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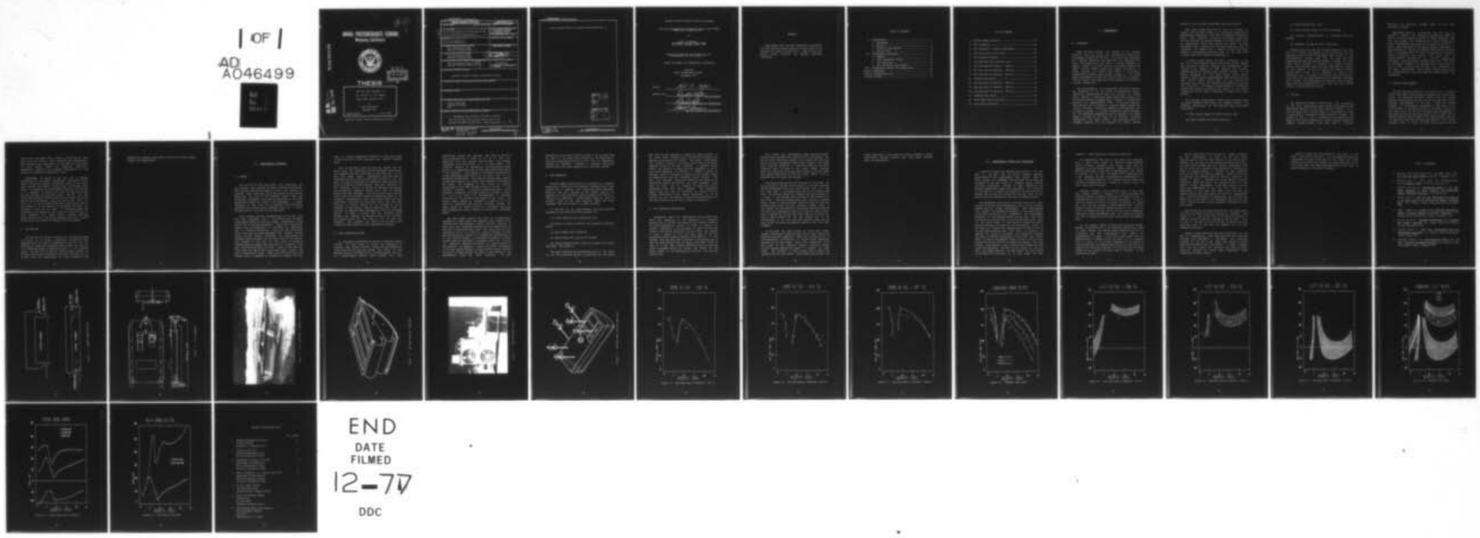

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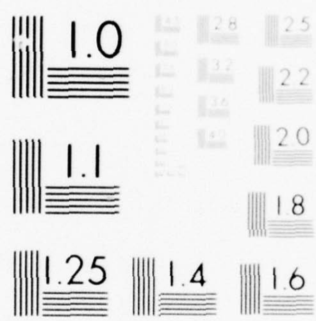

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THESIS

LIFT AND DRAG ANALYSIS ON
THE BOW SEAL OF THE SURFACE
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by
Paul Allen Alfieri

September 1977

Thesis Advisor: D. M. Layton

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LIFT AND DRAG ANALYSIS ON THE BOW SEAL OF THE SURFACE EFFECT SHIP TESTCRAFT XR-3

by

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Lieutenant, United States Navy
B.S., Naval Science, USNA, 1969

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

September 1977

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ABSTRACT

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I. INTRODUCTION

A. BACKGROUND

Since the early sixties, the concept of air cushion vehicles (ACV) has grown into an extensive research and development program for the Navy. ACV's have been developed for overland operation, sea operation, or a combination of both. The general term for such a vehicle designed to operate solely on or over water is the Surface Effect Ship (SES). Surface effect ships are usually classified as either captured air bubble craft (CAB) or hovercraft. Hovercraft are severly size limited because of the large power requirements to lift the vehicle clear of the surface. For this reason, the hovercraft is unsuitable to the Navy as a large tactical SES.

The CAB principle , as a high-speed, over-water vehicle, was conceived at the U.S Naval Air Development Center, Johnsville, Pennsylvania in 1960. The captured air bubble craft requires a relatively small power plant because much of the craft weight is supported by a bubble of pressurized captured air (approximately 80%). As the name suggests, this captured air is trapped in a plenum chamber beneath the craft's wet deck. The plenum chamber of the testcraft XR-3 is shown in Figure 1. In order to maintain plenum pressure, air is continually supplied from a fan system to the bubble region to account for air loss due to venting, turbulent entrainment, and other losses. The relatively small air resupply required for the captured air bubble vehicle results in the low power requirement mentioned earlier.

Since such a small amount of the ship is actually in contact with the water, there is a significant reduction in hydrodynamic resistance as the ship is propelled through the water. This reduction in drag is the primary reason that CAB type vehicles can achieve speeds up to three times that of conventional ships that cleave the water. In early experiments with a two-ton SES, the Navy found that only 80 horsepower was needed for a speed of 30 miles per hour, whereas a conventionally designed ship of the same size requires about 500 horsepower (Reference 1).

In order to fully exploit the future potential of the SES, the Navy's Surface Effect Ship Project Office (SESPO) has sponsored extensive research and accumulated much valuable data. Results of this research have begun to materialize and are becoming more and more visible to the public (Reference 2). One early design target was to produce a craft weighing approximately 4000 tons and able to make 80-100 knots. Today there are two 100-ton SES testcraft and a 22-ton SES testcraft in operation as well as the 3-ton XR-3. In addition, the Department of Defense has ordered the design of a 3000-ton SES known as the 3KSES. Construction of the 3KSES is scheduled to begin in the early 1980's.

The tactical advantages of large modern warships which can attain speeds of 100 knots are awesome indeed. For military applications the SES possesses these significant attributes:

(1) high surface speed and quick reaction time

(2) multi-thousand ton payload potential

(3) multi-thousand mile range

(4) loiter ability either on or off the bubble

(5) relative invulnerability to torpedoes, mines and missiles

(6) stability in high sea state conditions.

Perhaps one of the most far reaching effects of the SES will be to restore the primacy of the surface ship over the submarine, since the SES is extremely well suited to the anti-submarine warfare (ASW) role. The Navy has long recognized the need for advanced weapons systems and high speed marine vehicles to maintain its national defense posture. This research thesis has been performed in support of this mission. In order to improve the design of future surface effect ships, it is necessary to identify and investigate all the sources of lift and drag on the craft. Only after lift and drag characteristics have been optimized will overall craft performance be optimized. This research deals with the determination of the lift and drag forces acting on the bow seal of the XR-3.

B. THE XR-3

The captured air bubble testcraft XR-3 was constructed by the David Taylor Model Basin (Naval Ships Research and Development Center) in 1965. This three-ton vehicle is 24 feet in length with a 12-foot beam It is propelled by a pair of long-shaft 55 horsepower Chrysler outboard engines. See Figures 2 and 3. Air is provided to the plenum and the seals by five single-cylinder air cooled internal combustion engines through single stage axial fans. A 110-volt, 1500-watt a.c. generator provides power for the data acquisition system.

Immediately after its construction the XR-3 was put through a limited test program by personnel at NSRDC. In July of 1967 the Annapolis Division of NSRDC (ANNADIV) took over the project and conducted both calm and rough water tests. Modifications were made in the design of the XR-3 to make it less vulnerable to structural failure (Reference 3). Full operation of the XR-3 at ANNADIV NSRDC was not achieved until mid-October 1967, and the test program was terminated shortly thereafter. The project was taken over by Aerojet-General Corporation for further testing and evaluation. Aerojet-General conducted more than 100 hours of waterborne testing in San Diego Bay in the summer and fall of 1968. In March 1970, the XR-3 was transferred to the Naval Postgraduate School (NPS), Monterey, California for investigation of basic and advanced surface effect ship technology.

C. NATURE OF THE PROBLEM

The lift and drag exerted on the bow seal of a surface effect ship result from aerostatic pressure and hydrodynamic action. The aerostatic pressure results from the plenum pressure acting across the rear face of the bow seal and the internal over-pressure of the seal. Since the plenum pressure is not constant, measurement of this force is not an easy task. A thorough analysis of the forces acting on the stern seal of the XR-3 has been done in Reference 4. The forces on the bow and stern seals are not equal due to several reasons. The two seals are of similar shape and both are raked aft from top to bottom (see Figure 4). The plenum pressure tends to force the stern seal up and out of the water, but at the same time, it tends to force the bow seal down into the water. Also, the stern seal experiences a much different flow environment in that some air vents under the seal during almost all operating conditions. Information regarding the pressure distribution in the plenum is contained in References 5 and 6.

Measurement of forces on the bow seal is further complicated by the seal's flexibility. The ability of the seal to absorb wave energy is desirable since it acts like a shock absorber and creates a smooth ride, even through rough water. To determine the hydrodynamic forces on the bow seal it is necessary to measure the total lift and drag forces and then subtract the aerostatic force. The lift and drag forces were measured directly from the load cells from which the bow seal was mounted. Since the seal is not rigid and there is no way of knowing the exact shape of the seal at any instant, it is not possible to accurately determine the aerostatic force on the seal. A television camera was installed in the plenum to take pictures of the bow seal to help determine its shape during various operating conditions, but due to the large "rooster-tail" wake created by the seal, the picture was useless for this purpose.

D. THE BOW SEAL

The bow seal of the XR-3 consists of a rectangular frame 120 inches by 46 inches, constructed of two-inch angle aluminum stock. The seal is reinforced in the fore and aft direction by three-inch aluminum channel stock. The seal bag is a rubberized fabric, riveted and glued to the aluminum frame. The face of the seal has twelve equally spaced 4 by 48 inch spring stays to maintain its shape. The seal bag is divided into two compartments by a center membrane. This membrane has several large holes to allow air to flow freely between the compartments.

II. EXPERIMENTAL PROCEDURES

A. GENERAL

The site for all test runs during this experiment was San Antonio Lake, located 110 miles southeast of Monterey. This lake was originally chosen as a test site because it offerred clean, relatively calm, deep water and was sixteen miles long. As a part of the Monterey County Parks and Recreation Department, this lake is accessible to the Naval Postgraduate School at no cost to the government. A great advantage of this site is its excellent local facilities including wide (twelve lane) launching ramps, and a secure storage area for the XR-3 and the chase boat.

