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QUALITATIVE INVESTIGATION OF BOOSTER RECOVERY IN OPEN SEA

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Prepared by

Preston E. Beck
Advanced Engineering and Planning Branch
Kennedy Space Center, Florida 32899

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2. TR-1180, Revision 1

1.0 INTRODUCTION

Limited tests were conducted using a 1/27 scale model of a Titan IIIC booster plus 1/32.9 and 1/15.6 scale models of a solid rocket booster case to establish some of the characteristics that will effect recovery operations in open seas. This preliminary effort was designed to provide additional background information for conceptual development of a waterborne recovery system for space shuttle boosters, pending initiation of comprehensive studies, Reference 1. The models were not instrumented; therefore, all data are qualitative (approximations) and are based on observations plus photographic coverage.

1.1 PLANS. The current plans call for performing quantitative testing in a towing tank(s) at the Naval Ship Research and Development Center, Carderock, MD. These tests will be conducted using an 8 percent (1/12.5) scale model furnished by the Marshal Space Flight Center, Ala. Tests will also be conducted at the Long Beach Naval Shipyard using a 77 percent model. Test results will be published in separate reports.

2.0 SCOPE

Inexpensive dynamically similar models were constructed to permit observation of the response of the booster cases when floating and being towed in the water. Dimensions were adjusted slightly to reduce the cost of the models by using available materials.

3.0 ASSUMPTIONS

It was assumed that:

A. The design and descent to the ocean surface will be such that the booster cases will remain intact and not sink due to flooding.

B. The space shuttle boosters will not have thrust vector controls (TVC).

C. Parachutes will be used to help control the descent and may, or may not, remain attached to the booster after splashdown.

4.0 BACKGROUND INFORMATION

4.1 TITAN IIIC BOOSTERS. In the early stages of the Titan program, an investigation was made into the feasibility of recovering the boosters. In this program, the boosters are jettisoned after burnout in the same manner as proposed for the space shuttle. However, the Titan boosters free fall instead of making a controlled descent to the water.

Qualitative reports showed that observers were able to optically track the boosters during the free fall and establish the general locale of the splashdown. The cases would float anywhere from one to several minutes before sinking. The Titan TVC parts generally separated from the booster on impact. This leads one to conclude that parachutes would be very effective in preventing flooding due to structural failure of the booster cases.

4.2 MODEL DESIGNS. The details of the model designs are presented in Appendices A, B, and C. Emphasis was placed on simplicity and low cost; therefore, an "exact model" was not considered necessary. The size, center-of-gravity, weight. and moment of inertia in pitch (Figure B1 in Reference 2) were scaled. Other booster design details could not be considered due to a lack of sufficient data. The scale relationships are shown in Table 1.

4.3 TEST CONDITIONS. The tests were conducted using a C23 Sportcraft inboard/outboard boat and a Tarpan 27 sailboat with an auxiliary engine. All tests were made in the Banana River and adjacent canals which are salt water (but of lower salinity than the open ocean). The waves were either wind driven or formed by the wake of boats.

5.0 DISCUSSION AND QUALITATIVE RESULTS

5.1 BASIS FOR DEDUCTIONS. Testing of the small models, Appendices A and B, was inconclusive due to scaling problems. Working from a boat in a river was considered feasible; therefore, the space shuttle booster model scale was increased from 1/32.9 to 1/15.6. (The odd scale numbers resulted from use of available materials for the tube that formed the body of each booster case.) Going to the larger sized model, Appendix C, made it easier to simulate full scale conditions and to take measurements.

5.2 1/27 SCALE TITAN IIIC MODEL. Limited testing was conducted without ballast water (assumed the nozzle will be plugged) in the case. The results are presented in Appendix A.

When there is no ballast water in the case, it floats very high and is sensitive to wind velocity. This also results in substantial heave (movement in the vertical plane) that would complicate recovery.

These tests were terminated as soon as sufficient data were obtained to test a space shuttle booster configuration.

5.3 1/32.9 SCALE MODEL OF A SPACE SHUTTLE BOOSTER. Limited testing was accomplished on this configuration, Appendix B. Testing was without water ballast except when the model sprung a leak. The increase in weight due to the water ingestion resulted in an increase in magnitude of an undesirable dynamic response to the wave action.

These tests were terminated when it was decided that the model was inadequate and it would be better to change the model scale. This would allow conducting more precise tests.

Table 1. Scale Relationships

λ = Scale of Model

Quantity	Full-Scale Value	Scale Factor	Model Value
Length	ℓ	λ	$\lambda \ell$
Area	A	λ^2	$\lambda^2 A$
Mass	m	λ^3	$\lambda^3 m$
Moment of inertia	I	λ^5	$\lambda^5 I$
Time	t	$\sqrt{\lambda}$	$\sqrt{\lambda}$
Velocity	v	$\sqrt{\lambda}$	$\sqrt{\lambda}\, v$
Linear acceleration	a	1	a
Force	F	λ^3	$\lambda^3 F$
Angular acceleration	α	λ^{-1}	$\lambda^{-1} \alpha$
Pressure	P	λ	λP

5.4 1/15.6 SCALE MODEL OF A SPACE SHUTTLE BOOSTER. Data on the model and scale relationships are presented in Appendix C.

5.4.1 Towing Vessel. A sea anchor was found to be effective in controlling the velocity of the towing vessel. Thus, the equivalent of full scale velocities of 10 knots and less were achieved, and this is the range of operation of the current state-of-the-art towing equipment.

5.4.2 Static Attitudes. The initial tests were conducted in a swimming pool free from wind and water currents. The model was built so that the amount of water ballast in the case could be controlled. Measured quantities of water were added in step increments and the unfilled portion was vented to the atmosphere. A check of the model response when free on the water was made after each step in the fill operations. The results are shown in Figure 1.

The transition from no ballast water to a little over 40 percent flooding resulted in the model going from floating level to becoming somewhat unpredictable, Figures 1A, 1B, and 2. When the neutral stability region was reached, bow up or tail up, Figure 2, depended soley on which direction the ballast water initially started to move. The model responded like a spar buoy as the ballast weight was further increased. The value at which it sinks was calculated rather than determined empirically to preclude any chance of damaging the pool.

5.4.3 Towing — No Ballast or Parachutes. The initial towing rests were in waves of the equivalent full scale of 1.3 to 5.2 feet. The results are shown in Table 2 and Figures 3 and 4. Towing was through a bridle that simulated a four-point attachment to the booster's forward thrust structure inside the nose cone, as proposed by the contractor, for runs numbered 10 through 16. Subsequent runs used a two-point attachment 180 degrees apart.

The response to towing under the various conditions indicated considerable unsymetrical loading of both bridle configurations. This would impose high loads over small areas of the nose cone, particularly when the case is pitching rather violently. The nose cone also acts as a water scoop with considerable flow going both in and out. This leaves doubt as to whether the nose cone would survive actual towing in even moderate (up to 5-foot) seas. It appears that a bridle would have to be developed that would preclude interference between the towing hardware and the nose cone structure or else consider the latter to be expendable hardware.

5.4.4 Towing — With Ballast (No Parachute). Towing tests were conducted with water ballast in the case in the equivalent of waves near zero to 5.2 feet high. The amounts of ballast tested are shown in Table 3.

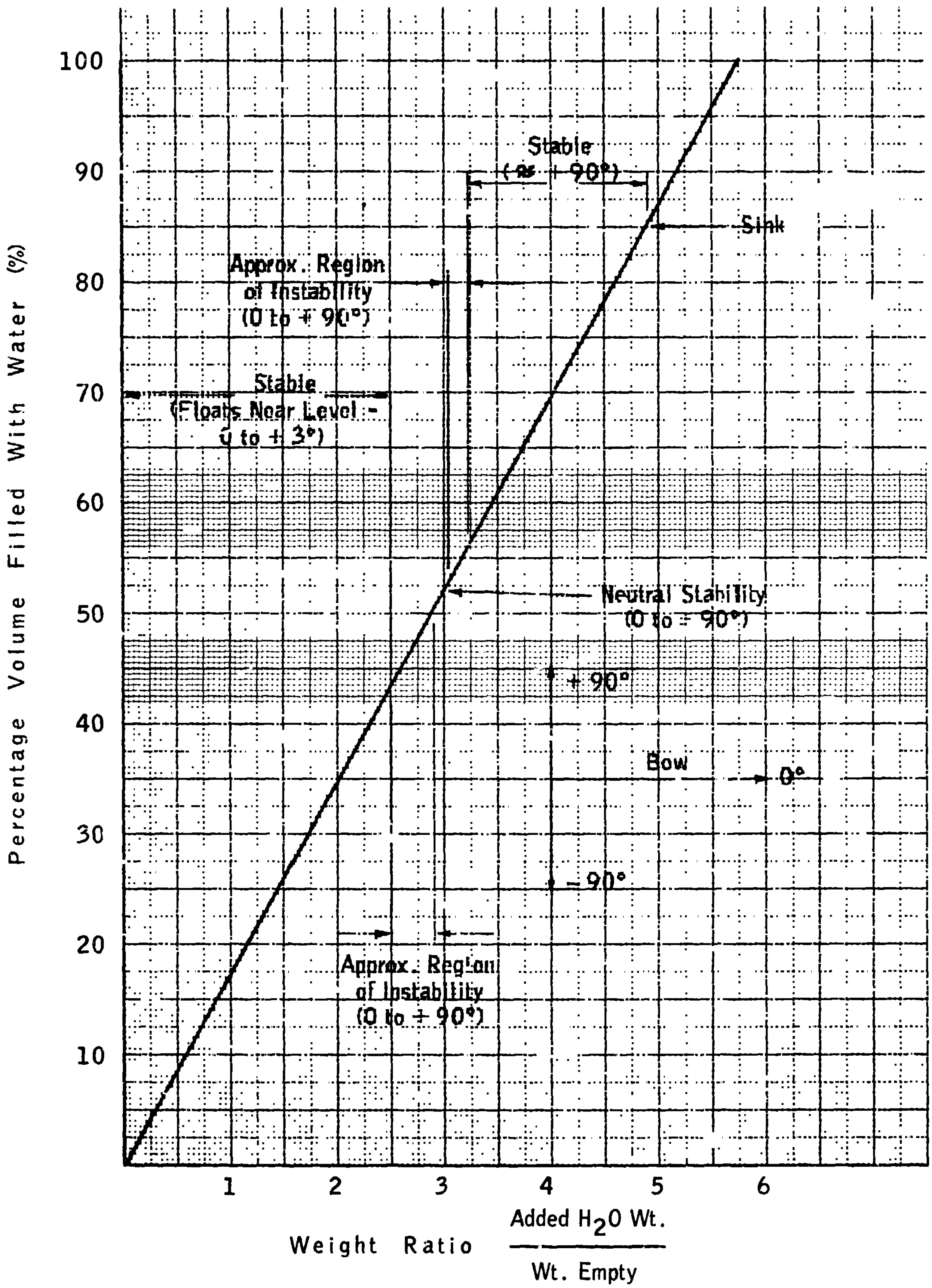


Figure 1. Effect of Flooding on Response of Booster Case in P· ·h Plane (Static-Calm Water)

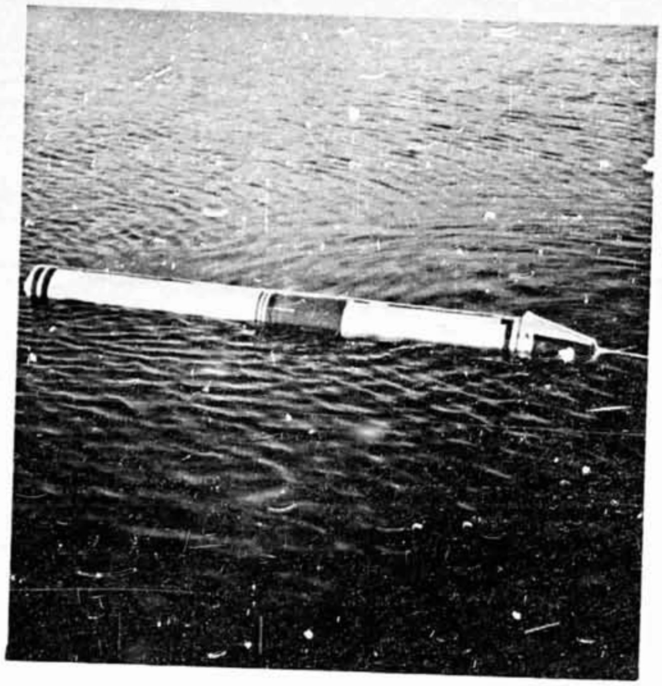


Figure 1A. Model Static Attitude with 50% of the Internal Volume Flooded

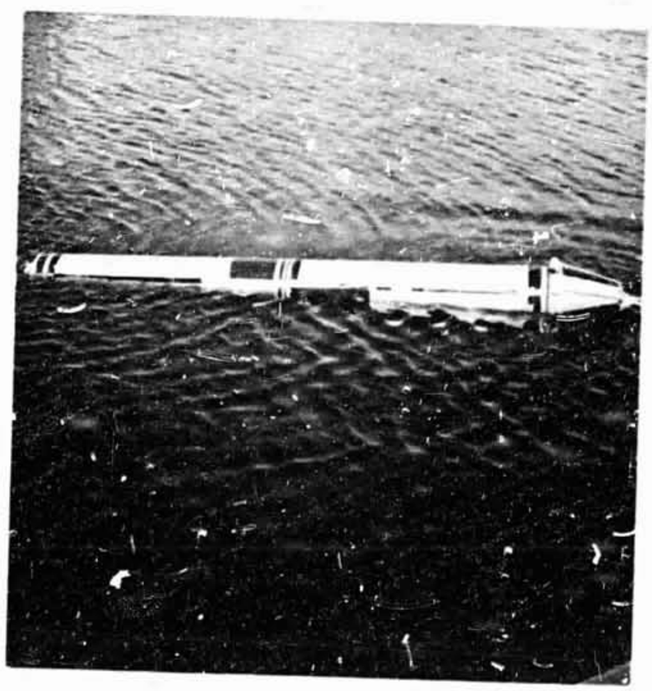


Figure 1B. Model Static Attitude with 55.4% of the Internal Volume Flooded

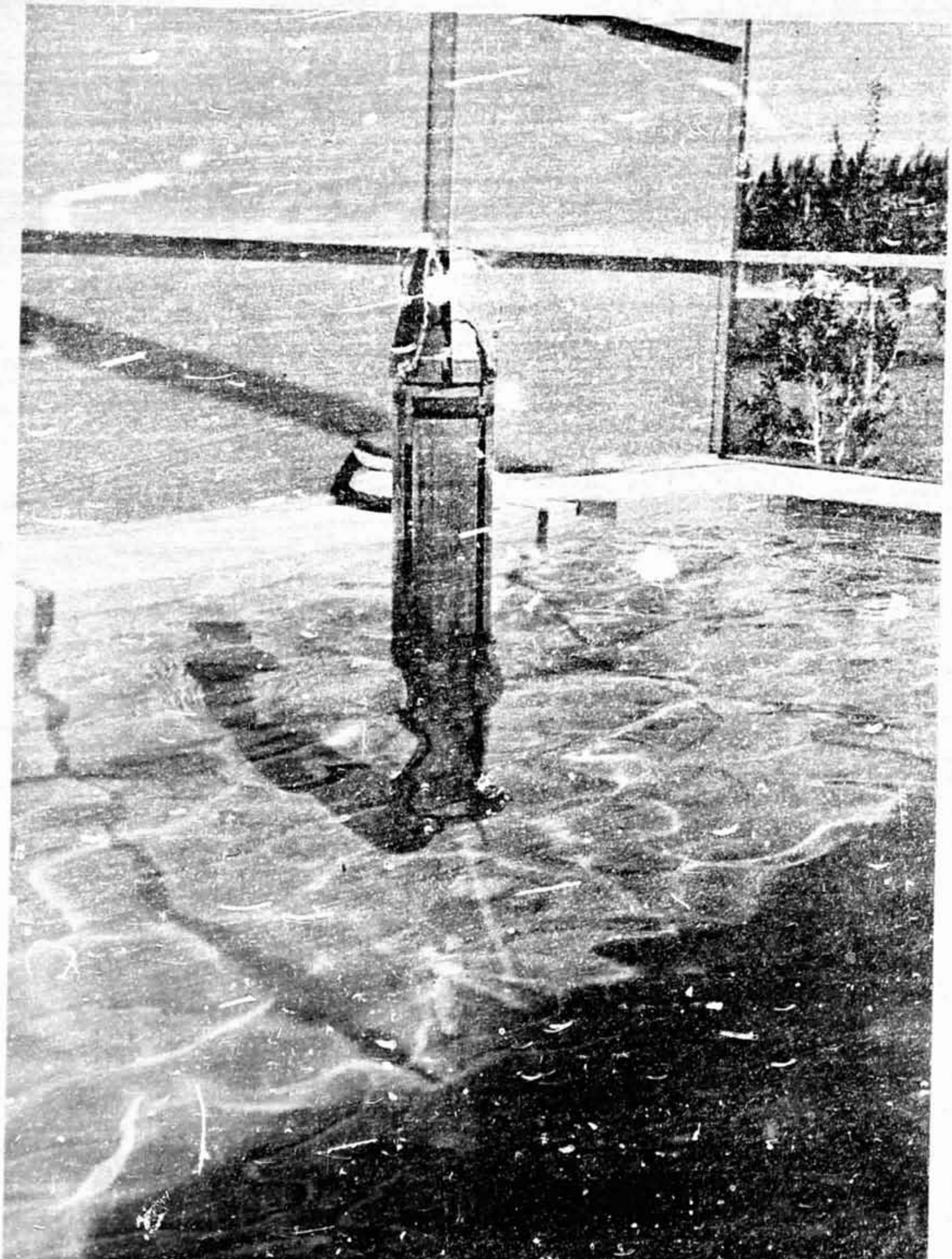


Figure 2. Ballast Water, With Over 55 Percent of the Internal Volume Flooded, Makes the Booster Case Respond Like a Spar Buoy

Table 2. Open Water Characteristics - No Ballast or Parachute

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
10	5.2	190	6	4	Wind N 8 kts. Into wind, considerable motion in pitch, some yawing.
11	"	"	"	"	Tow crosswind. Case rolls and tries to turn into wind; yaws into wind.
12	"	"	"	0	Free floating.
13	"	"	"	4	Tow downwird. Yaws left.
14	"	"	"	"	Tow into wind. Tracks better than run 10; still considerable pitch.
15	"	"	"	"	Tow crosswind. Results same as run 11.
16	1.3 - 2.6	32	4	11.8	Higher velocity did not improve characteristics.
17	5	100	6	4	Wind SE 5 - 8 kts. Shorter wave lengths (see run 10) increase response in pitch.
18	"	"	"	6	Crosswind (similar to run 11).
19	"	"	"	"	Downwind. More pronounced yaw.
19A	"	"	"	8	Into wind. Higher speed emphasizes the instability.
19B	Neg.	"	"	6	Yawing, and nose cone dips in and out of water.

