CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE

REPORT

NO. 63-13-M-(M-20)(R) DATE: 25 April 1963

DEVELOPMENT AND TESTING OF FULLY SUBMERGED HYDROFOILS WITH DRAG VANE CONTROL INSTALLED ON 15 FOOT RUNABOUTS

CODE 26512

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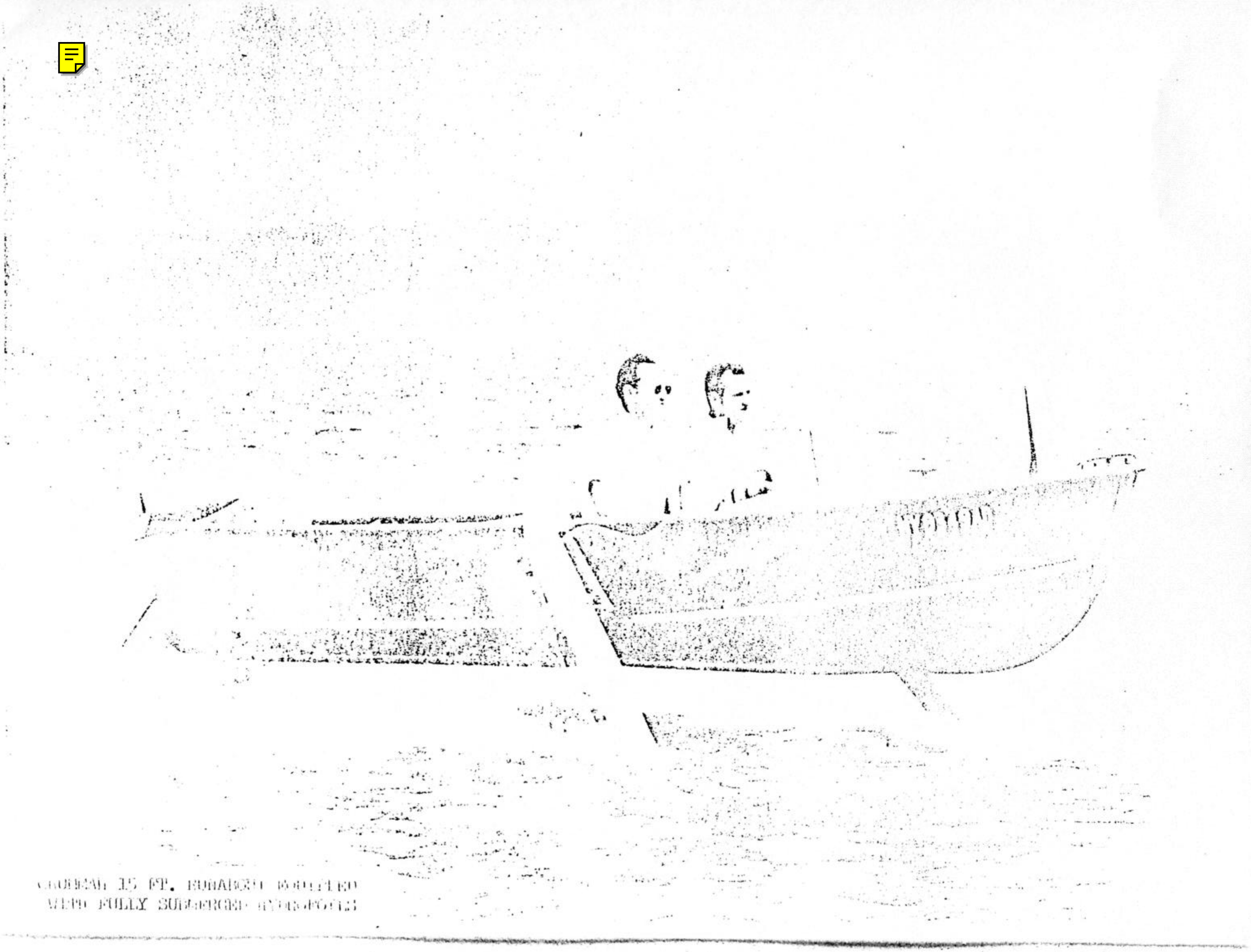

GRUMMAN 15 FT. RUNABOUT FITTED
WITH FULLY SUBMERGED HYDROFOILS

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INTRODUCTION

This report summarizes the development and test of three fully submerged hydrofoil configurations, with "drag vane" flap control, as installed on 15 foot runabouts. The program described herein was funded by the Grumman Aircraft Engineering Corporation, and performed between July, 1962 and March, 1963. All testing was conducted from the Grumman Barge Facility at Jakobson's Shipyard, Oyster Bay, Long Island, New York.

During the same time period, preliminary work was also accomplished utilizing a "lift vane" for flap control of fully submerged foils. This work is separately reported in Reference (1). In addition, work directed toward qualitative evaluation of "Sea Wings" surface piercing performance as affected by C.G. location was accomplished. This work is separately reported in Reference (2).

SUMMARY

The work described herein has demonstrated the feasibility of a new type of hydrofoil control system through open water testing.

The boat hulls are Grumman 15 foot aluminum runabouts. Three fully submerged hydrofoils are employed. Two foils are located forward of the boat center of gravity, one on each side of the hull, and support most of the vehicle weight. The third foil is located aft of the transom. Each forward foil incorporates a trailing edge flap. Attached to each flap is a base ventilated vane which extends upward from the flap behind the hydrofoil's supporting strut.

A change in forward velocity or waterline position due to waves causes a change in drag on the vane which in turn causes a change in flap hinge moment and hence a change in flap position. The result is automatic control of hydrofoil lift which has enabled stable flight in smooth and rough water. The particular merits of this foil system are considered to be:

1. Simple construction.
2. Relatively high lift to drag ratio in rough water.
3. Relatively good lift recovery characteristics after a main foil broach.

The work described herein has been qualitative to demonstrate feasibility. It has not included component load measurement or optimization of control system component design. Recommendations for future work to accomplish such optimization are included herein.

DESCRIPTION OF THREE FULLY SUBMERGED FOIL CONFIGURATIONS

The basic foil arrangement is of the "conventional" type with three fully submerged foils. Two foils are located forward of the boat center of gravity, one on each side of the hull, and support most of the vehicle weight. The third foil is located aft of the transom.

Three different forward (main) foil designs have been fabricated and tested. Each main foil design was tested with the same tail foil which was retained from the "Sea Wings" hydrofoil kit.. The tail foil has adjustable incidence in pitch. This typical arrangement is shown in Figures 1 and 2.

Each of the three forward foil designs was installed on the 15 foot runabouts in a similar manner and location. The forward struts and foils were installed with 15 degrees of dihedral. A forward strut sweep of about 36 degrees was necessay to utilize the existing "Sea Wings" foundation assembly. The installation was such as to allow a foil incidence change in pitch by rotation of the strut.

Each of the three forward foil designs has an area of 200 square inches. Two of the foils have drooped leading edges. The third foil has a 16 series section with a = 1 camber. The two drooped nosed foils have aspect ratios of 1.85 and 2.70. The 16 series foil has an aspect ratio of 3.00. The aspect ratio 1.85 foil is shown in Figures 3 and 4; the aspect ratio 2.70 foil is shown in Figure 5; the aspect ratio 3.0 foil is shown in Figures 6 and 7. The photographs of Figures 4 and 7 show minor modifications (discussed later), made during testing, from the drawings of Figures 3 and 6.

Trailing edge flaps for immersion, pitch, and roll control are employed by each of the three designs. The flaps are of rectangular planform, cover about 75% of the foil trailing edge span and about 20 - 25% of the foil mean geometric chord. When in the neutral position, the flap cross section is a continuation of the foil cross section. The flaps were originally attached to the foil by a thin flexible plastic sheet recessed in the bottom surface of the foil and flap. The plastic was later replaced by stainless steel piano hinges. A typical plastic hinge arrangement is shown in Figure 3.

Flap movement is controlled by base (trailing edge) vented upright drag vanes. A typical drag vane design is shown in Figures 8 and 9. The drag vane consists of a 3/16 inch x 3/4 inch aluminum post with an .050 inch thick aluminum wedge shaped angle spot welded on the leading edge. The included angle of the wedge can be varied to increase or decrease drag. The trailing edge of the wedge is tapered from one inch in width at the top into a flush condition one to two inches up from the bottom. The bottom cross section is streamlined to reduce drag and to prevent ventilation of the flap. The drag vane is fastened to the flap by four flush head screws through a thin plate welded to the bottom of the vane. The plate is contoured and faired to the flap to reduce drag.

The design for adjusting the up stop position of the main foil flaps for immersion control, and to produce asymmetric flap movement for banking in turns, is shown in Figures 8 and 10. The photograph of Figure 10 shows minor modifications (discussed later), made during testing, from the drawing of Figure 8. The system consists of a quadrant with provision to adjust the ratio of steering wheel movement to flap movement and teleflex cables from the quadrant to bellcranks on the trailing edge of each forward strut. Each drag vane rests against one end of the bellcrank. Turnbuckle adjustment of cable length is available to control the up limit of the drag vane motion.

METHOD OF LIFT CONTROL

The upright base vented drag vane as previously described is the device used for main foil lift control. The wedge shaped, tapered vane leading edge presents varied frontal area as foil and vane immersion change.

Flap position for steady state conditions must be such as to represent the case of zero net flap hinge moment. Drag loads on the vane tend to cause a hinge moment which rotates the flap in a trailing edge down direction. Lift loads on the flap cause hinge moments which rotate the flap trailing edge in an upward direction. At low forward speed and high foil and vane immersion, this equilibrium condition results in maximum positive flap deflection (trailing edge down). At higher forward speeds, this equilibrium condition allows the flap deflection to decrease. At maximum speed, the vane is surface piercing and rests against its up stop. The flap deflection is near zero.