Until recently the only disadvantages to this test site have been geographic ones - its distance from the Naval Postgraduate School and the high summer temperatures there (about 100-110 degrees Fahrenheit). These high temperatures require that the electronics be sheltered and ventilated well to preclude overheating. During the time period when these tests were run (June-September 1977) another problem became quickly obvious. California was experiencing an extremely severe drought, and the water level at San Antonio Lake dropped so low that the XR-3 could no longer be launched from the normal operating ramp (an alternate ramp some distance away had to be used). Also, by this time the water level was some 50 feet lower than normal causing the lake to become more narrow. While there was still more than adequate space to maneuver as necessary to complete the test runs, it became increasingly difficult to find large areas of calm water due to wake turbulence from smaller pleasure craft.

Prior to each day's runs, the tape was marked and the voice track was annotated with any pertinent information. All equipment was then calibrated on the level area of the boat ramp before launch. Experimental runs were made to determine the total lift and drag forces acting on the bow seal and also to determine the effects of seal pressure and center of gravity on these forces. Runs were conducted at the different centers of gravity as indicated and the bow seal by-pass was adjusted during these runs to achieve various bow seal pressures. Data points were taken over the entire range of testcraft speeds by increasing power to the outboards incrementally until each desired speed had fully stabilized. Data near the transition point was the most difficult to obtain because of the instability of the testcraft in this region; however, accurate data could be obtained by reducing power incrementally from the post-hump region. In order to verify that the recorded plenum pressure was actually the pressure acting on the bow seal, the pressure along the rear face of the bow seal was measured. This pressure was found to be the same as the recorded plenum pressure within experimental accuracy.

B. DATA ACQUISITION SYSTEM

An extensive instrumentation system is available aboard the XR-3. In this series of tests, the parameters of interest were thrust, velocity, plenum and seal pressures, pitch angle and all load cell forces. The thrust of each outboard motor is transmitted to a balanced-bridge load cell by a parallelogram linkage, which ensures that only longitudinal forces are recorded. The output of the load cell is amplified to a range of 0.0 to 1.0 volt d.c. compatible with the onboard tape recorder. This voltage corresponds to a thrust range of 0 to 500 pounds. The testcraft velocity is measured by a Potter velocity meter located on a supporting strut in the undisturbed water ahead of the testcraft . This device is a flowmeter consisting of a small magnetized free turbine in an axial duct in the projectile shaped probe. The rotating turbine wheel induces a sinusiodal voltage in a pickup coil located in the body of the probe. The frequency of this signal is directly proprotional to the flow through the meter, so also to the testcraft velocity. A velocity conditioning unit , which contains a frequency to voltage converter, produces a signal of 0.0 to 5.0 volts d.c. corresponding to testcraft velocities of 0 to 40 knots. The signal is then split, one branch being reduced in voltage to a range of 0.0 to 1.0 volts d.c. compatible with the data recording system. The other signal is used to drive a d.c. voltmeter, which has been calibrated in knots, located on the pilot's instrument panel.

All data taken onboard the XR-3 are automatically recorded on a Pemco model 120-B magnetic tape recorder. This recorder will simultaneously record fourteen channels of data from the electronic sensors plus the observations of the pilot on the voice edge track. The input range for each channel is -1.0 to 1.0 volts d.c. with an accuracy of 1/2%. The recording unit, located in a compartment immediately aft of the pilot's cockpit, is controlled by means of a remote control panel on the pilot's instrument panel. The 110-volt a.c. generator supplies the 26-volt d.c. power required by the recorder. In addition, a digital voltmeter is connected to the data inputs through a rotary selector switch enabling the pilot to easily monitor the input to any channel as the experimental tests are being conducted. The easy portability of the Pemco recorder allows it to be taken from the XR-3 to the mobile data facility at the completion of each day's operations so that the data may be immediately reduced and analyzed. Reference 7 contains additional information on the data collection and recording system.

C. DATA REDUCTION

The XR-3 mobile data facility is contained in a Champion motor home. A portion of the interior furnishings have been removed and a complete data reduction system installed. Power for the data systems in the mobile facility is supplied by a self contained gasoline powered 110 volt a.c., 5000 watt a.c. generator. A Pemco power supply is used to provide power to the tape recorder, while all other equipment uses the 110-volt a.c. power directly .

In addition to the tape recorder, the data reduction equipment in the mobile facility consists of:

(1) Signal selector and conditioning unit

(2) Analog to digital converter and calculator interface module

(3) Monroe Model 1880 calculator

(4) Monroe Model PL-4 digital X-Y plotter

(5) Hewlett-Packard Model 7100-B two channel strip chart recorders. See Figure 5.

The signal selector and conditioning unit is the heart of the data reduction system. It conditions the raw analog data from the tape recorder to supply the proper signals to the strip chart recorder and to the Monroe calculator for display on the Monroe X-Y plotter. The signal conditioning unit accepts fourteen raw analog inputs from the fourteen channels of data on the tape recorder. A selector panel allows the operator to output any given parameter on any of nine output channels. In addition, a summing circuit is provided which is utilized to provide a total thrust signal by combining the port and starboard thrust signals. The unit also provides a means for adjusting the range of the conditioned output, and filters out high frequency noise from the data. Any two channels of analog data may be displayed on each strip chart recorder. The conditioned analog data may also be converted to digital form for further calculations on the Monroe calculator, or to be plotted on the X-Y plotter.A more thorough description of the data reduction system may be found in Reference 8.

D. XR-3 TESTCRAFT MODIFICATION

Immediately after the experimental work regarding the stern seal (Reference 4) was completed, an extensive modification of the XR-3 was begun by the technical staff at the Naval Postgraduate School. In order to perform the desired experiment, it was necessary to remove the bow seal (since it was bolted directly to the wet deck) and suspend it from a system of lift and drag cells so that the applicable forces could be measured (see Figure 6). It was decided that the most direct solution to the problem was to swap the seals because then the former stern seal could be used as a bow seal without rebuilding the lift and drag cells' attachment points. Of course, new mounts for the cells needed to be constructed on the hull , but that was easily done.

Even though this modification seemed straightforward, several major problems were encountered in the process. The bow and stern seals were thought to be exactly the same size since they were constructed identically; however, the frames were slightly different in size which made the fit quite difficult. Also, the holes in the seals' frames (through which the seals were both originally bolted to the wet deck) were spaced differently so that the holes didn't line up properly when the seals were swapped.

The by-pass ducting from the bow seal to the plenum was also modified to achieve better control of bow seal pressure during experimental test runs. This by-pass exit duct was cut down from a 192 square inch area to a 64 square inch area. The by-pass system for adjusting bow seal pressure is a lever in the cockpit which controls a door covering the exit duct . With the by-pass fully open, the seal pressure drops almost to plenum pressure (about 20 psf) and with the by-pass fully closed, the seal pressure reaches about 35 psf. Before this modification, the by-pass mechanism used by the pilot was essentially always fully open or fully closed. This is because the by-pass exit duct area was so large that even a small opening of the door caused most of the overpressure to be lost. This new smaller by-pass ducting area allows for better incremental control of the bow seal pressure.

On the first day this series of tests were begun, another problem was discovered that did not exist before the modifications were completed. There was a strong source of electromagnetic interference on the XR-3 which completely blanked out all data inputs. After this intolerable noise was traced to the starboard engine's ignition system, on-site trouble-shooting was unable to isolate the exact cause. The solution to this problem was to replace all ignition parts to the engine. Even though this problem was easily corrected, it did cause the testing schedule to slide three weeks , wasting valuable test time while awaiting parts and maintenance.

III. EXPERIMENTAL RESULTS AND CONCLUSIONS

A system of complex and varying forces acts on the bow seal of the XR-3 over the entire velocity spectrum investigated in this experimental test series. Many of these forces are dependent upon the shape of the seal and the amount of the seal which is immersed during various operating conditions. Neither of these quantities was directly measureable during this experiment. The intention of this work is to isolate all forces on the bow seal and to measure them as they are transmitted from the seal to the hull of the XR-3 through the load cell attachment points.

The predominant drag force on the bow seal is the force created by the bow seal overpressure, which is only slightly greater than the plenum overpressure. This overpressure acts against the atmospheric pressure on the upper portion of the seal and against the hydrostatic and hydrodynamic pressures on the immersed portion of the seal. This force is actually a negative drag in the conventional sense. That is, the force tends to push the XR-3 through the water. Another drag force is caused by the hydrodynamic action of the water as it impacts the immersed area of the bow seal as the XR-3 moves forward. This drag force is positive and opposes the motion of the craft. The hydrostatic pressure also adds a positive contribution to the total drag force. There is also an aerodynamic source of drag on the bow seal created by the air flow as it impacts the exposed bow seal frontal area; however , due to the low test velocities this force was negligible. The sum of drag forces on the bow seal was always negative. In other words, the total effect of the drag of the bow seal is to help propel the XR-3 through the water during all operating conditions.

All experimental test runs in this series were performed with a total craft weight of 6090 lbs. Three different center of gravity positions were tested. These will be referred to as the forward (FWD CG), middle (MID CG) or aft (AFT CG) positions. In the FWD CG configuration, the center of gravity of the XR-3 is located 119.6 inches from the stern. Likewise, the MID CG configuration corresponds to a center of gravity which is 117.3 inches from the stern, and the AFT CG configuration has a center of gravity which is 113.5 inches from the stern.

Figures 7 through 10 show graphical plots of bow seal drag against velocity. Figures 7, 8, and 9 represent the different center of gravity positions and Figure 10 gives a combined plot of all center of gravity positions. It can be seen from Figure 10 that as the center of gravity is moved aft, the bow seal creates a larger negative drag. This is because an AFT CG position causes the bow of the craft to pitch up slightly so that less of the bow seal is immersed, resulting in less hydrodynamic drag. At the FWD CG position the bow is digging into the water causing more hydrodynamic drag.

At the higher speeds, the bow seal drag force becomes smaller in magnitude due to the increased hydrodynamic drag at these speeds. The maximum speed reached by the XR-3 as configured for this experimental test series was approximately 24 knots. If the drag curves (Figure 10) are extrapolated to a speed of about 30 knots, it is apparent that at about 25 to 29 knots (depending on the center of gravity position) the hydrodynamic portion of drag begins to dominate the aerostatic portion. At this point and at higher speeds the net effect of bow seal drag is positive in the conventional sense.

