full-scale values and are given in meters (ft).

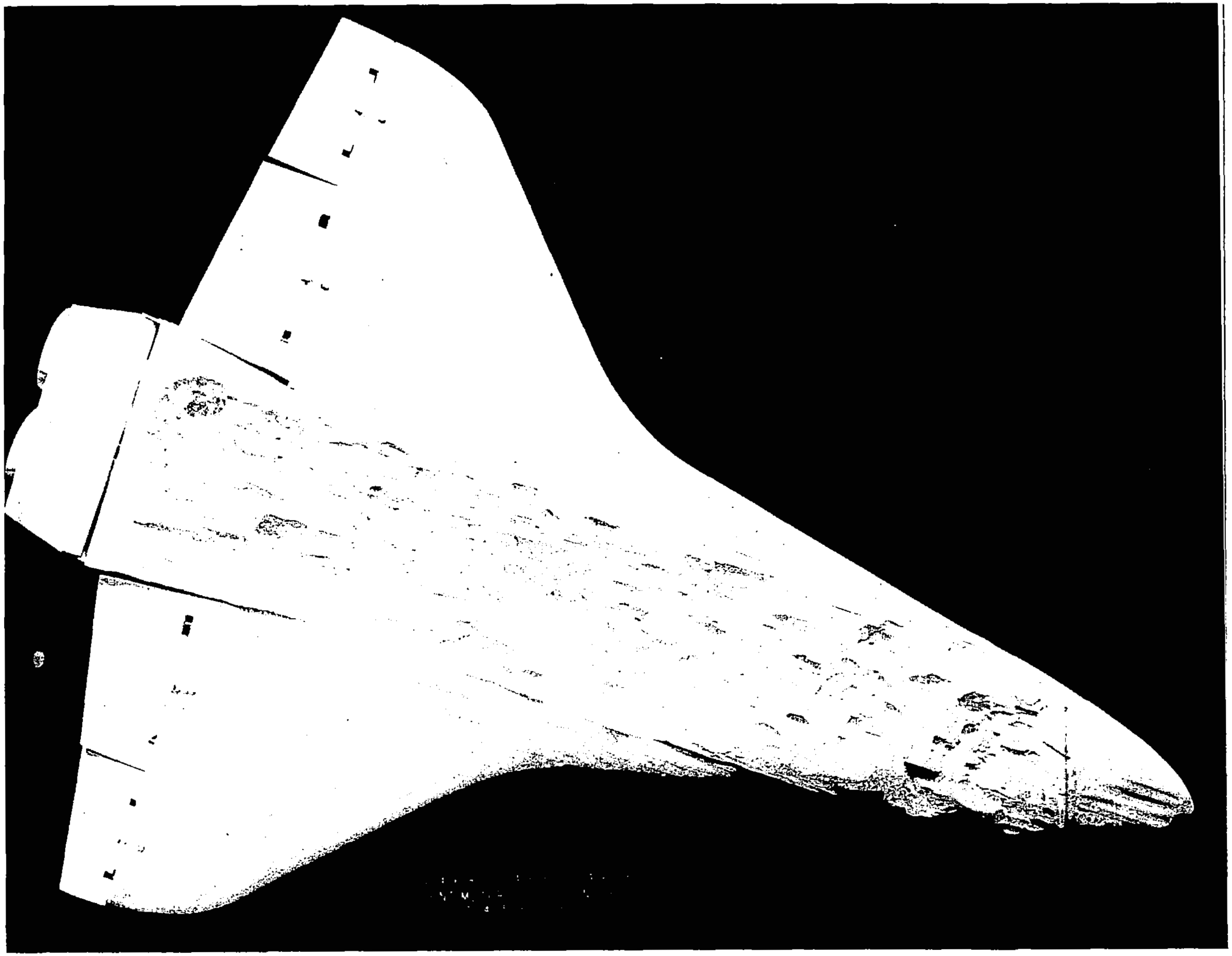

Figure 2 1/20 Scale Model-Bottom View with Fuselage Insert Installed

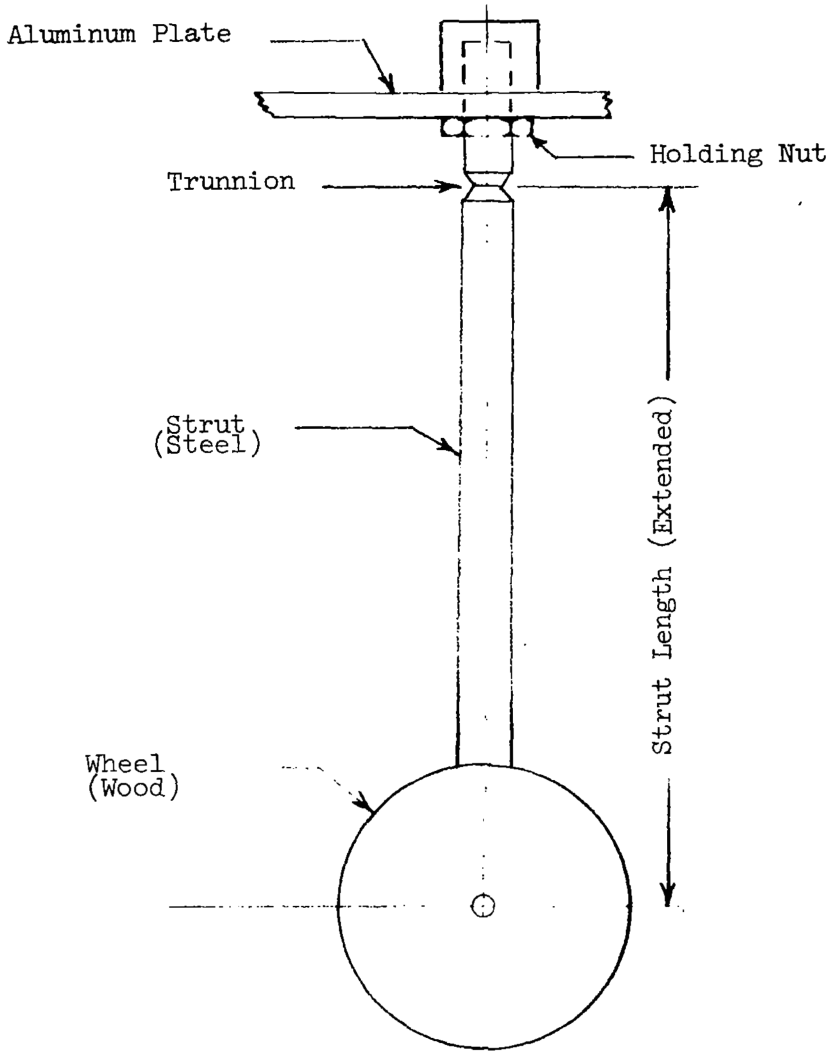

Fig. 3 Landing Gear Installation On Model

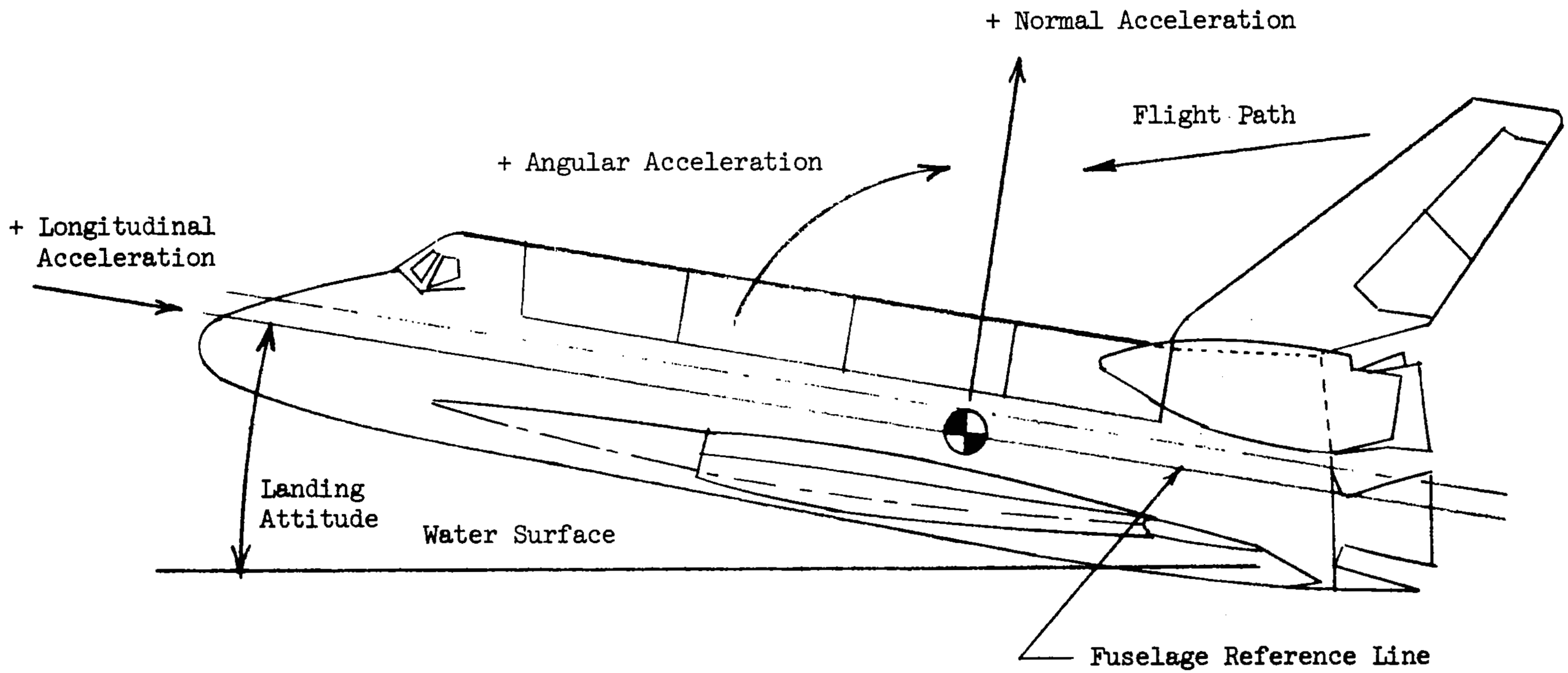