When flying in waves at a given speed, an increase in immersion causes a higher water line on the drag vane and the associated increase in drag rotates the flap trailing edge down so as to cause an increase in overall foil lift. A decrease in immersion causes a lower water line on the drag vane and the associated decrease in drag allows the flap to rotate trailing edge up so as to cause a decrease in overall foil lift. Through this action, the drag vane control system becomes a wave contouring device.

Flap action can be affected by changing the drag characteristics of the vane. By reshaping or changing the tapered profile of the wedge, the amount of drag for a given immersion is changed.

Flap position to maintain the desired cruise hull clearance and foil immersion is controlled by positioning the drag vane up stops.

INITIAL TEST AND DEVELOPMENT

The first tests were made with the aspect ratio 1.85 drooped leading edge foil design. Initial runs indicated this configuration to have a high degree of stability, in both head and following seas with excellent rough water capabilities.

These initial runs also indicated items which required modifications to improve performance. These items are separately discussed below.

A tendency to "skid" outboard during high speed turns (low main foil immersion conditions) was observed. This condition led to the design and installation of the banking system previously described. Turning qualities were greatly improved but are still restricted to a nominal turning radius. This restriction is imposed by the marginal strength of the main foil struts, which have been retained from the "Sea Wings" kit, and occasional ventilation of the struts during sharp turns.

On two occasions during turns, the struts were bent at the intersection of upper and lower sections. To help remedy this situation, a four inch extension was welded to the upper struts. A failure of this welded section also occurred during a rough water demonstration. Further strengthening was accomplished by the addition of a doubler plate over the welded section. Forward strut strength still remains as a limitation on maximum turning capability.

Ventilation of the struts during turns was observed. This was attributed to the aforementioned skidding and to installation geometry resulting in strut angles of yaw even during straight ahead running. Tapered shims were installed on strut support structure to minimize this strut yaw condition. Combined with the modification to induce banking, this shimming improved turning performance. Occasional strut venting still limits turning capability. When a forward strut ventilates there is an abrupt loss in strut side load and an associated increase in turning radius. Turning capability is now considered adequate to demonstrate practicability but should be further improved on future designs such as an XCH-6 design referred to on page 21.

During take-off, the base of the drag vane would vent suddenly with an associated abrupt change in flap position and vehicle pitch. This situation was corrected by the addition of a fence like plate within the wedge cross section of the drag vane. This caused base ventilation of the vane to occur in a more gradual manner and has resulted in a smoother take-off.

This first configuration, as shown in Figure 11, did not utilize a vane up stop. Cruise flap position depended upon vane drag and flap lift hinge moment equilibrium which produced sensitive and unnecessary flap movement and oscillatory foil immersion. The drag vane up stop to limit the flap up position was devised. To be able to control the foil cruise immersion, the up stop was made adjustable and further improved by incorporation into the banked turn system.

It was also observed that flap action could be improved through modifications in drag vane geometry. The bottom of the vane was modified by giving it a streamlined section to reduce drag. The drag vanes were also reshaped by reducing the wedge angle and changing the slope of the tapered trailing edges to reduce drag and improve flap action.

Areas were observed which tended to cause local ventilation and/or cavitation. "Cleaning up" of various areas was carried out and drag reduced to the extent that a noticeable improvement in performance was obtained. Fairing was accomplished in the up stop attachment region. Fairing was also accomplished in the region of drag vane attachment to the flap with replacement of round head screws by flat head screws. (See difference between Figure 8 and Figure 9.) In certain areas the flap protruded above the foil upper surface. These areas were filed flush. At a later date this condition was found to be caused by stretching of the plastic flap hinge. The plastic hinge was then replaced by a stainless steel piano hinge.

The modifications resulting from initial test of the aspect ratio 1.85 foils were incorporated in the construction of the other two foil systems.

GENERAL PERFORMANCE OF THREE FULLY SUBMERGED FOIL CONFIGURATIONS

The aspect ratio 1.85 drooped leading edge foils were evaluated in various sea states from flat calm to over 2.0 foot waves with head, following, quartering and beam seas. In the normal test configuration with standard equipment, driver and observer, the boat gross weight was approximately 1,000 pounds. In flat calm conditions, foilborne attitude at full throttle is obtained in approximately 6 to 7 seconds at a speed of 15 mph. Top speed of 32 to 33 mph is obtained in approximately 30 seconds. Keel clearance at the main foil is 10.5 in., stern clearance is 9.5 in., and boat keel trim is + ½°. Under ideal conditions with driver only, 34 mph was obtained. To obtain this speed, the main foils were run with the foil tips just breaking the smooth water surface.

In a one foot chop, take-off characteristics are not affected as compared to smooth water performance. Top speed of approximately 30 mph can be maintained. Some broaching of the main foils is experienced with excellent recovery. Recovery is extremely rapid resulting in a "hard" ride.

When operating upwind (head seas) in limiting sea states, where waves of 1½ feet and greater are encountered, "falling in" and hull impacts begin. As a series of these bigger waves are encountered, speed fluctuates from 20 to 22 mph. Downwind (following seas) under these conditions results in similar behavior with somewhat greater speed fluctuation. While in quartering seas, very few "fall ins" are experienced. While broadside, speeds of 25 to 30 mph can be maintained with ease.

The second set of foils to be tested was the aspect ratio 2.70 drooped leading edge foils. During the foil adjusting and trimming process, cavitation of the foil lower surfaces was evident as the incidence angle was lowered to decrease foil angle of attack. A satisfactory incidence angle was reached and cavitation reduced after the lower concave section of the foils was filled with a plastic. Performance of this foil fell short of the standard set by the aspect ratio 1.85 foils in both speed and sea state capability. Further improvement was postponed and has not been completed to date.

The third set of foils tested incorporated the 16 series section and aspect ratio 3.00. The performance of these foils compared favorably with the aspect ratio 1.85 foils. At 1,000 pounds gross weight, top speed is 31 to 32 mph in smooth water.

Comparative tests of the aspect ratio 1.85 drooped leading edge foils and aspect ratio 3.00, 16 series foils were made in calm water and chop up to two feet. The boats were run side by side with the same gross weights. Identical drag vanes were used and engines were switched from one boat to the other to eliminate performance differences due to engine output.

In calm water, at a gross weight of 1,000 pounds, the take-off characteristics are about the same. During foilborne runs, the aspect ratio 1.85 foils were run with the outboard tips just breaking the water surface to reach a top speed of 32 to 33 mph. The aspect ratio 3.00 foils were run at their top speed of 31 to 32 mph with the outboard tips $\frac{1}{2}$ to 1 inch below the water surface.

At a maximum gross weight of 1,650 pounds in smooth water the aspect ratio 1.85 foils will reach a maximum speed of 20 mph; the aspect ratio 3.00 foils reach 26 to 27 mph at a maximum weight of 1,688 pounds.

In an 8 to 10 inch chop, top speed of the two foils at the 1,000 pounds gross weight is about equal at 31 mph. A noticeable difference in ride is experienced. The ride with the aspect ratio 1.85 foils is harder. The cause of this can be seen by observing the foils as they go through the waves. The aspect ratio 1.85 foil outboard section comes out of the water more often in the wave troughs and gives a decided bump as the bottom of the foil is hit by the next wave. The more deeply immersed aspect ratio 3.00 foil cuts through the wave and generally stays covered through the trough. The difference of ride is similar to the ride of a stiffly sprung truck compared to a softly sprung car.

In 1 to $1\frac{1}{2}$ foot waves, and at the 1,000 pounds gross weight, the aspect ratio 1.85 foils begin to show a speed advantage. They show excellent recovery after broaching, which again gives a hard bouncy ride. The aspect ratio 3.00 foil recovery is not as pronounced. The foils immerse further. This results in a smoother ride, but greater loss of speed and occasional hull impacts. Both boats, in quartering and beam seas can maintain speeds around 29 to 31 mph with a comfortable ride for the given sea state.

The excellent sea keeping abilities of the fully submerged foils were demonstrated in several ways. The Grumman 27 foot Pearson escort boat has been used to generate sizeable waves through which the boats were run, demonstrating the broaching and recovery capabilities. The boats were also demonstrated in waves up to two feet high and over in Long Island Sound. On one occasion a three foot to four foot swell was running. The boat was able to contour the bigger waves and at the same time negotiate the one foot chop on top of the waves.

In general, the smaller aspect ratio foils provide a better rough water lift to drag ratio and greater sea state capability. The higher aspect ratio foils provide a better smooth water lift to drag ratio at high gross weights and a smoother ride.

COMPARISON OF THE FULLY SUBMERGED FOILS WITH "SEA WINGS" SURFACE PIERCING FOILS

Both the aspect ratio 1.85 and 3.00 foils were compared and evaluated in various sea states. Their performance for discussion purposes in the comparison with "Sea Wings" surface piercing foils will be considered equal and they will be referred to simply as the fully submerged foils. "Sea Wings" surface piercing foils are shown in Figure 12. Unless otherwise stated, all comparisons were made with boat gross weights of approximately 1,000 pounds.

In calm water, the fully submerged type foils have a top speed of 31 to 33 mph. trim angle of $+ \frac{1}{2}^{\circ}$ to 1.0° and keel clearance at the main foils of 8 to 10 inches. Take-off occurs in 4.5 to 6.5 seconds at 14 to 15 mph; terminal speed is reached in 20 to 31 seconds.

The "Sea Wings" surface piercing foils have a take-off speed of 12 mph in 6.5 seconds. Terminal speed of 35 mph is reached in 20 seconds, keel clearance at the main foils is 10 inches and boat trim is $+ 2\frac{1}{2}^{\circ}$.