The net lift force on the bow seal is caused primarily by the displacement of water by the seal. Other contributions to the lift force are due to the flow of water beneath the bow seal and the planing action of the seal as the craft moves forward. The lift values represented here are the total lift, including that necessary to overcome the seal's own weight. Figures 11 through 14 show graphical plots of bow seal lift against velocity. Figures 11,12, and 13 represent the different center of gravity positions and Figure 14 gives a combined plot of all center of gravity positions. These lift plots are presented here to show general trends. Measurement of the lift forces on the bow seal was complicated by the fact that there was no opportunity to get good calm water data. Bow seal lift varies directly with wave action and since all experimental test runs were conducted in choppy water, the lift data did spread into a wide band. It is recommended that further calm water testing be done to more accurately determine bow seal lift values.

Even though the data show some scatter, the variation of lift with the center of gravity position is apparent. From Figure 14 it can be seen that as the center of gravity is moved aft there is less lift created by the bow seal. This is due to the fact that as the center of gravity position moves aft, less of the seal is immersed and the seal displaces less water.

Figure 15 shows the total seal drag of the XR-3 in the MID CG configuration. Stern seal drag data used here were obtained from Reference 4. Throughout the operating envelope of the XR-3, the stern seal creates a totally positive drag and the bow seal creates a totally negative drag. The net effect (or the total seal drag) is always positive, reaching its lowest value immediately after transition at about 9 knots.

Figure 16 shows the contribution of the seals to the total craft drag of the XR-3 . At low speeds the seals are responsible for most of the drag of the craft, but after transition the seals only account for about one-fifth cf the total craft drag. The remaining four-fifths of the drag is caused primarily by the craft sidewalls.

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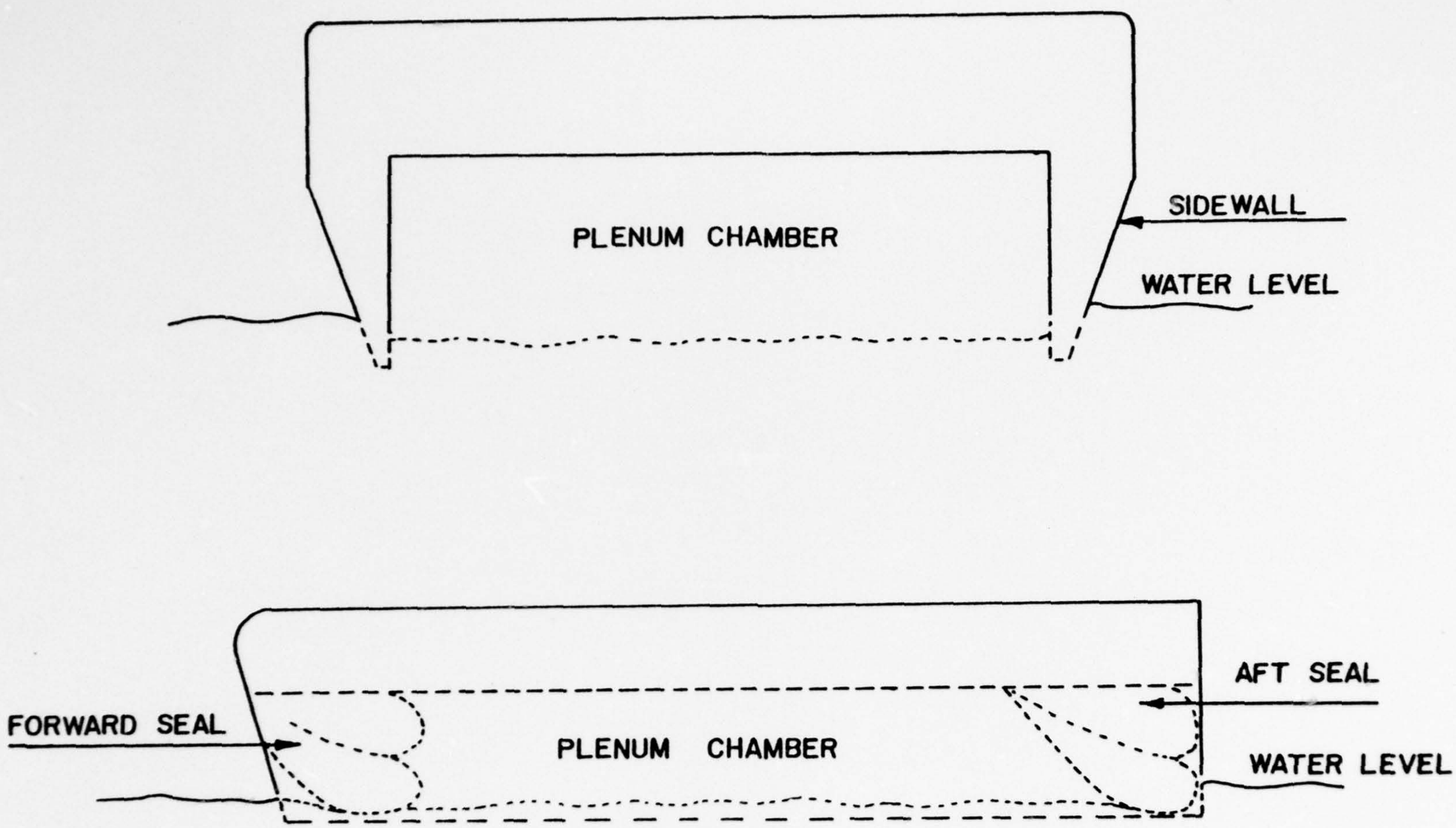