Figure 4 . - Sketch Identifying Acceleration Axes, Attitude and Flight Path

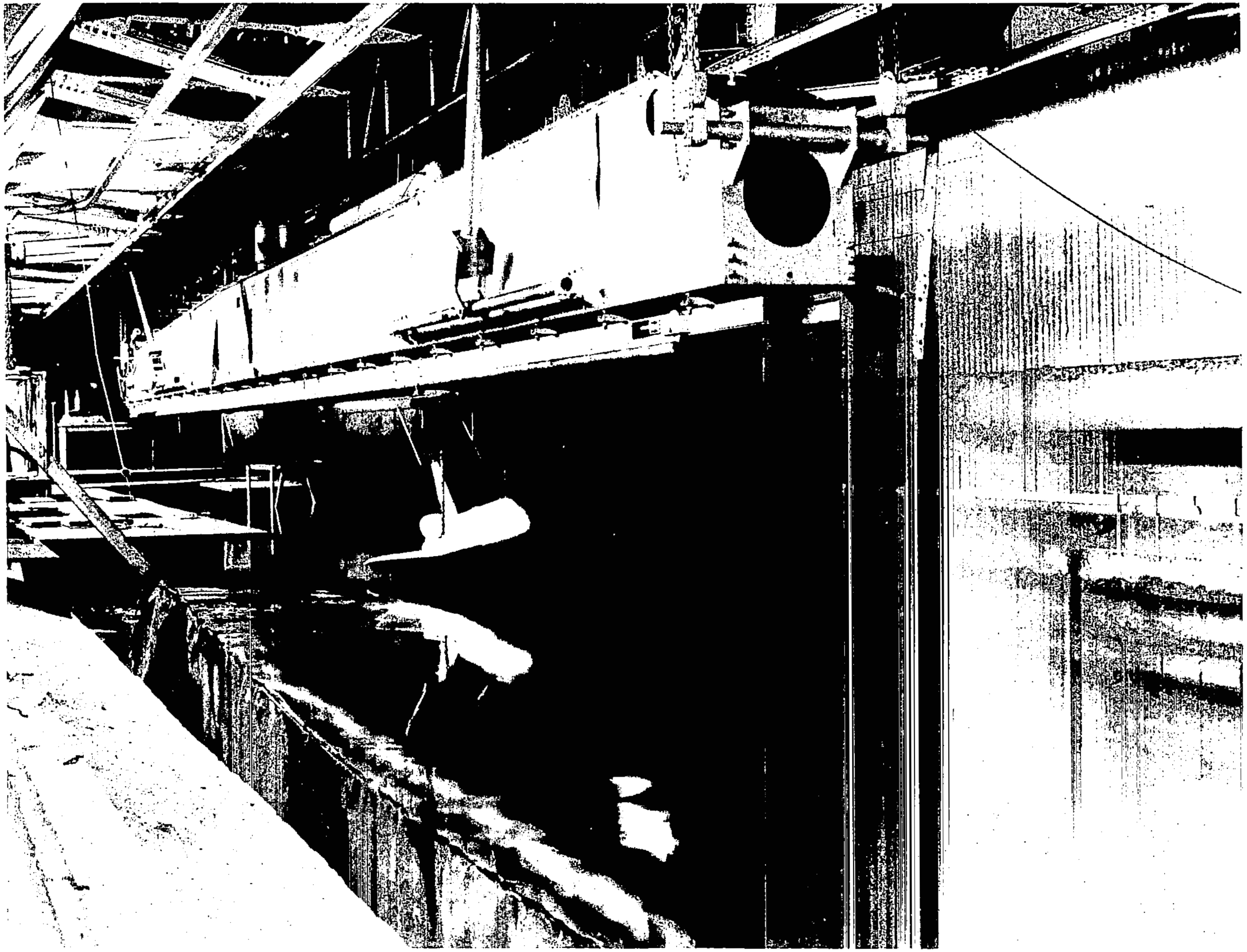

Figure 5 1/20 Scale Model Ready for Launching

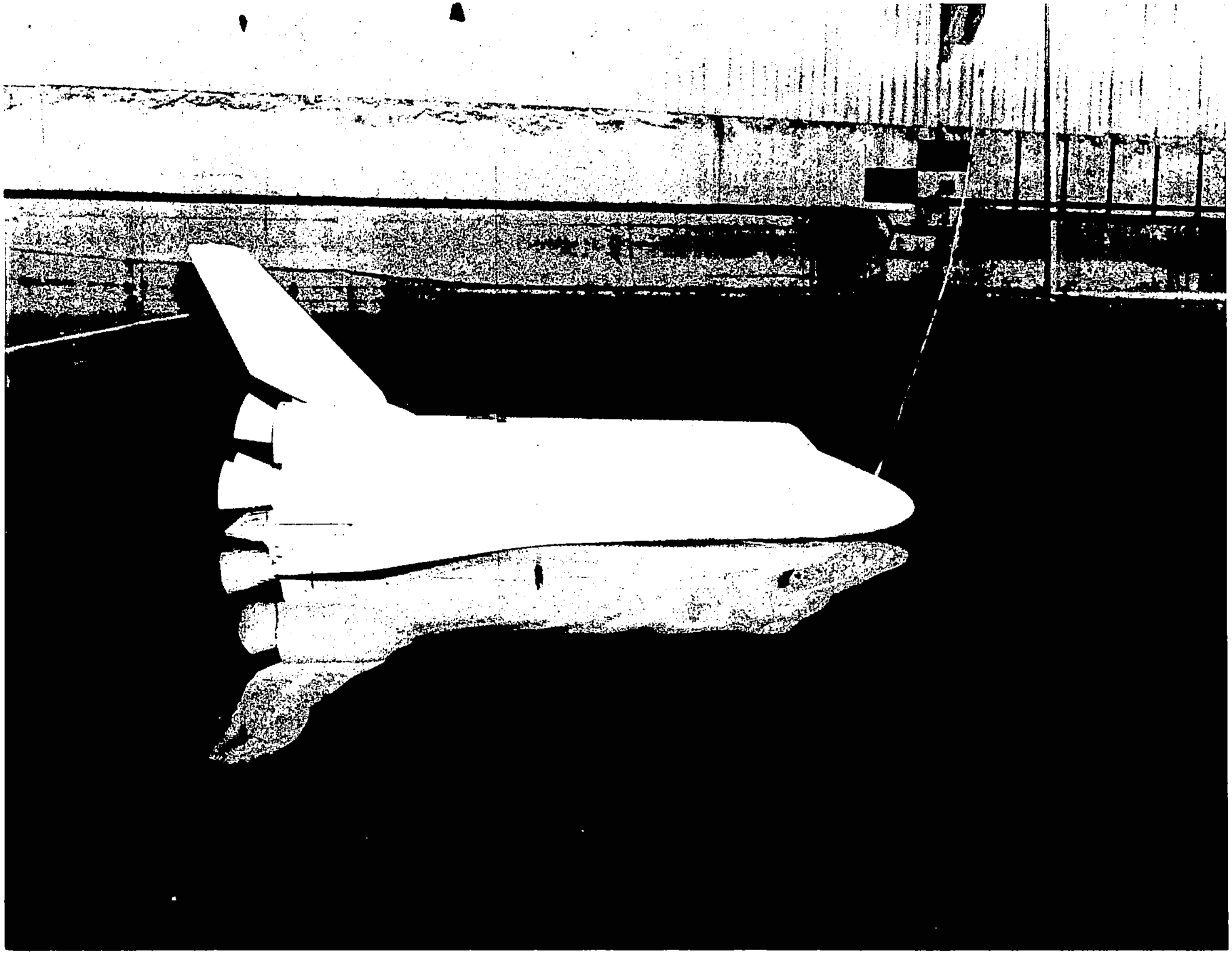

Figure 6 1/20 Scale Model Afloat

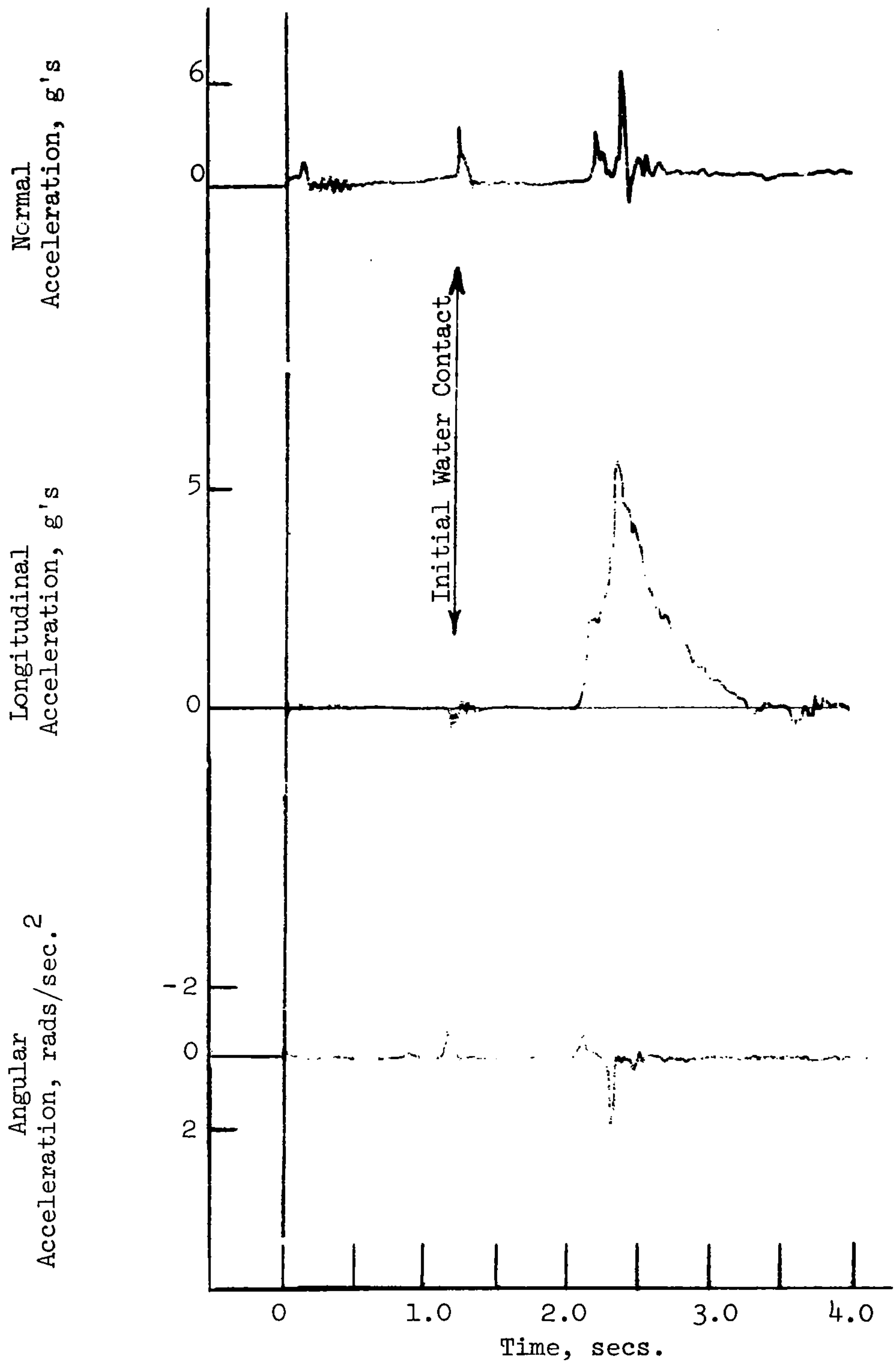

