(1)

DEPARTMENT OF THE NAVY
DTNSRDC

EXPERIMENTAL STUDY OF AIR FLOW OVER A 2% SCALE MODEL OF THE FFG-7 INCLUDING SIMULATION OF GAS TURBINE INLET FLOW

by

Kenneth Phillips and Henry Ozarko

Approved for public release: distribution unlimited

Report ASED-356

September 1976

DAVID
W.
TAYLOR
NAVAL
SHIP
RESEARCH
AND
DEVELOPMENT
CENTER

BETHESDA
MARYLAND
20084

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASED 356	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Experimental Study of Air Flow Over a 2% Scale Model of the FFG-7 Including Simulation of Gas Turbine Inlet Flow		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kenneth A. Phillips and Henry S. Ozarko		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Aviation and Surface Effects Department (Code 1611) Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Element No. 63508N Project No. SSL24 Task Area No. SSL24001 Work Unit 1611-400
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Energy Conversion and Explosive Devices Div. Washington, D.C. 20362		12. REPORT DATE September 1976 13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Wind Tunnel Testing
Flow Visualization
Gas Turbine Inlets
Wind-Over-Deck
FFG-7

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Flow visualization studies were conducted on the gas turbine inlets on the FFG-7. Smoke, helium bubbles, and tufts were ~~utilized~~. Flows were investigated at 0 and 10 degrees pitch and several yaw angles from 0 to 225 degrees at 10 to 25 knots wind-over-deck speed.

The present gas turbine inlet arrangement and several modifications were tested and it was shown that flow at the inlet area is affected by the ship configuration bridge structure and bow. The bow effects at the inlet

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

become significant on the down wind side inlet when winds are quartering off the bow.

TABLE OF CONTENTS

LIST OF FIGURES

Page

ABSTRACT

Flow visualization studies were conducted on the gas turbine inlets on the FFG-7. Smoke, helium bubbles, and tufts were utilized. Flows were investigated at 0 and 10 degrees pitch and several yaw angles from 0 to 225 degrees at 10 to 25 knots wind-over-deck speed.

The present gas turbine inlet arrangement and several modifications were tested and it was shown that flow at the inlet area is affected by the ship configuration, bridge structure and bow. The bow effects at the inlet become significant on the down wind side inlet when winds are quartering off the bow.

ADMINISTRATIVE INFORMATION

This work was authorized by the Naval Ship Engineering Center (NAVSEC 6146). Funding was provided by the Naval Sea Systems Command (NAVSEA 0331G) under Program Element 63508N and Task Area SSL24001.

INTRODUCTION

The Navy recently put into service several large displacement ships powered by gas turbines. This innovation has come about through the introduction of larger hydrofoil craft and the design of the first large displacement vessels with gas turbine power plants. The use of gas turbines aboard ship has several advantages such as a decrease in space required for machinery, readily available fuel, and a power plant that does not require a warm-up period. However, there are some disadvantages that need to be addressed during design. The gas turbine produces larger quantities of exhaust gases at high temperatures. Disposing of these gases so that they do not interfere with operations can be a problem. The gas turbine is more sensitive to the contamination of intake air and large quantities of air are needed for gas turbine operation.

The Naval Ship Engineering Center is concerned about these problems, especially those of air inlets and the effect of their location on the performance of future Navy ships. In order to study this problem and establish specifications, NAVSEC requires that background data be generated on the effects of various shipboard environmental conditions on inlet performance. David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was tasked to investigate wind tunnel testing techniques that would be suitable for generating these data and based on analysis of this data, recommend testing procedures for future ship designs.

A 2-percent scale model of the FFG-7, formerly known as the PF-109, was modified to provide air intakes and ducting. The original test schedule, which included several wind-over-deck speeds and a yaw angle range, was changed after experience was gained with the extremely low scale and flow visualization techniques. The test was carried out at 10 to 15 knots wind-over-deck.

Three intake arrangements on the present ship configuration and a straight sided ship configuration with one intake arrangement were investigated. A pitch angle of 0 and 10 degrees and yaw angles of 0, 25, 45, 180, and 225 degrees were investigated. Although the model could be rolled in the range of ±30 degrees, this parameter was not felt to be of any practical consequence in this investigation and therefore was not investigated.

The results of this investigation were obtained mainly through the use of the Sage Action Inc. helium bubble generator and tufts. The smoke source used was generally ineffective in this investigation. This was due to the smoke generated from mineral oil dispersing rapidly in a moving air stream making it difficult to photograph clearly.

This investigation was conducted in the 8- by 10-foot subsonic wind tunnel at DTNSRDC.

MODEL AND TEST FACILITY

A 2-percent scale model of the FFG-7 which was built and tested by the Hydromechanics Department of DTNSRDC was modified for use in this investigation (Figure 1). The modifications consisted of:

- Hardware to adapt the hull to the model support system of the south subsonic wind tunnel;
- Hardware to permit pitch and roll angle settings of the model of ±10 and ±30 degrees, respectively;
- Providing simulated ducting through the intakes;
- Adapting suction fans to draw air through the intakes and ducting system.

The suction was provided by two ROTRON PROPIMAX-3 fans. These fan models operated on 400 Hz power and provided approximately 60 cubic feet per minute air flow, the approximate mass flow necessary to simulate full scale engine operation at full power.

The basic model (Figure 1) was modified to position the intake as shown in Figure 2. This intake was also provided with a hood facing inward as shown in Figure 3.

A straight sided hull configuration was also investigated. This configuration is shown in Figure 4.

Photographs of the model installed in the tunnel are shown in Figures 5, 6, and 7.

The wind tunnel utilized in this investigation is one of two subsonic speed closed circuit facilities at the Aviation and Surface Effects Department. It has a test section 8 feet high by 10 feet wide and is powered by an electrically driven fan capable of test section speeds of 180 mph.

To provide a simulated water surface, a ground board was installed. Beneath the ground board space was provided for mounting the suction fans, adapting hardware and clearance for pitching the model. The ground board can be seen in the installation photos (Figures 5, 6, and 7).

Flow was visualized with the aid of a helium bubble generator. This bubble generator, developed specifically for flow visualization, produces small diameter bubbles on the order of 3/16-inch diameter which are illuminated by a high intensity light. The bubbles are neutrally buoyant and respond well to air flow. Tufts were also used to aid in flow visualization.

TESTS

Flows around the intake area and along the ship were observed at wind speeds of 10 to 30 knots, pitch angles of 0 to 10 degrees, and yaw angles of 0, 25, 45, 180, and 225 degrees. Test runs were made with the bubble source positioned at several locations to insure that a complete description of the flow field could be constructed.