Figure 1 - PLENUM CHAMBER OUTLINE

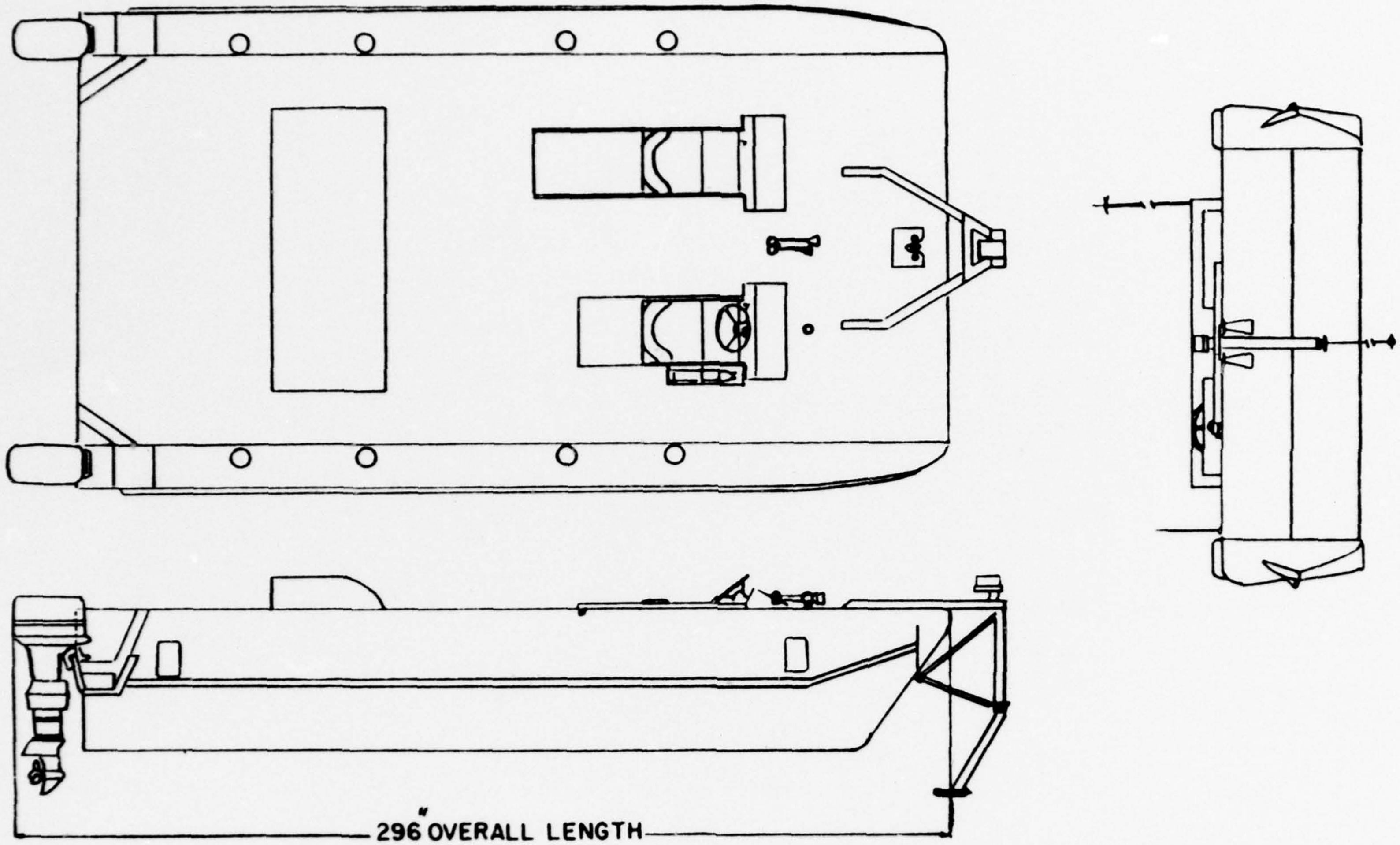

Figure 2 - XR-3 SCHEMATIC

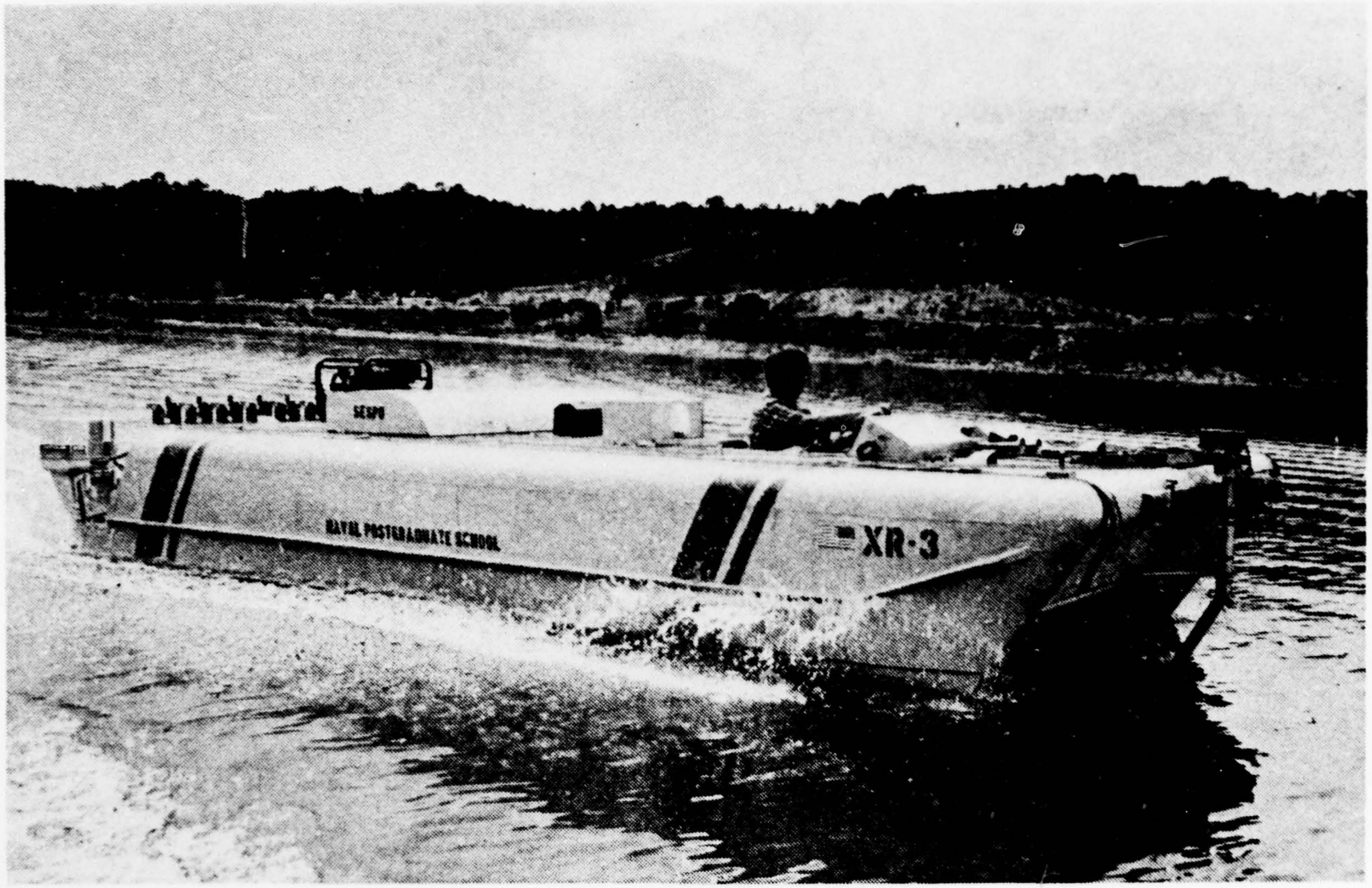

Figure 3 - XR-3 TESTCRAFT - GENERAL APPEARANCE

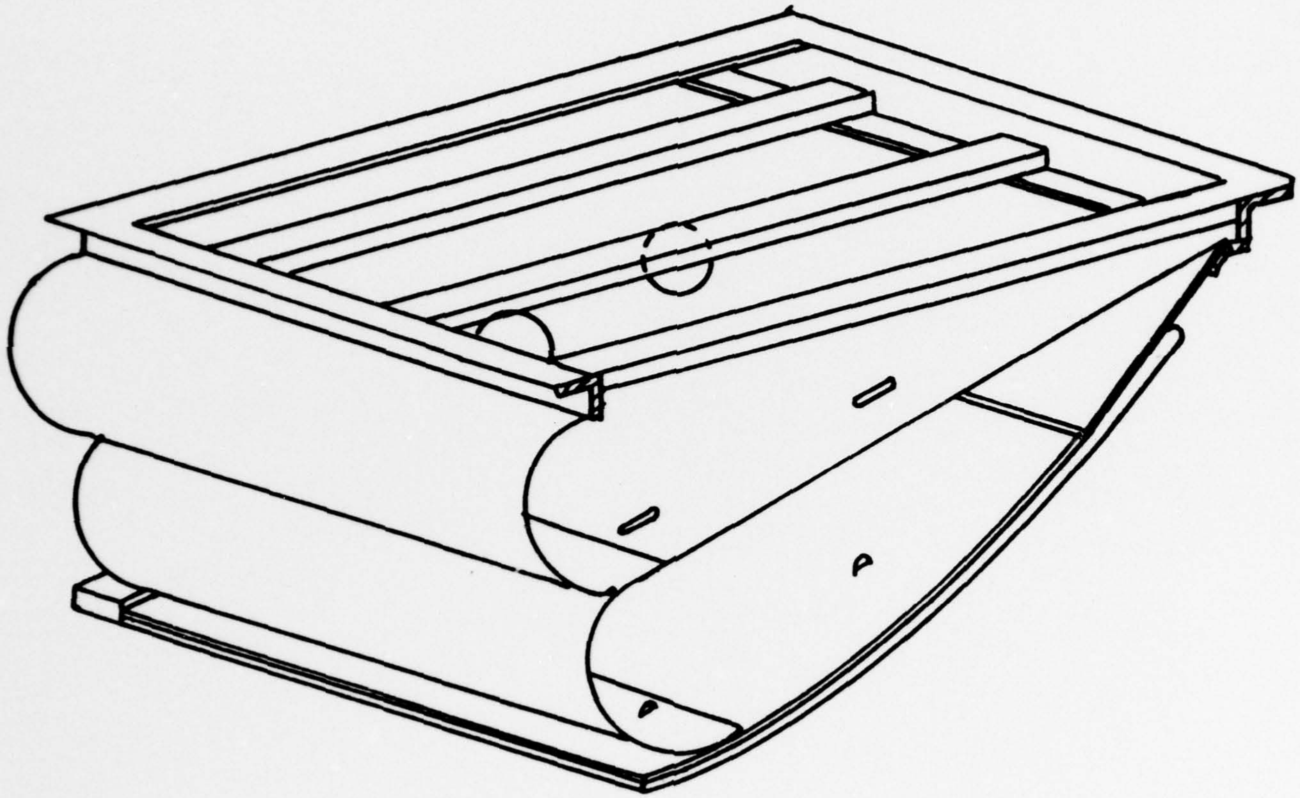

Figure 4 - BOW SEAL SECTION - PORT HALF