The "Sea Wings" take-off characteristics are smoother than those of the fully submerged foils. "Sea Wings" take-off with near constant acceleration rising smoothly. The craft trims up to $+ 5^{\circ}$ at take-off speed and then trims down to $+ 2\frac{1}{2}^{\circ}$ at maximum speed. The fully submerged foil boats, due to the drag vane venting, take-off in two steps. The boat trims up, hull clearing the water surface, then trims down, accelerates and trims up again to about $+ 3^{\circ}$ and then continues to accelerate to terminal speed trimming down simultaneously to $+ \frac{1}{2}^{\circ}$ to 1.0°.

Better stability and performance of the fully submerged foils become apparent in a chop of 10 inches and higher. In an 8 to 10 inch chop top speed for the two foils is about the same. The fully submerged type begin to show better ability to keep a constant altitude and better directional stability. The ride is harder due to the rapid recovery characteristics of the fully submerged foils.

In a 1 to $1\frac{1}{2}$ foot chop, the fully submerged foils are able to maintain speed and keep foilborne considerably better than the "Sea Wings", particularly downwind. The "Sea Wings" have a tendency to "fall in" due to loss of lift after broaching. The fully submerged foils will occasionally "fall in"; however, it appears to be due to a loss of speed after encountering a series of the bigger waves rather than loss of lift due to broaching. Their ability to recover after broaching is exceptionally good. The photograph in Figure 13 shows a broaching condition from which the fully submerged foils will recover without experiencing hull impact. The "Sea Wings", in a similar situation, "fall in" with high hull impact.

Maneuverability of the "Sea Wings" is superior to the present fully submerged foil strut configuration. "Sea Wings" have the ability to turn, at full throttle, in at least half the diameter of the tightest turn allowed for the existing configuration of the fully submerged type foils. "Sea Wings" turns can be tightened to the point where drag decreases speed until the boat is no longer foilborne.

At a high gross weight of about 1,600 pounds, top speed of the aspect ratio 3.00 foils is 26 mph; top speed is 20 mph for the aspect ratio 1.85 foils and 22 mph for the "Sea Wings" foils. At this gross weight, "Sea Wings" lose some of their lateral stability with a tendency to roll easily. During turns, the fully submerged foils occasionally lose lift on one foil due to the strut ventilation problem (previously discussed), resulting in a high degree of roll.

In general, the fully submerged foils provide a better rough water and high gross weight lift to drag ratio and greater sea state capability. The "Sea Wings" foils provide a better smooth water lift to drag ratio at low gross weights, a smoother take-off and better turning capability.

FACTORS AFFECTING RECOVERY

The tests have indicated that to obtain the most rapid recovery after a foil broach, it is desirable to have a low span and high camber. The low span, for any given dihedral, enables the most rapid immersion of total foil area. This enables the most rapid elimination of upper surface ventilation paths. The high camber appears to increase the initial impact load upon first contact with the water surface. Surface piercing foils tend not to recover as quickly as fully submerged foils because an upper surface air path is provided by the surface piercing element.

In actual design of fully submerged foil systems, camber will be limited by considerations of design to prevent cavitation at full scale maximum speed. Foil span will be the maximum consistent with the highest structurally feasible aspect ratio in order to minimize induced drag. The performance of the tested aspect ratio 3.00 foils (low camber) is, therefore, more representative of full scale vehicle performance than that obtained with the aspect ratio 1.85 foils (high camber).

EFFECT OF GROSS WEIGHT ON SMOOTH WATER PERFORMANCE

The aspect ratio 1.85 and 3.00 foil systems and the "Sea Wings" surface piercing foils were tested to determine take-off and maximum speed characteristics at various and maximum gross weights. The data obtained are tabulated in Table II and are discussed below.

All tests were made in flat calm water. To eliminate possible differences in engine performance, the same engine, a 40 HP Evinrude, was used for all tests. The tests were performed on the same day or days with similar atmospheric conditions. Prior to being tested, each boat was run at a gross weight of about 1,000 pounds. Tail foil incidence angle and main foil up-stops were then adjusted to give maximum performance. Increments of ballast were added and the test runs repeated at various gross weights until each boat would not take-off. At this point, adjustments to the tail foil incidence angle only were made and weight shifted to obtain take-off and top speed for this heavy or maximum gross weight condition.

Each test run was made from a standing start. Full throttle was quickly applied and held throughout each run. Take-off speed and time for take-off, maximum speed and time to reach maximum speed, trim angles and foil immersions were recorded for each run. Other boat information required to determine C.G. locations and foil loadings were also recorded.

Table I summarizes data for the three tested configurations at minimum and high gross weights of about 1,000 and 1,500 pounds respectively. Since it was not feasible to run the three configurations at identical gross weights, these weights have been chosen from the test data such that variation in minimum gross weight is about 6%, and the variation in maximum gross weight is about 2%. This percentage variation is considered small enough to be ignored for a comparison of overall results and is probably within the accuracy of all speed and time measurements.

As the gross weight of the tested configuration is increased by about 50%, it is seen that:

1. Percentage decrease in maximum speed is least (best) for the aspect ratio 3.00 foils, next largest for the aspect ratio 1.85 foils, and largest (worst) for the "Sea Wings" foils.

2. Percentage increase in take-off speed is least (best) for the aspect ratio 3.00 foils, next largest for the aspect ratio 1.85 foils, and largest (worst) for the "Sea Wings" foils.

3. Percentage increase in time to reach maximum speed is least (best) for the aspect ratio 1.85 foils, next largest for the aspect ratio 3.00 foils and largest (worst) for the "Sea Wings" foils.

4. Percentage increase in time to take-off is least (best) for the "Sea Wings" foils, next largest for the aspect ratio 3.00 foils, and largest (worst) for the aspect ratio 1.85 foils.

In the case of the effect of gross weight on maximum smooth water speed, all test data has been plotted in Curve I. Here, bands have been shown to allow for scatter, effects of change in C.G. location and change in tail foil incidence.

It is important to realize that, for the tested configurations, the "Sea Wings" (surface piercing foils) have a much higher loading than the fully submerged foils. This is shown for all test runs in Curve II. Accordingly, they have less foil wetted area and less foil friction drag in smooth water which accounts for their higher top speed capability at the minimum gross weights. At the increased gross weights, the "Sea Wings" still have less wetted foil area, but due to increased immersion, they begin to use the relatively inefficient (high dihedral) area of the surface piercing element. The aspect ratio 3.0 fully submerged foils become the faster configuration at gross weights of about 1,300 pounds or greater. Strut drag increase with gross weight is about the same for all configurations because immersion increase with gross weight is about the same for all configurations.

Maximum gross weights for the tested configurations have not been limited by loading or flow breakdown (ventilation or cavitation) on the main foils. Instead, they have been limited by the inability to trim the craft to higher nose-up pitch angles before reaching the point where insufficient thrust was available to force the craft to higher speeds. This is strongly dependent on the hull shape of the outboards, realizing that changes in main foil incidence values were not used to favor take-off capability.

It is not possible to generalize on the overall effect of foil loading. For full scale vehicles, the horizontal projected area employed at cruise speed will be primarily selected to maintain lift (vertical) loadings within cavitation boundaries. This loading will be essentially the same for any configuration. Here the lower dihedral foils will tend to have less friction drag through less wetted (planform) area. The ability of these craft to take-off at a minimum speed for any given gross weight is now a function of what kind of high lift devices are employed such as extra area or trailing edge flaps, within practical limitations of hull afterbody keel angle (ability to trim nose up), thrust available, device weight and cost. Perhaps the best way to compare take-off characteristics is to consider the value of take-off speed/max. speed for several existing designs.

