AN EXPERIMENTAL ANALYSIS OF THE HYDRODYNAMIC CHARACTERISTICS OF THE MONOFORM; A NOVEL HULL FORM

by

Steven George Hittel

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Mechanical Engineering

APPROVED:

A. G. Szeless, chairman

L. D. Mitchell

J. R. Thomas

May, 1985

Blacksburg, Virginia

AN EXPERIMENTAL ANALYSIS OF THE HYDRODYNAMIC CHARACTERISTICS OF THE MONOFORM; A NOVEL HULL FORM

by

Steven G. Hittel

(ABSTRACT)

This thesis presents the results of an experimental investigation of the hydrodynamic characteristics of the Monoform hull in calm water. The forces acting on a 1.7 meter model were measured as the model was held captive and towed in calm water. The model was tested at speeds up to three meters per second. The rudders were held straight during one part of the study and were deflected during another to test both their ability to correct for pitching moment and to create yaw moments. The draft of the model was also varied during this study and included drafts of 1.90, 2.21, and 2.42 hull diameters. All three forces and all three moments were measured. The model was tested in a 31 meter towing basin located at Virginia Polytechnic Institute and State University. The results are presented in Figure form in the thesis body and in numerical form in an appendix. Recommendations for future work and improvements to the instrumentation are presented along with conclusions at the end of the thesis.

ACKNOWLEDGMENTS

During the pursuit of my master's degree I have come to realize how many people have helped me along the way. Some have given me support during the inevitable failures, both of equipment and of my own. Others have given me advice which came from years of experience. No list of people to whom I owe thanks could ever be complete.

I would like to thank Dr. Szeless, my committee chairman, who guided my efforts with patience and wisdom. I would like to thank Dr. Mitchell and Dr. Thomas for serving on my committee. I would like to thank Dr. Leonard who acted as a sounding board for many potential solutions to instrumentation problems. The technicions in the mechanical engineering shop deserve a special thanks for the large amount of help they gave me during the designing and building of some of the instrumentation that I used. Finally I owe a large amount of thanks to my family for the support that they gave me during this work.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

List of Illustrations (continued)

List of Illustrations (continued)

List of Illustrations (continued)

LIST OF TABLES

Appendix D contains the reduced data in the form of tables which are not numbered.

1.0 INTRODUCTION

Ever since man began using waterways for transportation, he has attempted to find vessels which better fitted his needs. Even now we are looking for ships which are faster, more economical, and can operate under more hazardous sea conditions than their predecessors. One type of vessel which might fit this need is the Small Waterplane Area Twin Hull (SWATH) ship, while another is the Monoform.

This thesis describes an experimental investigation of a Monoform model. The objective of the investigation was to design an instrumentation system for measuring the forces and moments on the model, and its velocity, thus developing a data base on the Monoform model. A total of 97 runs were conducted. Three different sets of rudder angles were tested at three drafts each. The rudders were held straight in one set of tests, positioned to give a turning moment in another set, and positioned to create a bow-up pitching moment in the final set. The bow-up pitching moment was desired to reduce the bow-down pitching moment caused by the underwater hull of the Monoform.

This thesis begins with a brief literature review of the small waterplane area ship concept, then it presents the instrumentation used, the results, and finally a set of conclusions and recommendations.

2.0 REVIEW OF THE LITERATURE

Since the Monoform concept is relatively new, the literature on the SWATH will be used to demonstrate attributes common to both. Section 2.1 gives a general description of the SWATH and the Monoform. Section 2.2 discusses the advantages and disadvantages of the SWATH ship concept. Section 2.3 presents the differences between the SWATH and the Monoform. Section 2.4 combines a brief description of the present and proposed future missions of the SWATH vessel, to indicate the possible mission definitions of the Monoform.

2.1 GENERAL DESCRIPTIONS OF THE SWATH AND MONOFORM

Figure 2.1[*] presents a sketch of a typical SWATH vessel. It has two underwater cylindrical hulls connected to a rectangular above-water hull by slender surface-piercing struts. The SWATH uses a stern stabilizer and two bow-mounted canards to control pitching and roll moments, as well as heave. Rudders are placed on the back of each strut for directional control. The SWATH has been built in both one strut per side and two strut per side versions.

---

[*] Numbers in square brackets, [ ], in this figure and in the remainder of this thesis indicate the reference number as found in the reference section.