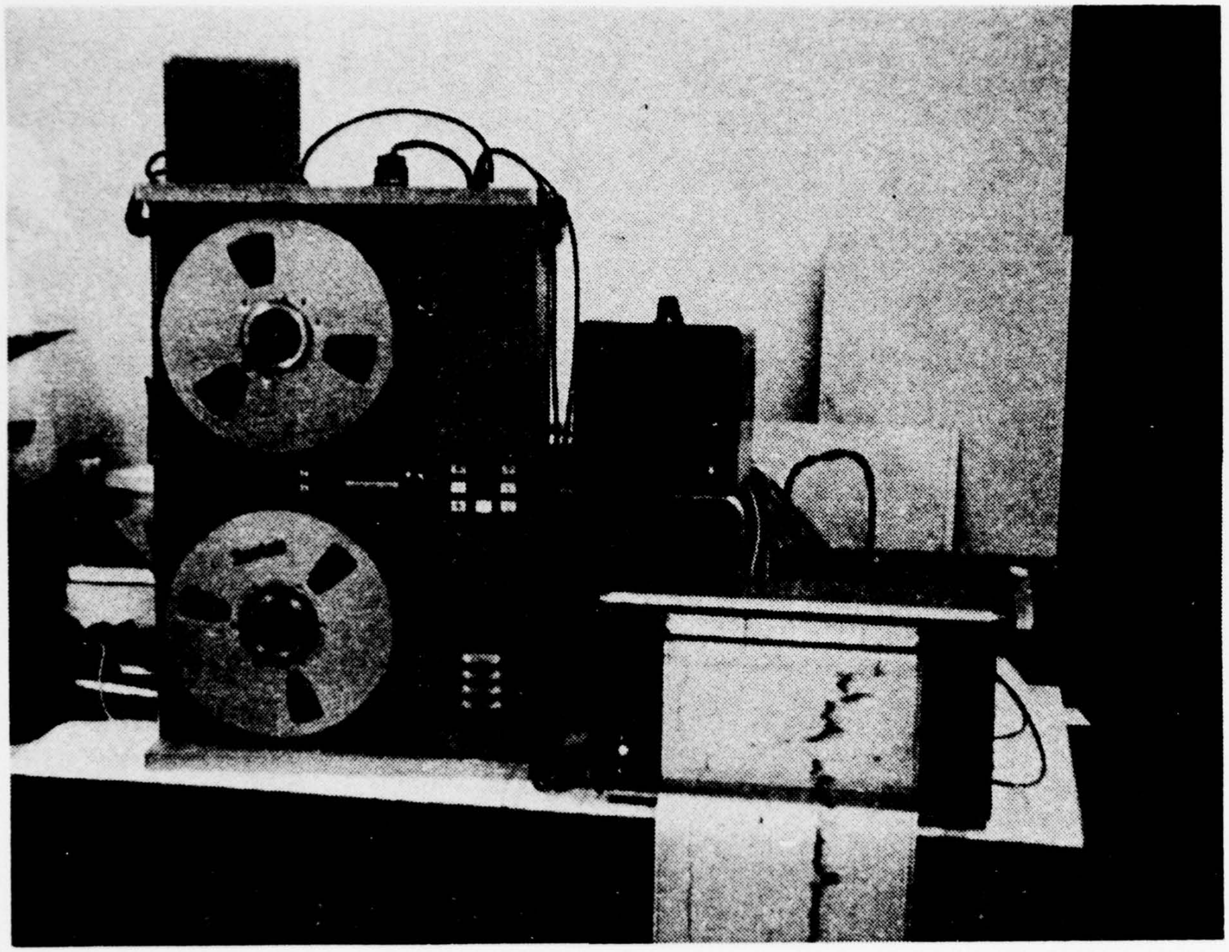

Figure 5 - DATA REDUCTION SYSTEM

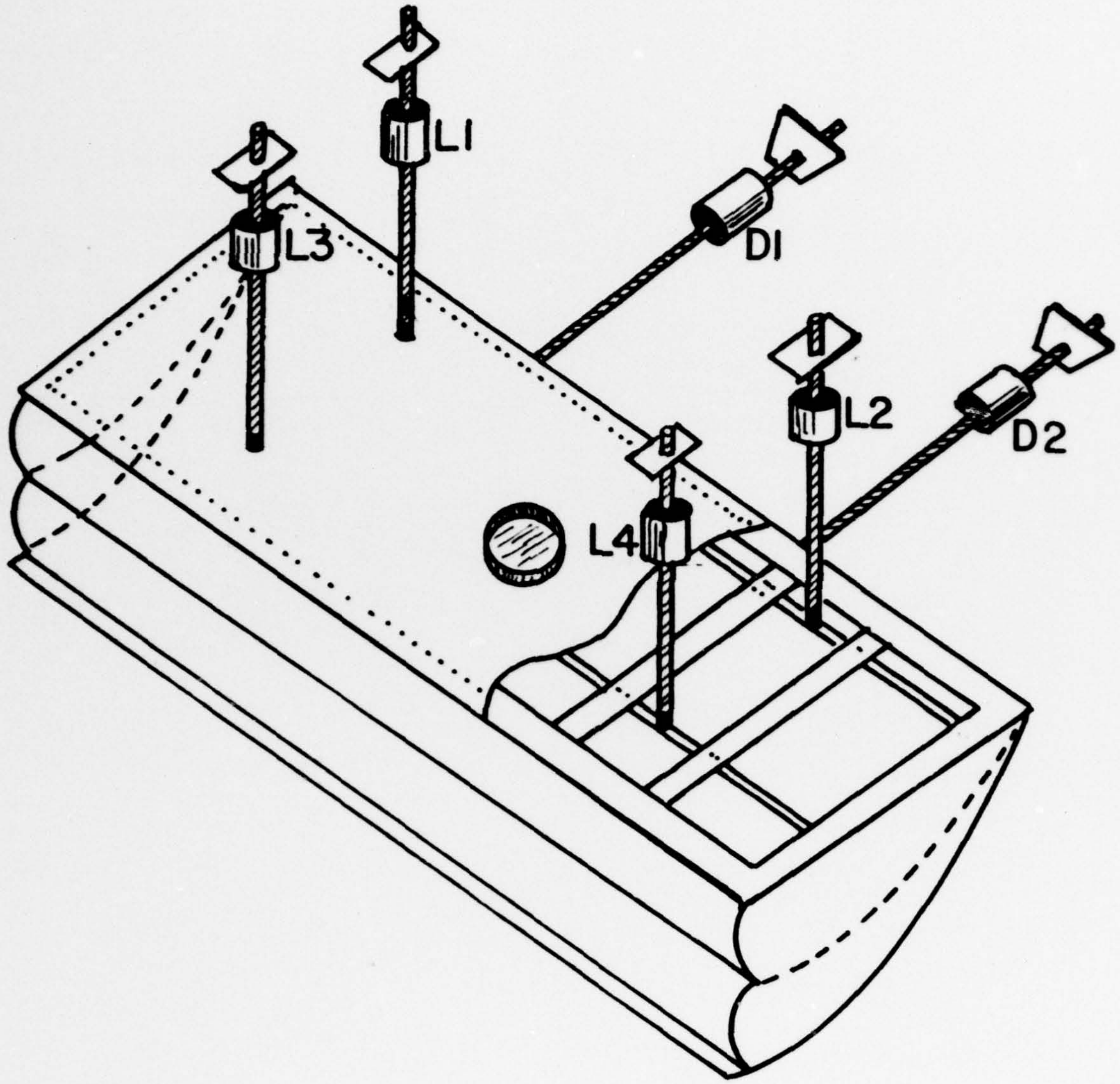

Figure 6 - BOW SEAL WITH LIFT AND DRAG CELLS

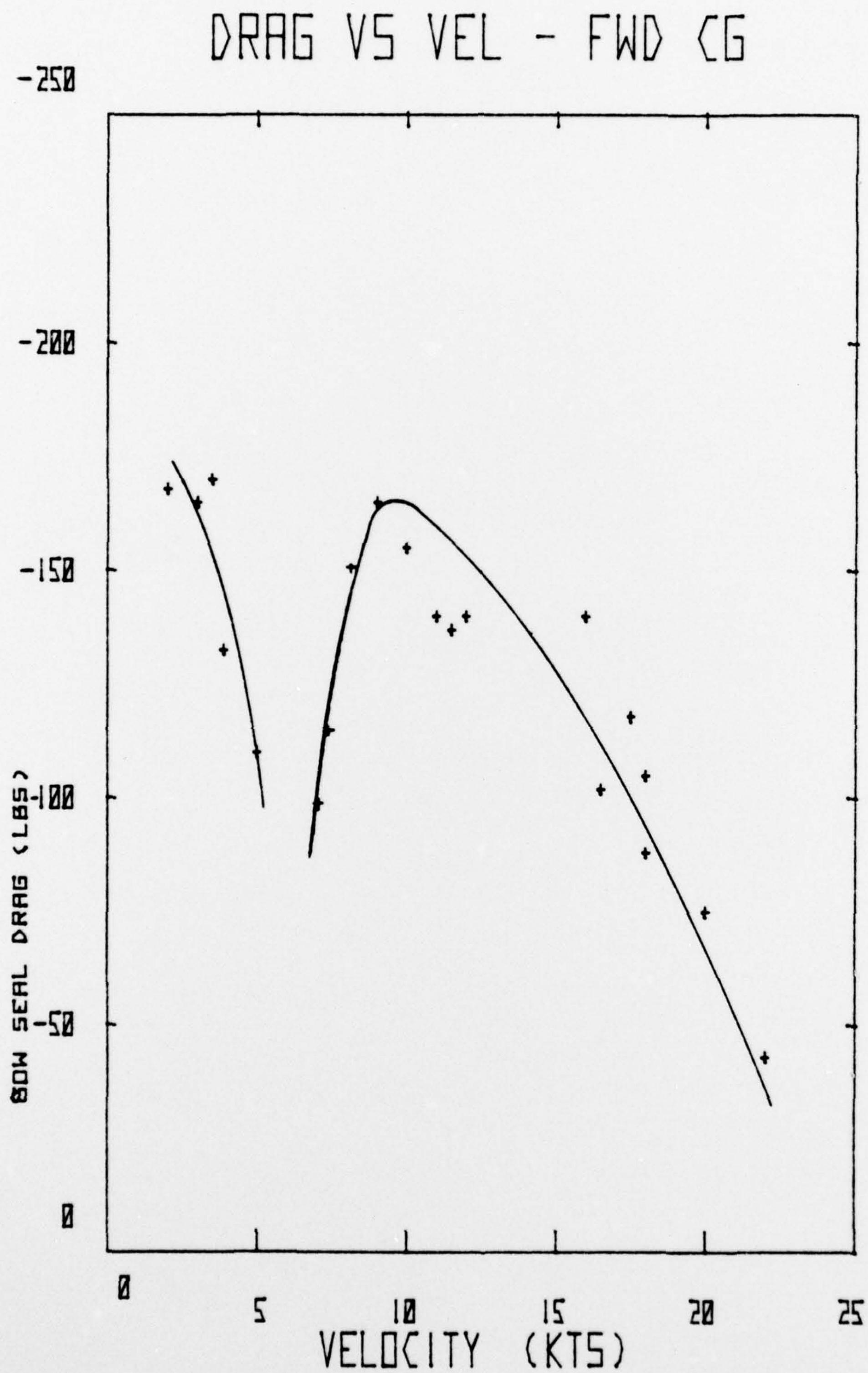

Figure 7 - BOW SEAL DRAG VS VELOCITY - FWD CG