*Values shown are equivalent full scale.

Figure 3. Towing in Equivalent of 5-Foot Waves (Bow in Up Portion of the Pitching Motion)

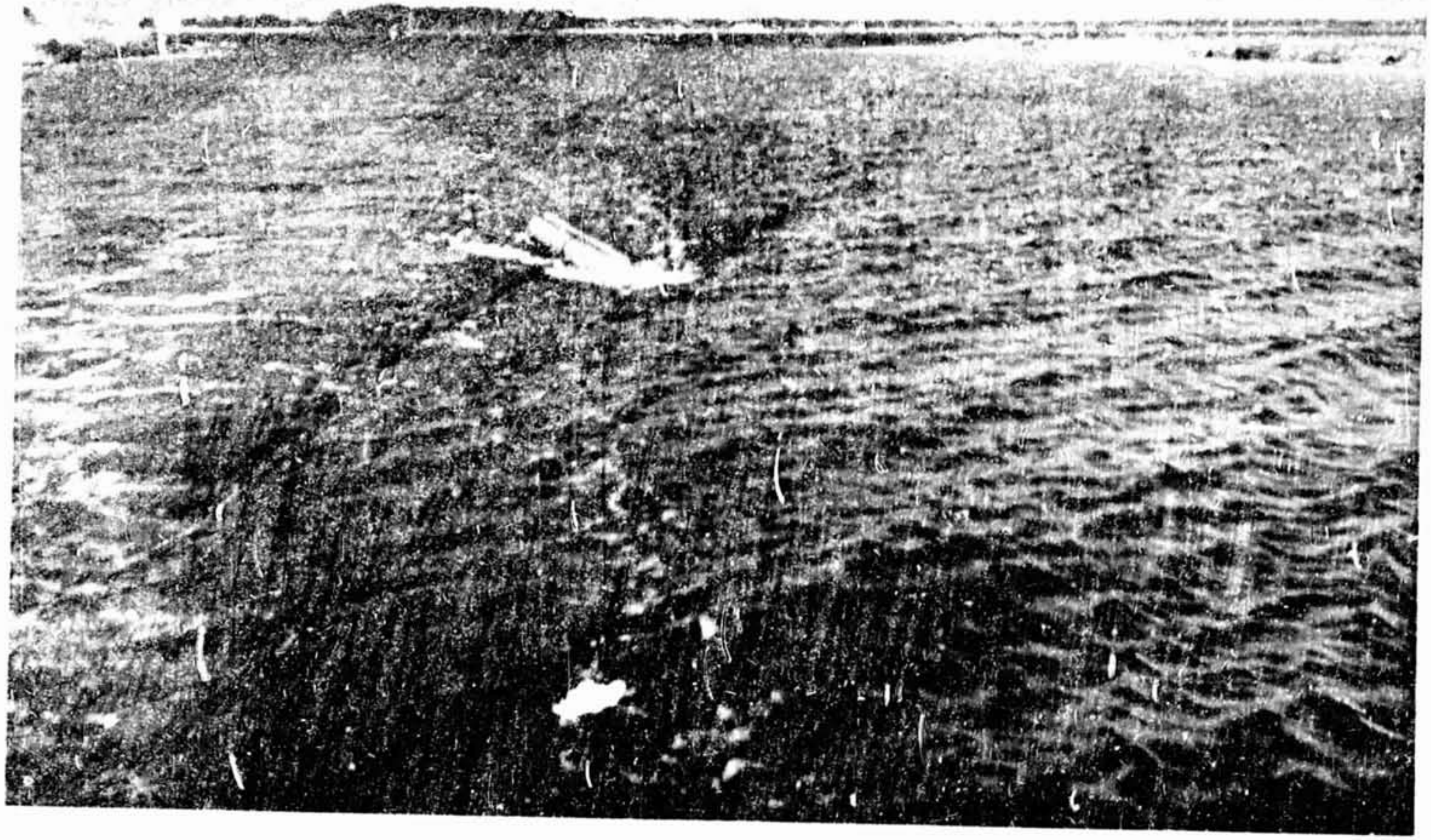


Figure 4. Towing in Equivalent of 5.2-Foot Waves (Bow in Down Portion of the Pitching Motion)

Table 3. Open Water Characteristics - Ballast But No Parachutes

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
20	Neg			0	Wind N 1 kt. Ballast to 50% of volume.
21	"			4	Wind N 1 kt. Ballast to 50% of volume.
22	"			0 - 4	Started from rest - accelerated to 4 kts.
23	1.3	60.3	6	2 - 4	Wind N 2 kts.
24	"	"	"	0	Increased ballast to 55.4% of volume. Free floated tail up.
25	"	"	"	0	Rotated by hand to horizontal - went back to tail up.
26	"	"	"	0 - 11.8	Increase in velocity did not improve response.
27	"	"	"	11.8	Would not stabilize.
28	"	"	"	11.8	Could not get the nose to come up.
29	"	"	"	0 - 11.8	Repeat of run 26.
30	"	"	"	0 - 8	Increased ballast to 62% of the volume. Runs bow down and stays there.
31	"	"	"	0 - 11.8	Increase in velocity makes case run deeper.
32	"	"	"	0 - 15.8	Varied velocity up and down. At highest speed the case submerged.

Table 3. Open Water Characteristics - Ballast But No Parachutes (Continued)

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
33	Neg.			15.7 - 0	Ballast at 50% of volume. Two-point towing harness 180° apart. Tow point at towing vessel connection 62* feet above the water for this and subsequent tests listed in this Table.
34	"			8	Slack in tow line allows nose to pitch down.
35	"			"	No slack in tow line.
36	"			15.7	No slack in tow line.
37	3.3	23	4	11.8	Ballast at 55.4% of volume. Wind WSW 8 - 10 kts. No slack in tow line for this and subsequent tests listed in this Table.
38	5.2	62		8.9	Ballast at 62% of volume. Model noticeably lower in water. Wind WSW 10 - 12 kts.
39	"	"	"	6.9	Tow into wind. Wants to yaw and roll.
40	"	"	"	8	Ballast at 67% of volume. Riding fairly low in water.
41	"	"	"	"	Ballast at 74.5% of volume. Towed crosswind; very low in water; high drag forces, especially when in yawed position.
42	"			"	Towed into wind. Same results as run 41.
43	"			"	Increased tow line length. Towed into wind. No appreciable loss of control compared to run 41.

Table 3. Open Water Characteristics - Ballast But No Parachutes (Continued)

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
44	"			8	Increased tow line length again, into wind. Resulted in high bow wave and increased instability characteristics.
45	"			15.7	Increase in speed did not change handling (except for appreciable increase in drag).
46	"			19.7	Same results as run 45.

*Values shown are equivalent full scale.

At 50 percent flooding, the case rides low in the water and, if the nozzle were not plugged, would probably take on more water. At 55.4 percent flooding, the case went tail up and the bow could not be brought up even by increasing the towing velocity (runs numbered 24 through 32).

Flooding to 62 percent made the towing response worse. Increasing the towing velocity made the case run deeper until it submerged at the equivalent of 15.8 knots in run number 32. These tests were terminated at this point to preclude the chance of losing the model.

In all tests prior to run number 33, Table 3, the models pitched nose down (negative α in Figure 5) as soon as a towing force was applied.

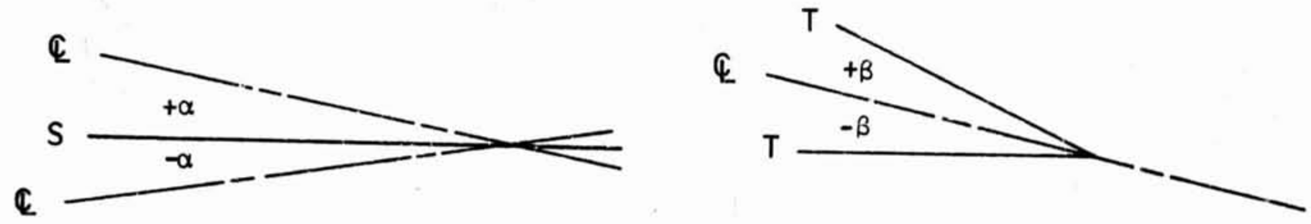
If the volume flooded was less than approximately 57 percent, Figure 1, the nose down pitch due to a towing force would result in the water in the case starting to move forward (towards the towing vessel). (Either waves or a towing force can result in movement of the ballast water inside the case.) It was usually possible to easily follow the reaction of the model due to this water movement, Figure 6. If the resultant negative moment was adequate to cause the angle α to go negative approximately 20 degrees or more, the model would try to go to $\alpha = -90$ degrees. Once this happened, it was not possible, by towing, to get the angle back to near zero (see runs numbered 24 through 32 in Table 3).

Case flooding in excess of approximately 57 percent of the volume resulted in the booster case acting like a spar buoy (see paragraph 5.4.2). In this situation, towing did not result in α reaching or passing through zero (horizontal).

5.4.5 Towing Geometry. It was apparent that regardless of the degree of flooding the towing geometry should be such that α and β remain positive, Figure 5. Then the case could be towed. The towing hardware was therefore changed, Figure 7, to meet these conditions for runs numbered 33 through 46, Table 3. In these tests, the model was being "pulled." This is the terminology used by commercial towing organizations to denote a straight towline. When "towing," the line has a catenary shape.

In this instance, the towline contact point with the towing vessel was the equivalent of 62 feet above the water, Figure 7. This would be unrealistic, since that is approximately the height of the flight deck of a U.S. Navy aircraft carrier. This distance could be reduced to one-half or less of this value. However, study of the tow harness configurations was terminated at this point.

The forces in the towline were not measured, due to a lack of adequate instrumentation. This parameter can best be investigated in towing tank tests that are scheduled to be conducted in 1973. It is apparent that the condtions where the booster fishtailed, dove, and/or rapidly oscillated in pitch will introduce undesirable surge loads on the towing vessel. If the case is flooded 60 percent or more, causing most of



Moment Force Due To Towline = TM (+ as shown)

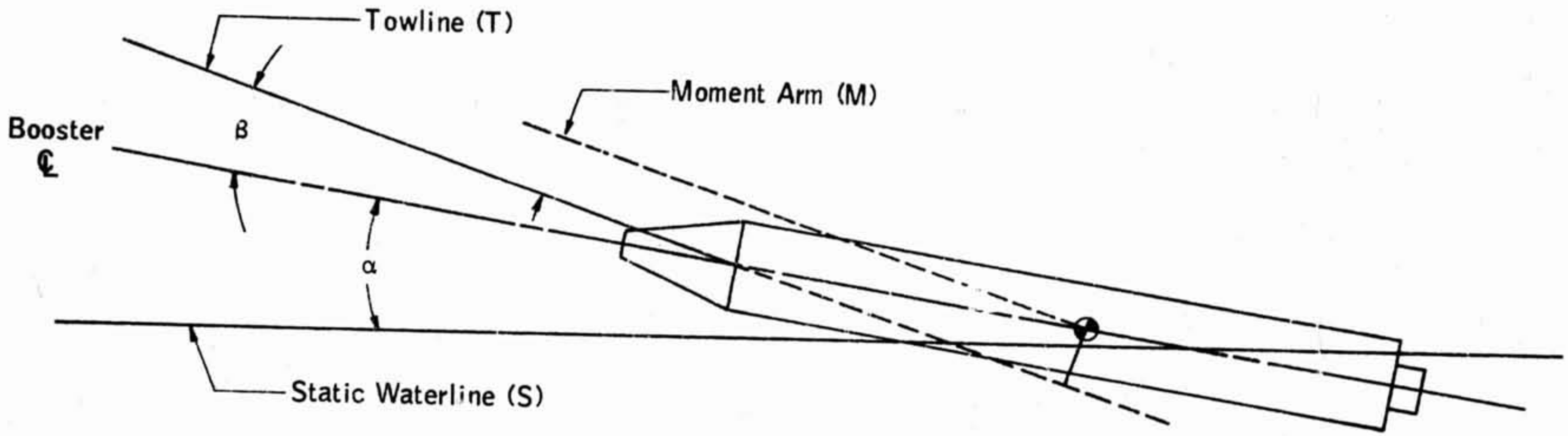


Figure 5. Geometry for Towing

Figure 6. Bow Going Down and Creating a Substantial Wave (Approximately 15 Feet High Full Scale)

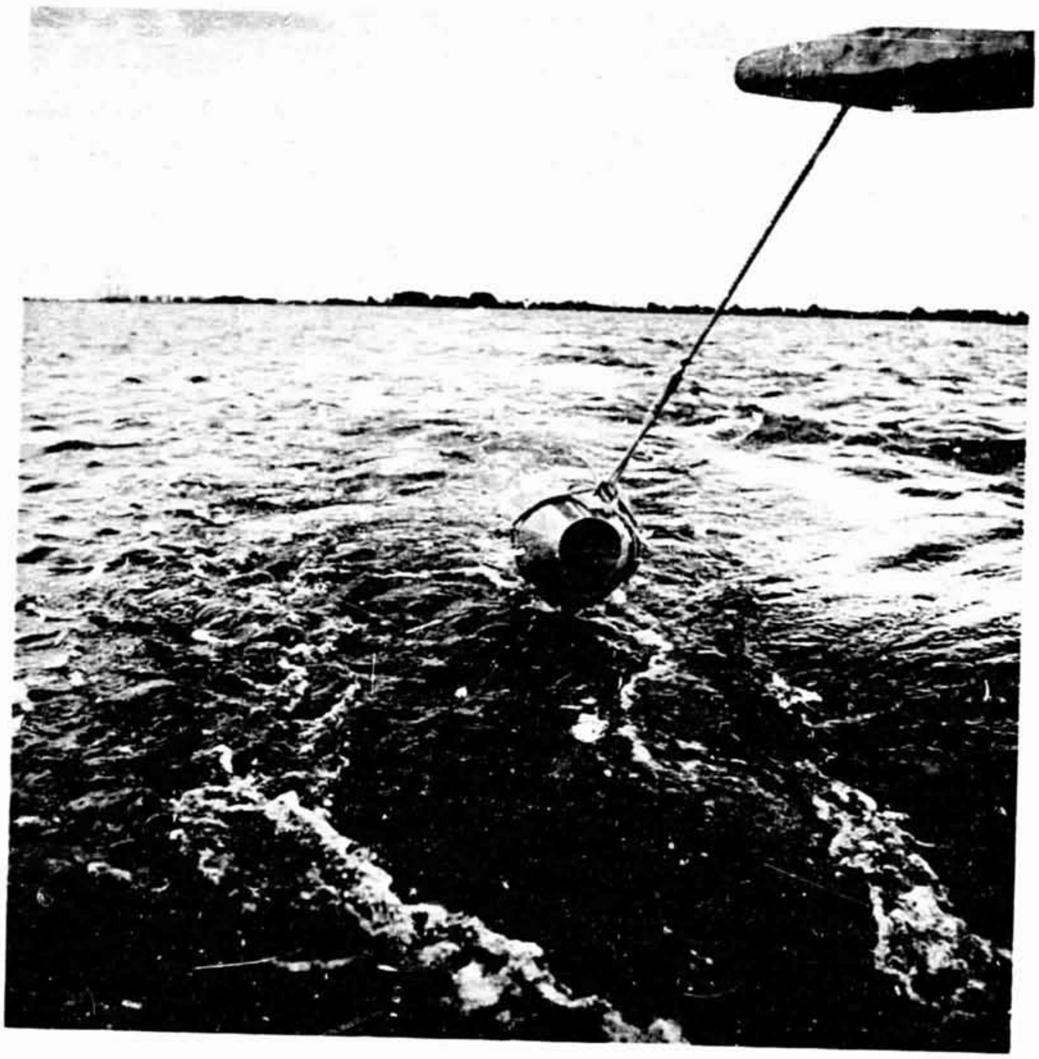


Figure 7. Configuration for Two-P‹ int Towing Harness 180° Apart. Run Number 33, Table 3.

the booster to run under water (see Figure 8), the sheer weight and drag loads may be more than a tug could cope with, even in moderate seas.