Figure 7 Full Scale Acceleration Time-History Curves of Run #6

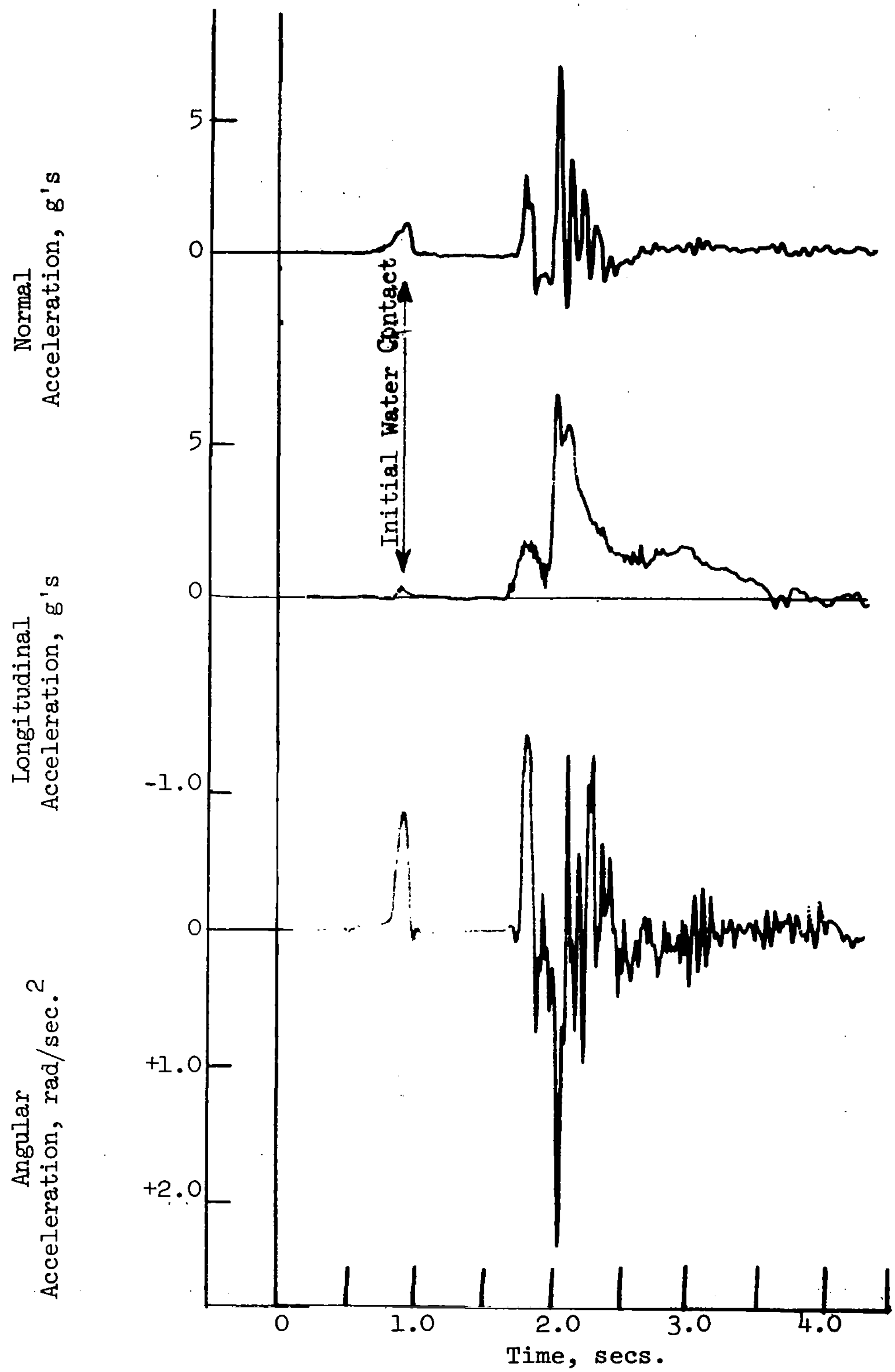

Figure 8 Full Scale Acceleration Time-History Curves of Run #12

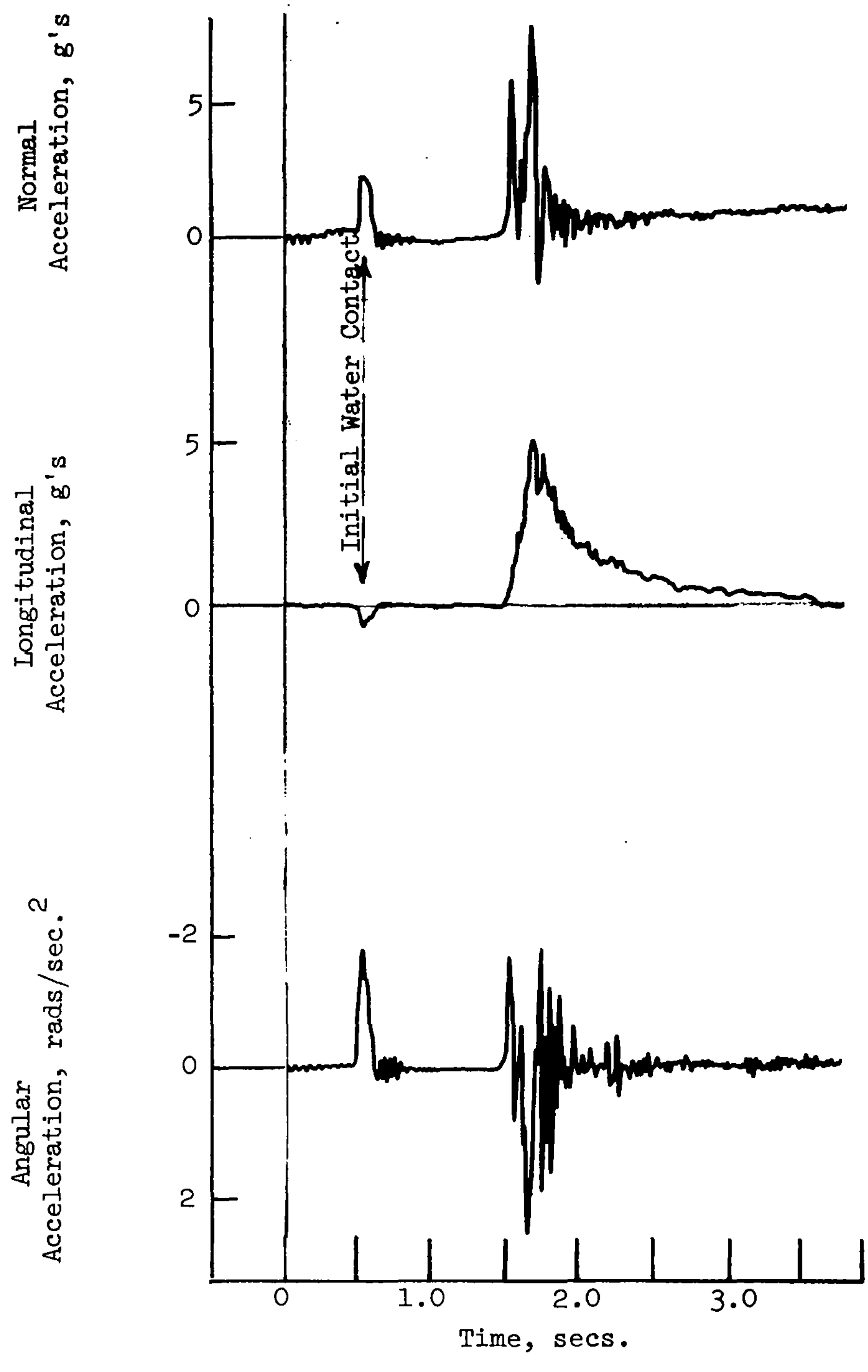

Figure 9 Full Scale Acceleration Time-History Curves of Run #15