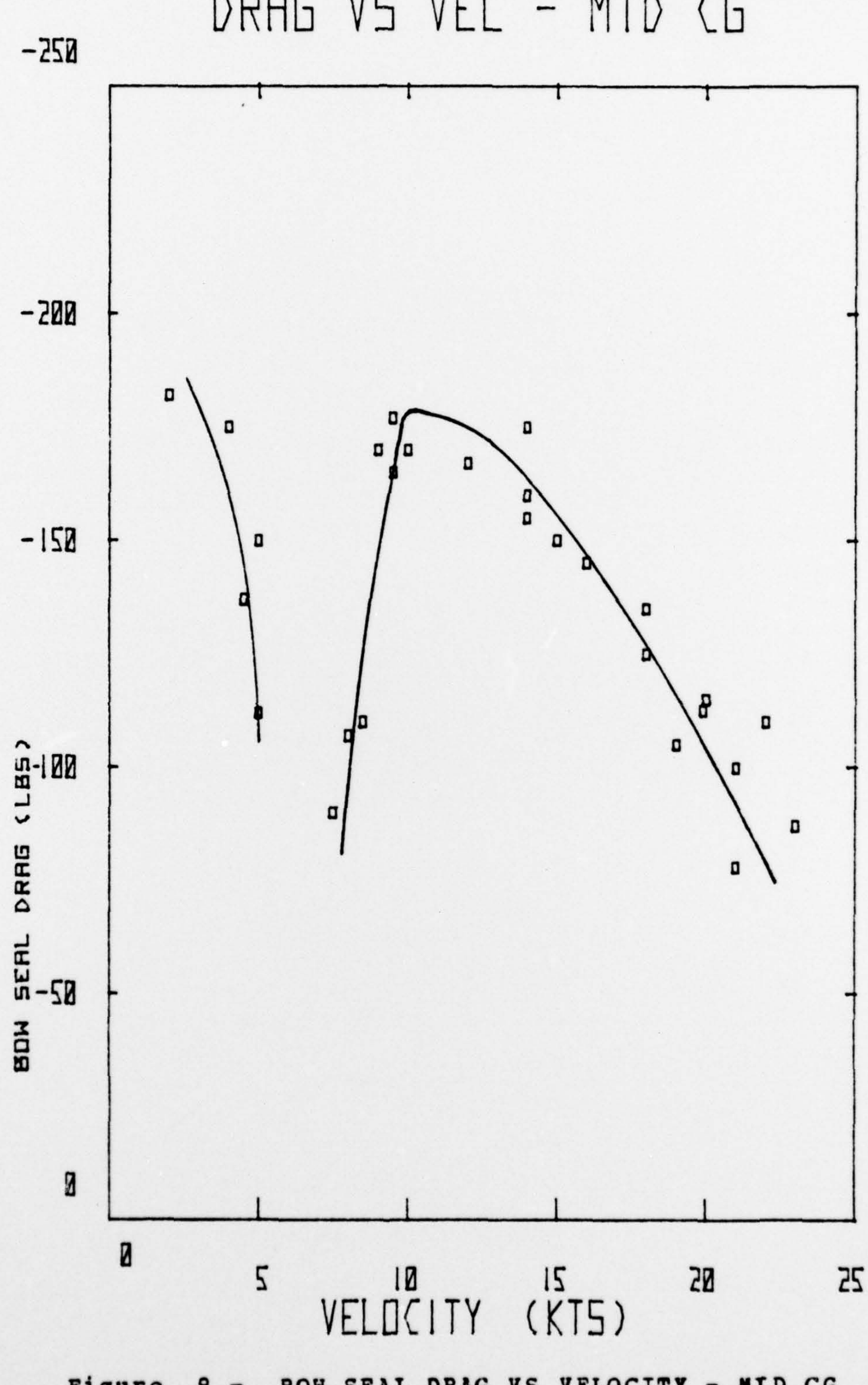

Figure 8 - BOW SEAL DRAG VS VELOCITY - MID CG

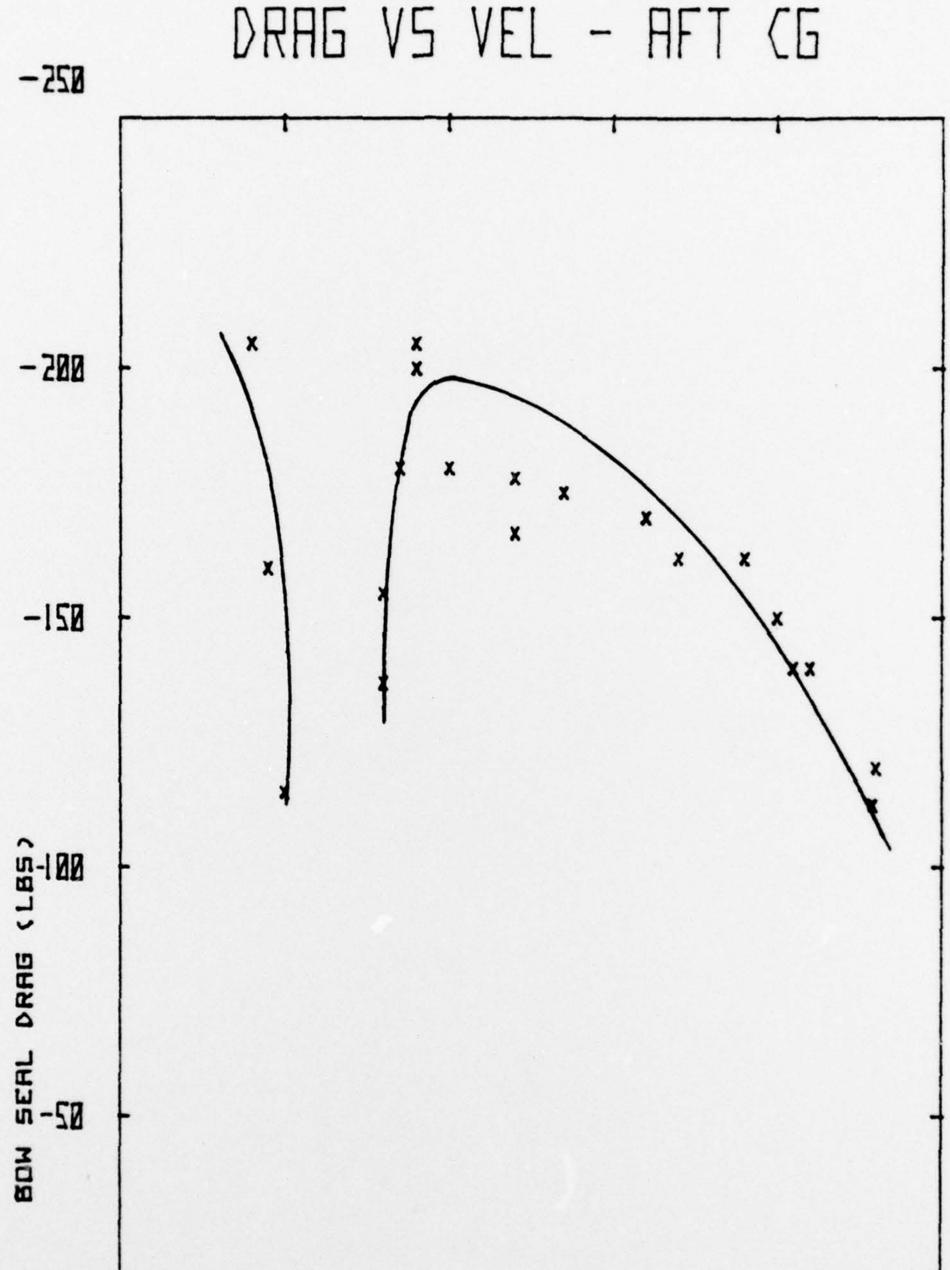

Figure 9 - BOW SEAL DRAG VS VELOCITY - AFT CG

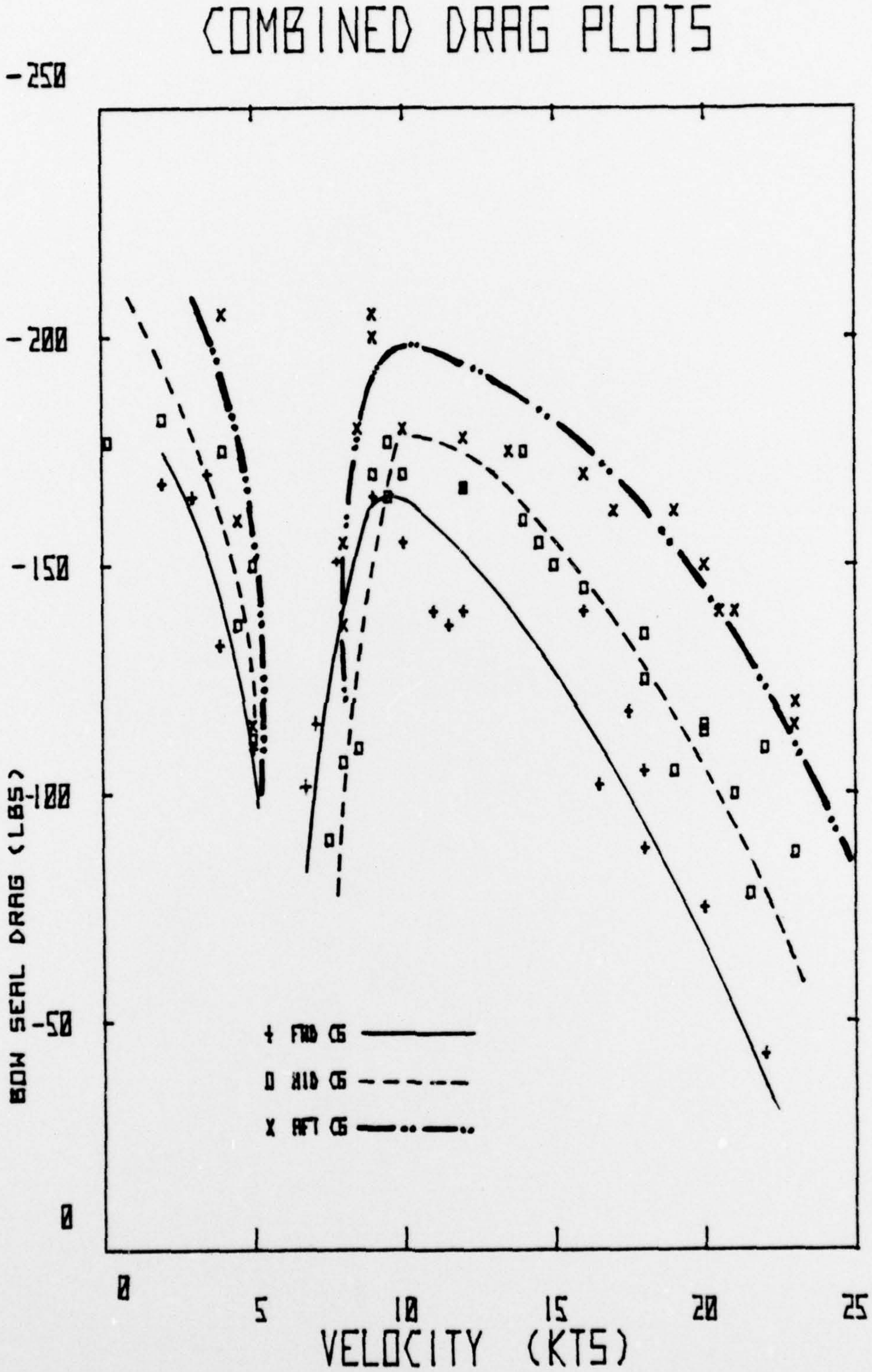

Figure 10 - COMBINED DRAG PLOTS

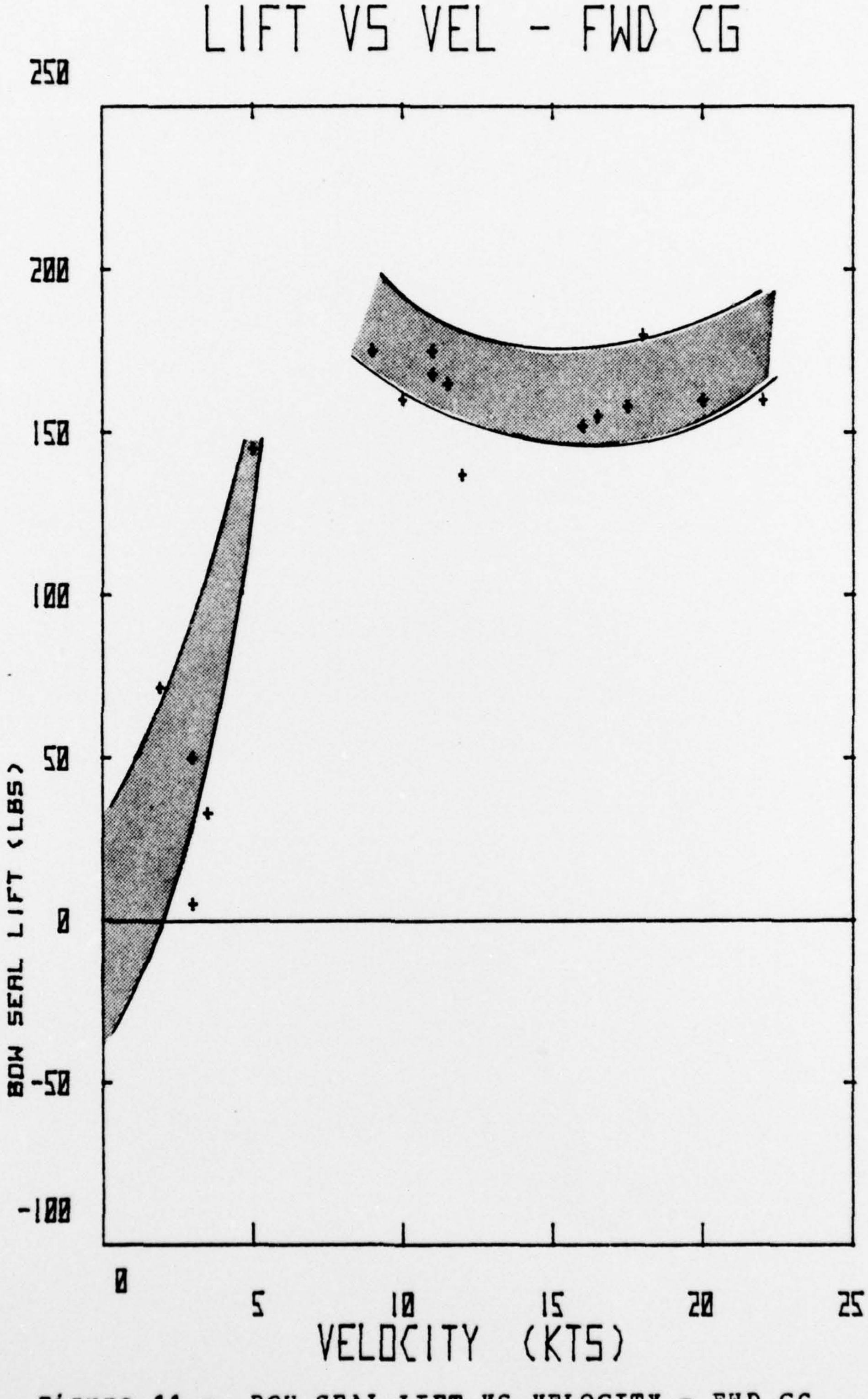