The range of wave heights, towing velocities, and degree of controlled flooding tested are shown in Figure 9. This range of testing was considered adequate for this investigation.

6.0 OPEN NOZZLE TESTING

6.1 BACKGROUND. Consideration has been given to leaving the rocket nozzle in the booster case open after burnout. The case would then enter the water in this configuration. If feasible, the boosters would then be returned to land in this configuration to avoid the cost and effort that would be needed to plug the hole during recovery operations. The model was therefore modified to have the full-scale equivalent of a hole 3.9 feet in diameter symmetrical with respect to the longitudinal centerline in the nozzle.

6.2 INITIAL TESTS. The model was dropped into calm water nose first, and also nozzle end first. In both cases there was sufficient rebound to have the model hit the water the second time in a near horizontal attitude. This was done without benifit of pressure and temperature scaling of the nozzle and internal case conditions; therefore, the observed reaction may or may not represent the full-scale condition. However, there was little or no water ingestion into the case at this time. The model floated high enough that, while free floating in the equivalent of up to 2-foot waves, no water entered the case. The characteristics were identical with those where the nozzle was closed and there was no ballast water inside the case.

6.3 INTENTIONAL FLOODING OF THE CASE. The nozzle end of the model was held underwater for the next test. Enough water was allowed to enter the case, in the equivalent of 2-foot waves, to have the open nozzle submerged and the internal gas stopped from venting to the atmosphere. Model reaction in the free-floating mode was the same as that for 40 to 50 percent of the volume filled with water, Figure 1. In approximately 10 minutes after being released, the model tended to go to a bow up position and slowly oscillate between approximately 65 to 80 degrees from the horizontal. It would not go nozzle up; therefore, it was assumed that the neutral stability point, Figure 1, had not been reached.

6.4 TOWING IN OPEN WATER. Towing in significant wave heights, Figure 10, gave considerably different results than those noted in paragraphs 6.2 and 6.3. The model reactions are noted in Tables 4 and 5. Each series of runs were initiated with the booster case empty.

Any appreciable wave conditions resulted in water intering the case through the open nozzle. Flooding rates and degree appear to be a function of both wave heights and towing velocity, Figures 11 through 16. This situation was not further defined, because the test setup did not provide a measurement of the amount of water in the case

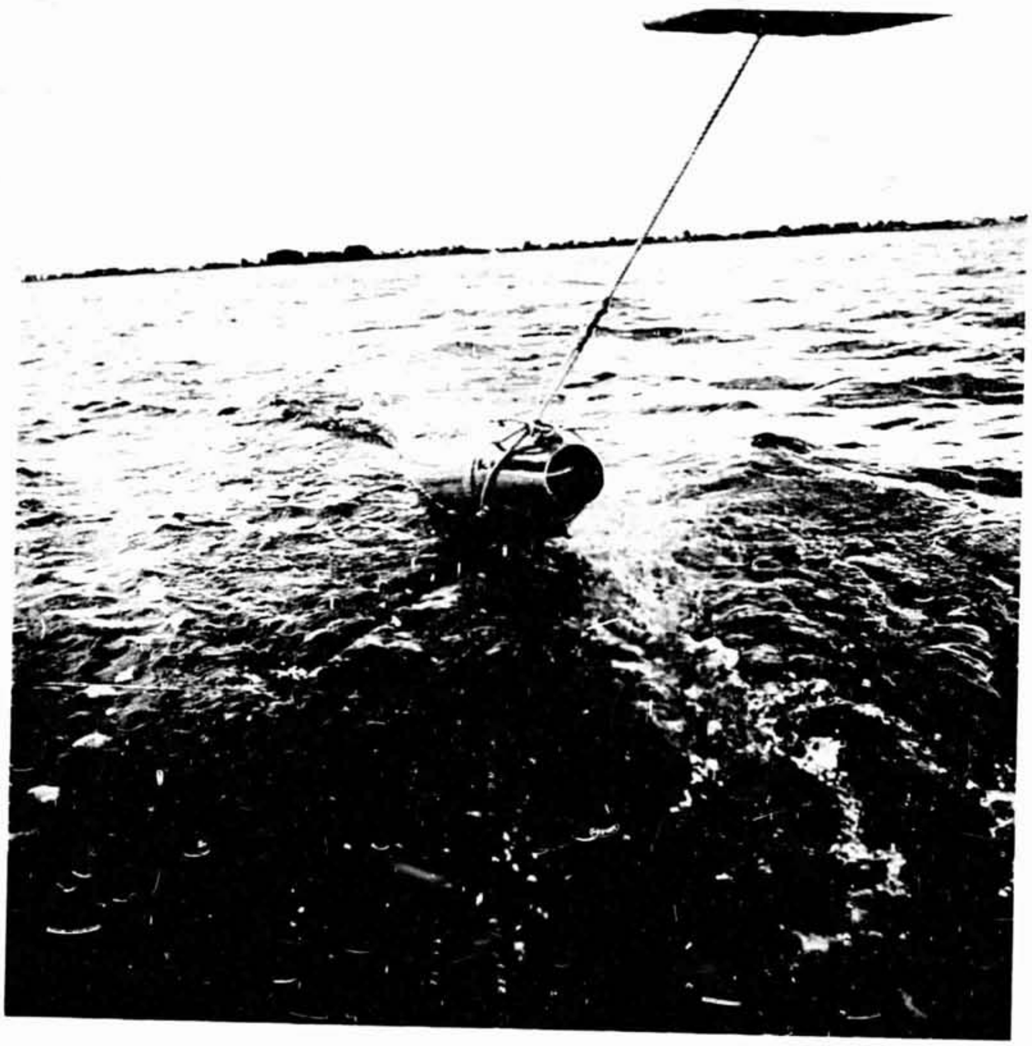


Figure 8. 67% of Internal Volume Flooded. Towing Velocity 8 Knots (Equivalent Full Scale).

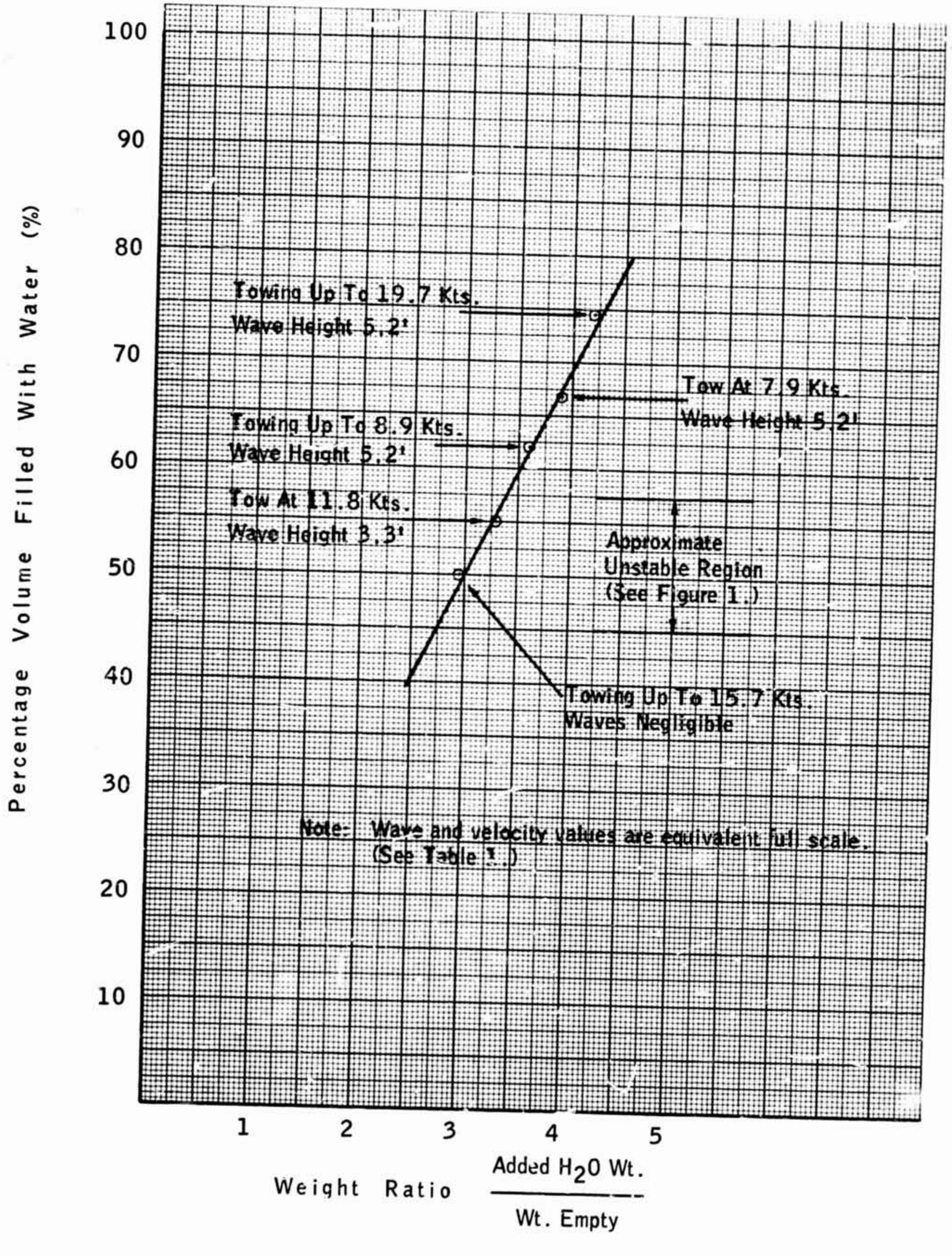


Figure 9. Range of Towing Tests with Ballast

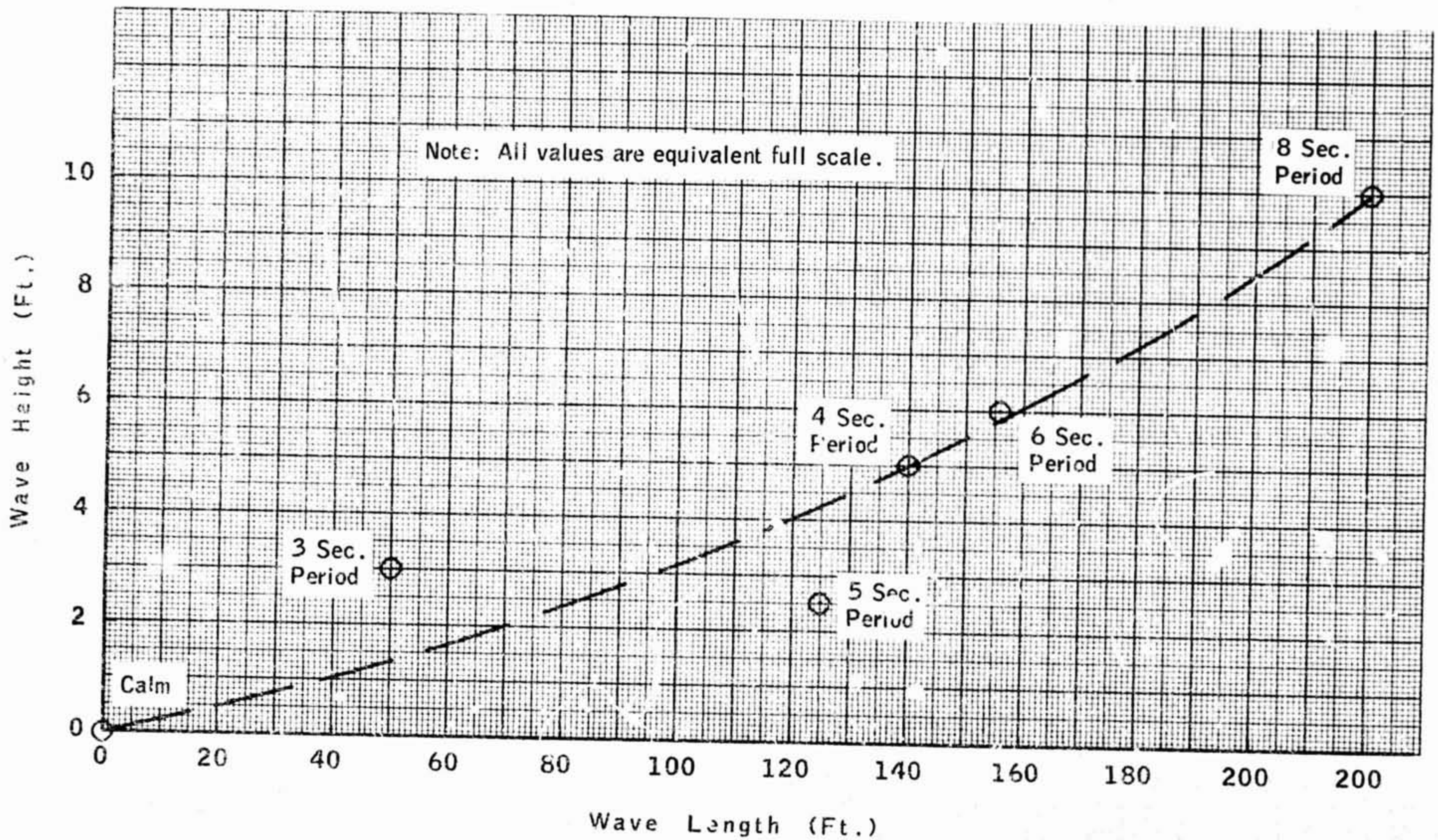


Figure 10. Range of Test Conditions for Towing with Open Nozzle

Table 4. Open Water Characteristics - Open Nozzle - No Parachutes

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
47	10	220	8	8	Towed reasonably well, except when the bow pitched down in wave troughs and water went over the top of the model. Tow was into the wind.
48	"	"	"	6	Tow into the wind. Extreme yawing. Apparent that some water had entered the case.
49	"	"	"	4	Tow downwind. Same results as run 48.
50	"	"	"	4	Tow downwind. Model erratic in pitch and yaw.
51	"	"	"	0	Free floating. Model exhibited neutral stability (see Figure 1) characteristics.
52	5	140	4	4	Into wind. No apparent entry of water into case.
53	"	"	"	12	Into wind. Model tended to tow with nose down slightly. Considerable pitching.
54	"	"	"	"	Crosswind showed same effects as into wind, except for some roll when going from crest to trough of the waves.
55	"	"	"	"	Downwind. Overtaking waves induced additional yawing. No apparent flooding of the case.
56	"	"	"	6	Downwind. Same as run 55.
57	"	"	"	4	Downwind. Same as run 55.
58	"	"	"	4	Downwind. Bow suddenly went up approximately 40°, apparently due to water in the case. No warning that the model was taking on water.

Table 4. Open Water Characteristics - Open Nozzle - No Parachutes (Continued)

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
59	5	140	4	0	Oscillated due to wave motion with bow up.
60	3	50		12	Continued run 59 off the lee side of a causeway, moving crosswind. After approximately 5 minutes, the model rotated to the horizontal position and then went to a continuing nose down position.
61				10	Severe oscillation along the centerline axis with an amplitude of approximately 4 feet.
62				8	Oscillation stopped but began again after approximately 2 minutes.

*Values shown are equivalent full scale.

Table 5. Open Water Characteristics - Open Nozzle - No Parachutes

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
63	6	156	6	0	Free floating; started with case empty. Model turned crosswind.
64	"	"	"	4	Into wind. Model appeared sluggish and ran slightly nose down. This suggests that there was some flooding during the free-floating test run.
65	"	"	"	4	Downwind. Bow under water.
66	"	"	"	2	" " " "
67	"	"	"	9	Downwind. Bow deeper than previous two runs.
68	"	"	"	0	Nozzle up approximately 60°.
69	3-1/2	125	5	0	Started this series with the case empty.
70	"	"	"	4	Downwind. Model started yawing, which indicates some flooding of the case. After approximately 10 minutes, the bow pitched down slightly and then went to an approximately 45° up position and stayed there.
71	"	"	"	8	Downwind. Maintained the nose-up attitude, but tracked well. High drag condition due to the large area under water.
72	"	"	"	0	Went to bow straight up (90°).
73	"	"	"	4	Into wind. Little yaw, but a noticeable oscillation along the case centerline axis.
74	"	"	"	9	Reaction similar to run 73.
75	"	"	"	11-1/2	Oscillation along the case centerline axis became more pronounced.