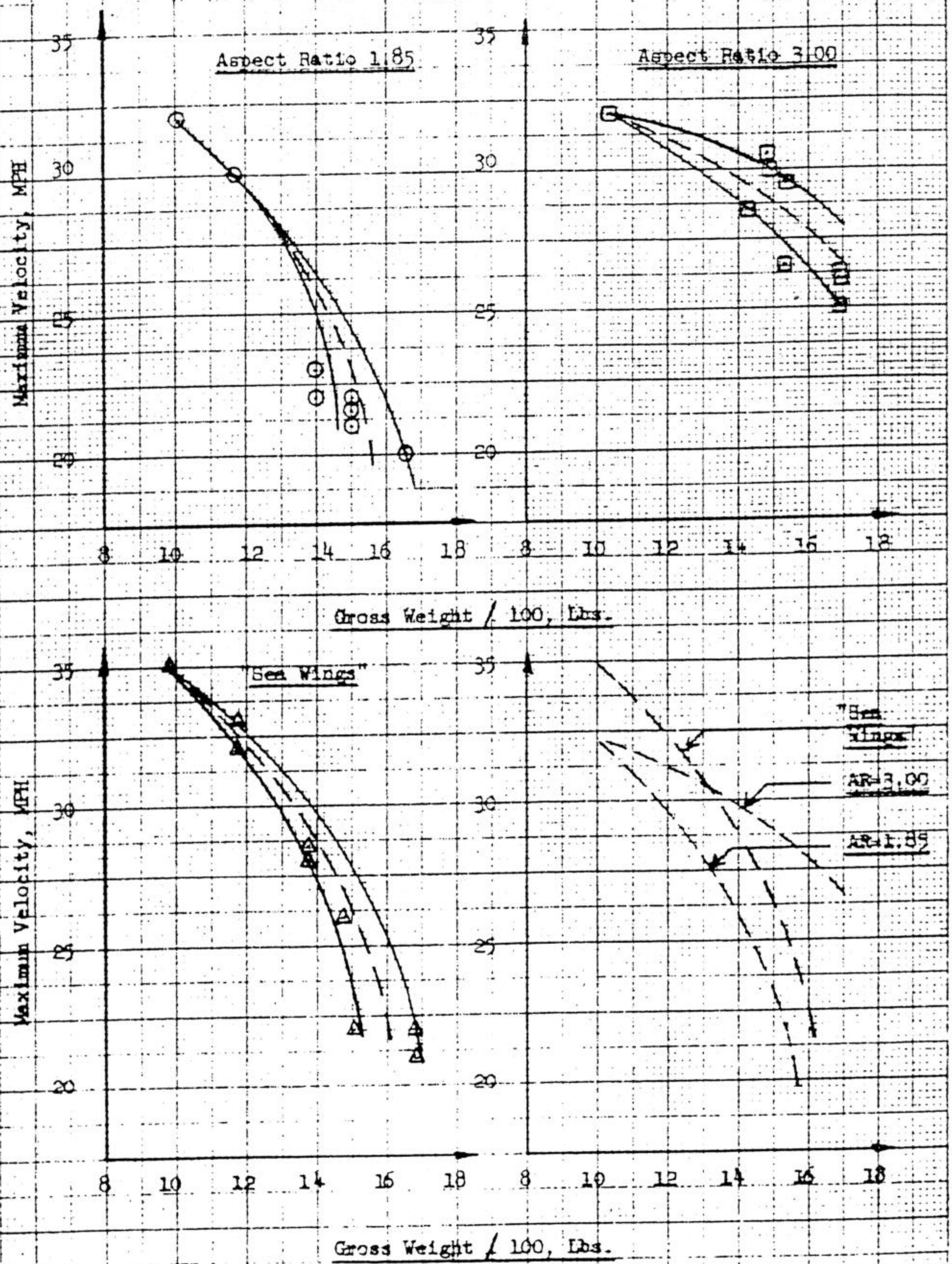
Design	Configuration	G.W. Long Tons	S.W.* V max. Knots	** V_{To} Knots	$\left(\frac{V_{To}}{V\ max.}\right)$
"Sea Wings"	Surface Piercing	.52	28.2	12.1	.43
HS Denison	Surface Piercing	80	62+	27	.44
COIN Proposal A	Surface Piercing	50	55+	21.5	.39
AR = 3.00 Runabout	Fully Submerged	.53	26.1	12.1	.46
AGEH Design	Fully Submerged	310	57+	28	.49
COIN Proposal B	Fully Submerged	50	55+	21	.38

* S.W. refers to smooth water.

** V_{To} refers to drag hump speed.

The only generalization which appears proper now is to state that the drag hump speed during take-off can be about 40% of the smooth water V_{max}, at design gross weight and for any of the contemplated vehicle configurations.

MAXIMUM SMOOTH WATER SPEED VS. GROSS WEIGHT FOR ASPECT RATIOS 1.85, 3.00, AND "SEA WINGS"



CURVE I

TABLE I

EFFECT OF GROSS WEIGHT INCREASE ON PERFORMANCE OF ASPECT RATIOS 1.85, 3.00, AND "SEA WINGS"

Configuration	Min. Gross Wt., Lbs.	High Gross Wt., Lbs.
Aspect Ratio 3.00	1033	1533
Aspect Ratio 1.85	996	1496
Sea Wings	972	1502

Configuration		Max. Speed, MPH		
	Min. Wt.	Max. Wt.	ΔSpeed	% Decrease
AR = 3.00	32	29.5	2.5	7.8
AR = 1.85	32	21.5	10.5	32.8
Sea Wings	35	22	13.0	37.2

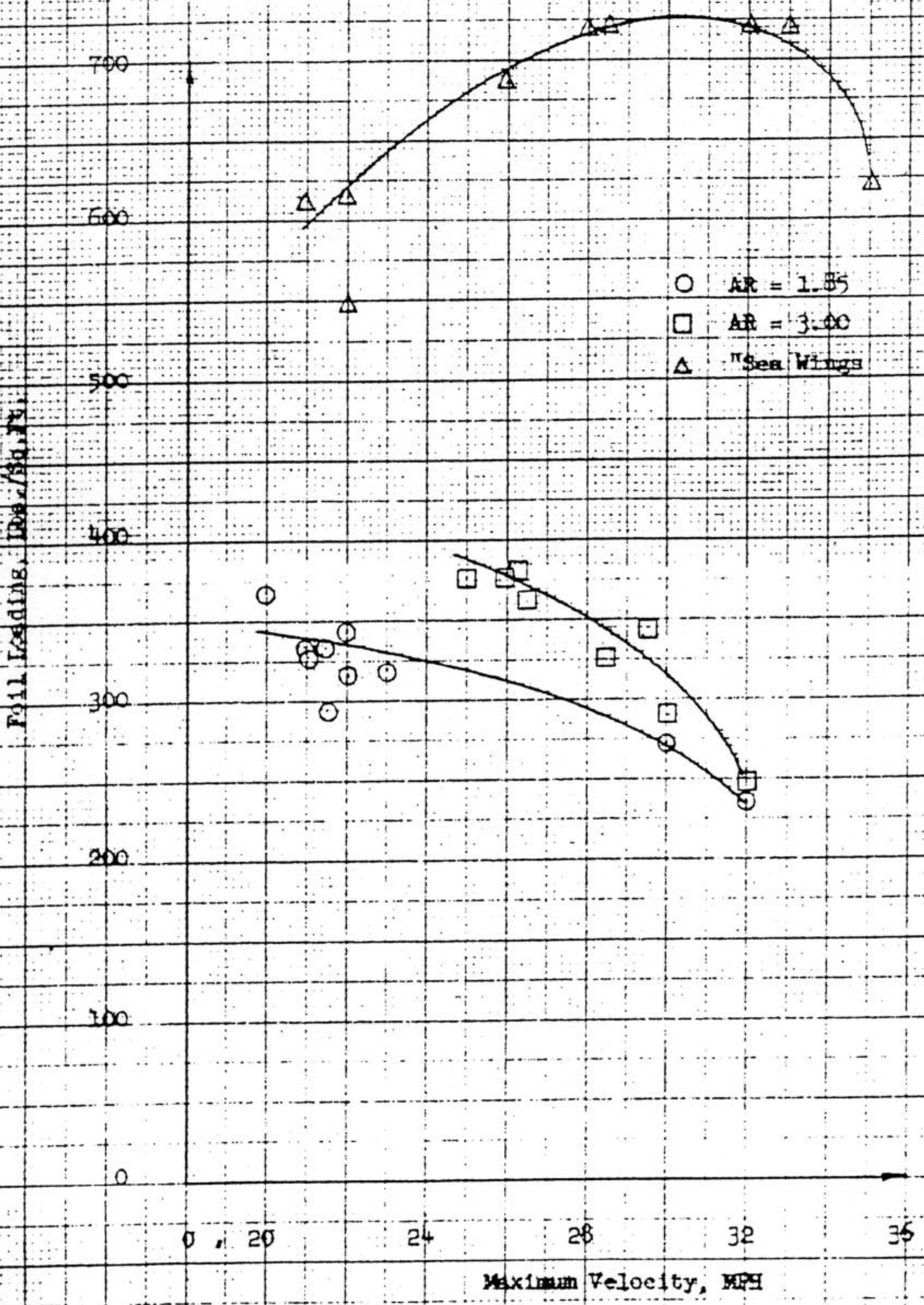
Configuration		Take Off Speed, MPH		
	Min. Wt.	Max. Wt.	ΔSpeed	% Increase
AR = 3.00	14.0	14.0	0	0
AR = 1.85	15.0	18.0	3	20
Sea Wings	12.0	18.0	6	50

Configuration		Time To Max. Speed, Seconds		
	Min. Wt.	Max. Wt.	Δ Time	% Increase
AR = 1.85	31.5	40.0	8.5	27
AR = 3.00	20.0	45.0	25.0	125
Sea Wings	20.0	55.0	35.0	175

Configuration		Time To Take Off, Seconds		
	Min. Wt.	Max. Wt.	Δ Time	% Increase
Sea Wings	6.5	10.0	3.5	54
AR = 3.00	4.5	11.0	6.5	145
AR = 1.85	6.5	20.0	13.5	208

FOIL LOADINGS VS MAXIMUM SMOOTH WATER SPEED

FOR ASPECT RATIOS 1.85, 3.00 AND "SEA WINGS"



CURVE II

ACTIVE DEVELOPMENT PROGRAM

Stability Measurement Program

An instrumentation package and a function generator system has been designed and fabricated for an A.D. stability measuring program. The system will be used with the 16 series, aspect ratio 3.00, fully submerged foils. Constant motion cams have been mounted in place of the drag vane up-stops on the main foil struts. When actuated, the cams push the drag vanes aft to cause a five degree positive movement of the foil flaps with instantaneous release back to the neutral position. Pitch angle and acceleration are sensed by a gyro and accelerometer and are recorded on an oscillograph. Natural frequencies and damping ratios for longitudinal dynamics will be obtained. Figures 14 and 15 show the cam installation and the instrumentation and cam actuation mechanism. The results of these measurements will be compared with analytical predictions.

Flap Hinge Repair

Stainless steel piano hinges with rubber seals are now installed on the fully submerged outboard foils. They tend to bind due to stretching of the seals. Redesign and repair is in progress.

Drag Vane and Flap Optimization

Design studies are in progress to optimize drag vane and flap design. This work is directed toward minimum drag and improved vehicle motions in a seaway at speeds up to 60 knots. Designs include provision for pilot control to allow mean flap position selection for take-off and for banking in turns. The XCH-6 will be used as a test vehicle with speed capability of about 60 knots.

CONCLUSIONS

1. The sea state capability of the fully submerged foils exceeded expectations. The ability of the 15 foot runabouts to remain foilborne in $1\frac{1}{2}$ to 2 foot waves shows good potential for the fully submerged foil system with vane type, trailing edge flap control.