Figure 11 - BOW SEAL LIFT VS VELOCITY - FWD CG

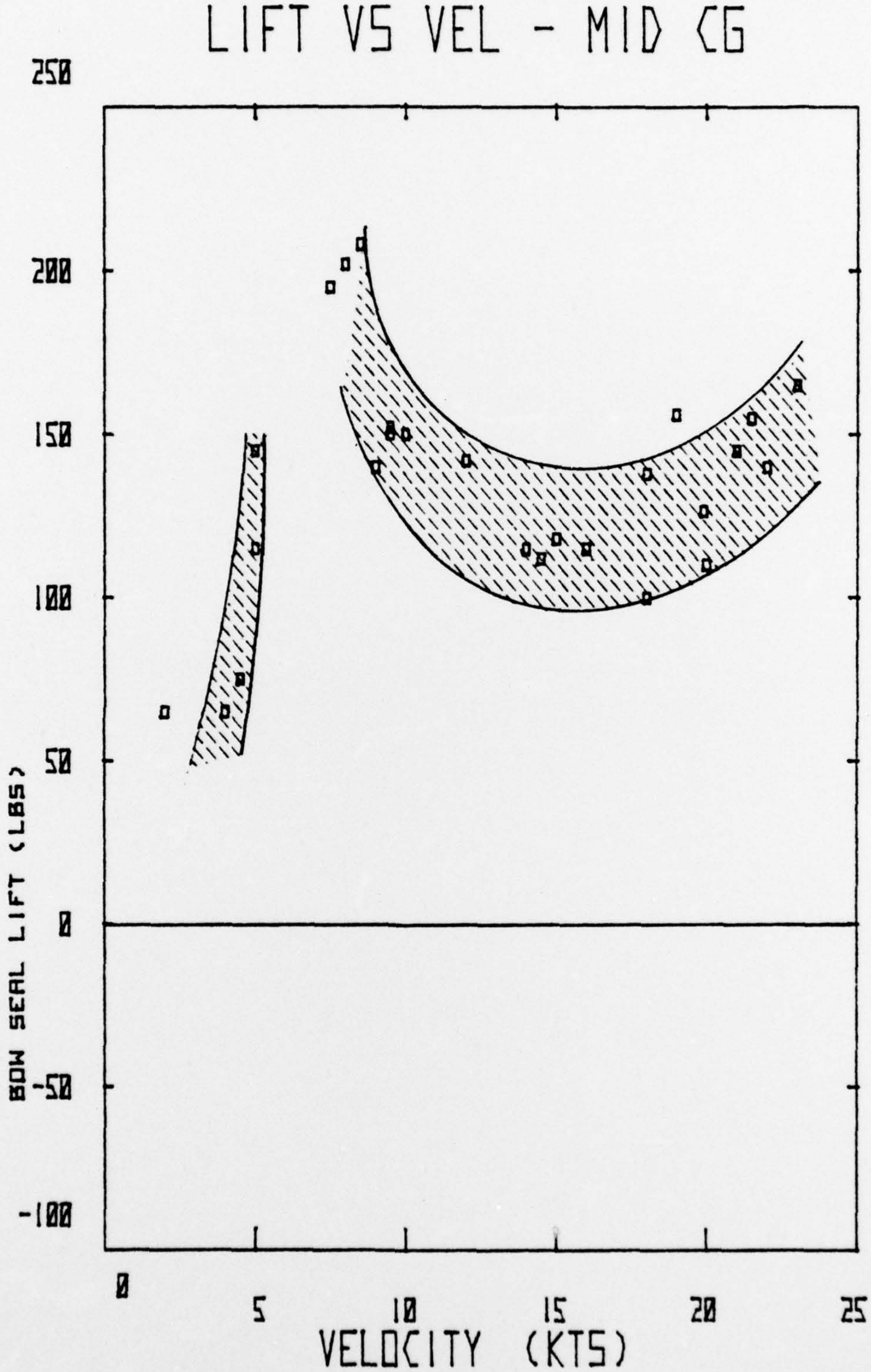

Figure 12 - BOW SEAL LIFT VS VELOCITY - MID CG

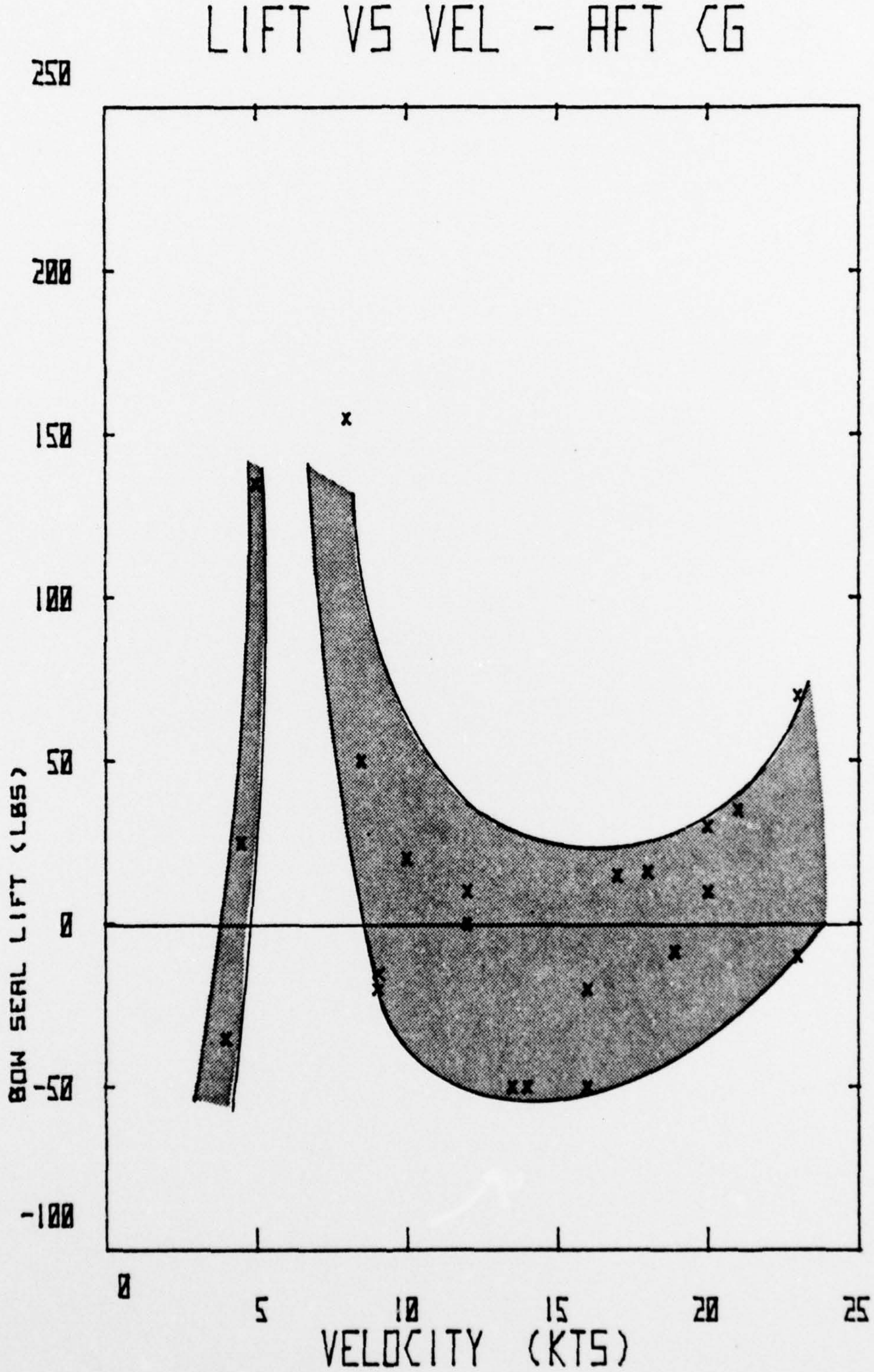

Figure 13 - BOW SEAL LIFT VS VELOCITY - AFT CG