Table 5. Open Water Characteristics — Open Nozzle — No Parachutes (Continued)

Run Number	Waves*			Tow Velocity (Kts.)*	Comments
	Height (Ft.)	Length (Ft.)	Period (Sec.)		
76	Neg.	Neg.	Neg.	4	Started this series of runs with the case empty.
77	"	"	"	9	Towed okay.
78	"	"	"	0 - 9	" "
79	"	"	"	13	Bow went down enough to be covered by the bow wave.
80	"	"	"	13 - 4	Went back to level attitude at lower velocity. Some flooding of the case (less than 40% of total volume).

*Values shown are equivalent full scale.

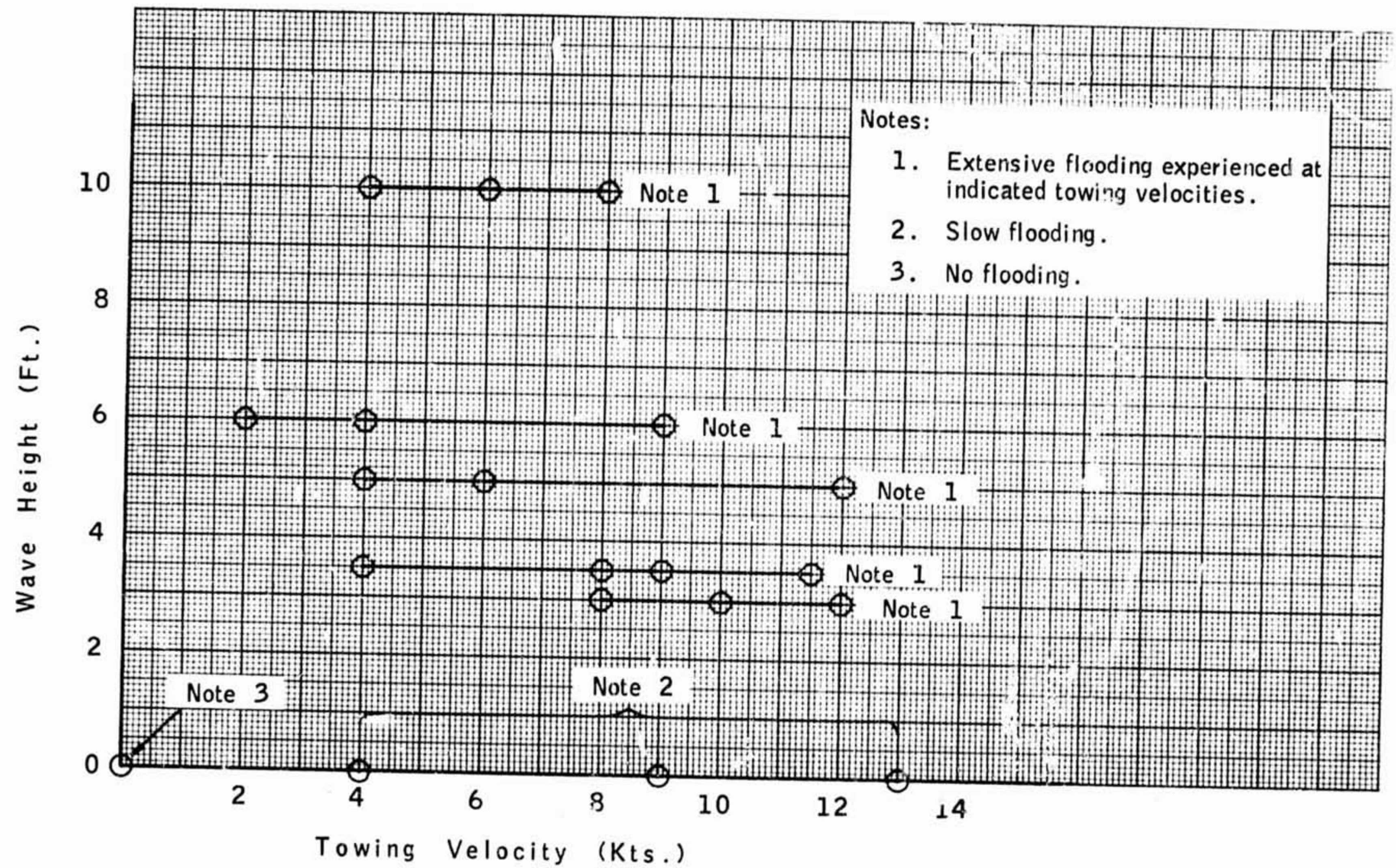


Figure 11. Effect of Open Nozzle

Figure 12. Free Floating in 6-Foot Waves with Open Nozzle (Start of Tests, Table 5)

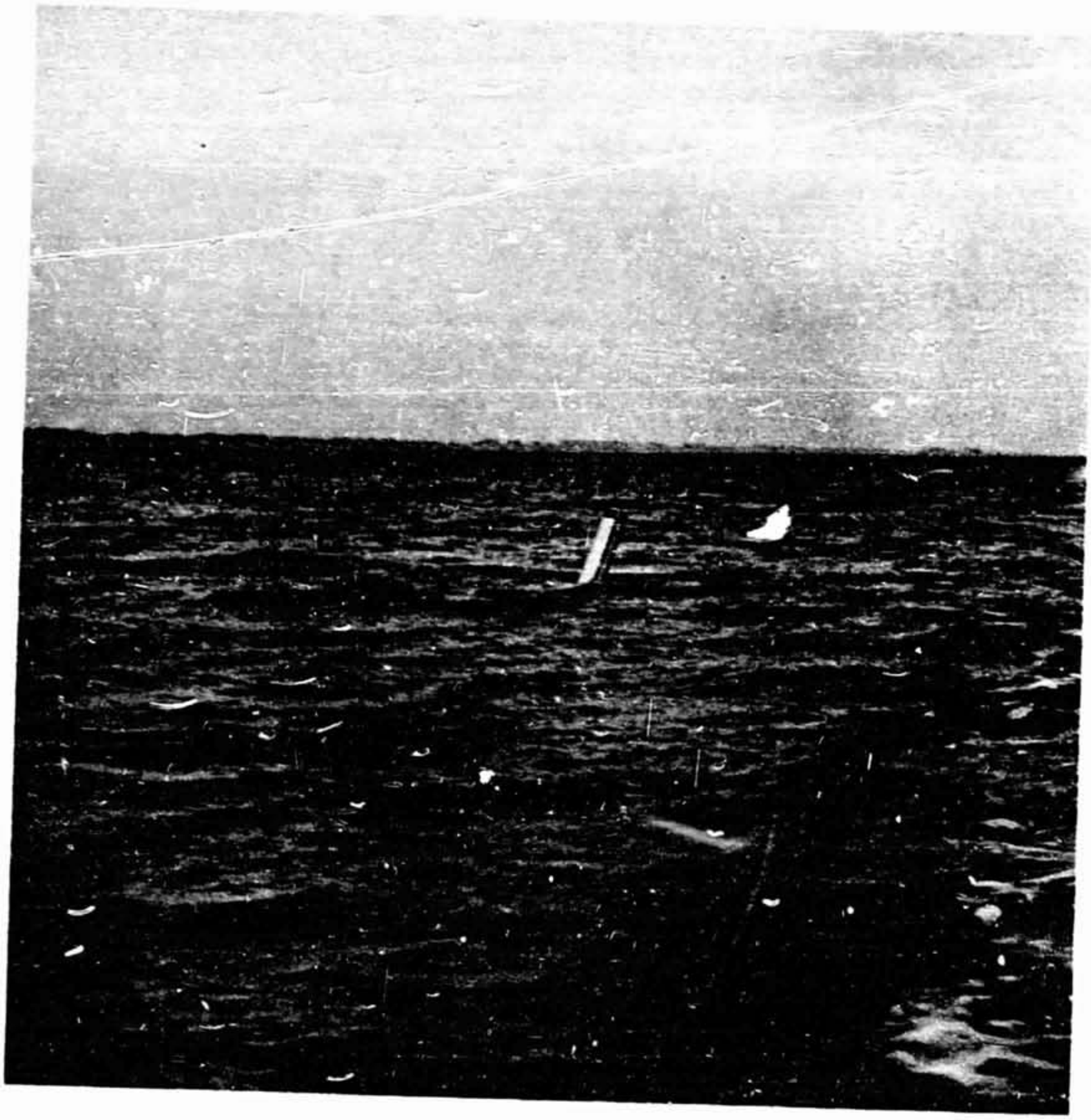


Figure 13. Booster Attitude After Towing with Open Nozzle at 4 Knots Downwind (6-Foot Waves)

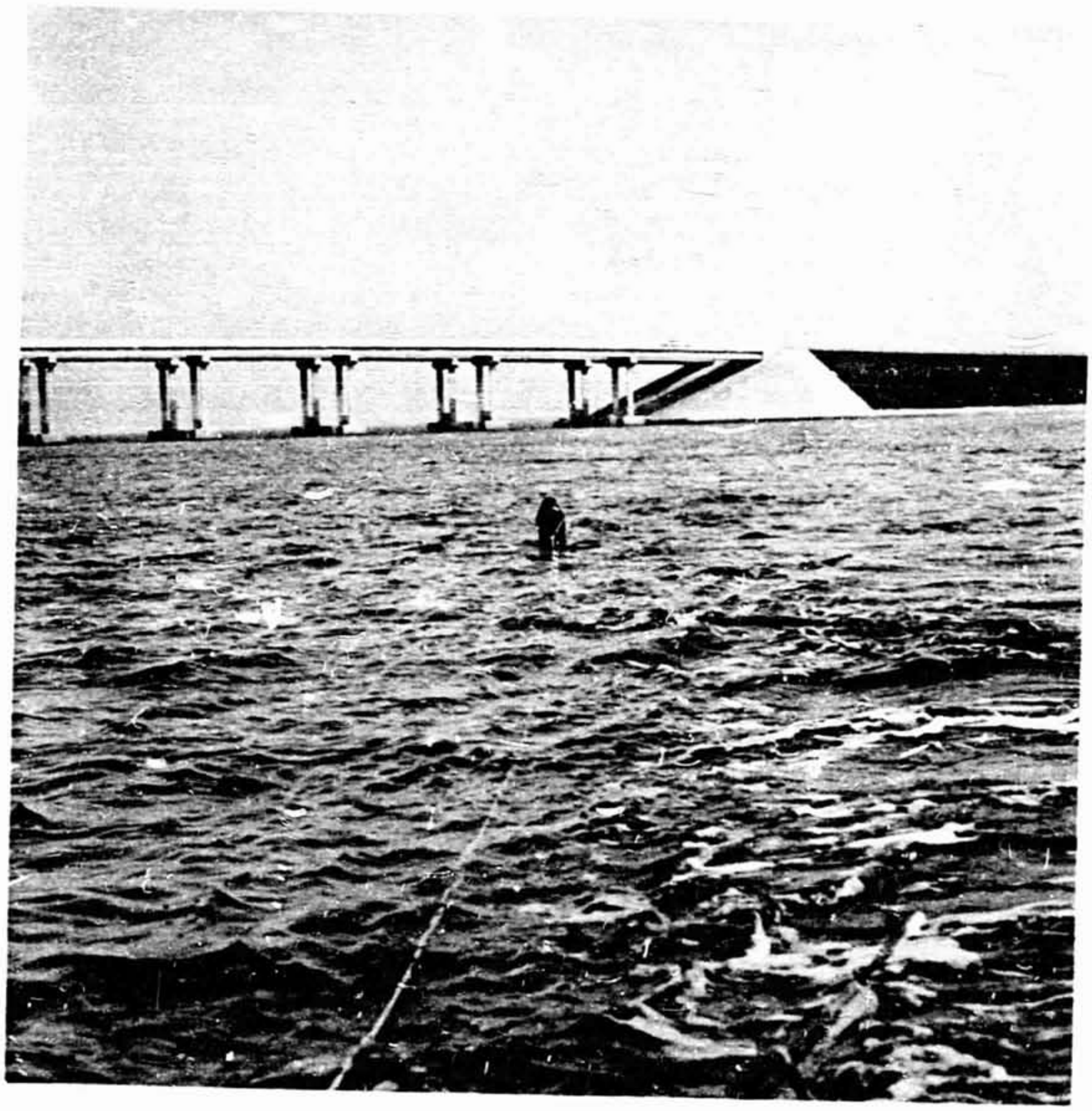


Figure 14. Booster Attitude After Tow at 4 Knots in 3-1/2 - Foot Waves

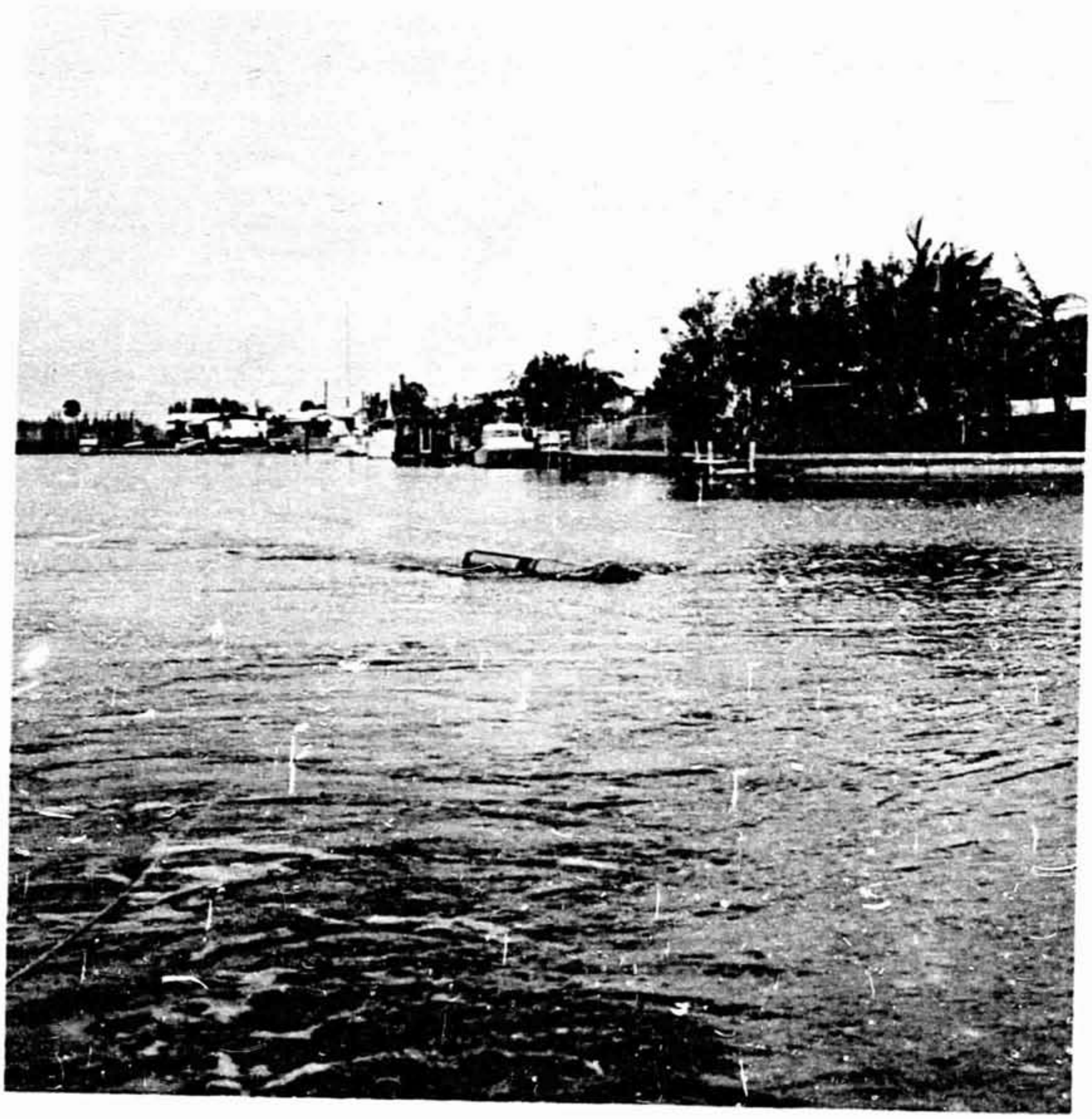


Figure 15. Slowly Flooding During Tow in Calm Water

Figure 16. Yawing due to Case Flooding (Less Than 40% of Total Volume)

at any particular time. The water quantity could only be estimated based on the model reactions and the data in Figure 1.

When free floating in calm water, the geometry of the nozzle opening relative to the waterline precluded any flooding. However, when towing in calm water, the model would slowly flood, Figure 11. In this test series, it was estimated that the degree of flooding was less than 40 percent of the volume.

7.0 PARACHUTES ATTACHED

7.1 BACKGROUND. It is not yet known if it would be best to cut the parachutes loose just as the booster hits the water, before the booster hits the water, or leave them attached. The tests covered in paragraphs 5.0 and 6.0 were conducted without the presence of parachutes. The effect of leaving the parachutes attached was therefore conducted as the next step in the evaluation.