RESULTS

The data recorded during the test were photographs of helium bubbles and tufts. The helium bubble source was moved to provide data on the flow at several locations on the model to obtain as extensive a description as possible of the flow field.

Photographs are presented in Figures 8 through 12.

DISCUSSION OF RESULTS

The helium bubbles proved to be adequate to show the character of gross flow but unsatisfactory to show fine flow details such as one would look for in areas of the gas turbine intake.

The photographs presented in Figures 9 through 12 illustrate the type of information that was recorded through the use of helium bubbles. The entire flow field around the ship could be visualized by relocating the source of bubbles.

At zero angle of yaw the helium bubbles graphically illustrate the tendency of flow originating at the bow and along the hull-water intersection to progress toward the upper regions of the ship (see photos in Figure 9). This flow would, of course, carry a greater concentration of sea mist to the intake region. The bubbles also show the fairly severe vortices generated at the bow and off the end of the bridge structure (Figures 10 and 11). These vortices, with regard to the flow at the intake, can be both beneficial and harmful. They are beneficial from the standpoint that the vortex can mix with the free-stream flow bringing it to a lower speed within the intake region and enhance the efficiency of the intake. However, the vortices can be harmful because they would tend to entrain more sea mist.

The model was tested at several yaw angles to determine the effects of yaw on the flow patterns. There are significant changes in the flow pattern when the wind over the deck is not directly on the bow. Once the pattern is set by a change from zero yaw, it remains essentially the same until the yaw angle exceeds 45 degrees. Figure 13 represents the flow pattern for conditions with the wind off the bow.

There are several important features of this flow field that need to be discussed. First, the air on the up-wind side tends to flow toward the stern and the upper part of the superstructure. This flow originated very near the water surface and is fairly uniform. Second, the flow around the bow and over the superstructure combine to form a very well organized vortex downwind of the ship. This vortex tends to produce rather uniform flow up the side of the ship in the general area of the inlets. However, it is made up of air from around the bow and passes near the water surface before flowing up the side of the ship and contains sea mist. The sketches shown in Figure 13 and 14 help to illustrate this flow.

When the wind-over-deck is approaching from astern (yaw > 90 degrees), the flow is basically similar to the flow coming from the bow. The phenomenon of the flow moving up the side of the ship and combining with the flow off the superstructure to form a vortex on each side of the ship is present. This is especially true when the wind-over-deck is quartering from the stern. In that case up-wind side of the ship receives flow from the sea surface, and on the downwind side a large vortex forms such that the flow comes over the superstructure, down to the surface, reverses direction along the surface and then moves up the side of the ship. However, since the inlet is located aft the flow off the water does not have as much time to rise to the inlet location.

In addition to yaw angle, pitch angle and its effects were also studied during the test.

A pitch of 10 degrees bow up was investigated, and again the helium bubbles were employed to visualize the flow. There was very little change in flow due to pitch angle change. The most notable was a strengthening of the vortices produced at the deck edges; however, this had little effect on the basic flow patterns observed at zero degrees pitch angle.

As pointed out earlier, the helium bubbles did not provide much information on the details of the flow entering the inlets. To fill this void, tufts were used near the inlet to determine flow directions. Using this method, it was noted that there was a severe degradation of the flow going into the intake as the flow progressed downstream along the intakes. This can be observed in the photograph of the tufts in Figure 8. The tufts are approximately one intake height away from the hull. This is the point at which flow was first observed to draw the tuft into the intake. It is noted that the downstream tufts, for the same distance away from the plane of the intake and within the longitudinal intake boundary, are not drawn in and are essentially aligned with the free flow toward the downstream end. This flow into the intake is characteristic for all three inlet configurations and may be the result of the internal arrangement of the ducting system. The ducting entrance is forward of the inlets forcing the air flow to make a direction change. This change of flow direction may cause pressure and velocity disturbances that can be sensed at the inlet face. These flow effects will be present independent of inlet configuration.

The configurational changes discussed earlier had very little effect on the overall flow patterns around the model. In addition, changes to the inlet itself had no significant effect on the flow. With these different configurations, the overall flow pattern remained the same.

Also, it appears that the simulation of the inlet flow is not particularly critical. The flow patterns were essentially the same with and without inlet flow, since it is a very small part of the total air flow about the model.

CONCLUSIONS

Based on the above discussion, several conclusions can be drawn about the flow over this model and the particular testing techniques used during these tests.

First, the studies using the tufts indicate that the inlets, as they are now designed, are not as effective as they should be. In addition, the changes that were tried *did not* improve the flow around and into the inlets. Because these tests were limited in scope, the exact cause of the problem can not be defined and further testing at a larger scale may be warranted.

The second important finding was that the overall flow patterns are set by the major features of the model and its orientation to the flow, and detailed changes around the inlet have very little effect on the patterns. The flow patterns are determined by the height and solidity of the superstructure, the width and slope of the foredeck, and the direction of the wind.

Two conclusions about the flow on this specific model can be drawn:

1. Both sides of the ship are immersed in flow that originates near the water surface for all conditions and configurations investigated and this flow would contain large amounts of sea mist.

2. The flow over the top of the ship would have less mist and be more acceptable for the turbines.

A final conclusion that can be drawn from these tests is that simulation of the intake flow is not necessary when studying the flow patterns around ship models. However, for investigating the detailed flow into the inlet, such as that done with the tufts, a simulated flow would be needed.

RECOMMENDATIONS

Further exploration of the inlet region is recommended, particularly with several configurations that will improve the flow distribution across the inlet. This effort would lead to a more effective inlet and improve the flow conditions in the air ducting of the system. A larger scale model would be necessary for these follow-up tests.

In addition, it is recommended that an effort be made to correlate the flow seen in the wind tunnel with flow under full-scale conditions. This study would add validity to the wind tunnel results and fully determine the usefulness of data from the scale model tests.