2. In general, and for the fully submerged foils tested, the smaller aspect ratio high camber foil provides a better rough water lift to drag ratio and greater sea state capability. The higher aspect ratio foils provide a better smooth water lift to drag ratio and a smoother ride.

3. For the configurations tested, the fully submerged foils provide a better rough water and high gross weight lift to drag ratio, and greater sea state capability, than the "Sea Wings" surface piercing foils. The "Sea Wings" foils provide a better smooth water lift to drag ratio at low gross weights, a smoother take-off and better turning capability.

4. Increases in gross weight have been least detrimental, to significant smooth water performance parameters, for the fully submerged aspect ratio 3.00 foils. Performance deterioration was somewhat greater for the aspect ratio 1.85 fully submerged foils and largest for the "Sea Wings" surface piercing foils.

RECOMMENDATIONS

1. The active development programs described herein, directed toward drag vane and trailing edge flap design optimization, should be pursued with application to specific, full scale vehicle designs.

A70 FOILS

metal

Lift sections
Cross section

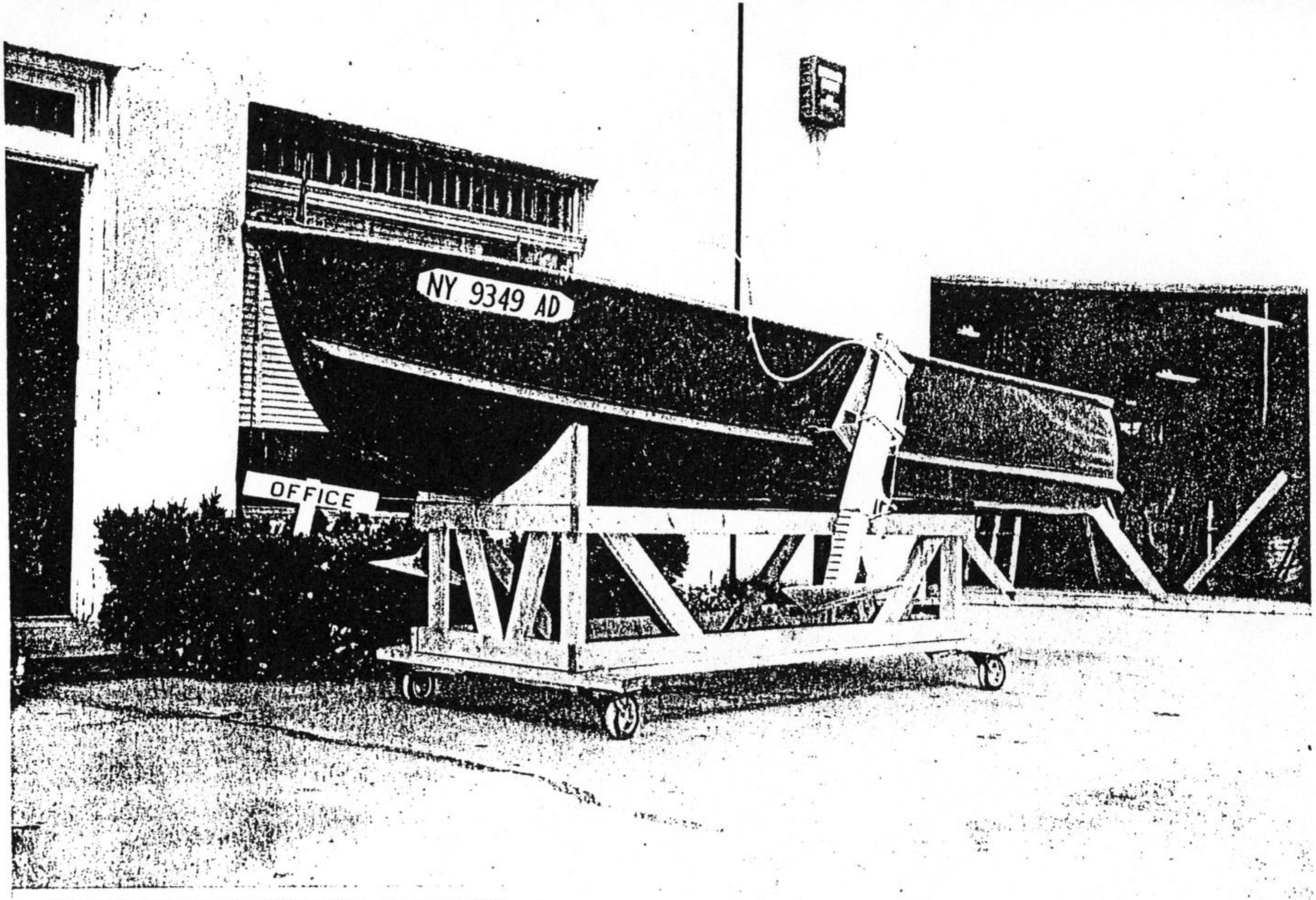
my boat

phanolic+fiberglass
these float

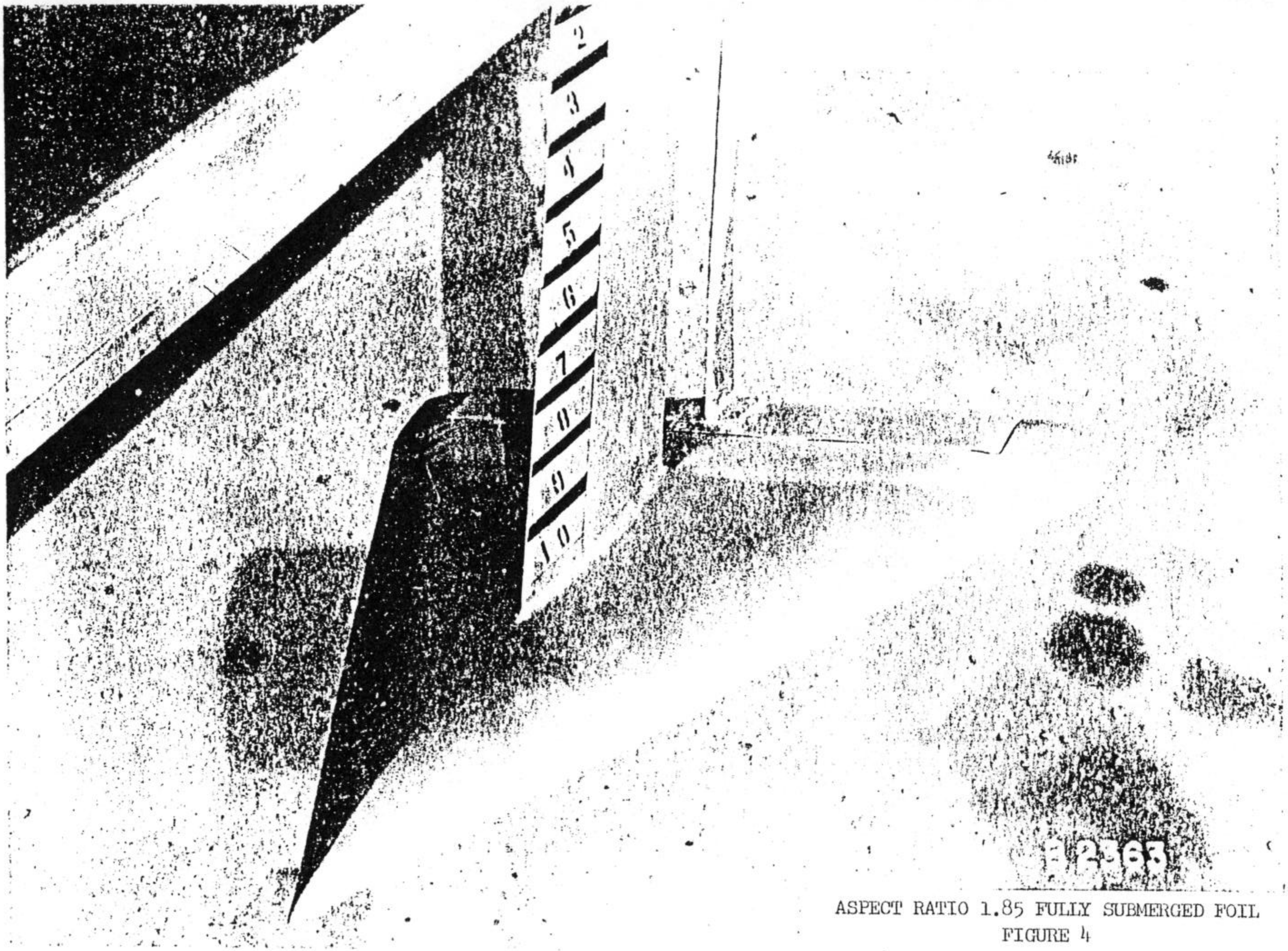
Acet.