7.2 RESULTS. The parachutes used for this test were the ribbon type, and each had an equivalent full-scale size of 129.5 feet. The risers were connected to a single nylon line that was, in turn, attached to the nose of the model at the centerline.

7.2.1 Calm Water. In calm water (free floating), the parachutes floated for several minutes and then began to slowly settle towards the bottom. There was no noticeable change in the attitude of the model (no ballast). It appeared that the effects of the parachutes sinking would not be significant unless the case was sufficiently flooded to be very unstable.

7.2.2 Waves. Free-floating tests in wind driven waves up to an equivalent of 4 feet did not disclose any undesirable reactions. The parachutes partially opened (blossom) and reduced the drift of the case to a very low velocity. This sea anchor effect also turned the model into the wind and had a dampening effect on the model motion in the waves.

The model could not be towed with the parachutes attached. The sea anchor effect was such that the towing vessel could not be maneuvered.

7.2.3 Parachute Recovery. Recovery was accomplished without the parachutes and lines fouling the towing vessels' screw and rudder. The method used was to encircle the parachutes with a lightly weighted nylon line which was subsequently drawn in like a fish net. This gathered the lines and collapsed the canopies. This made it easy to haul everything aboard, especially since the ribbon design allows the water to easily escape from inside the canopy.

8.0 MEASUREMENTS

Wave heights and lengths were taken from photographs by comparison with the known model dimensions. No correction was made for image errors due to camera position.

Wave periods were measured by stop watch and by observing the wave crests as they passed a fixed navigation marker. No attempt was made to measure the periods of the model when oscillating due to the tow forces.

Towing forces were not measured. Such data can better be obtained in the towing tank tests scheduled in 1973.

9.0 SUMMARY

9.1 NO BALLAST WATER IN BOOSTER - NO PARACHUTES. If the case is not flooded, the booster will sit high in the water in the horizontal attitude. Problem areas include:

A. Possible drift rate in high winds that will tax the capacity of a tug to overtake it.

B. Considerable heave and yawing when floating free in high wave states that will make approach by a vessel hazardous.

C. Booster will not tow reasonably well, especially crosswind and some downwind conditions, without a stabilization device(s).

D. Booster tows in a nose-down attitude that increases the drag; and also, water is thereby forced into the nose cone.

9.2 BALLAST WATER (FLOODING OF BOOSTER CASE - NO PARACHUTES. The degree of flooding of the case after splashdown has a major effect on the stability characteristics and attitude of the booster under static and dynamic conditions.

The ranges of the probable flooding of the booster after splashdown will have to be established before the recovery hardware requirements can be finalized. Drop tests were not attempted because of a lack of means to scale the pressure and temperature parameters inside the case.

9.3 TOWING - NO PARACHUTES. All three models exhibited similar behavior in the towing modes.

9.3.1 Towing Harness. The booster design is such that the towing point(s) is limited to the region of the forward thrust structure in the top dome of the propellant case (behind the nose cone). Towing harness attachment points tested were one, two, and four at this location. Available drawings did not indicate adequate structure to accommodate an attachment point on the centerline of the case. All attachments were therefore made at the outer ring of the forward thrust structure. In addition, a single-point attachment on the booster case centerline would cause the nose cone to saw the towline.

9.3.1.1 Single Attachment Point. A single point of attachment (off the centerline) caused the model to rotate until the line was straight between the towing vessel and the attach point. This induced a yawing moment that prevented the model from tracking the towing vessel.

9.3.1.2 Two-Point Attachment. This system, like the four-point attachment, exhibited interference with the nose cone structure. It was, however, a simpler harness and better than either a single- or a four-point attachment.

9.3.1.3 Four-Point Attachment. Four-point attachment resulted in the model being more stable. However, when the model responded to varying wave and water ballast conditions, the towing harness placed localized high loadings on the nose cone. In the full-scale case, this problem would undoubtedly cause damage to the nose cone and/or the towing harness.

9.3.2 Nose Cone. The tip of the nose cone will be separated from the case during the descent to allow the parachutes to deploy. This leaves an empty space in the nose cone forward of the dome of the propellant case. The open nose cone scoops up water in all the nose-down to up-pitch modes. In several test conditions, water was observed to flow in and out of this area. Sufficient data are not available to attempt to predict if this water movement will impose critical loading on the nose cone structure.

9.3.3 Effect of Water Ballast. Partial flooding of the booster case resulted in a marked change in the response characteristics of all three models. Such change was characterized by a deterioration in the handling qualities. The conditions encountered with approximately 50 percent water in the case were yawing (fishtailing or strong yaw in one direction), high bow waves, and traveling nose down, or diving.

Flooding over approximately 55 percent of the case volume resulted in the booster going to a vertical attitude. When vertical with the nose down, it was not feasible to tow at any reasonable velocity because the bow would not come to the surface. When vertical with the nose up, towing will require considerable power because of the large wetted surface, weight, and unfavorable angle of attack of the booster.

Flooding less than 45 percent of the case volume will result in considerable instability due to the shifting of the water inside the case caused by wave motion and towing forces.

9.3.4 Velocity. Towing speeds, equivalent to full-scale velicities of 2 to 20 knots, were investigated. The higher velocities only aggravated the undesirable responses of the booster models. These were characterized by:

A. High bow waves with attendant high drag.

B. Models diving below the surface.

C. Oscillations in pitch and/or yaw.

D. Oscillations along the axis of the case centerline when flooding was in excess of 55 percent of the case volume.

E. Radical changes in the attitude of the case when the degree of flooding changed.

9.4 OPEN NOZZLE.

9.4.1 Splashdown. The response and attitude(s) of the booster case is sensitive to the degree of flooding of the internal vloume. If splashdown is to be accomplished with an open nozzle, it will be necessary to establish the degree of flooding, if any, during this operation for various sea states. Such information will be vital to establish a recovery concept.

9.4.2 Free Floating. The booster case did not flood when floating empty in calm water. Waves, however, high enough to reach from the waterline to the lip of the nozzle resulted in flooding. Flooding continued until the nozzle opening was completely submerged. Significant waves (3-foot equivalent full scale) induced sufficient motion in pitch for portions of the trapped air to vent and allow additional flooding, even after the nozzle was underwater. The extent of such flooding was estimated to be less than 40 percent of the case internal volume.

9.4.3 Towing - No Parachutes. Flooding of the case was experienced at all of the test towing velocities and sea states, Figure 11. When towing in calm water, the rate and degree of flooding was very low compared to other test results. The higher the wave height the faster the rate of flooding. In each case tested (wave heights of 3 feet, and up to 10 feet), the flooding exceeded 55 percent of the volume and the case response became the same as a spar buoy, Figure 1.

9.5 EFFECT OF ATTACHED PARACHUTES.

9.5.1 Calm Water. Although the parachutes slowly sink, the effect on the model was not significant.

9.5.2 Waves. The parachutes proved to be excellent sea anchors that reduced the instability and drift of the model in wind driven waves.

9.5.3 Towing. The model could not be towed due to the drag induced by the parachutes.

10.0 CONCLUSIONS

10.1 BASIS. The results of these tests have indicated that an acceptable recovery concept can be developed. The conclusions made herein are contingent upon similar results from subsequent scheduled tests.

These tests were limited to a study of the stability and control characteristics of the case when floating in the ocean after splashdown. Consideration was not given to other vital factors such as corrosion.

10.2 NOZZLE OPENING. Flooding of the solid rocket booster complicates the recovery, especially when more than 40 percent of the volume of the case is filled with water. The recovery concept should include closing the nozzle before significant flooding and/or have a means to pump the water out.

10.3 TOWING. Towing the case with a commercial type "sea going" tug is feasible provided:

A. The flooding of the case is controlled as noted in paragraph 10.2.

B. A device is used to stabilize the case in yaw.

C. A device is used to prevent the case from running at a negative angle of attack (angle between the case centerline and the horizon).

D. Hookup can be accomplished without the tug getting close enough to the case to risk collision (with or without flooding of the case).

E. The towing harness configuration precludes interference between the towline and nose cone.

10.4 PULLING. The booster can be pulled (condition where the towline is so taut that there is not a noticeable catenary in the line) but would require considerable power if there is an appreciable amount of water inside.

10.5 PARACHUTES. The parachutes should remain attached to the booster after splashdown (effect on the splashdown was not examined). This is desireable because it:

A. Precludes loss due to sinking.

B. Helps stabilize the booster and decreases the down wind drift rate.

C. Provides a means for the towing vessel to get a line on the booster without getting close enough to risk a collision.

APPENDIX A

1/27 SCALE TITAN IIIC MODEL

A.1 MODEL DESCRIPTIO.

The Titan IIIC model shape and size was developed as shown in Figure A1. The cylinder of the model was a standard cardboard mailing tube. The end cones were shaped in styrofoam and then waterproofed. The tail cone was fabricated from sheet aluminum and the nozzle was plugged. Weights were placed inside the tube to obtain the necessary total weight and distribution.

Varnish was found to be inadequate to seal the cardboard from the effects of water. The model was therefore covered with fibre glass cloth and sealed with resin.

Towing and recovery was accomplished using a fishing pole with the line attached to an eye bolt located 5.4 inches behind the nose of the model.

A.2 TOWING

A.2.1 DISCUSSION. Wind and waves created the expected unstable reactions, Tables A1, A2, and A3. In the full scale situation, the fishtailing across the tug's wake would impose severe loads on the booster and the tug.

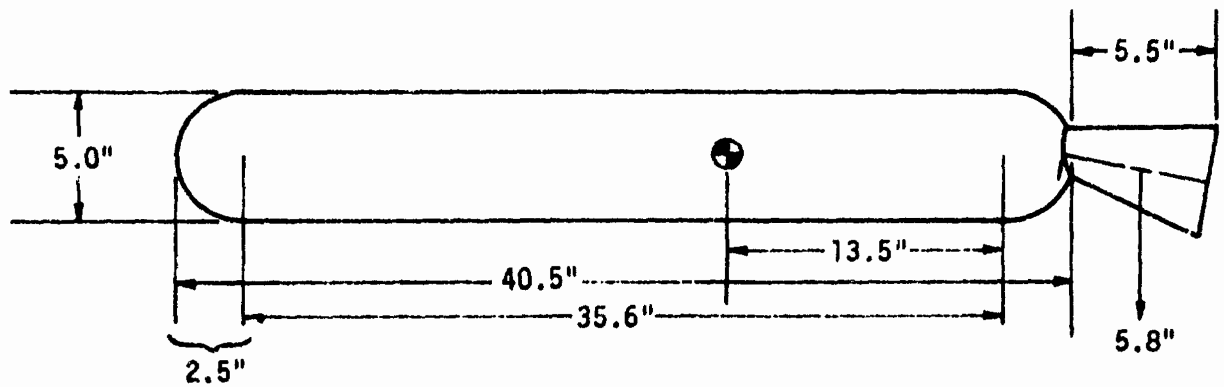
The adverse reactions noted in Test 4, Table A1, resulted when the wave height was approximately the same as the model diameter and the wave length approximately the same as the model length. This corresponds to a swell condition of 11.5 feet high and 103.5 feet in length. Such wave heights would be encountered approximately 9 percent of the time, Reference 2, when operating in the Atlantic Ocean areas. Swells of this magnitude occur approximately 15 percent of the time.

The bow of the model was too blunt (1/2 of a sphere) to tow properly. The waves from the bow tended to go over the top of the model, Figure A2, rather than the shape separating the waves like the bow of a ship. When the booster pitches down due to the effects of the wave action, the resulting splash is very high. In Figure A2, the splash due to this action is the equivalent of 38 feet high (full scale). This results in a high drag situation and is probably a major contributor to the instability situations such as observed in Test 14, Table A1.

The towing speed could not be reduced below approximately 4 knots due to the limitations of the towing vessel. This, in full scale, would be close to 20 knots. Such towing velocities are rare in the current state-of-the-art and should have been approximately one-half of the values tested. The higher velocities probably magnified the undesirable features of the dynamics of the model.

Towing in calm seas appears possible although instability will be introduced by the screw(s) and rudder movements of the tug(s).

Full Scale (1/27)			
Weight 185,000 lbs.	Diameter 135"	Length (Minus Nozzle) 1094"	Center of Gravity 365" From Rear



Weight = 9.75 lb.
Radius of gyration = 12.7 in.
Longitudinal moment of inertia = 704,000 gram-inch^2

The longitudinal moment of inertia and the center of gravity were based upon data from a Titan IIIC SRM. The roll inertia was not taken into consideration in the construction of this model.

Figure A1. Titan IIIC Model and Booster Characteristics

Table A1. Test Details*

Test Number	Date	Time	Wind (kts.)	Condition	Comments
1	7/20/72	1130	E10	Tow downwind. Towline 140" long. Attachment 5" above water.	Boat velocity about 4 kts. Model fishtailed back and forth across the wake of the screw whenever there was a disturbance (such as rudder movement).
2	"	1150	"	Tow downwind. Towline 180" long. Attachment 5" above water.	Boat velocity about 4 kts. Fishtailing dampened compared to Test 1 but movement was more abrupt.
3	"	1205	"	Tow downwind. Towline 325" long. Attachment 5" above water.	Boat velocity about 4 kts. Model swung wide of wake and stayed there except when boat turned (went outboard of turn).
4	"	1225	"	Tow into wind. Towline 325" long. Attachment 5" above water.	Boat velocity about 4 kts. Wake wave length same as model length and 5" high. Model pitch severe and of constant frequency.
5	7/27/72	0925	S5	Free float. Wave heights 1".	Model stayed crosswind occasionally swinging 3/4 of turn to downwind. Bobs up and down - some roll - no noticeable pitch.
6	"	0940	SSW10	Free float. Wave heights 6".	Same as Test 5 but considerably more motion, especially in roll.
7	"	0945	SSW8	Tow crosswind. Wave heights 2". Towline length 280".	Pitch motion results in waves breaking and going over the model.

Table A1. Test Details* (Continued)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
8	7/27/72	1010	SSW5	Free float. Wave heights 4".	Results consistent with Tests 5 & 6.
9	"	1015	"	Free float. Wave heights 5".	Results consistent with Tests 5 & 6.
10	"	1130	SE5	Towing 3/4 downwind. Wave height 1". Towline length 280".	Boat velocity 4 kts. Bow of model "plowing" through water (high drag condition).
11	"	1135	SE5	Towing 3/4 downwind. Wave height 1". Towline length 280".	Boat velocity 6 kts. Bad bow wave (high drag).
12	"	1140	"	Towing into wind. Wave height 1". Towline length 550".	Boat velocity 6 kts. Towline let out to get model out of effects of boat wake. Same results as Test 11.
13	"	1142	"	Same as Test 12.	Boat velocity 10 kts. Increased size of bow wave compared to Test 12.
14	"	1145	SE8	Towing into wind. Wave height 5". Towline length 550".	Boat velocity 10 kts. Pitching motion severe. At one point the model submerged and crossed the boat wake.
15	"	1155	"	Same as Test 14 except Towline length 1150".	Boat velocity 10 kts. Increased towline length to get farther from boat wake. No noticeable change in results except towline had a bow in it.

Table A1. Test Details* (Continued)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
16	7/27/72	1200	SE8	Same as Test 15.	Boat velocity 6 kts. No change in results.
17	"	1202	ESE5	Towing into wind. Wave height 1". Towline length 1150".	Boat velocity 6 kts. Bad bow wave (high drag).
18	"	1204	"	Same as Test 17.	Boat velocity 4 kts. Big bend in towline. Model leads away from boating heading. Bad bow wave.

* The variation in winds and wave conditions were primarily the result of operating in clear areas and off the lee side of islands and causeways.

Table A2. Test Details**

Test Number	Date	Time	Wind (kts.)	Condition	Comments
1A	8/3/72	0915	WNW0-3	Free floating. (No chute). Wave Height 1/2".	
2A	"	0925	5	Towing into wind. Wave height 1". (No chute).	Boat velocity 4 kts. Model yaws to starboard. Significant bow wave.
3A	"	0930	5	Towing into wind. Wave height 1 1/2". (No chute).	Boat velocity 6 kts.
4A	"	1000	5	Towing downwind. Wave height 1 1/2". Boat wake 3 1/2". (No chute).	Boat velocity 4 kts. Boat wake traveling in opposite direction to wind wave.
5A	"	1030	0	3-4" swell. Parachute attached to bow.	Parachute and lines exhibit considerable slack which has to be taken out before the sea anchor effect becomes noticeable.
6A	"	1040	0	4" swell. Parachute on.	Same as 5A.
7A	"	1045	0	5" swell. Parachute on.	Same as 5A.

** Motion Picture Coverage (24 frames rate).

Table Table A3. Test Details***

Test Number	Date	Time	Wind (kts.)	Condition	Comments
8A	8/3/72	1300	E5	Towing downwind. 6" wave (boat wake).	Boat velocity 4 kts.
9A	"	1310	"	Towing downwind. 6" wave (boat wake).	Boat velocity 8 kts.
10A	"	1320	"	Tow into wind. 3-4" boat wake.	Boat velocity 4 kts.
11A	"	1335	"	Tow crosswind. 8" boat wake.	Boat velocity 4 kts.
12A	"	1350	"	Tow crosswind. 2" boat wave.	Boat velocity 4 kts.
13A	"	1405	"	Free floating. 2" boat wave.	