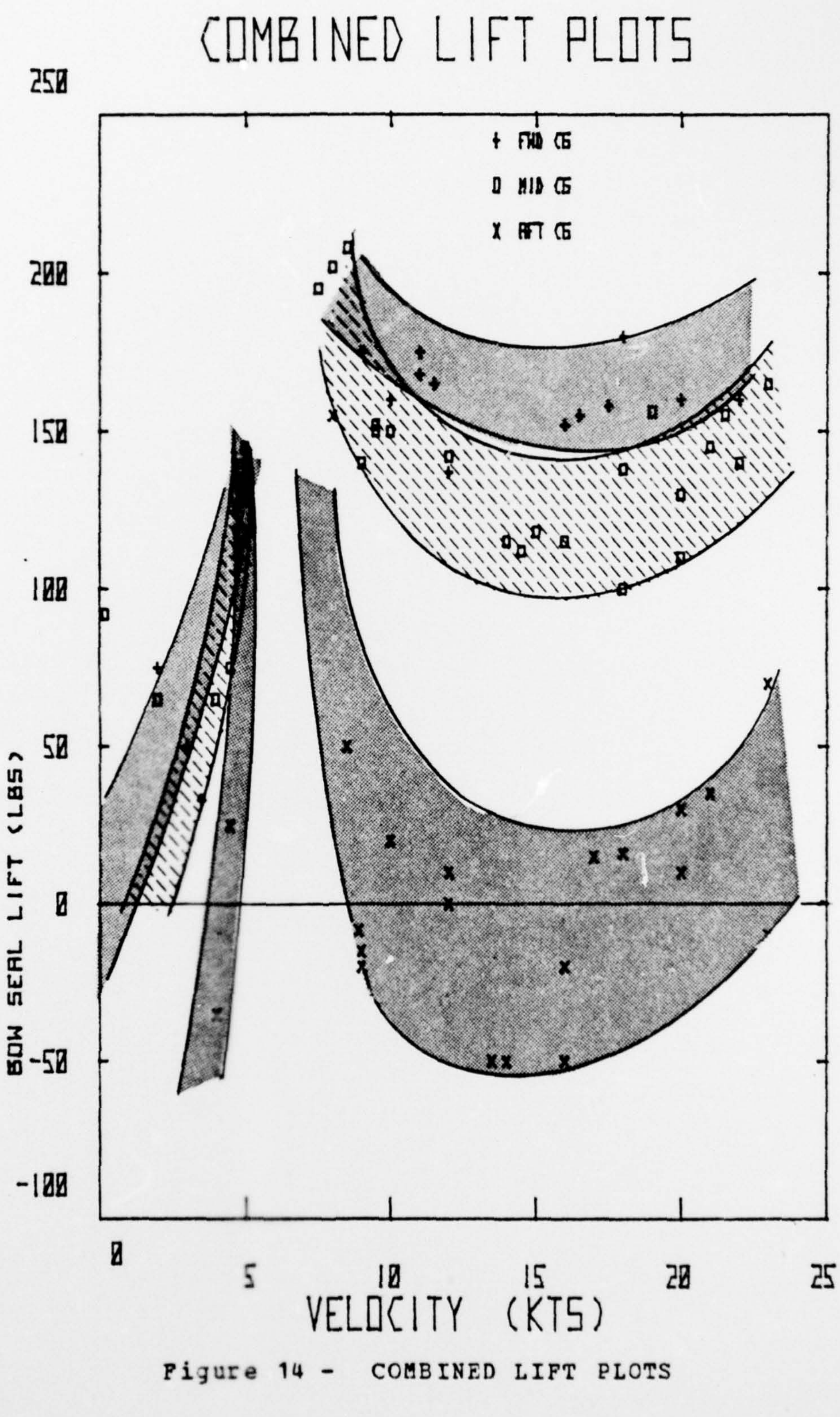

Figure 14 - COMBINED LIFT PLOTS

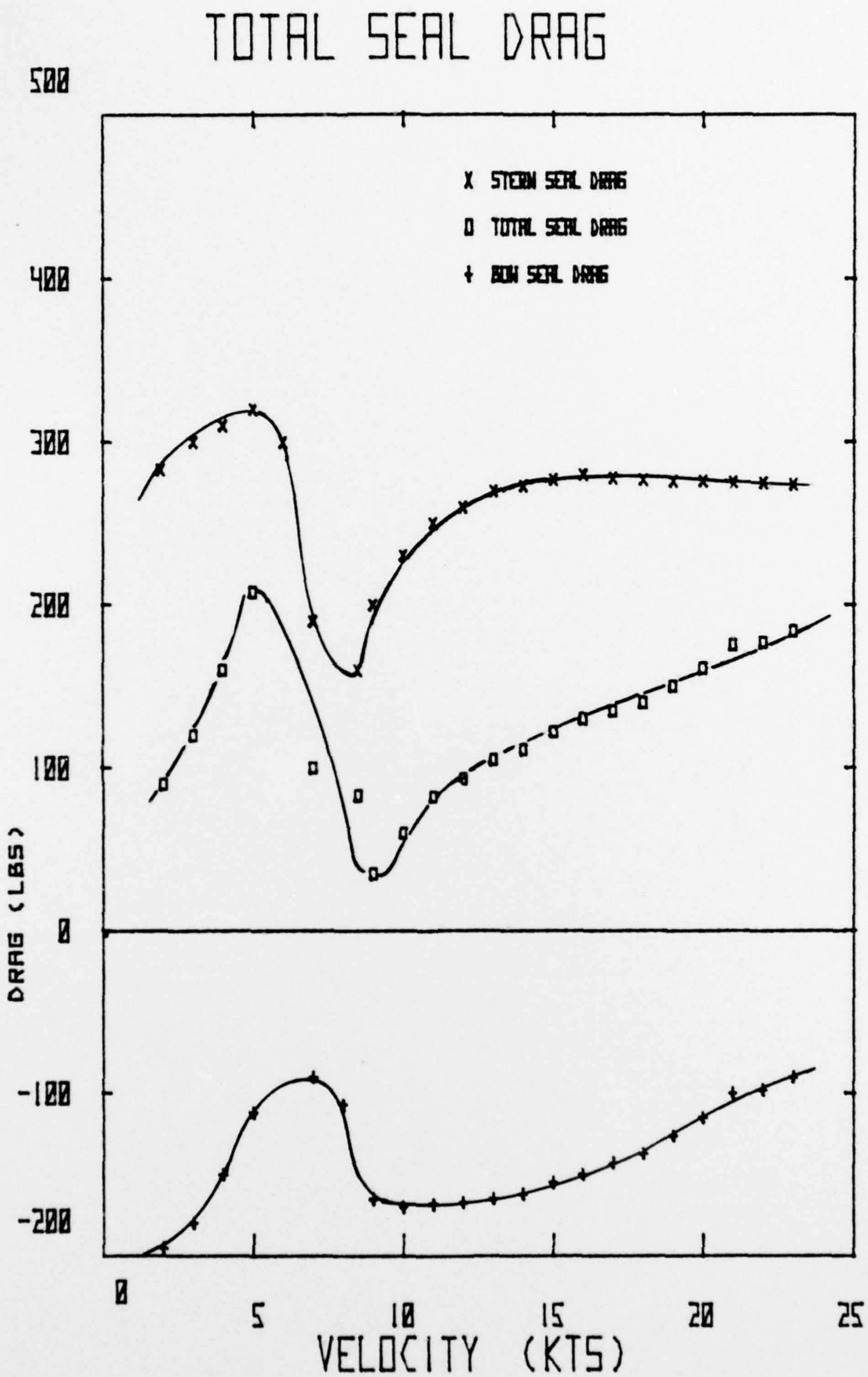

Figure 15 - TOTAL SEAL DRAG VS VELOCITY

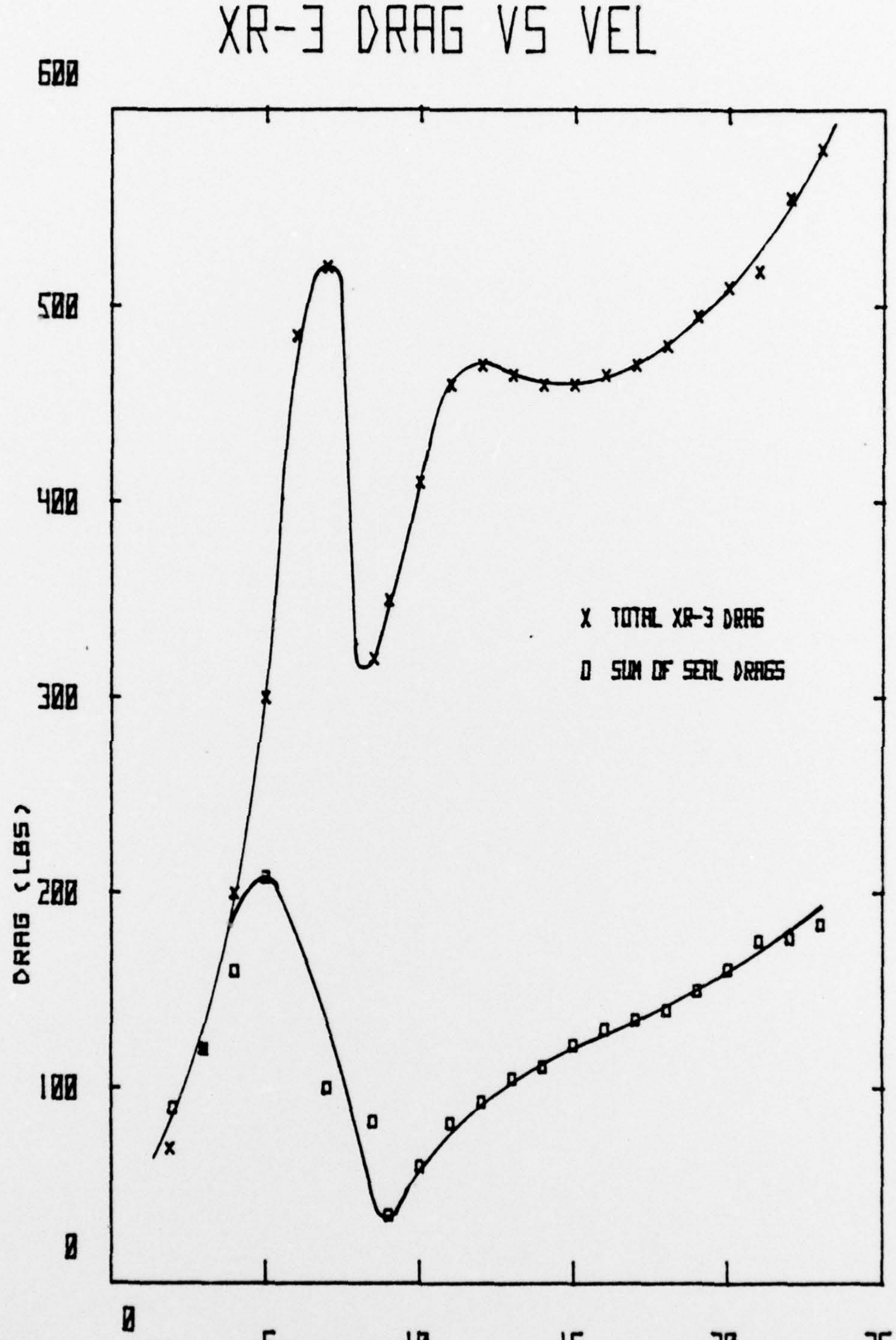

Figure 16 - XR-3 DRAG VS VELOCITY

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