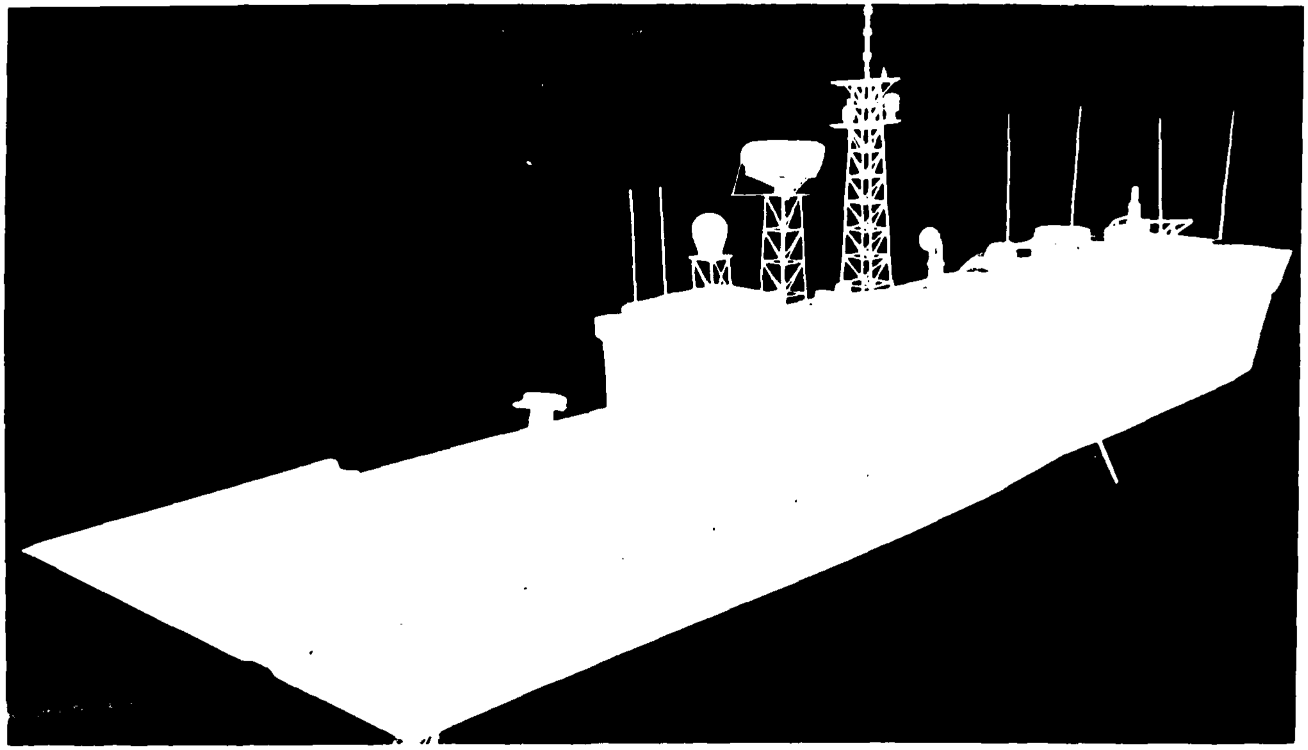


Figure 1 - Photograph of the 1/50-Scale Model
of the FFG7

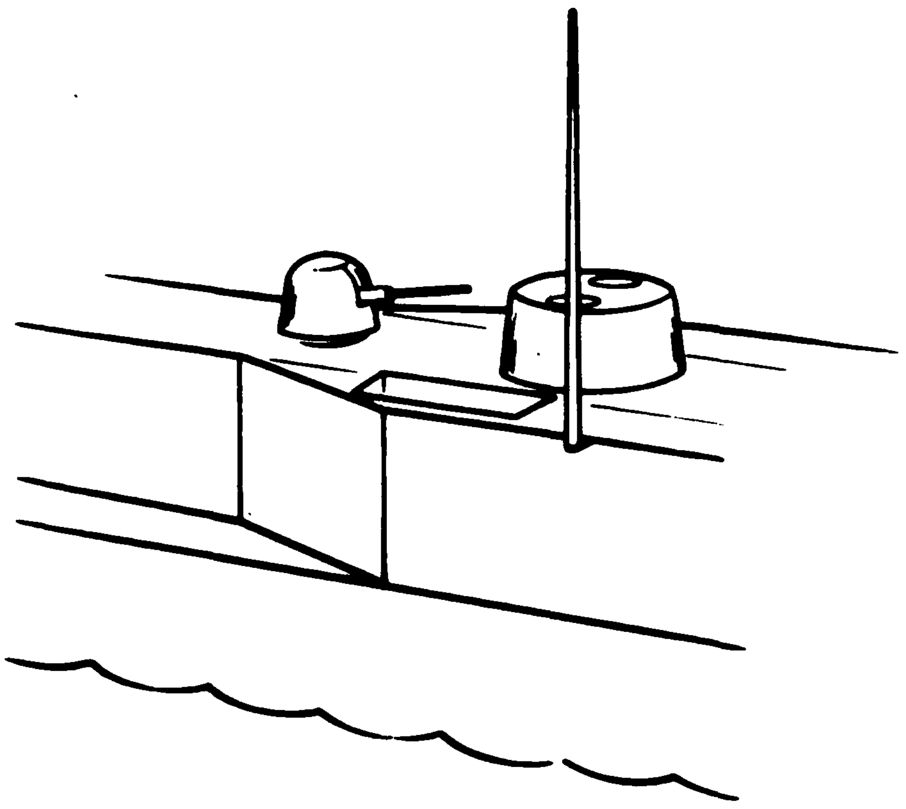


Figure 2 - Horizontal Intake

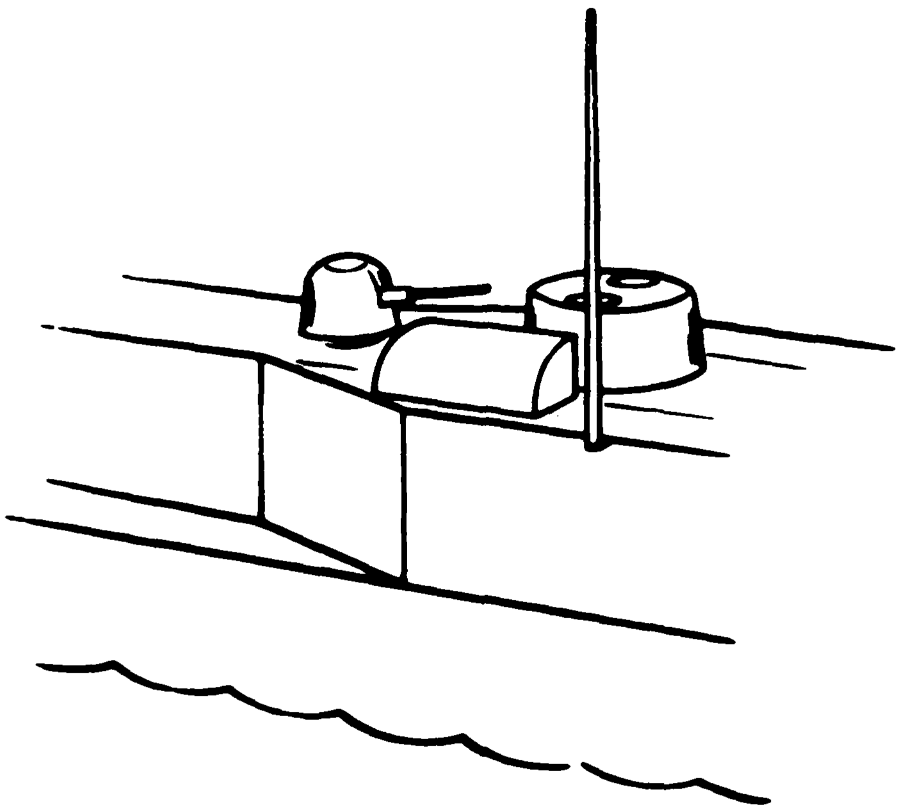