*** Motion Picture Coverage (32 frames rate).

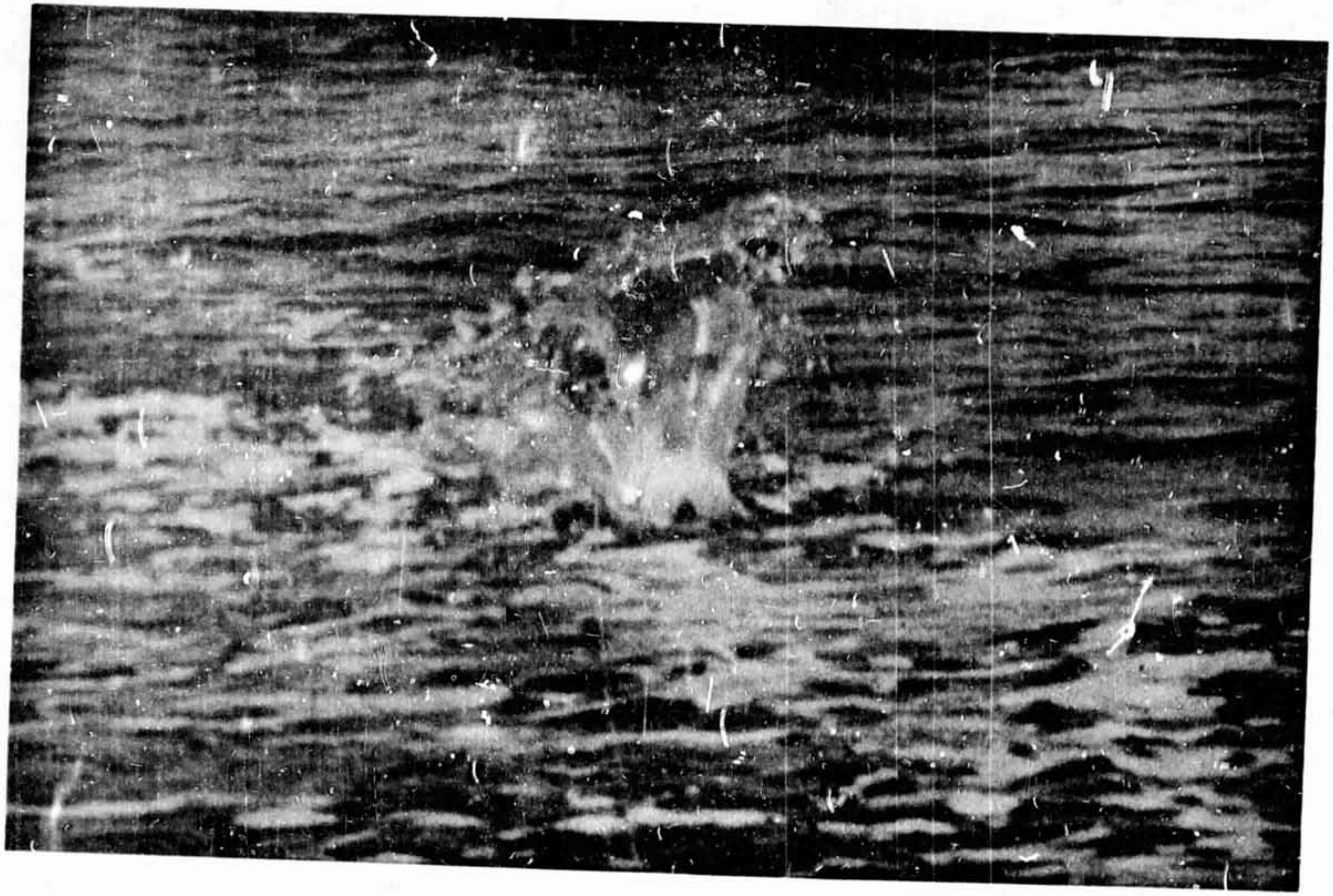


Figure A2. Bow Wave When Nose Pitches Down While Towing at 4 Knots into 2-Inch Wave (4.5 Feet Full Scale)

The stability improved (became more stable) when the towline point of attachment at the tug was well above the water. Such rigging is not practical, since for full scale this tow point would be more than 100 feet above the water. The tow point on the booster case has to be behind the dome at a structural attach point in the basic structure, Figure A3. The single point of attachment (booster) used for towing this model probably aggravated the yaw and roll actions. No attempt was made to optimize the towing rig for this booster, and tests were terminated as soon as adequate film coverage was obtained.

A.2.2 DETERMINATION. Cost effective repetitive towing operations in a variety of sea states, Reference 2, will require a stabilizing device(s) attached to each booster. Provisions would also be needed to improve the bow wave shape (lower profile) to reduce the towing drag loads in waves or swell, Figure A2.

A.3 FREE FLOATING

A.3.1 DISCUSSION. The free-floating tests were in waves that correspond to full-scale heights of 2 to 13.5 feet. The model floated in the crosswind attitude, except the bow would occasionally swing 45 degrees further down wind. Generally, the effect of the wave height was felt almost simultaneously along the length of the model. This resulted in substantial heaving accompanied by roll that was, as expected, amplified by higher wave heights. The wave heights in Tests 8 and 9, Table A1, duplicate wave heights of approximately 9 to 11 feet. Since such conditions can be expected over 9 percent of the time, these results are considered to be significant.

In full scale, the recovery vessel(s) would be faced with the capture of a large cylinder that will usually be exhibiting considerable movement about all three axes. This factor will complicate the recovery operation, as noted in Reference 1.

A check was made of the effect of a parachute, Table A2, attached to the bow of the model. The parachute was kept afloat by the model, but did not tend to appreciably affect the model motion in wave heights up to an equivalent of 7 feet. This appears to be due to considerable slack in the nylon parachute risers and the parachute. Considerable movement is required before the parachute will blossom under water and act as a sea anchor.

A.3.2 DETERMINATION. When free floating, the motion due to waves will complicate the capture of a booster. The combination of heave, roll, and yaw (even in waves less than 6 feet) results in a motion that would make an approach by a surface vessel a hazardous operation. This adds credence to a proposal from the Naval Ship System Command for capture by a submersible.

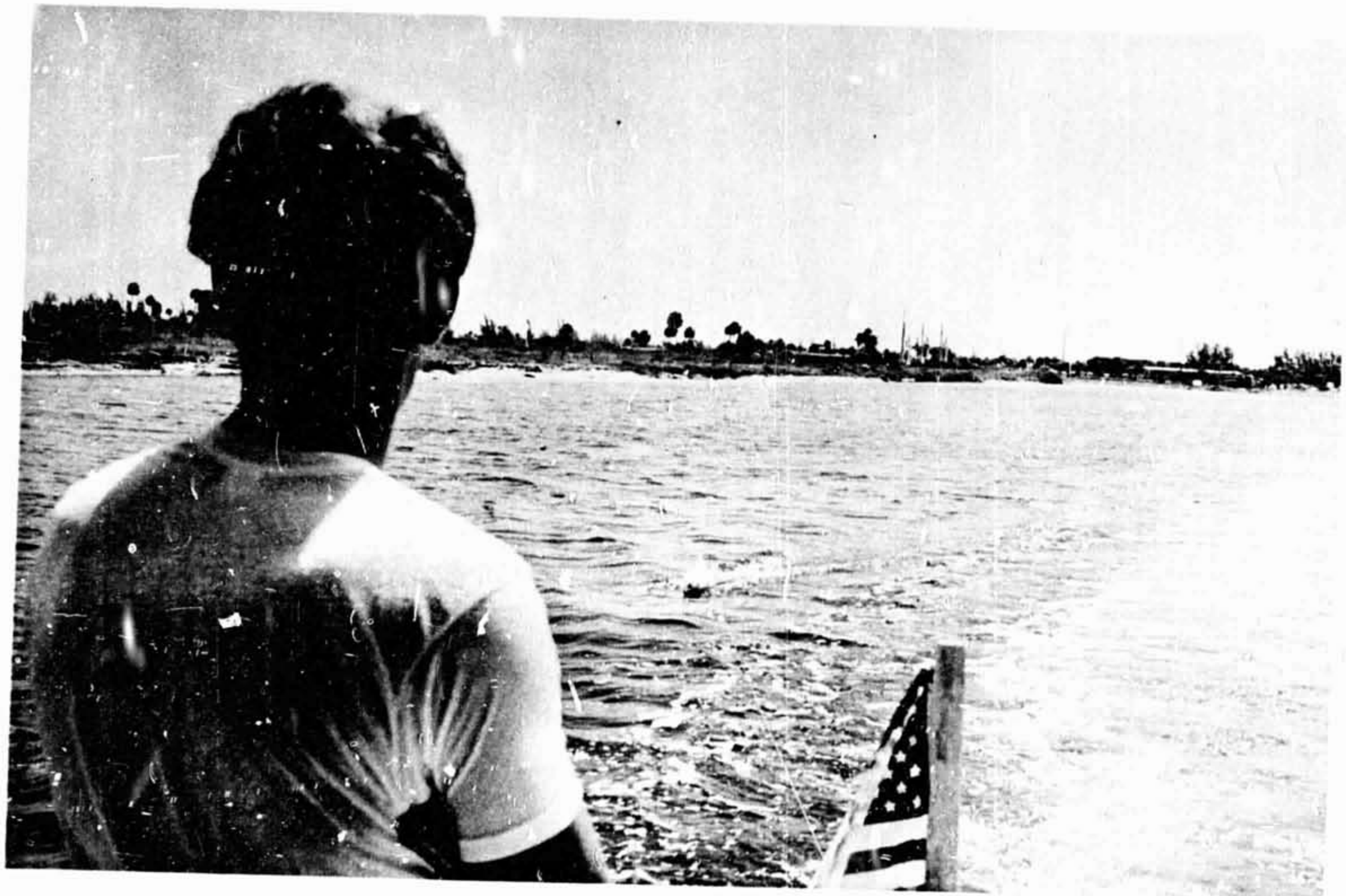


Figure A3. Towing Titan IIIC Model at 4 Knots into 1.5 to 2-Inch Boat Wake (3.4 to 4.5 Feet Full Scale)

APPENDIX B

1/32.9 SCALE MODEL OF 156-INCH DIAMETER SPACE SHUTTLE BOOSTER

B.1 MODEL DESCRIPTION

The model shape and size is shown in Figure B1. The cylinder of the model was a standard cardboard mailing tube. The nose cone was fabricated from sheet aluminum and the tail cone from balsa wood.

Weights were placed inside the tube to obtain the proper total weight and distribution. The model was covered with fibre glass and sealed with resin.

The full-scale length of 1784.0 inches was decreased to account for:

A. The nose cap being jettisoned during parachute deployment.

B. The loss of the outer portion of the nozzle bell during splashdown (not reusable; therefore, it would not be protected.).

The nose section is hollow and open to flooding. The nozzle opening was assumed to be plugged.

Towing and recovery was accomplished using a fishing pole and line. Four towing points 90 degrees apart were placed in the region of the forward thrust transmission structure.

B.2 TOWING

B.2.1 DISCUSSION. The single-point attachment for the towlines used on the Titan IIIC booster tests was not used for this booster configuration. Four attachment points were used equally spaced about the forward thrust transmission structure, Figure B1. The four lines from these points came together ahead of the nose cone to a single towline. This simulated the condition where a towline and buoy would leave the nose cone after splashdown to permit pickup by a recovery vessel.

This model rode in the wake of the boat, Figure B2, Tables B1 and B2, without exhibiting some of the instabilities noted in the Titan IIIC booster tests, Appendix A. This is believed to be due to:

A. Change in the towline attachment.

B. Higher finesse ratio (length/diameter) of 11.4 compared to 8.3.

It was noted that when oscillating in pitch, the nose cone (which is hollow and open) alternately scooped up water and then allowed it to drain out, Figure B3. Also, the bow waves were similar to the Titan IIIC booster design and would induce high drag and surging forces in the full-scale situation. There is some doubt that the nose cone structure could withstand such loadings, especially if the towing attachment lines were inside as proposed by a booster contractor.

MASS PROPERTIES							
Description	Gross Wt. lb.	C.G. (Missile Sta.)			Moment of Inertia (Slug-Ft.^{2})		
		X	Y	Z	Roll	Pitch	Yaw
Burnout	148,650	1522.4	99.6	100.6	170,800	8,129,000	3,127,000

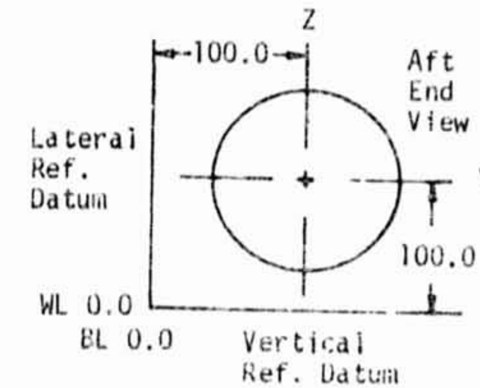
Model

Scale = 1/32.9
D = 5.0"
L = 48.7"

① = Spaces allowed to flood

Ⓧ = Pitch axis (about C.G.)

② = Locate four external towing points 90° apart



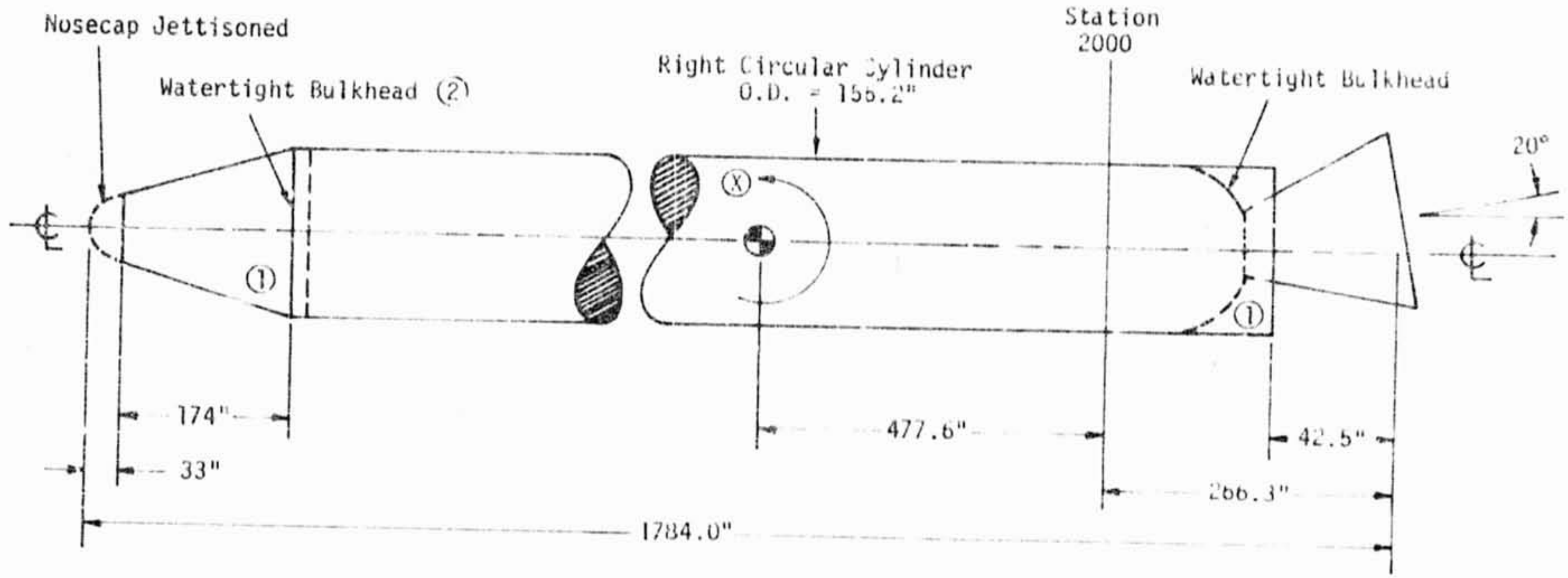


Figure B1. Space Shuttle Booster - Parallel Burn Configuration - 156 In. Dia. SRM