REFERENCES

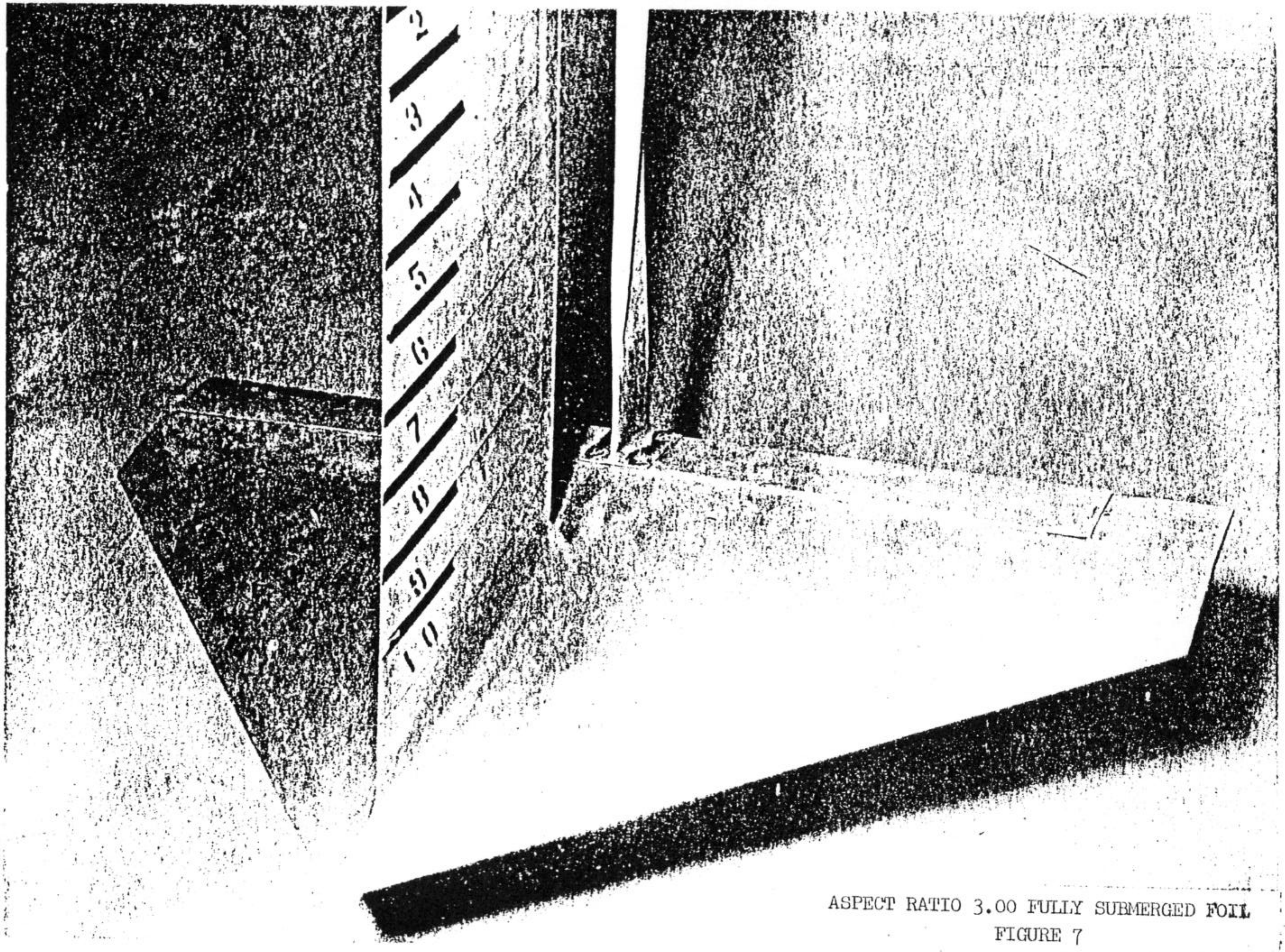
1. Grumman Interoffice Memorandum, ENG-MAR-MEMO-252, Testing and Evaluation of "Lift Vane" Flap Control Installed on the 15 Foot Runabout, May 1963
2. Grumman Interoffice Memorandum, ENG-MAR-MEMO-251, Testing and Evaluation of the 15 Foot Outboard Equipped With "Sea Wings" Surface Piercing Foils; 60 - 40% Weight Distribution, January 1963