Figure 3 - Horizontal Intake with Hood Facing Inward

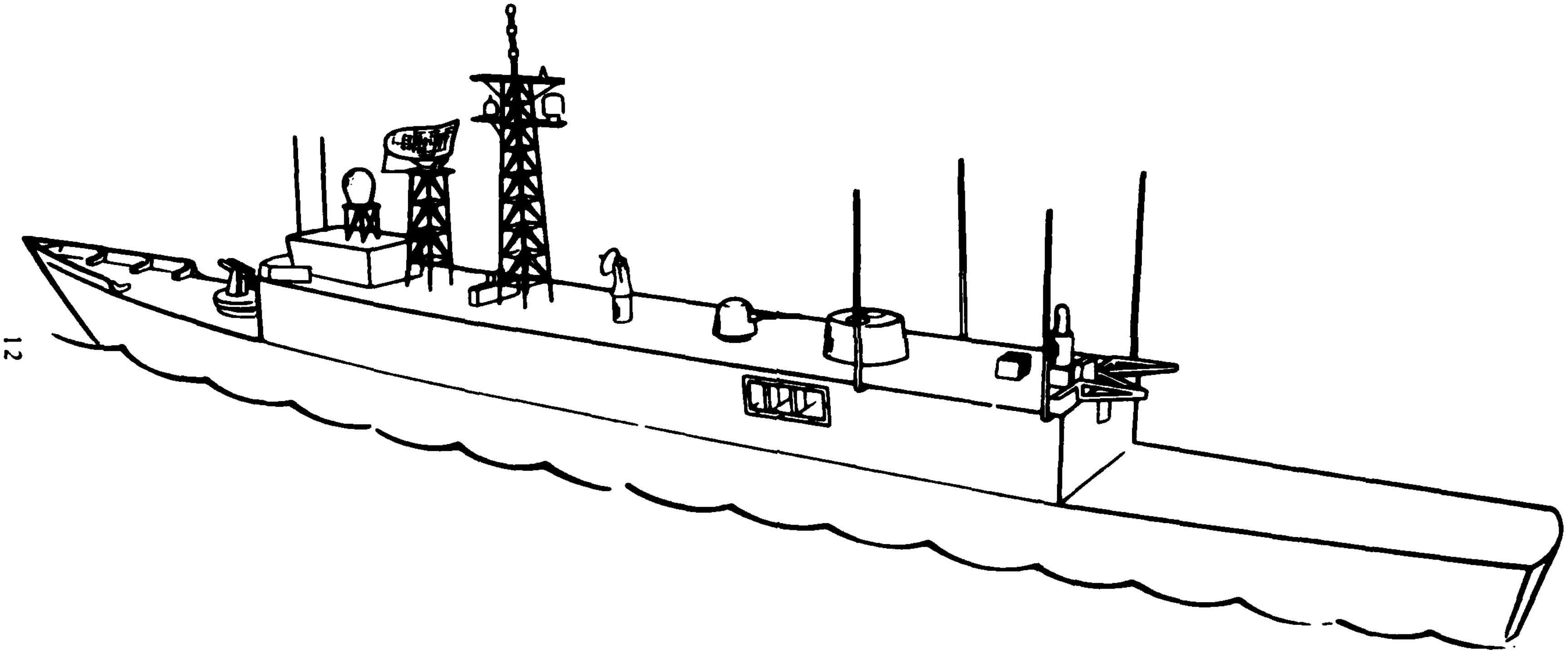


Figure 4 - Straight Sided Configuration

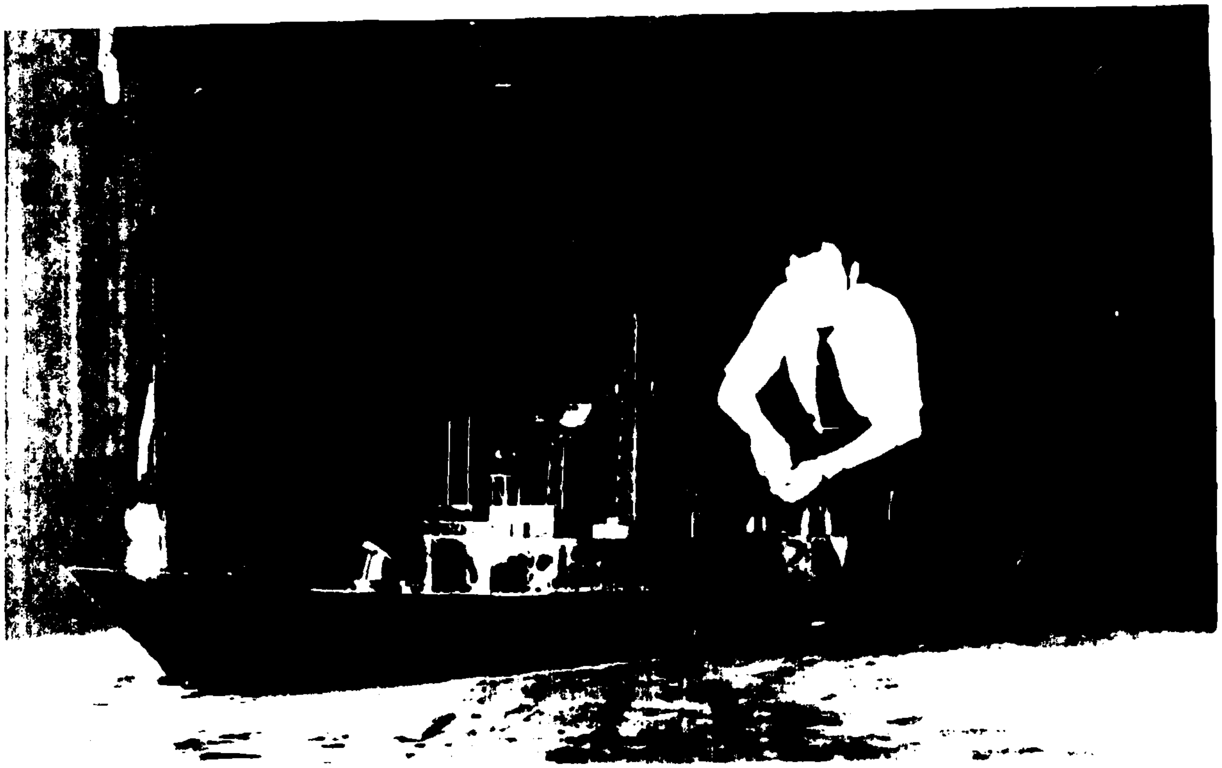


Figure 5 - Photograph of FFG-7 Two-Percent Scale