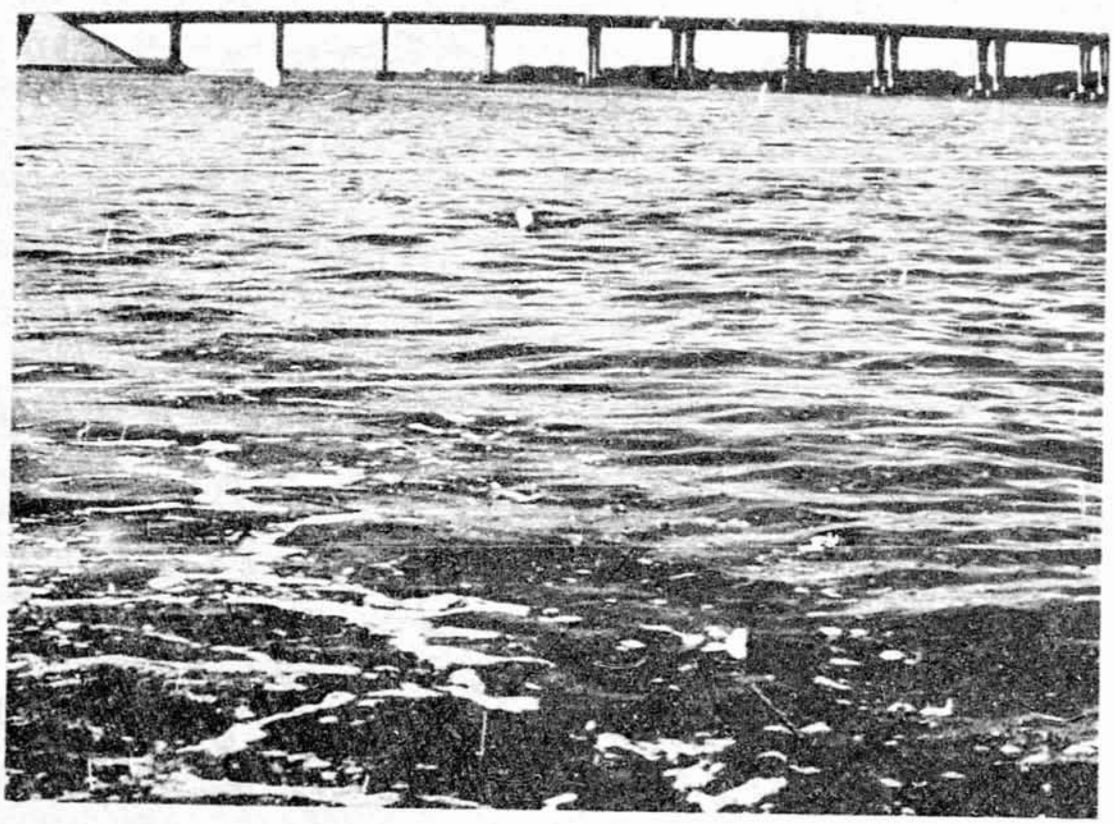


Figure B2. Booster Model Towed into Wind (4 to 6-Foot Waves)

Table B1. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
2-1	8/17/72	0925	NW1-2	Free floating. Wave 1/4".	Floats level. Wave was equivalent of less than 1 foot. Little motion.
2-2	"	0930	Calm	Tow	Boat velocity 4 knots. No unusual conditions — stayed in the boat wake.
2-3	"	0935	"	"	Boat velocity 6-7 knots. No appreciable change from test 2-2.
2-4	"	0940	"	"	Boat velocity 6-7 knots. Wake from other boats. Nose cone picks up water and tries to hold nose-down angle. Large bow wave.
2-5	"	0945	"	"	Boat velocity 6-7 knots. Wave approach from bow — diving tendencies.
2-6	"	1000	N3-5	Free float. Wave 2"-3".	Dumps water from nose cone when bow tilts down.
2-7	"	1005	"	Tow	Dynamometer on tow line shows average force of 1 lb. Rapid oscillation of force from 1/2-2 lbs. due to wave action. (Shortened tow harness so that the four tow attachment lines came together at nose cone entrance to simulate internal tow line.)
2-7A	"	1015	N5	Tow into wind. Waves 1 1/2"	Boat velocity 4 knots. Model yaws with any turning of boat. Considerable action in pitch at near random frequency.

Table B1. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
2-1	8/17/72	0925	NW1-2	Free floating. Wave 1/4".	Floats level. Wave was equivalent of less than 1 foot. Little motion.
2-2	"	0930	Calm	Tow	Boat velocity 4 knots. No unusual conditions — stayed in the boat wake.
2-3	"	0935	"	"	Boat velocity 6-7 knots. No appreciable change from test 2-2.
2-4	"	0940	"	"	Boat velocity 6-7 knots. Wake from other boats. Nose cone picks up water and tries to hold nose-down angle. Large bow wave.
2-5	"	0945	"	"	Boat velocity 6-7 knots. Wave approach from bow — diving tendencies.
2-6	"	1000	N3-5	Free float. Wave 2"-3".	Dumps water from nose cone when bow tilts down.
2-7	"	1005	"	Tow	Dynamometer on tow line shows average force of 1 lb. Rapid oscillation of force from 1/2-2 lbs. due to wave action. (Shortened tow harness so that the four tow attachment lines came together at nose cone entrance to simulate internal tow line.)
2-7A	"	1015	N5	Tow into wind. Waves 1 1/2"	Boat velocity 4 knots. Model yaws with any turning of boat. Considerable action in pitch at near random frequency.

Table B1. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster) (Continued)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
2-8	8/17/72	1030	N5	Tow into wind. Waves 1 1/2"	Boat velocity 6-7 knots. High bow wave when nose pitches down. Tendency to yaw more pronounced. Tow line stress 1 1/4 - 1 1/2 lbs.
2-9	"	1050	"	"	Model started to take-on water. Starts to hold steady yaw and tries to run submerged.

*The variation in winds and wave conditions were primarily the result of operating in clear areas and off the lee side of islands and causeways.

Table B2. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
3-1	8/18/72	0945	N3-5	Free float. 2 1/2" swell.	Floats in near horizontal attitude.
3-2	"	0950	"	Tow crosswind.	Boat velocity 4 knots.
3-3	"	0953	"	Tow into wind.	" " "
3-4	"	0955	"	Tow downwind.	" " "
3-5	"	0958	"	" "	Boat velocity 6-7 knots.
3-6	"	1000	"	Tow into wind.	" " "
3-7	"	1004	"	" " "	Boat velocity 8-10 knots.
3-8	"	1006	"	Tow downwind.	" " "
3-9	"	1010	"	Tow crosswind.	Boat velocity 6-7 knots.
3-10	"	1015	Calm	Tow	Crossed oncoming 6" boat wake. Towed at 4 knots.
3-11	"	1030	"	"	6" boat wake from side. Towed at 4 knots.
3-12	"	1100	"	Tow 1/2" ripple.	Crossed oncoming 3" boat wake. Towed at 4 knots.

Table B2. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
3-1	8/18/72	0945	N3-5	Free float. 2 1/2" swell.	Floats in near horizontal attitude.
3-2	"	0950	"	Tow crosswind.	Boat velocity 4 knots.
3-3	"	0953	"	Tow into wind.	" " "
3-4	"	0955	"	Tow downwind.	" " "
3-5	"	0958	"	" "	Boat velocity 6-7 knots.
3-6	"	1000	"	Tow into wind.	" " "
3-7	"	1004	"	" " "	Boat velocity 8-10 knots.
3-8	"	1006	"	Tow downwind.	" " "
3-9	"	1010	"	Tow crosswind.	Boat velocity 6-7 knots.
3-10	"	1015	Calm	Tow	Crossed oncoming 6" boat wake. Towed at 4 knots.
3-11	"	1030	"	"	6" boat wake from side. Towed at 4 knots.
3-12	"	1100	"	Tow 1/2" ripple.	Crossed oncoming 3" boat wake. Towed at 4 knots.

Table B2. Test Details* (1/32.9 Scale Model of 156-Inch Diameter Booster) (Continued)

Test Number	Date	Time	Wind (kts.)	Condition	Comments
3-13	8/18/72	1115	Calm	Free floating. 1/2" ripple.	4-5" overtaking boat wake. This is somewhat representative of a combination of sea and swell (Reference b).
3-14	"	1135	N3	Tow 1" waves.	Boat velocity 4 knots. Crossed oncoming 6" boat wake.
3-15	"	1145	Calm	Tow	Boat velocity 4 knots. Model again started to take on water. This induced yaw and diving tendencies.

*The variation in winds and wave conditions were primarily the result of operating in clear areas and off the lee side of islands and causeways.

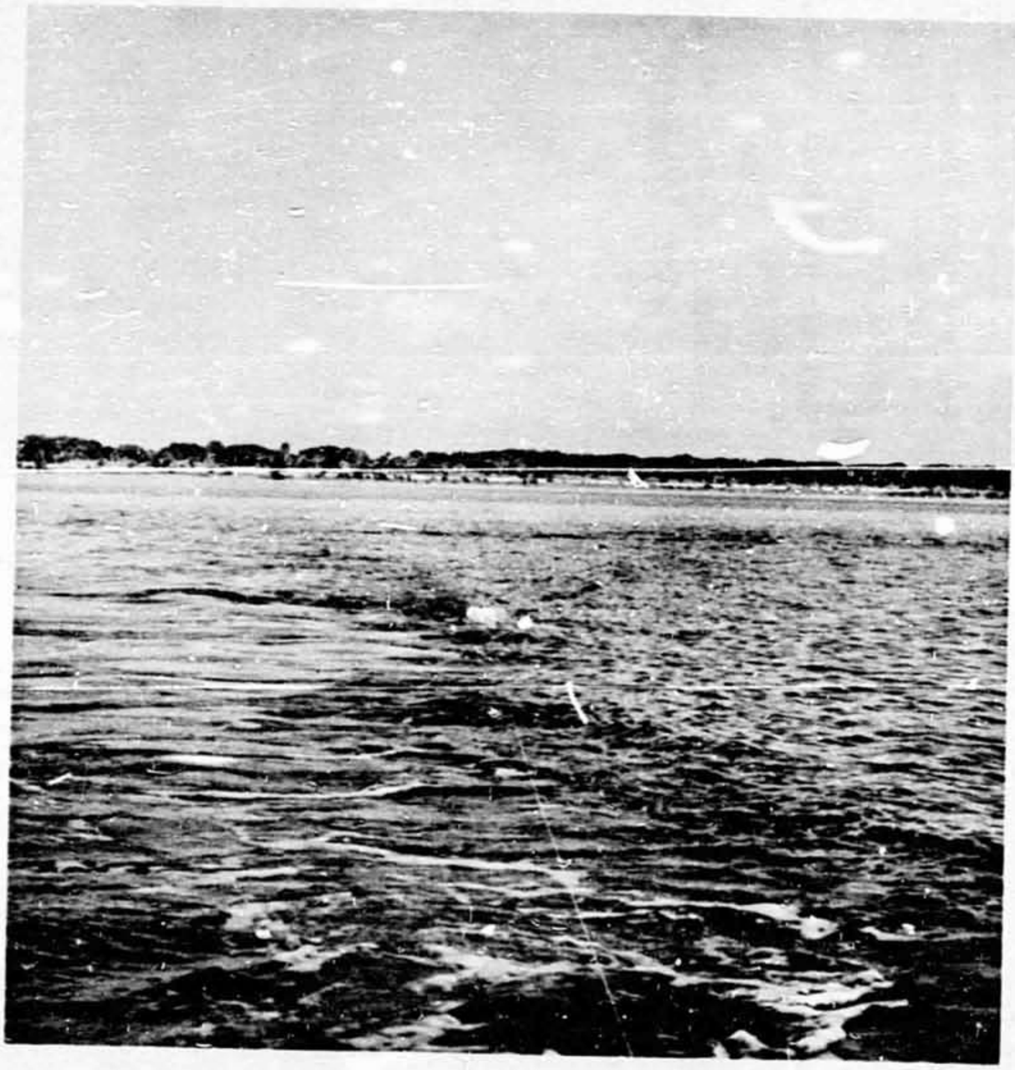


Figure B3. Nose Cone Acts as a Scoop and Interferes with the Towing Bridle

The multiple attachment lines undergo very noticeable dynamic reactions in that they load and go slack anytime there is any deviation from the straight line tow directly behind the boat.

Towards the end of both test periods, Tables B1 and B2, the model began to leak and take-on water. This flooding increases the weight and draft of the booster case. The effects of this flooding were very apparent in that the model would yaw as far as the towline would permit and try to run with a nose down attitude, Figure B4. This is in direct contrast to the results obtained earlier in the test periods. This would be an untenable situation in actual towing operations, especially in heavy seas.

The towing speed could not be reduced below approximately 4 knots due to the limitations of the towing vessel. This, in full scale, would be close to 23 knots. Such towing velocities are rare in the current state-of-the-art and should have been closer to 10 knots. The higher velocities probably magnified the undesirable features of the dynamics of the model.

B.2.2 DETERMINATION. These tests resulted in the same determinations set forth in Appendix A of this report regarding the Titan IIIC booster design. In addition, the method of attachment of the towline(s) to the booster needs further study.

B.3 FREE FLOATING

B.3.1 DISCUSSION. The model was allowed to float free, Figure B5, in waves of equivalent full-scale heights of less than 1 to 8 feet. This spans the majority of the wave conditions that can be expected in the open ocean, Reference 2. The results were not significantly different from those observed in the Titan IIIC model tests. The constant movement, especially in heave, would make an approach by a recovery vessel a hazardous operation.

B.3.2 DETERMINATION. The conslusions from these tests were the same as reported in Appendix A of this report.

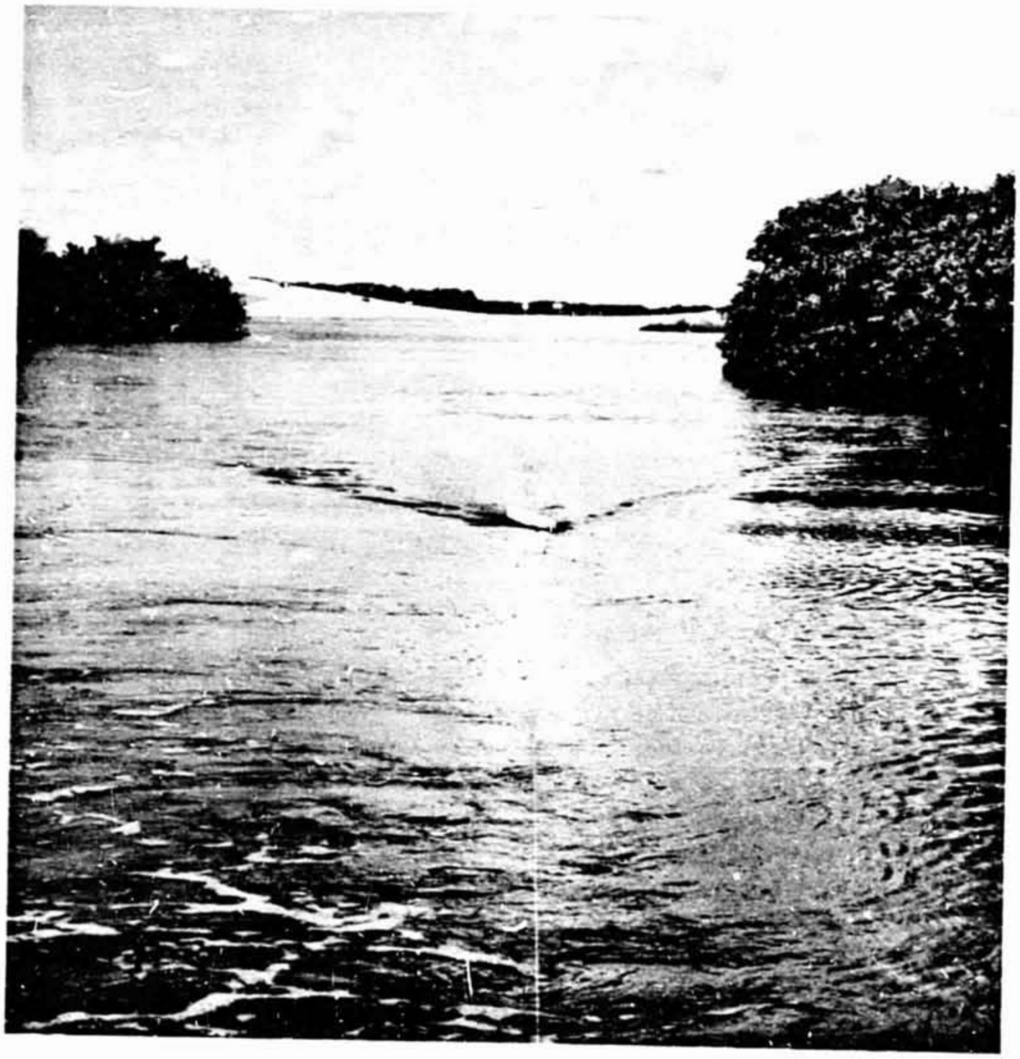


Figure B4. Water, due to a Small Leak, Increased the Weight and Caused the Model to Become Harder to Tow

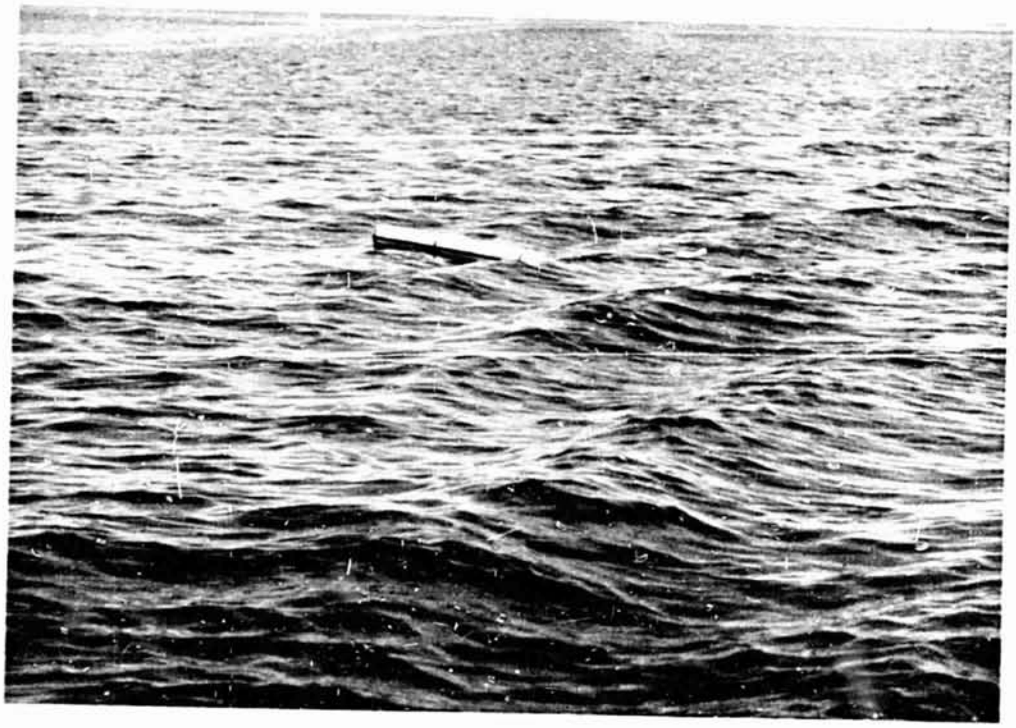


Figure B5. Empty Booster Case Floats High in Water and Quickly Responds to Wave Action and Wind

APPENDIX C

1/15.6 SCALE MODEL OF 156-INCH DIAMETER SPACE SHUTTLE BOOSTER

C.1 MODEL DESCRIPTION

The model was similar to the smaller scale, Appendix B, except that the weight was increased to reflect the current growth trends. The scale factors and particular data are shown in Table C1. Figures C1 through C3 show the model to full-scale conversions.