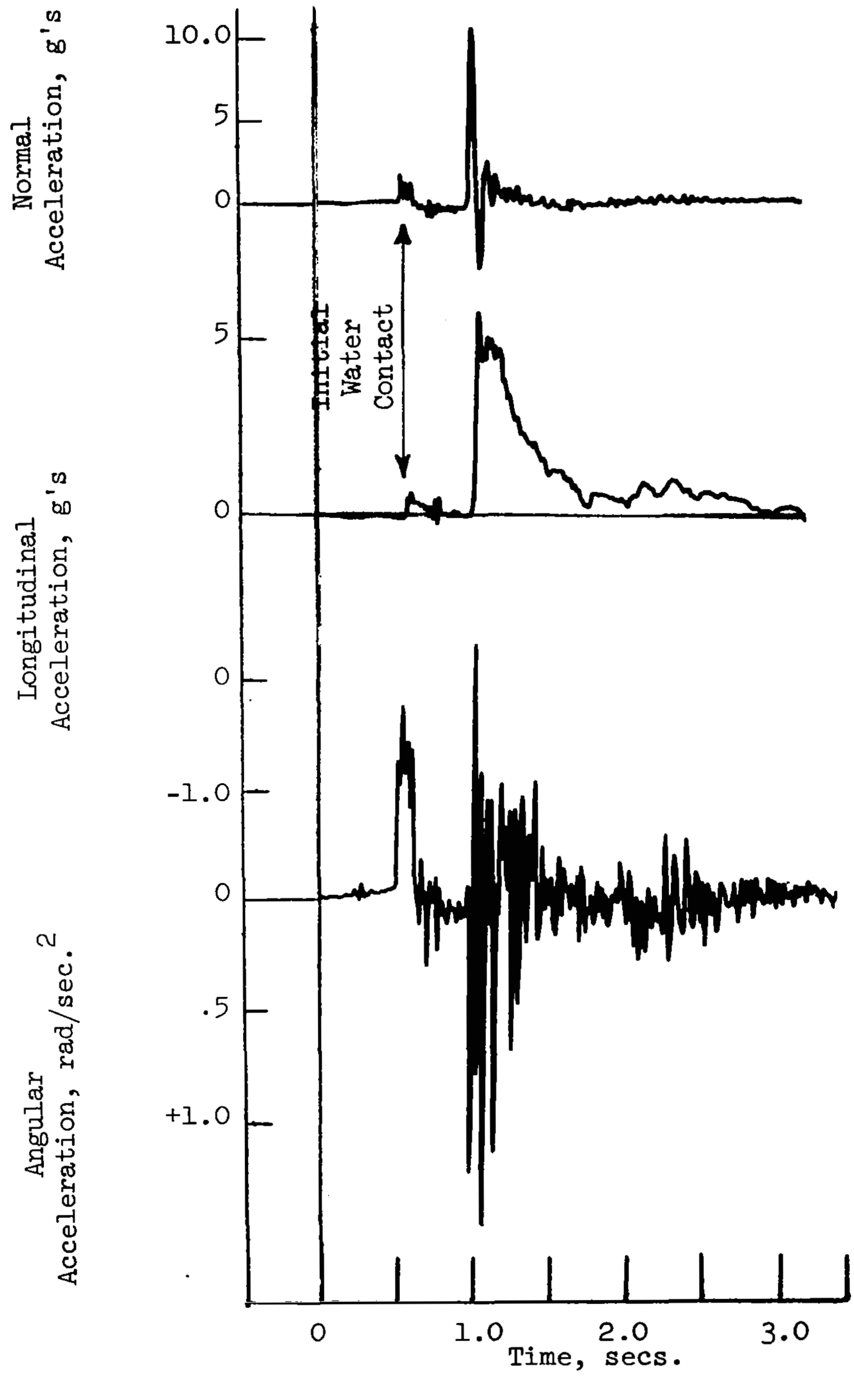

Figure 10 Full Scale Acceleration Time History Curves for Run #17

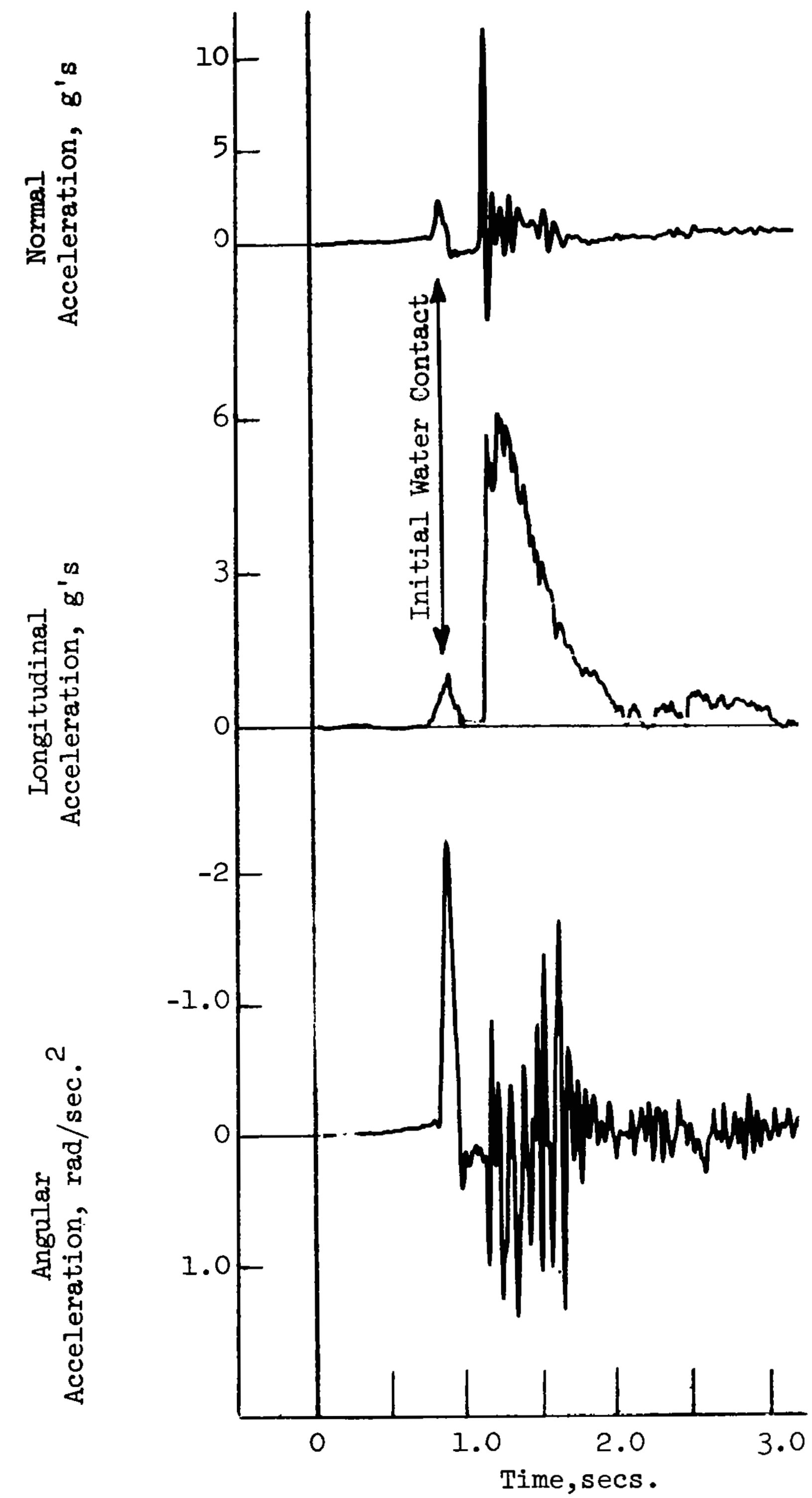

Figure 11 Full Scale Acceleration Time-History Curves of Run #20

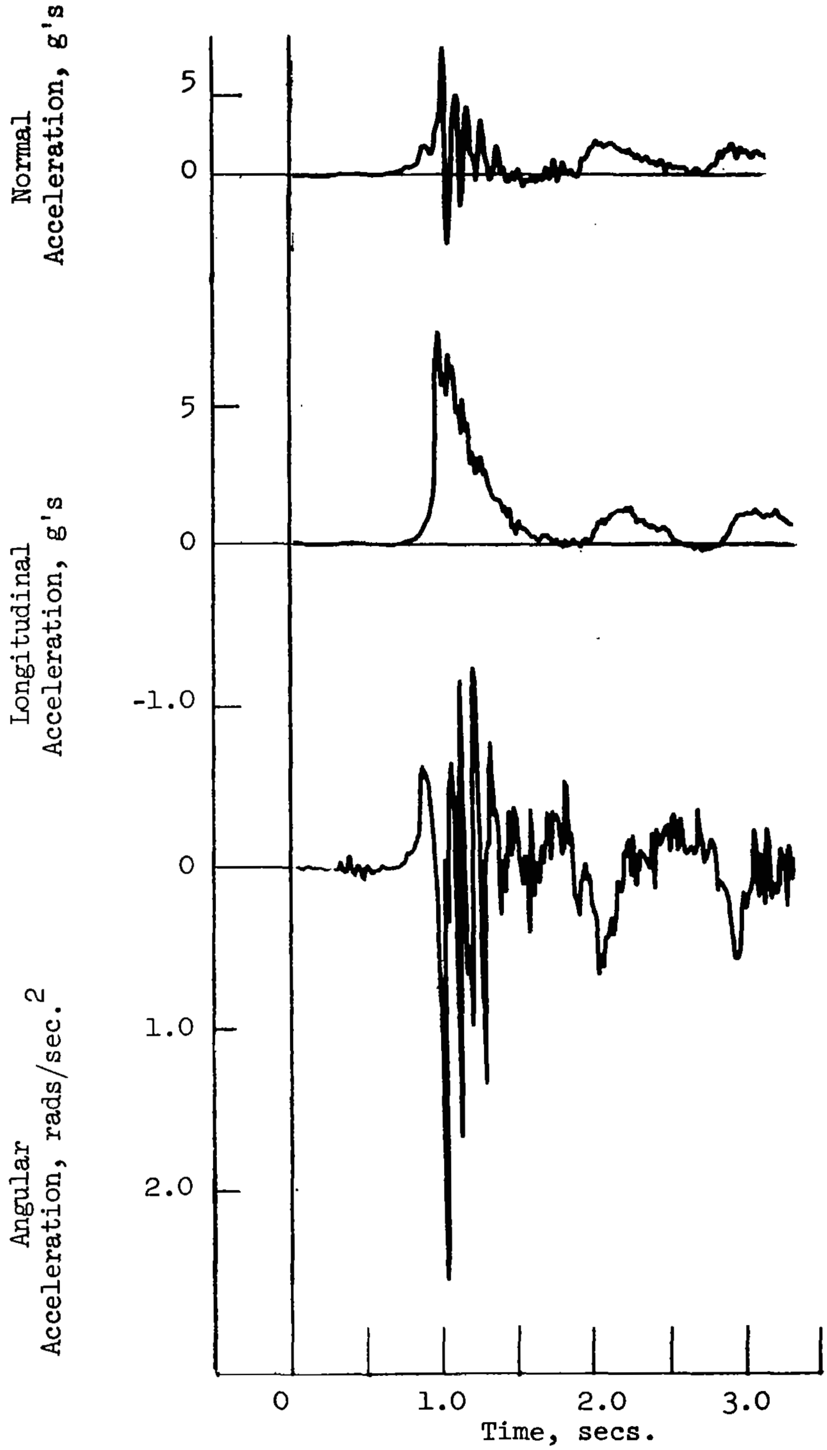