TYPICAL FULLY SUBMERGED FOIL ARRANGEMENT
FIGURE 2

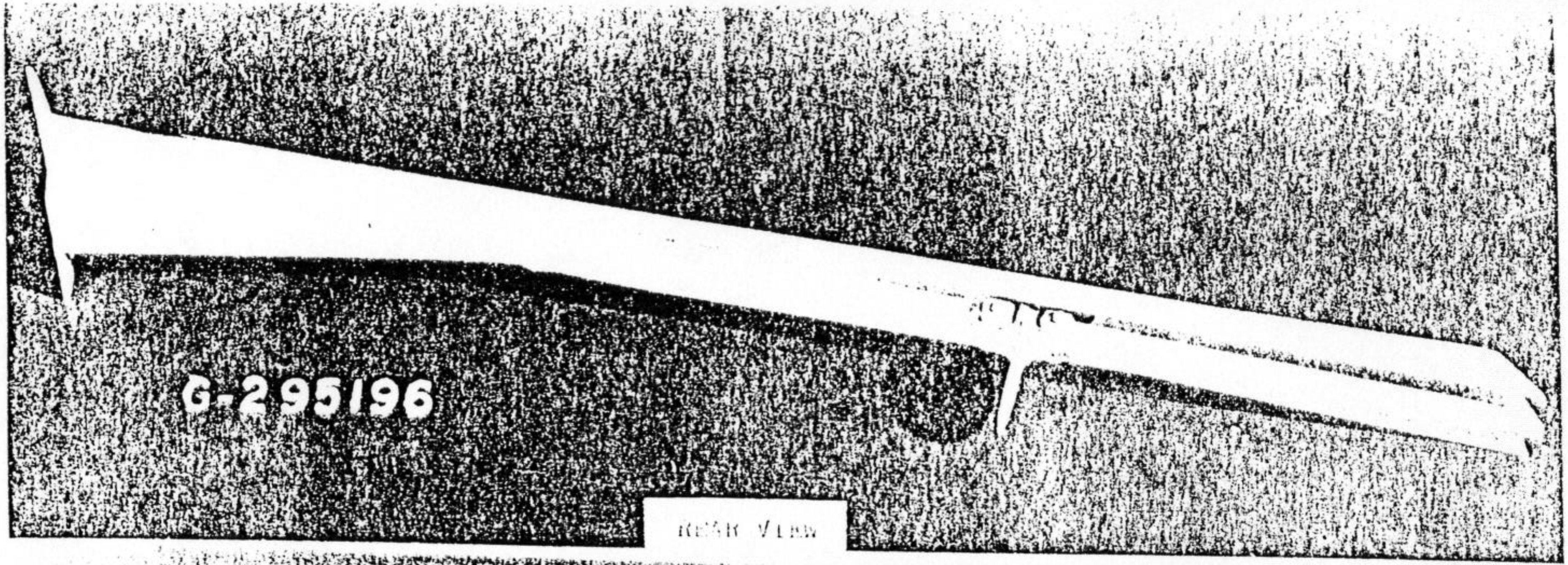


ASPECT RATIO 1.85 FULLY SUBMERGED FOIL
FIGURE 4

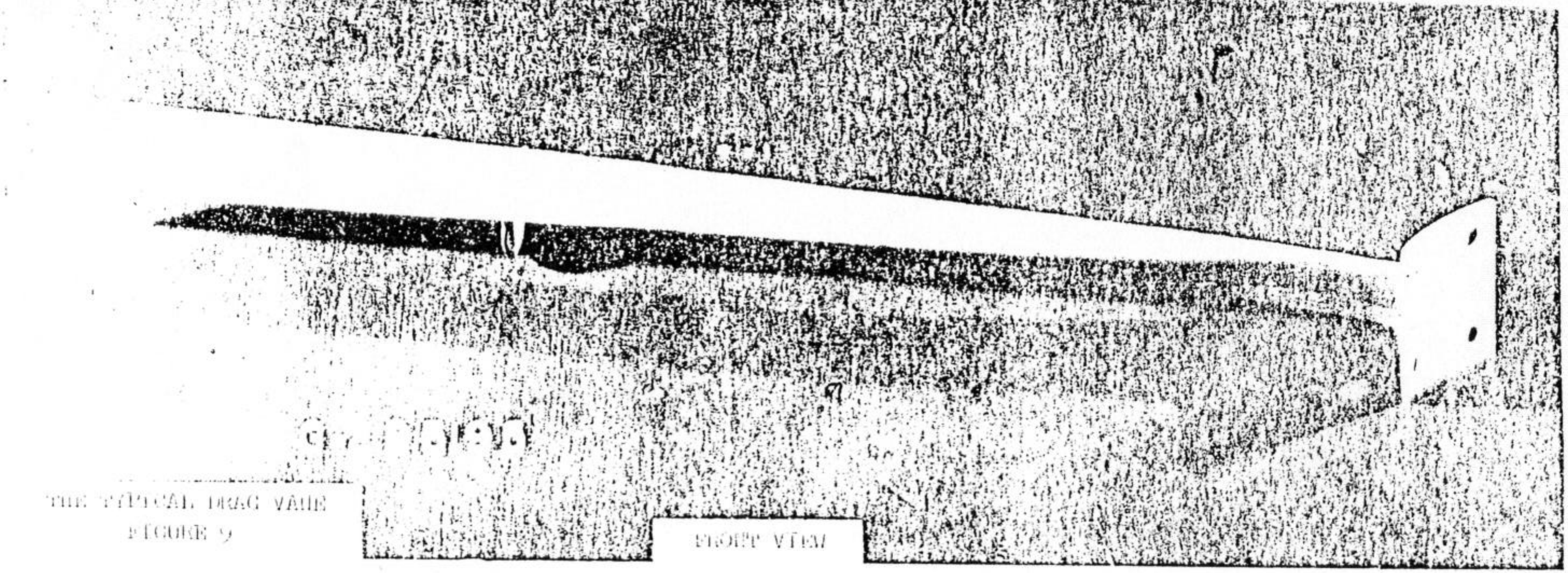


ASPECT RATIO 3.00 FULLY SUBMERGED FOIL

FIGURE 7

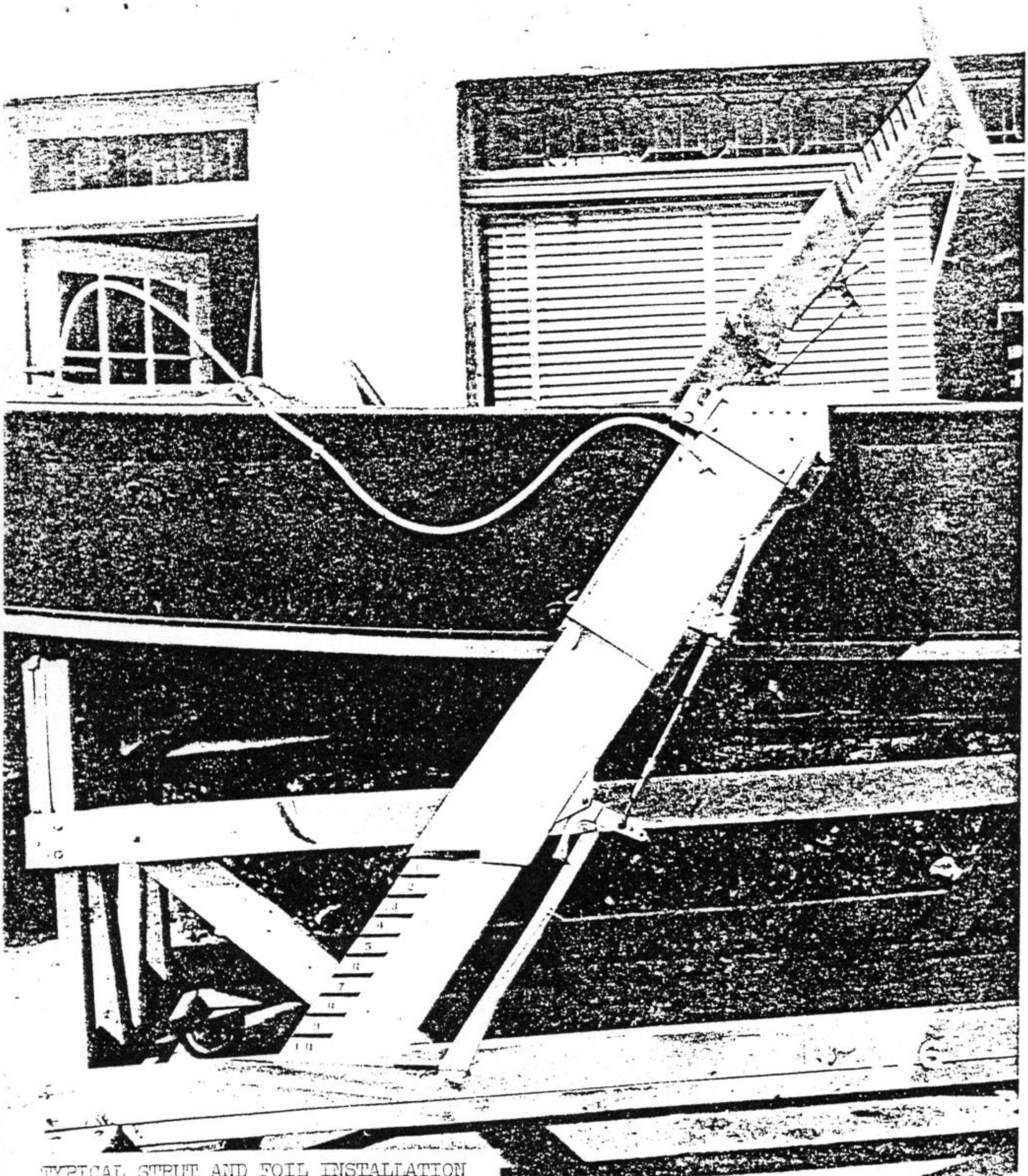


REAR VIEW



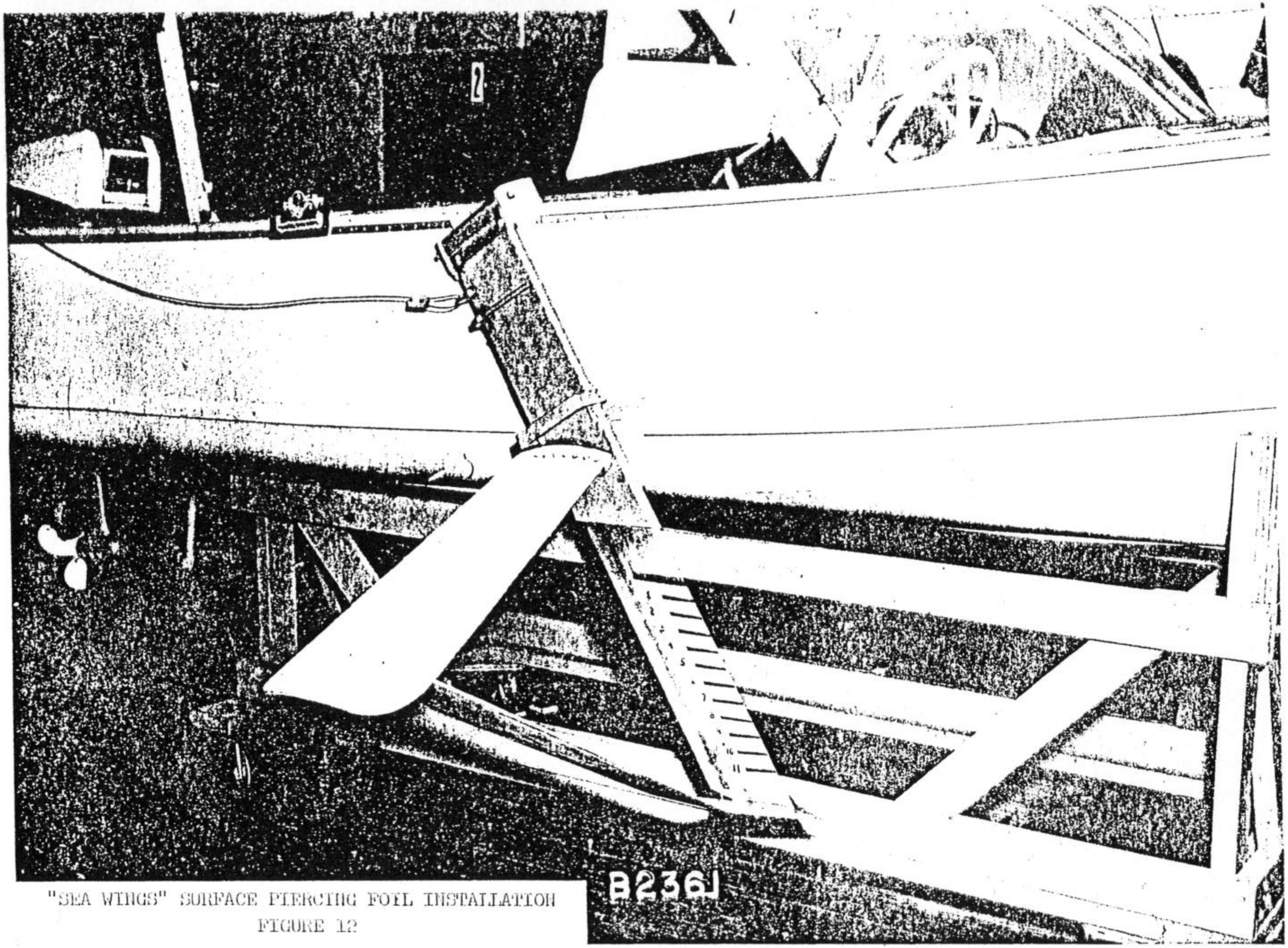
FRONT VIEW

THE TYPICAL DRAG VANE
FIGURE 9

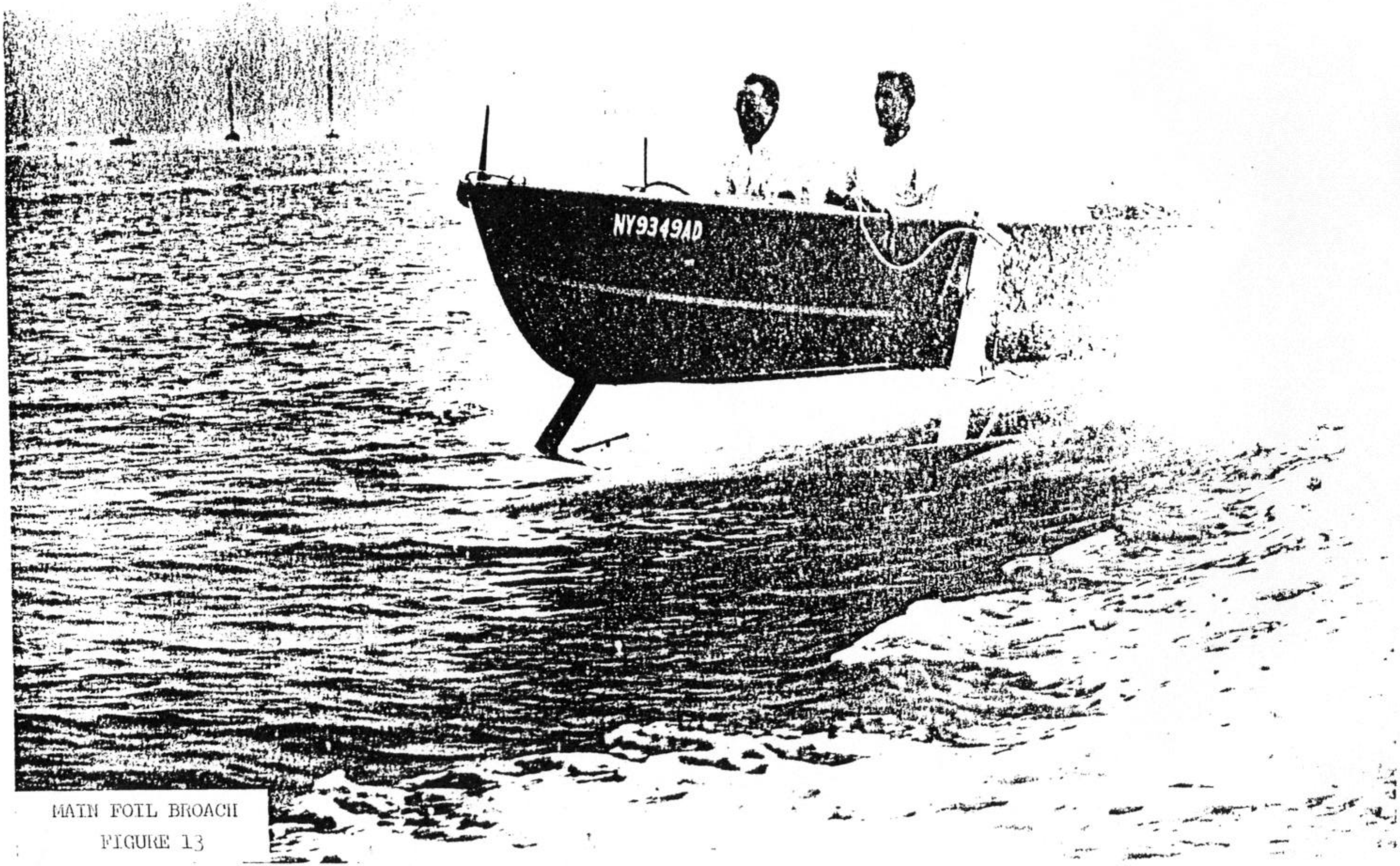