C.2 TESTING

The test plan is shown in Table C2. The tests were conducted in the same manner as the prior efforts, Appendices A and B. However, the larger scale improved the accuracy of the observations. Towing speeds were reduced to the proper levels by:

A. Having the towing vessel drag a sea anchor.

B. Using a sailboat for towing, which (due to the size) could operate in the 1 to 2-knot ranges when using the auxiliary engine.

Table C1. Scale Factors and Data

$$\lambda = 15.6$$

$$\lambda^2 = 243.36$$

$$\lambda^3 = 3{,}796.4$$

$$\sqrt{\lambda} = 3.949$$

$$\lambda^{-1} = 0.0641^{-1}$$

	Full Scale	Model
Length* - Inches	1716	110
Diameter - Inches	156	10
Weight - Pounds	184,505	48.6
Parachutes	3' x 129.5'	3' x 8.3'

*Assumes that nozzle bell breaks off during splashdown.

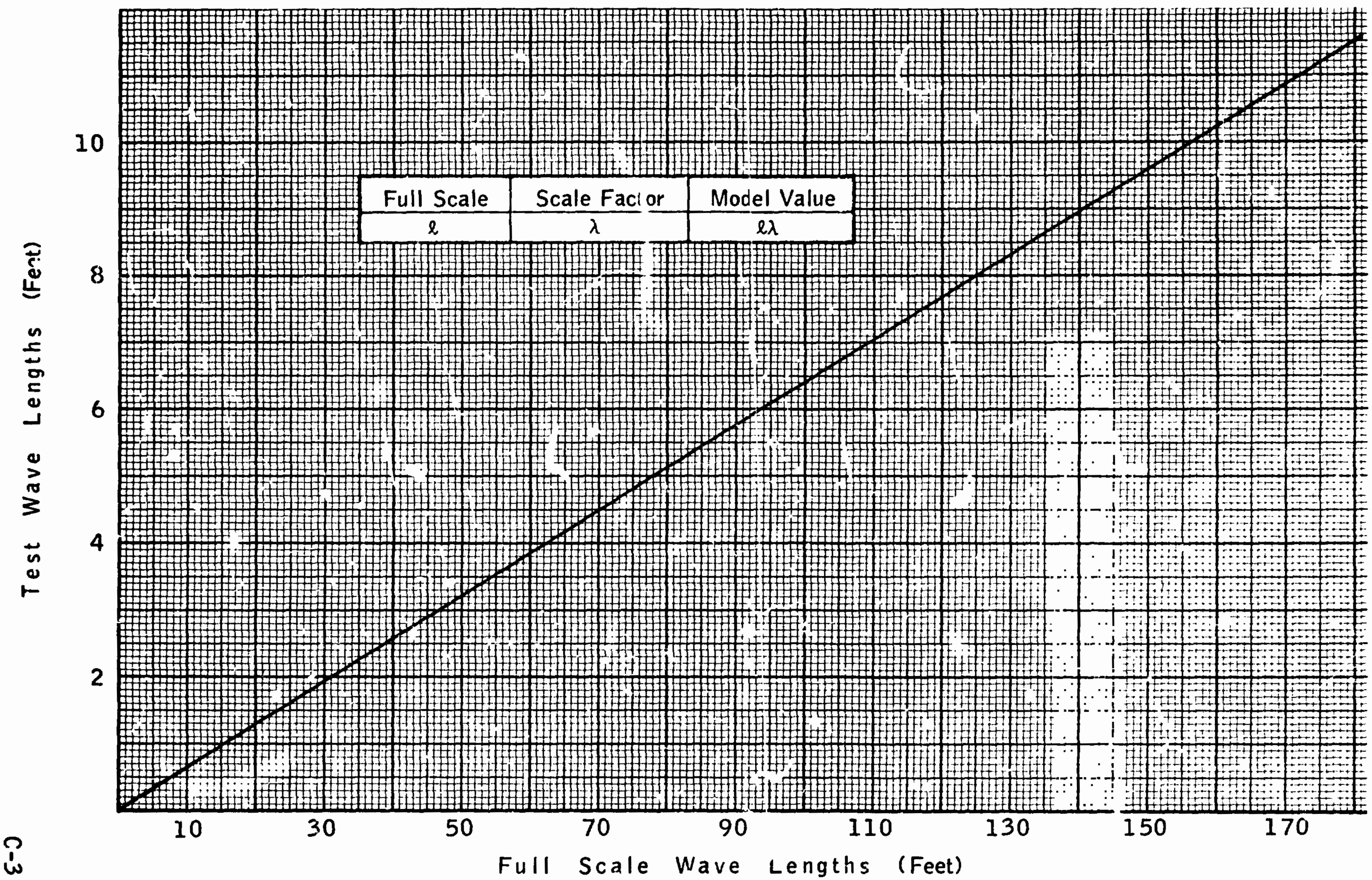


Figure C1. Model to Full Scale Wave Length Relationship

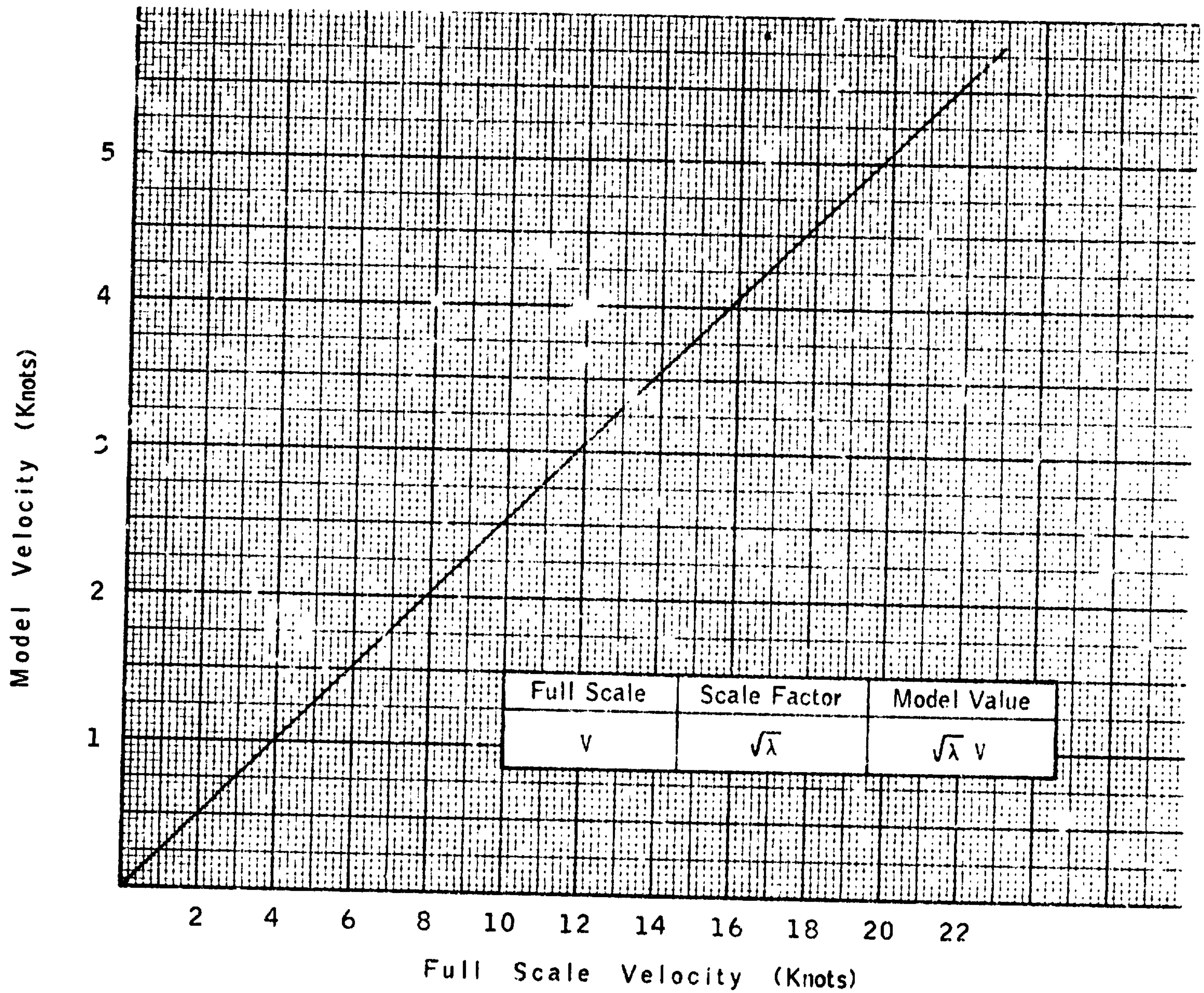


Figure C2. Model to Full Scale Velocity Relationship

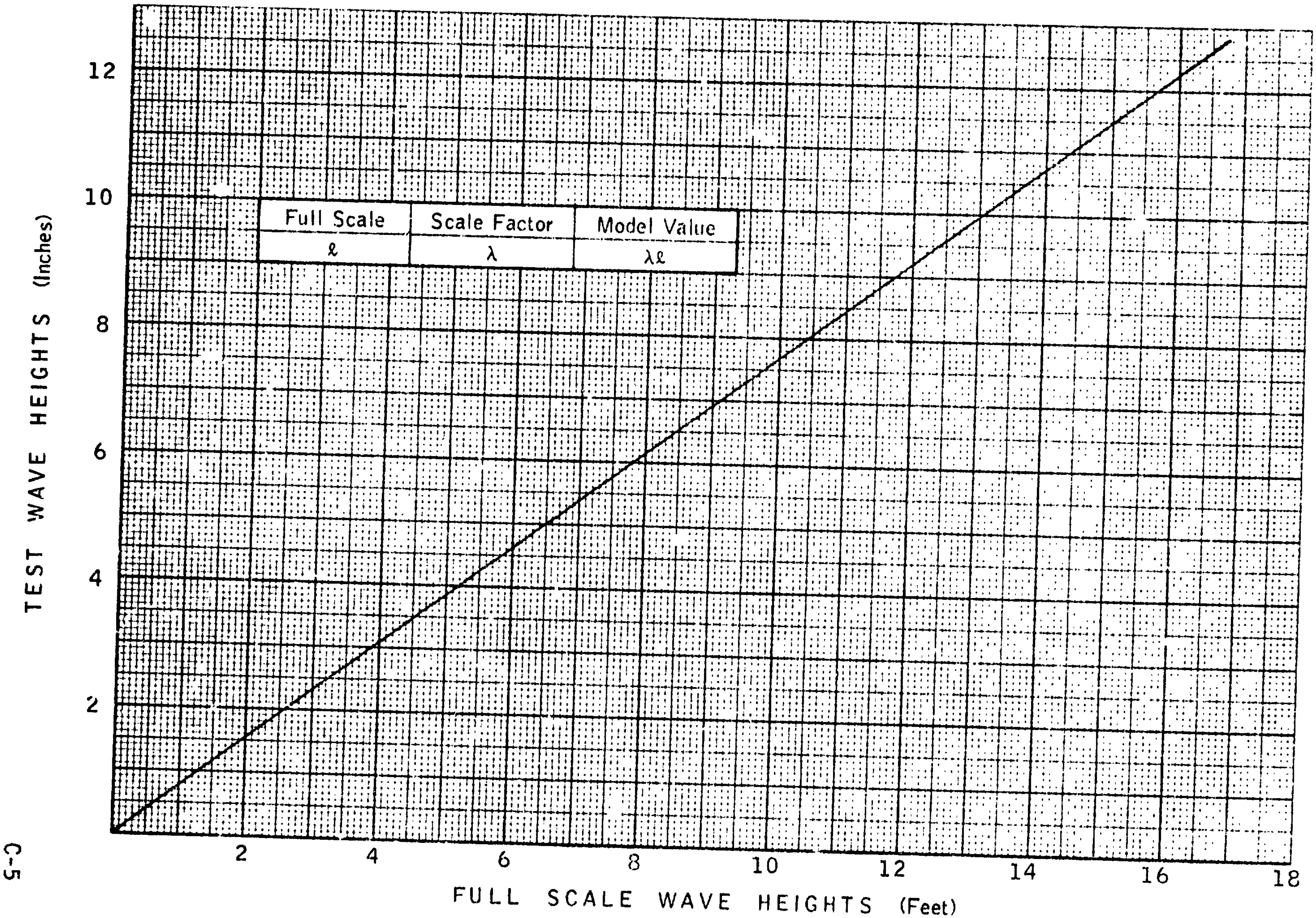


Figure C3. Model to Full Scale Wave Height Relationship

Table C2. Space Shuttle Booster Water Recovery Test Plan

I. Calibrate Towing Vessel Velocities

A. Timed runs on fixed course (both directions) at idle, 1000 rpm, and 1500 rpm.

B. Repeat A above towing model and sea anchor.

II. Free Floating (No Parachutes)

A. Water Calm

B. Wave Heights to 3"

C. Wave Heights to 5"

D. Wave Heights to 8"

E. Wave Heights to 12"

Record: Wave height, length, and period (actual)
Note model motion and orientation to the waves.
Photograph each significant condition.

Repeat (if not already observed)

A. Wave Lengths (actual) of 4'

B. Wave Lengths (actual) of 6'

C. Wave Lengths (actual) of 8'

Record: Same as above.

III. Free Floating (Parachute(s) Attached to Nose of the Booster)

A. Calm Water

B. Selected wave heights/lengths from II above where significant data points were obtained.

Record: Same as II above. Note orientation of the parachute for the various test conditions.

Table C2. Space Shuttle Booster Water Recovery Test Plan (Continued)

IV. Towing With 4 Point Bridle (No Parachutes)

A. Calm Water

B. Wave Heights to 3"

C. Wave Heights to 5"

D. Wave Heights to 8"

E. Wave Heights to 12"

Record: Same as II above.

Repeat (if not already observed)

A. Wave Lengths (actual) of 4'

B. Wave Lengths (actual) of 6'

C. Wave Lengths (actual) of 8'

Record: Same as II above.

V. Towing With 4 Point Bridle (Parachute(s) Attached to Nose of the Booster)

A. Calm Water

B. Selected wave heights/lengths from III above where significant data points were obtained.

Record: Same as I above.

VI. Repeat IV Above Using 3, 2, and 1 Point Bridles (No Parachutes)

VII. Effects of Flooding the Booster Case

A. Add 2 gallons of water; free float and towing in 1 or more wave conditions (with and without parachutes).

B. Repeat A above adding 2 gallons in steps up to loss of buoyancy and/or tow capability.

C. Determine if the booster can be towed when submerged.

Table C2. Space Shuttle Booster Water Recovery Test Plan (Continued)

VIII. Investigate Methods for Parachute Recovery

A. Paravane

B. Net

C. Buoy

D. Compare wet and dry weights

IX. Investigate Capture of Free Floating Booster

A. Line with buoy

B. Through parachute recovery

C. Other