Figure 12 Full Scale Acceleration Time-History Curves of Run #25

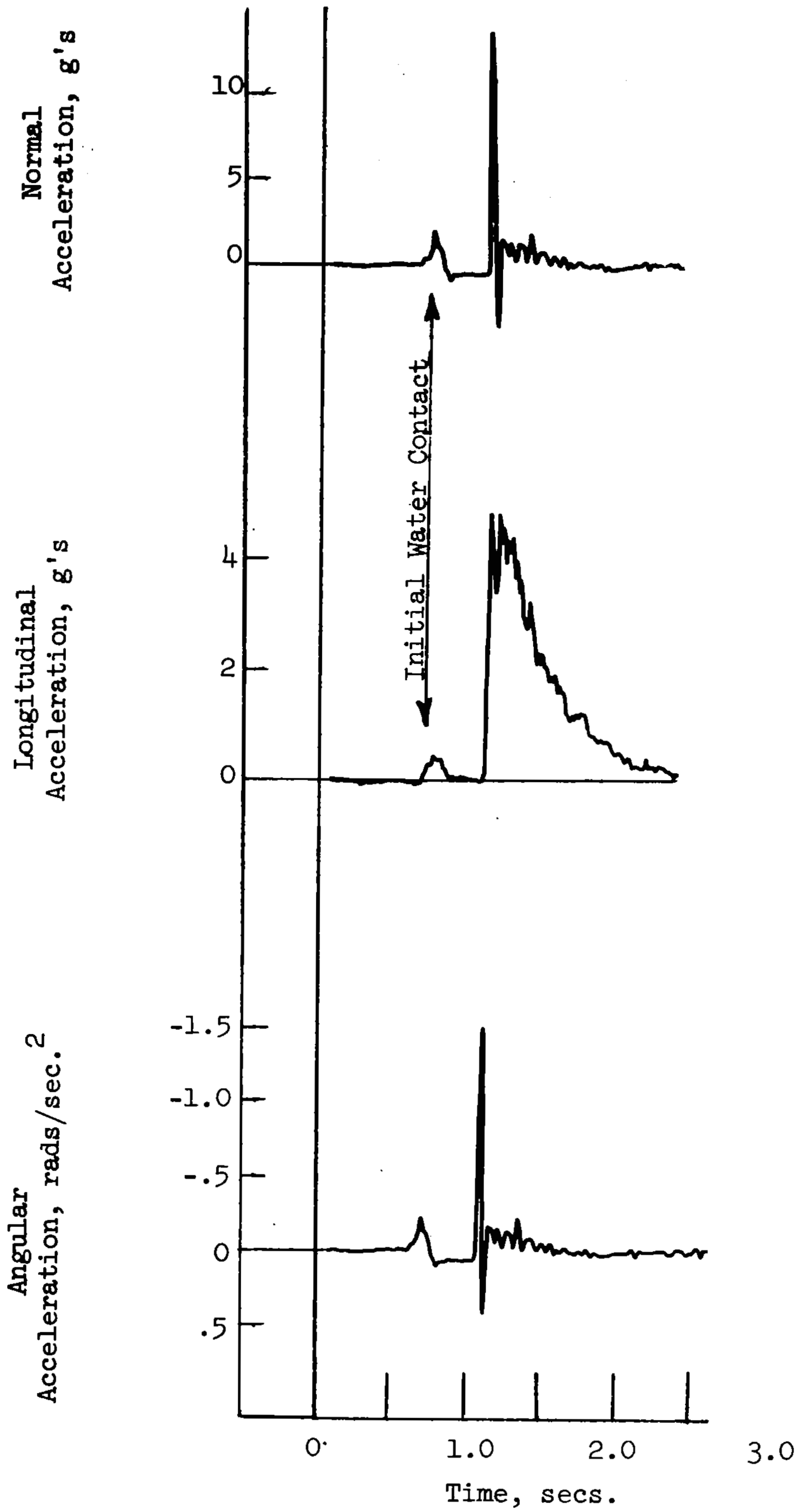

Figure 13 Full Scale Acceleration Time-History Curves of Run #30

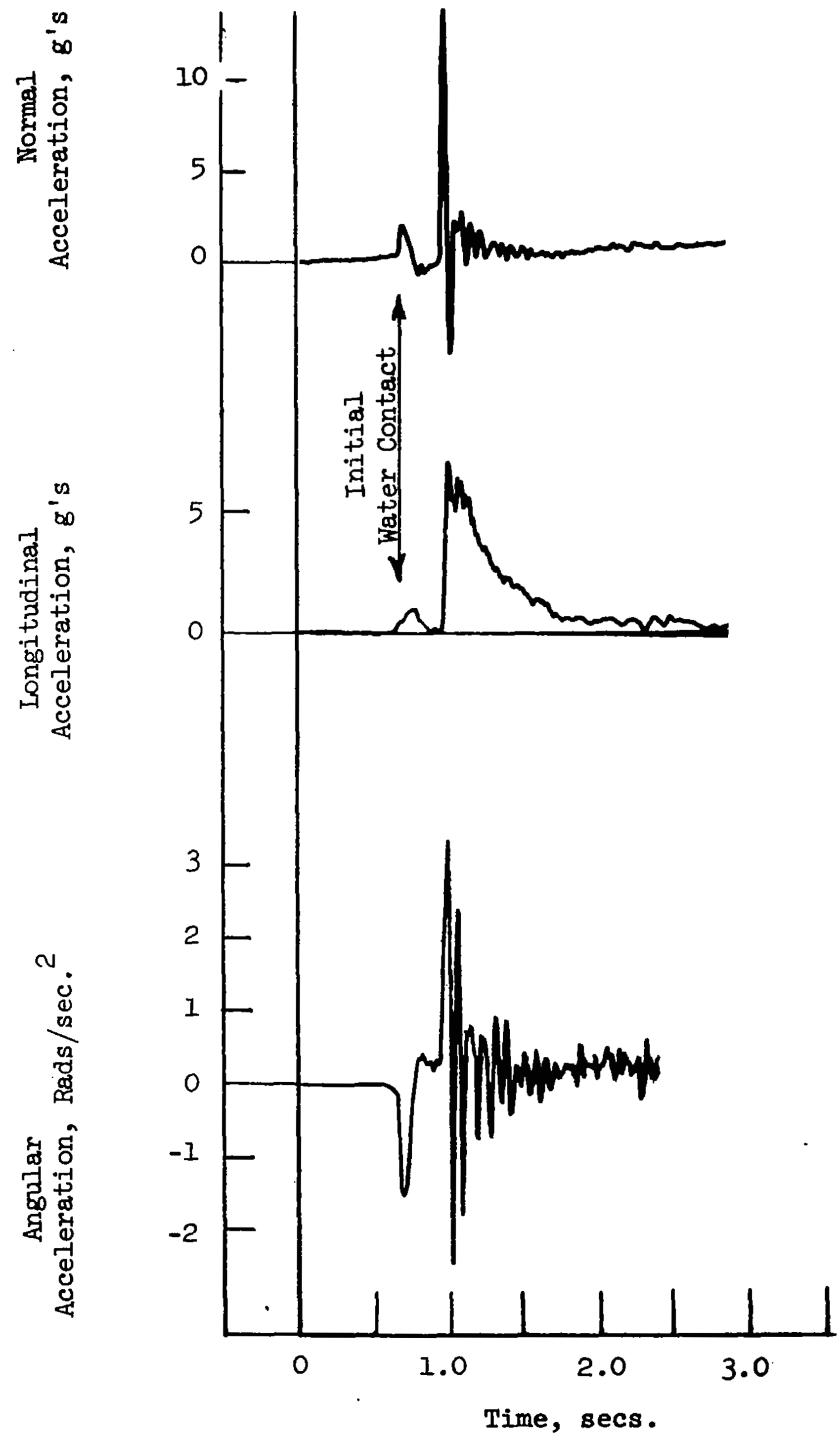

Figure 14 Full Scale Acceleration Time-History of Run #34

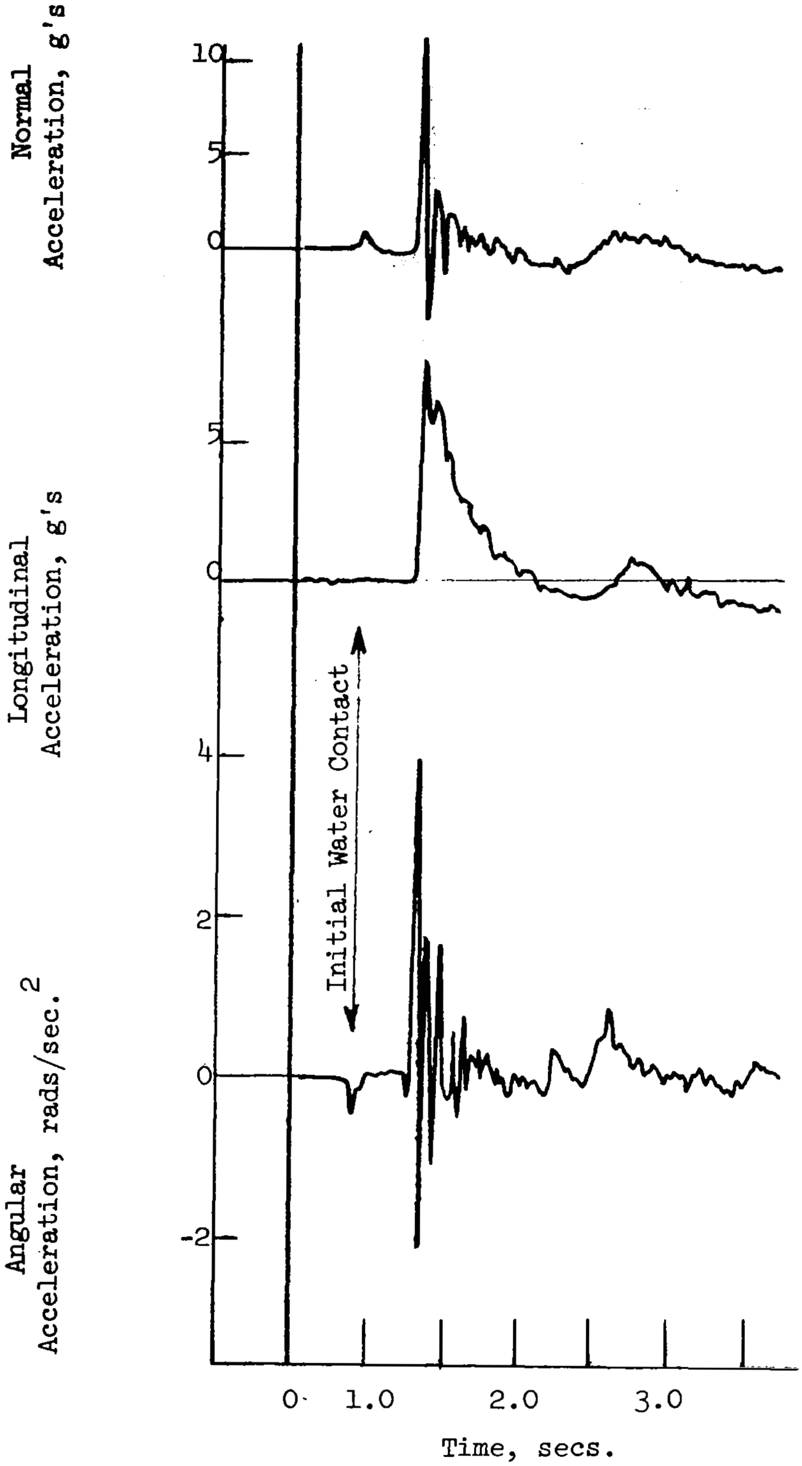