Model Installed in Wind Tunnel at 45 Degree Yaw Angle

Figure 6 - Photograph Showing the 2% Scale FFG-7 at 10 Degree Pitch and 45 Degree Yaw Angle in the Wind Tunnel

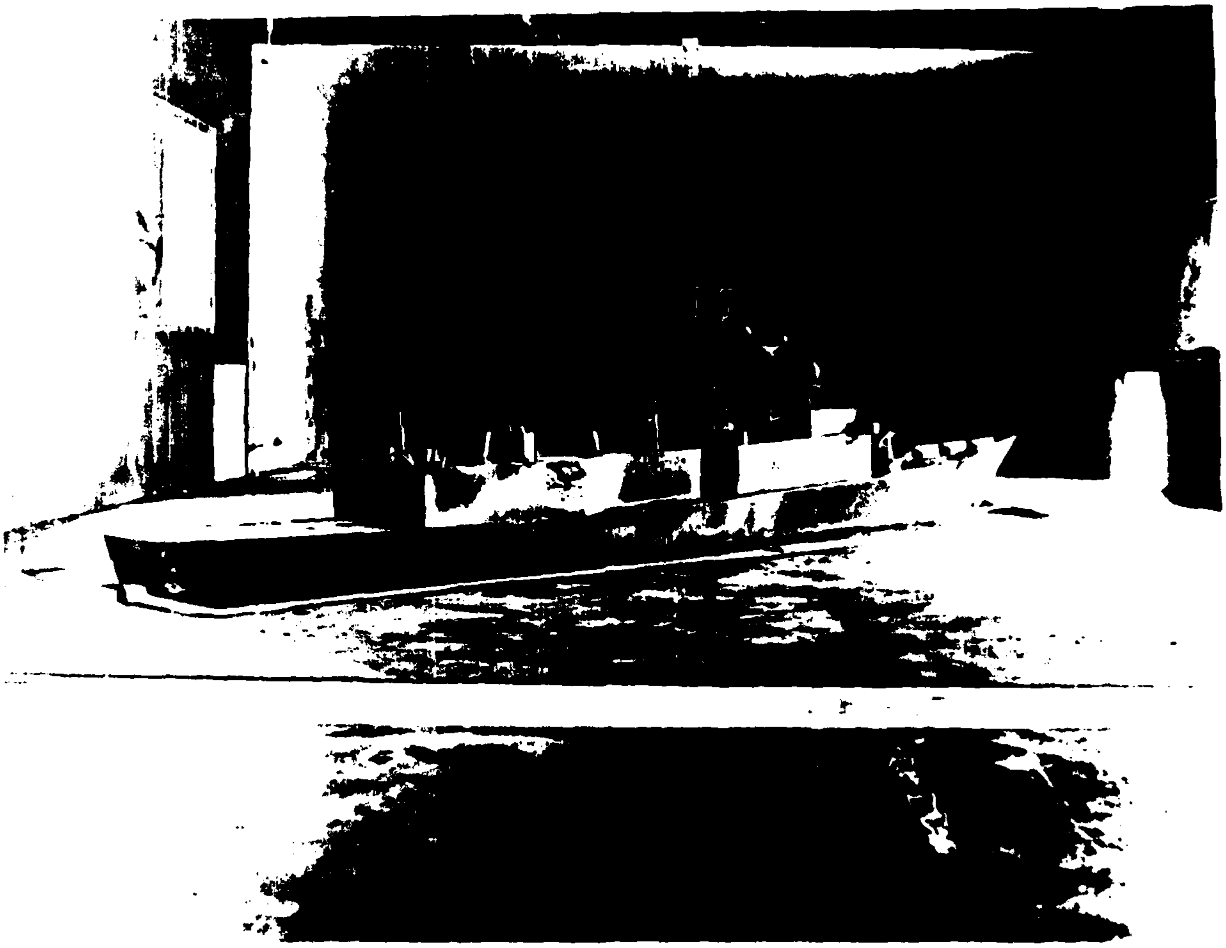
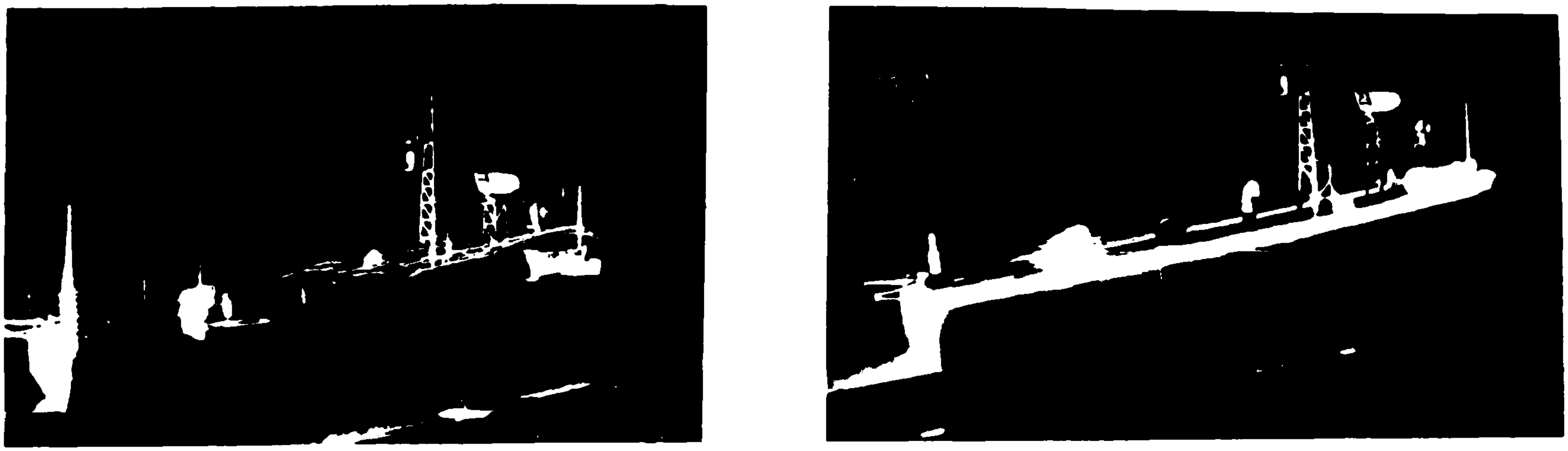