TYPICAL STRUT AND FOIL INSTALLATION

FIGURE 10

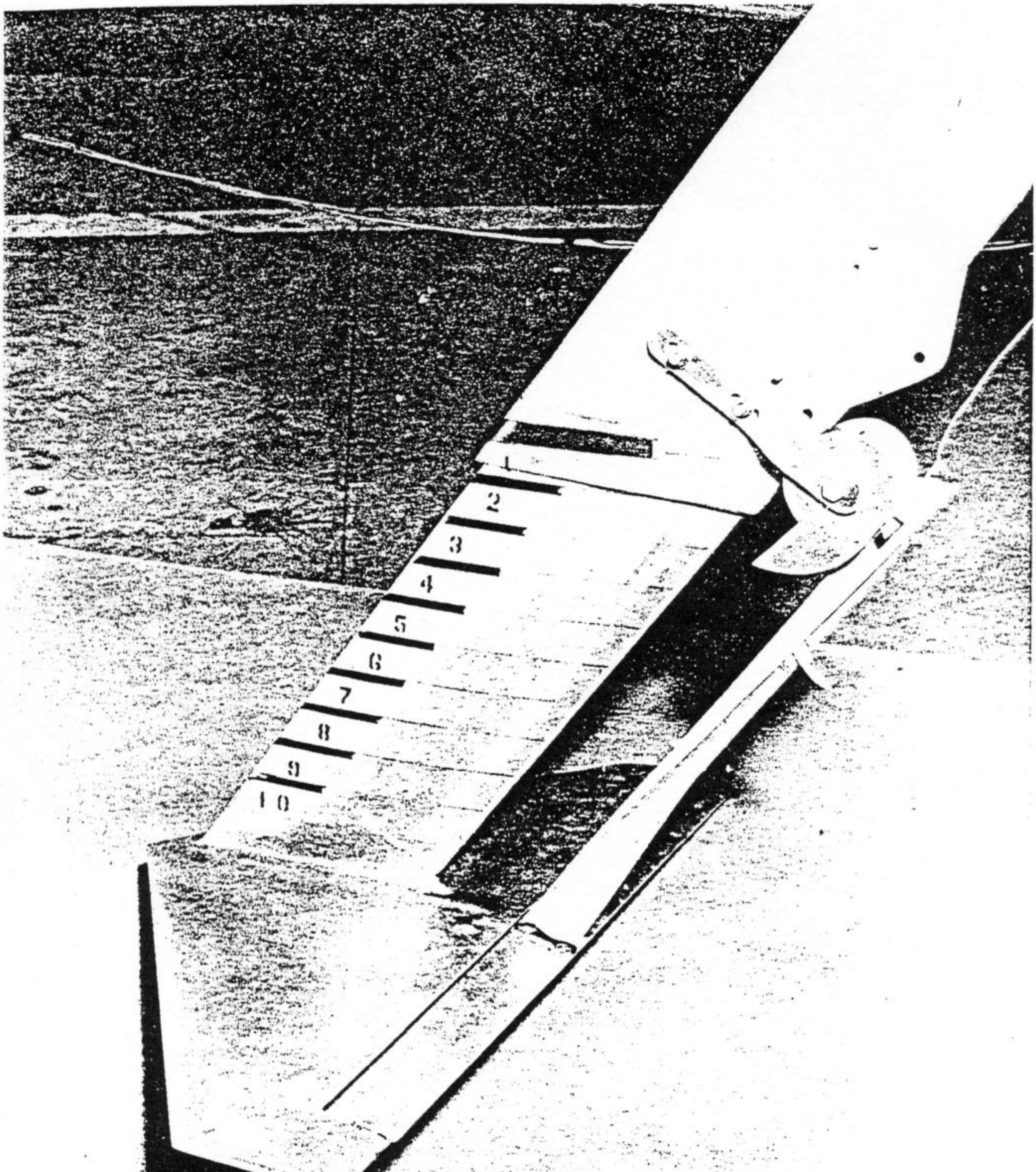


"SEA WINGS" SURFACE PIERCING FOIL INSTALLATION
FIGURE 12

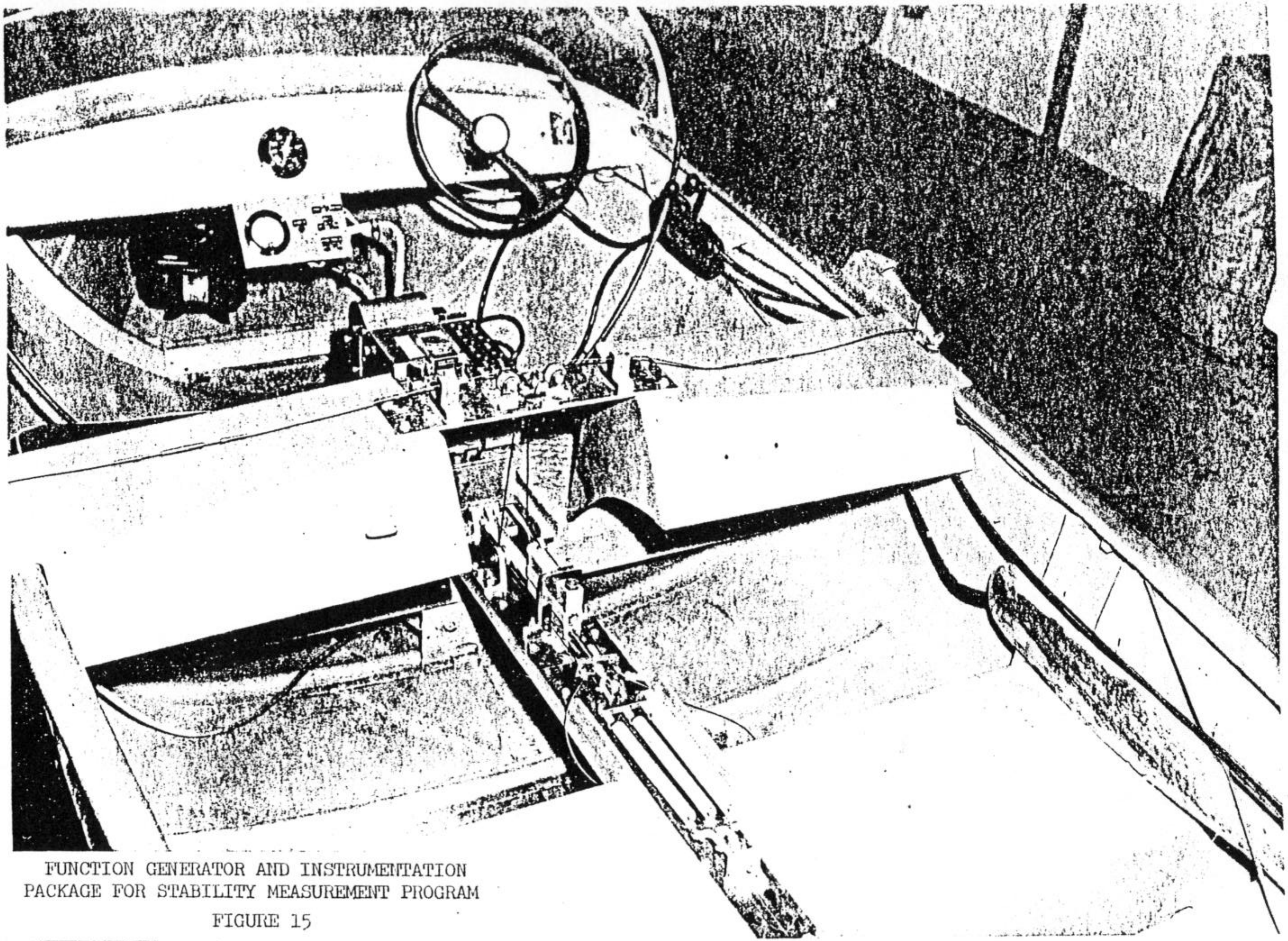


MAIN FOIL BROACH

FIGURE 13



CAM INSTALLATION FOR STABILITY MEASUREMENT PROGRAM
FIGURE 14



FUNCTION GENERATOR AND INSTRUMENTATION
PACKAGE FOR STABILITY MEASUREMENT PROGRAM

FIGURE 15