Figure 15 Full Scale Acceleration Time-History Curves of Run #37

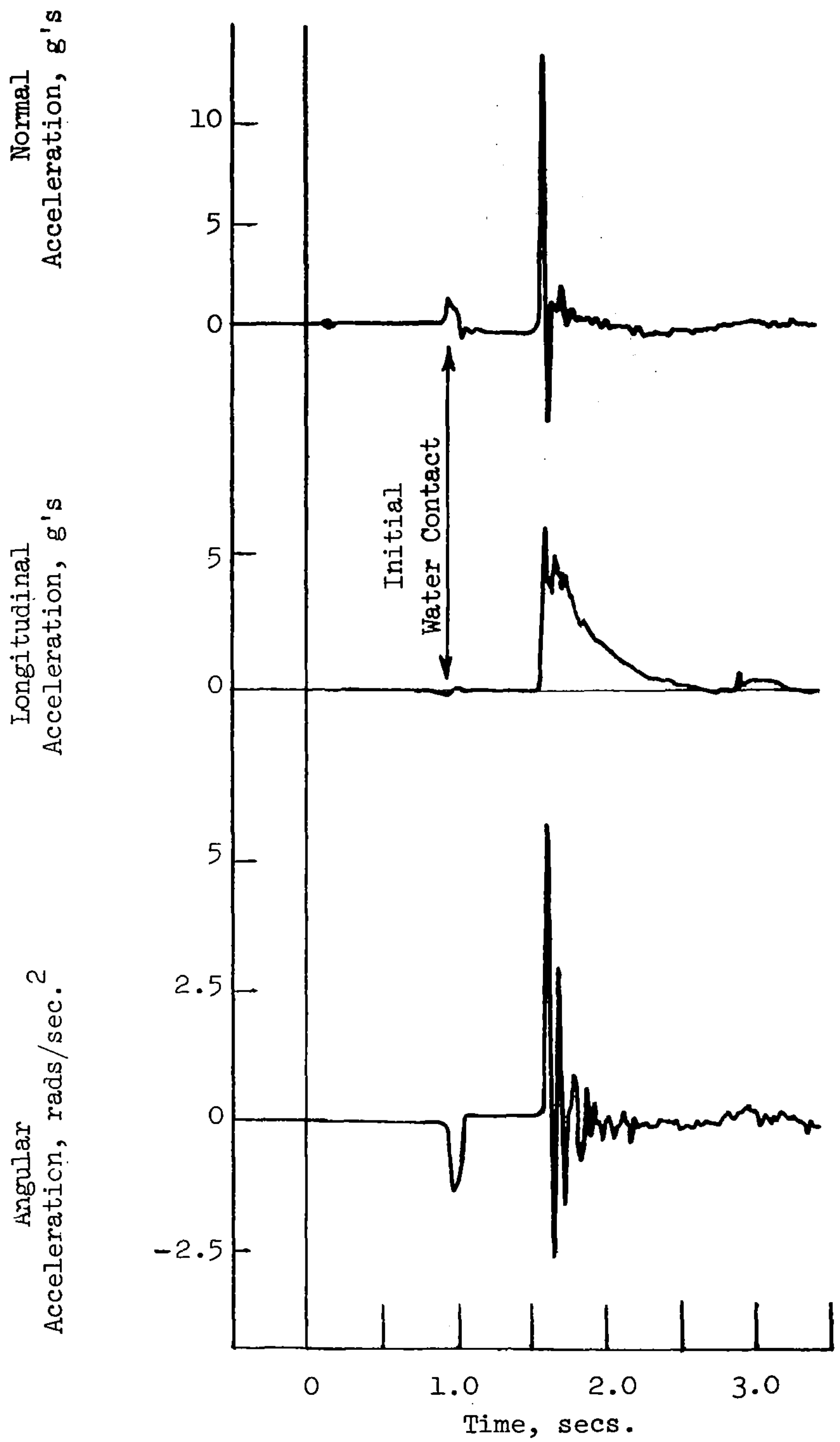

Figure 16 Full Scale Acceleration Time-History Curves of Run #40

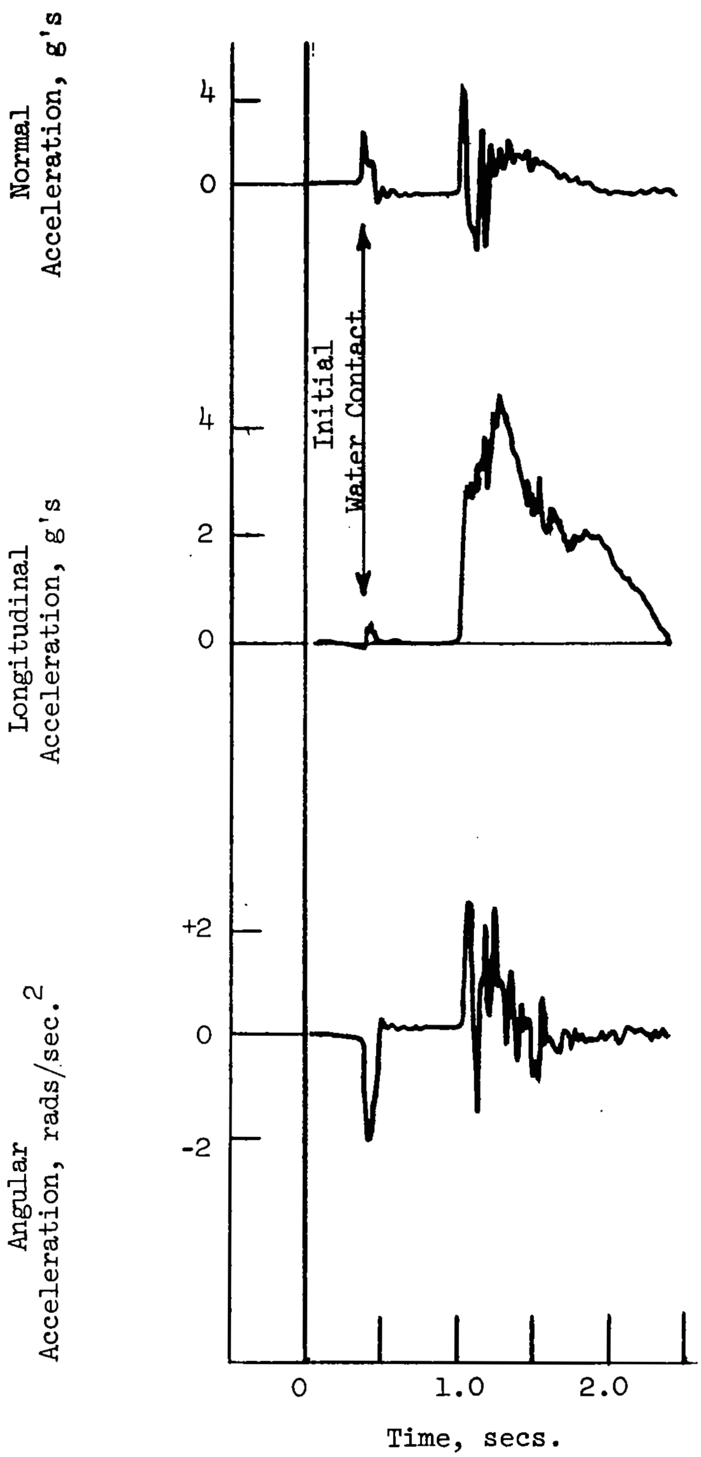

Figure 17 Full Scale Acceleration Time-History Curves of Run #41