Figure 7 - Photograph of the 2% Scale FFG-7 at a
225 Degree Yaw Angle; 0 Degree Pitch
in the Wind Tunnel

Figure 8 - Photograph of Tufts in Proximity of the Air Inlet for the Straight Sided Configuration



Pitch Angle = 0°
Yaw Angle = 0°

Pitch Angle = 10°
Yaw Angle = 0°

Figure 9 - Photograph Showing Helium Bubble Trace of Flow Tendency to go from Water Surface Upoward Toward Inlets. (Straight Sided Configuration)

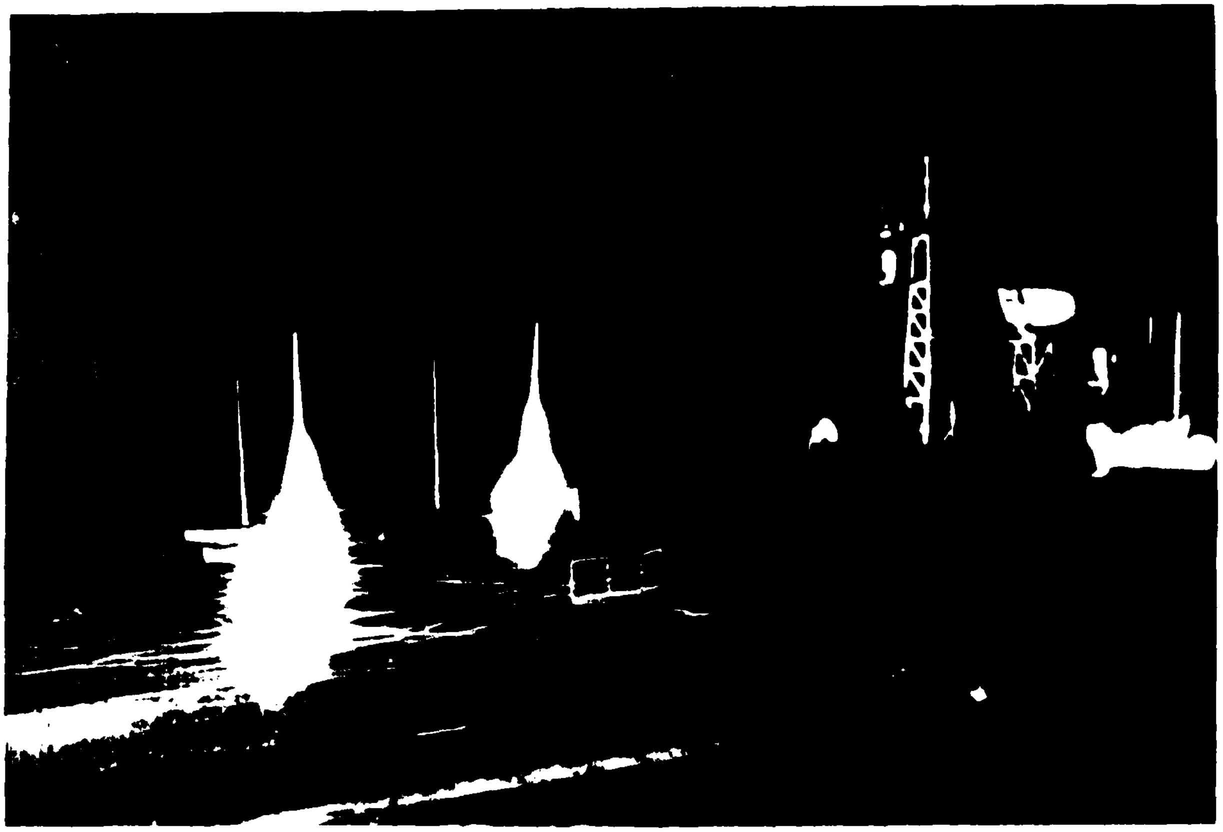


Figure 10 - Photograph Showing Helium Bubbles
Tracing the Vortex Generated at the Bow

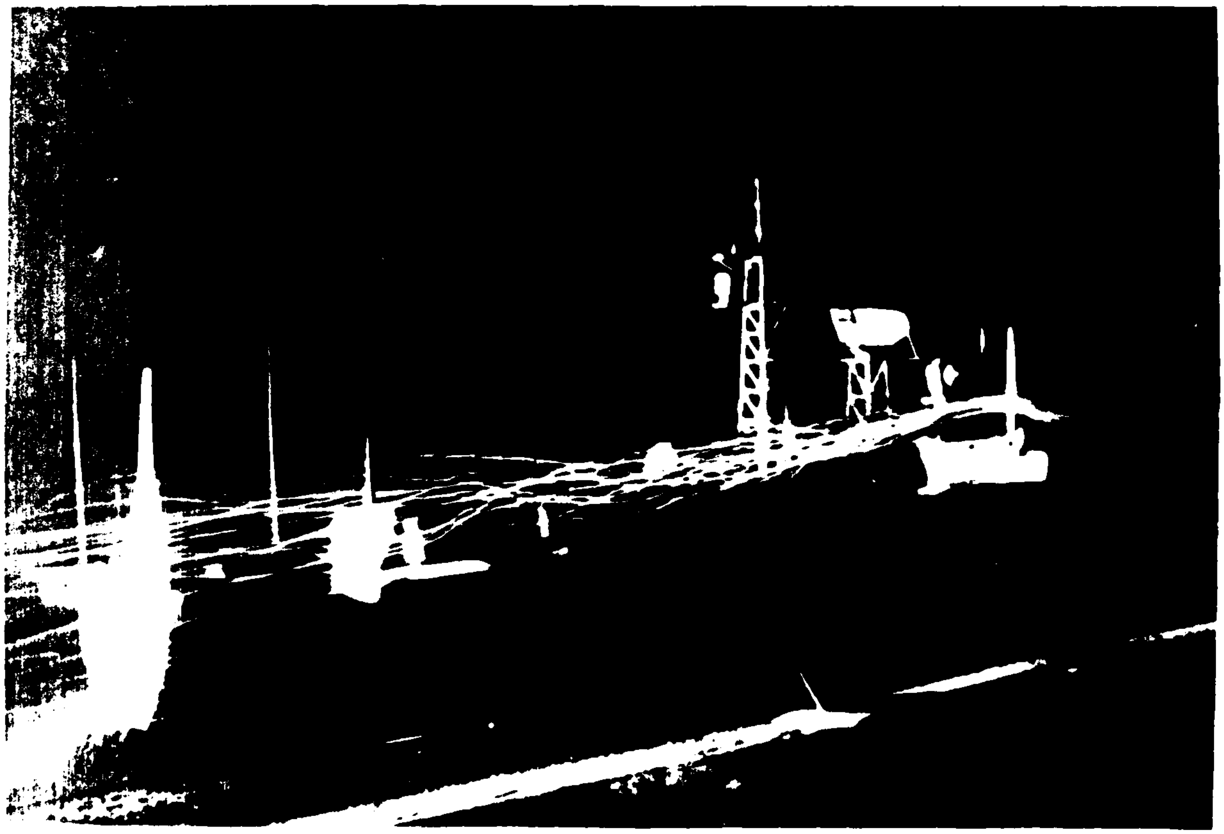


Figure 11 - Photograph Showing Vortex Flow Originating Over the Bridge Structure (Horizontal Intake Configuration)

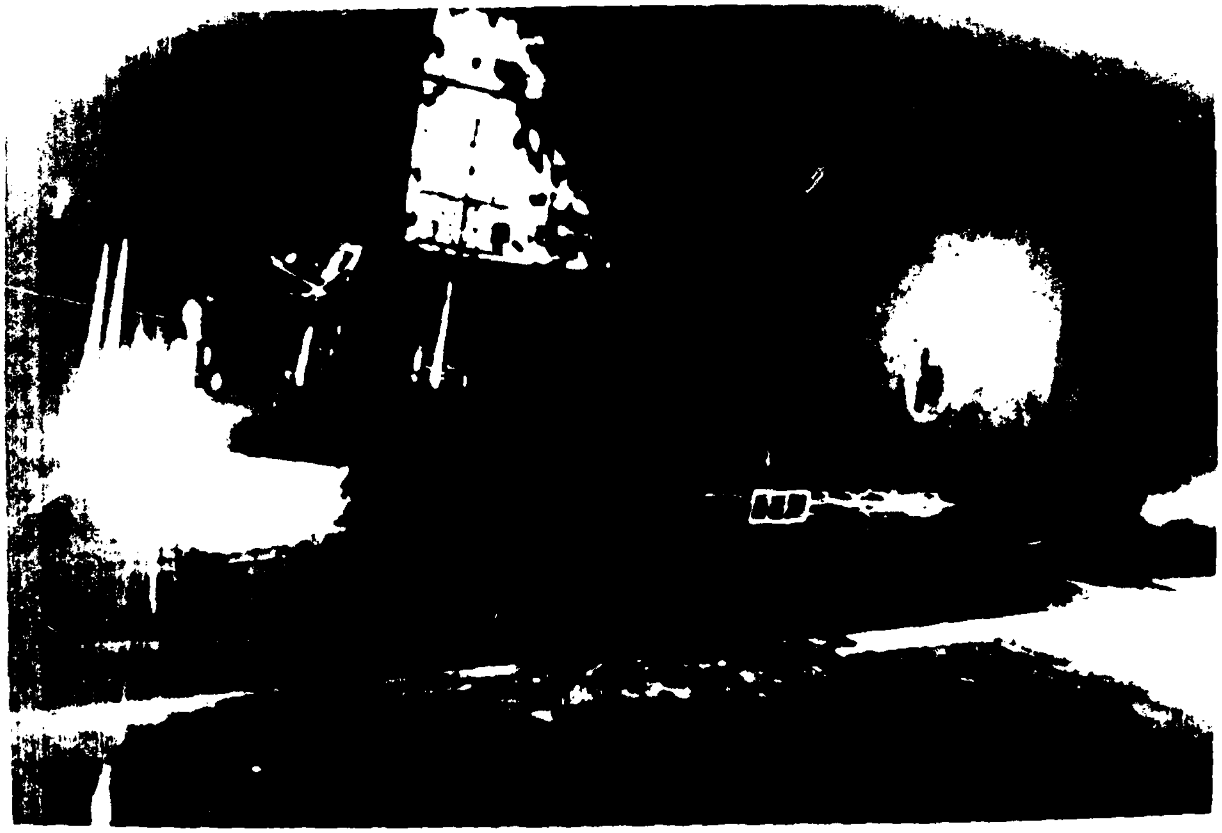


Figure 12 - Photograph of Helium Bubbles
Showing Flow from Astern
Straight Sided Configuration
Yaw Angle = 180°