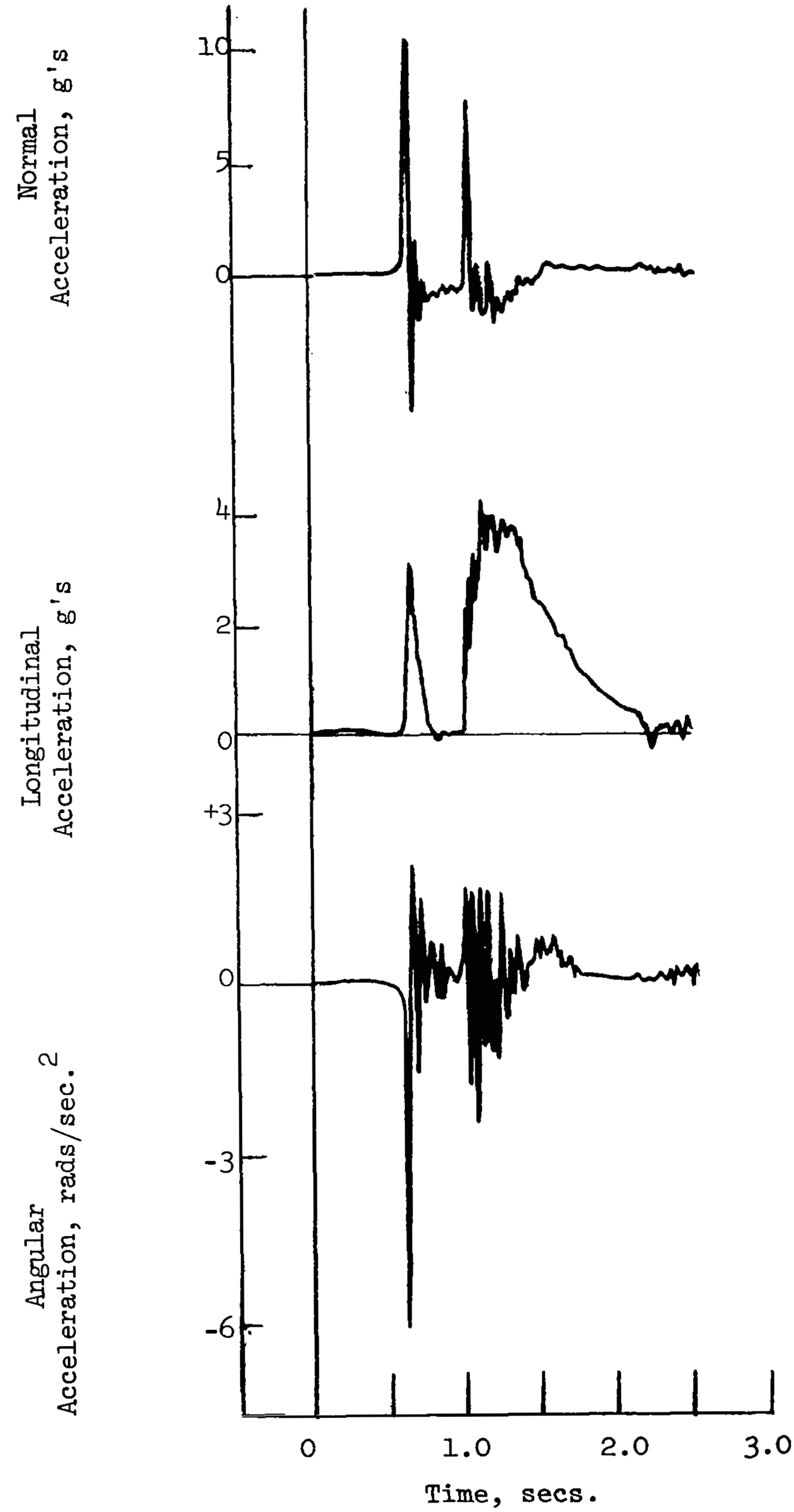

Figure 18 Full Scale Acceleration Time-History Curves of Runs #45

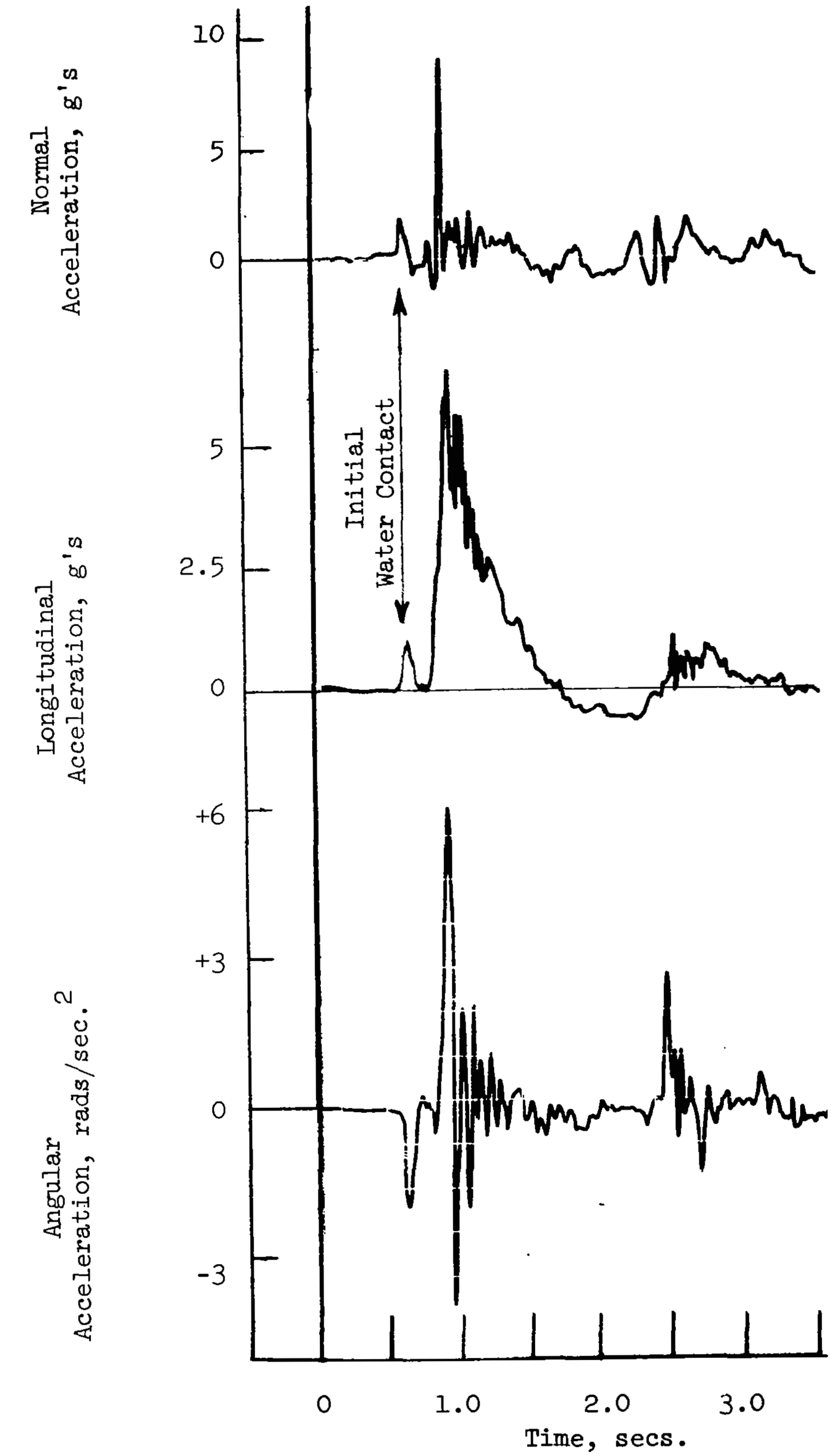

Figure 19 Full Scale Acceleration Time-History Curves of Run #48

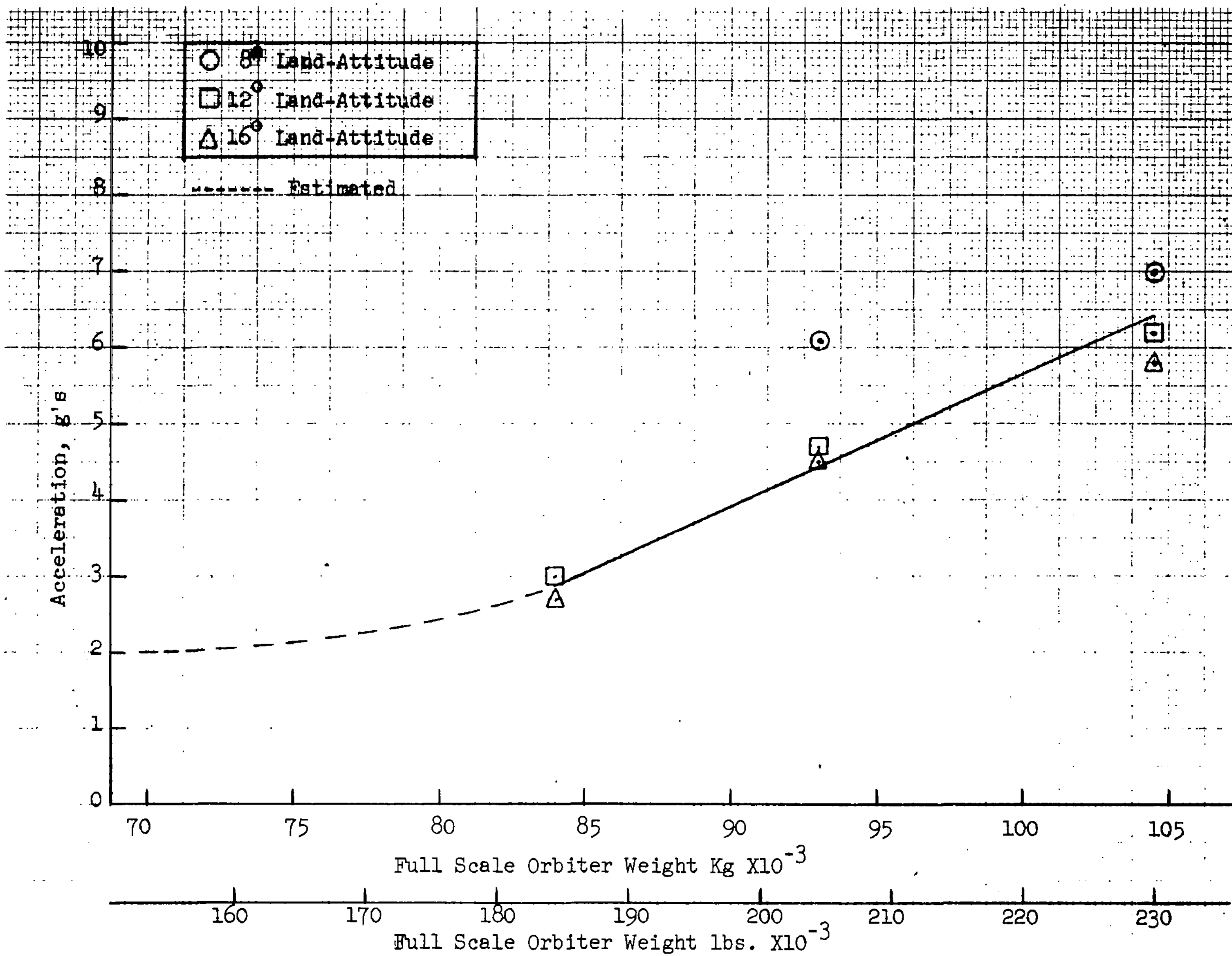

Figure 20. Average Maximum Longitudinal C. G. Accelerations (Calm Water)

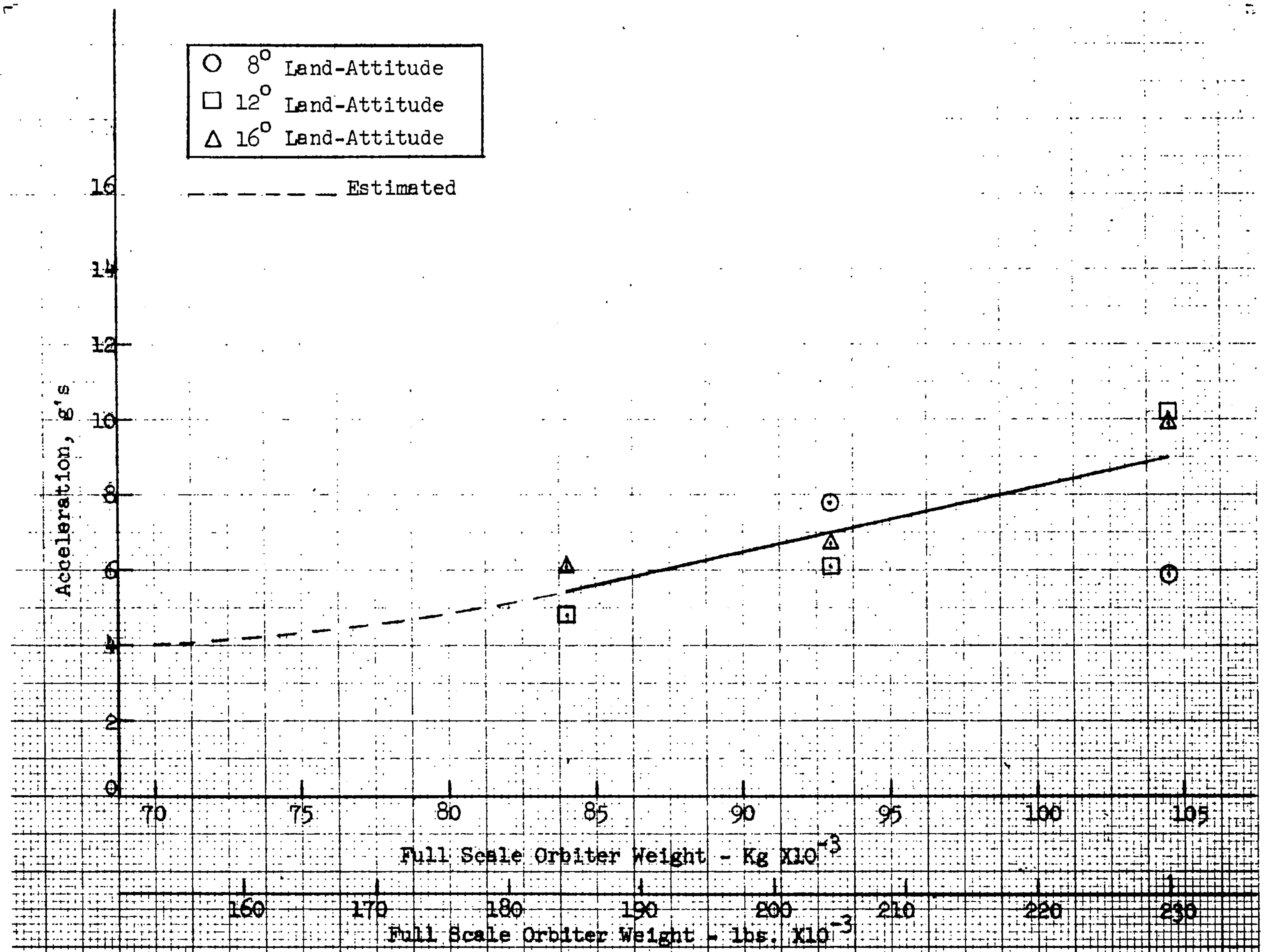

Figure 21. Average Maximum Normal C. G. Accelerations (Calm Water)

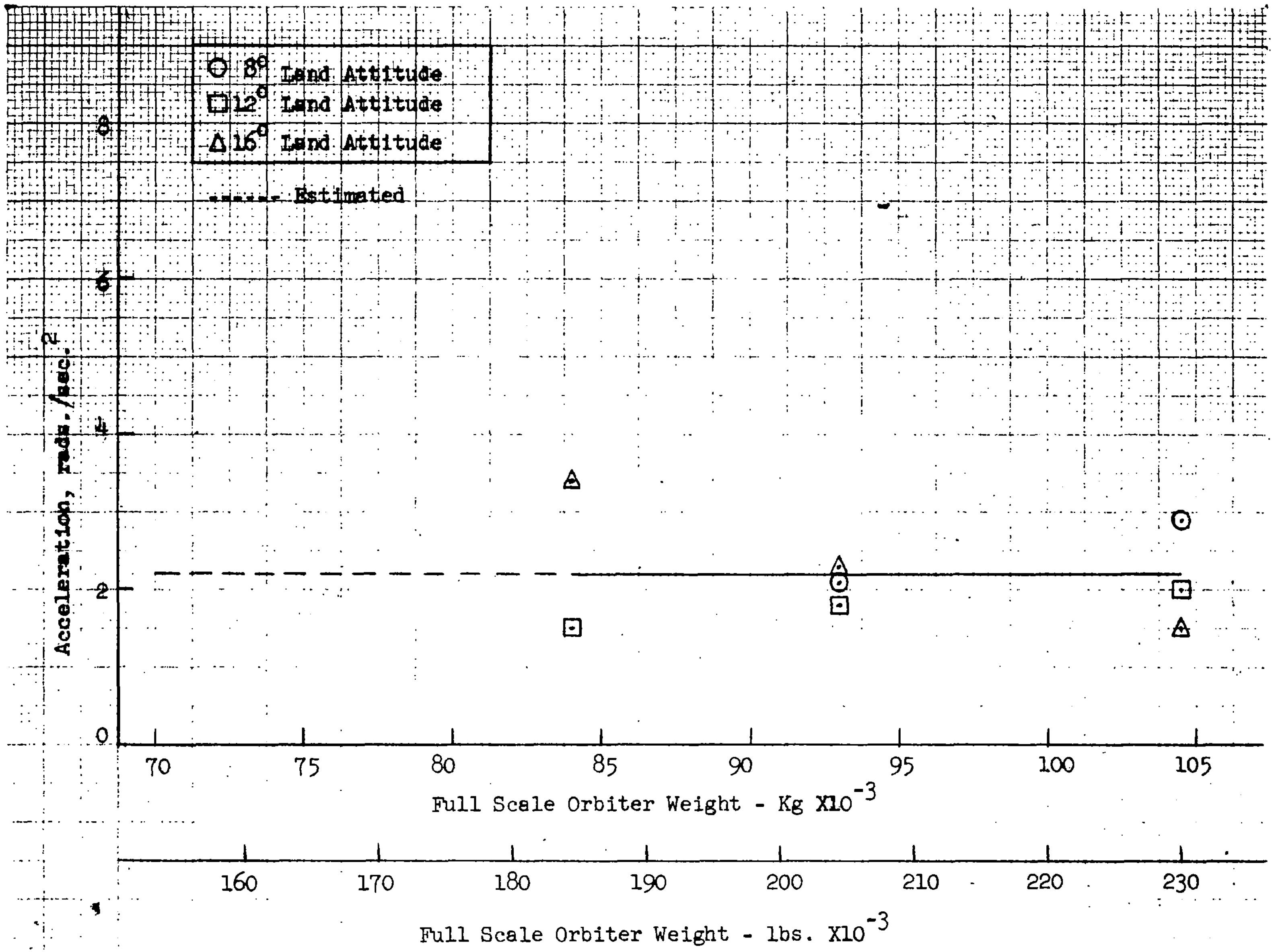

Figure 22. Average Maximum Pitch Accelerations (Calm Water)

NASA-Langley, 1975