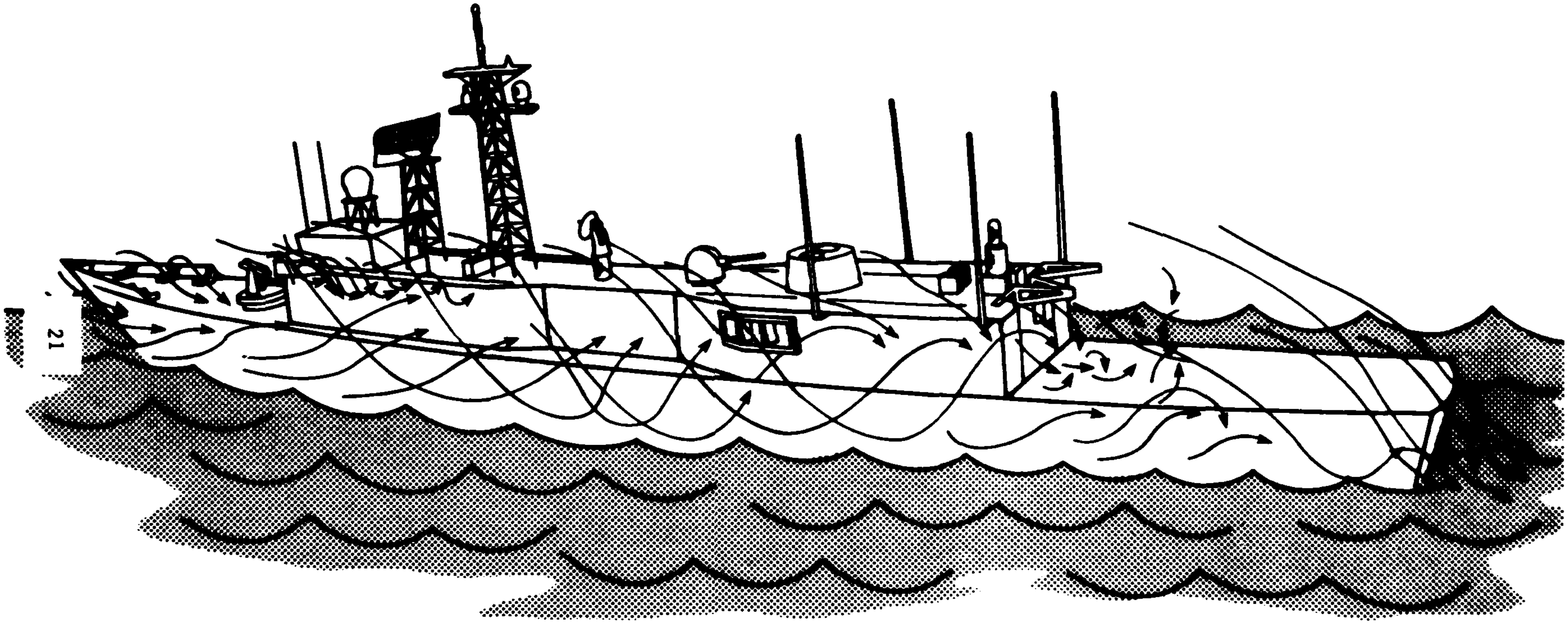


Figure 13 - Sketch Showing Flow on Downwind Side

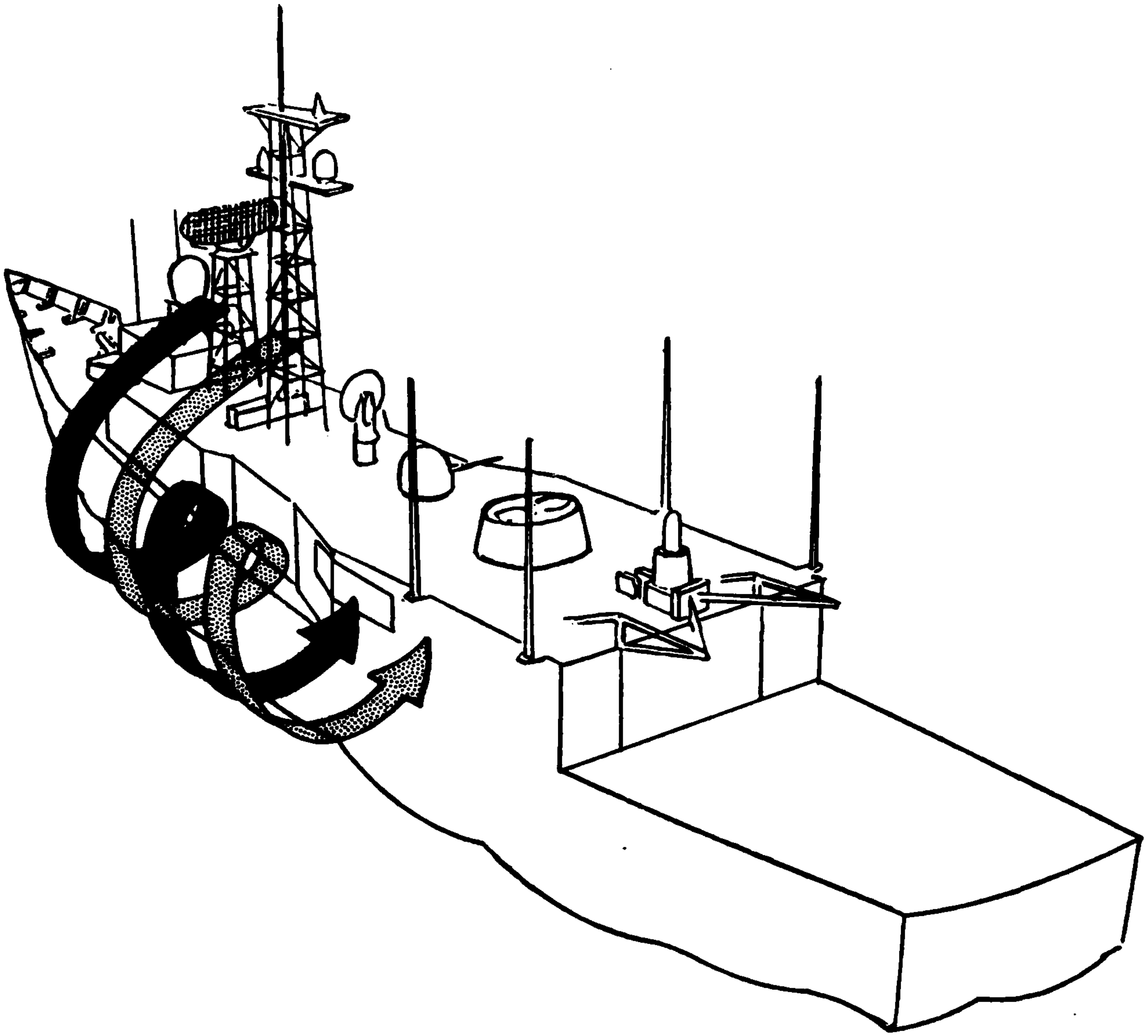


Figure 14 - Sketch Showing Nature of Flow on Downwind Side of Model

DTNSRDC ISSUES THREE TYPES OF REPORTS

(1) DTNSRDC REPORTS, A FORMAL SERIES PUBLISHING INFORMATION OF PERMANENT TECHNICAL VALUE, DESIGNATED BY A SERIAL REPORT NUMBER.

(2) DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, RECORDING INFORMATION OF A PRELIMINARY OR TEMPORARY NATURE, OR OF LIMITED INTEREST OR SIGNIFICANCE, CARRYING A DEPARTMENTAL ALPHANUMERIC IDENTIFICATION.

(3) TECHNICAL MEMORANDA, AN INFORMAL SERIES, USUALLY INTERNAL WORKING PAPERS OR DIRECT REPORTS TO SPONSORS, NUMBERED AS TM SERIES REPORTS; NOT FOR GENERAL DISTRIBUTION.