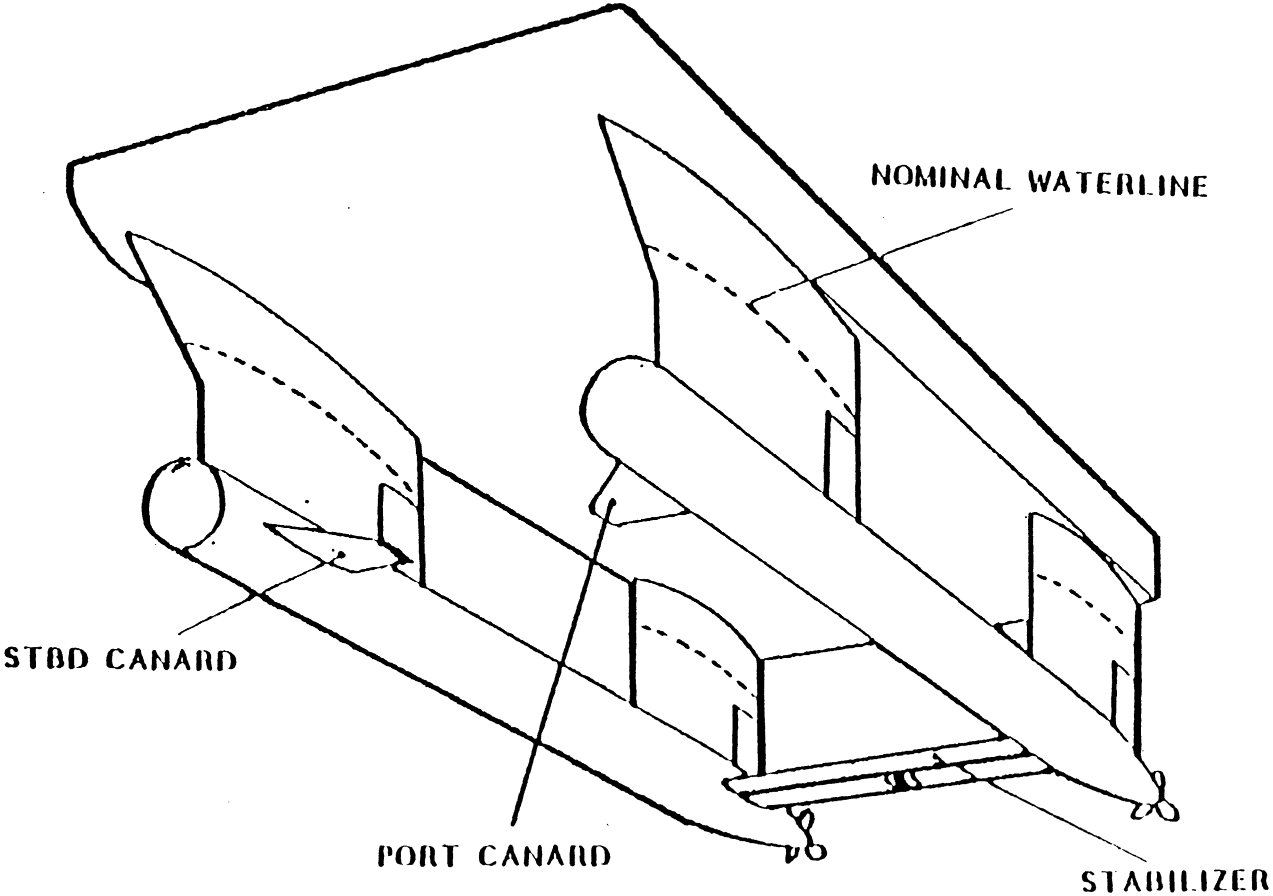


Figure 2.1 Sketch of the SWATH [1]

Figure 2.2 presents a sketch of the Monoform ship concept. The Monoform has a single underwater hull connected to the above surface hull by two pairs of V-configured struts. On the rear of each strut a rudder is mounted to provide control over direction, pitching and roll moments, and heave.

2.2 ADVANTAGES AND DISADVANTAGES OF THE SWATH

The benefits and drawbacks of the SWATH have been well discussed in the literature [1-6]. As most often presented, the benefits are reduced wave-making resistance and improved seakeeping capability. Both of these improvements are due in a large degree to the reduced waterplane area of the ship.

Reduced Wave-making Resistance

Unlike a submarine or airplane, a ship operates at the interface of two dissimilar fluids; air and water. As the ship moves along this interface, a moving pressure field is generated which forces the surface of the water to deform into waves. The energy necessary to create these waves must come from the ship. If the ship can be removed from this interface, either underwater or into the air, then the pressure field will be dissipated before it can cause any significant wave motion. The

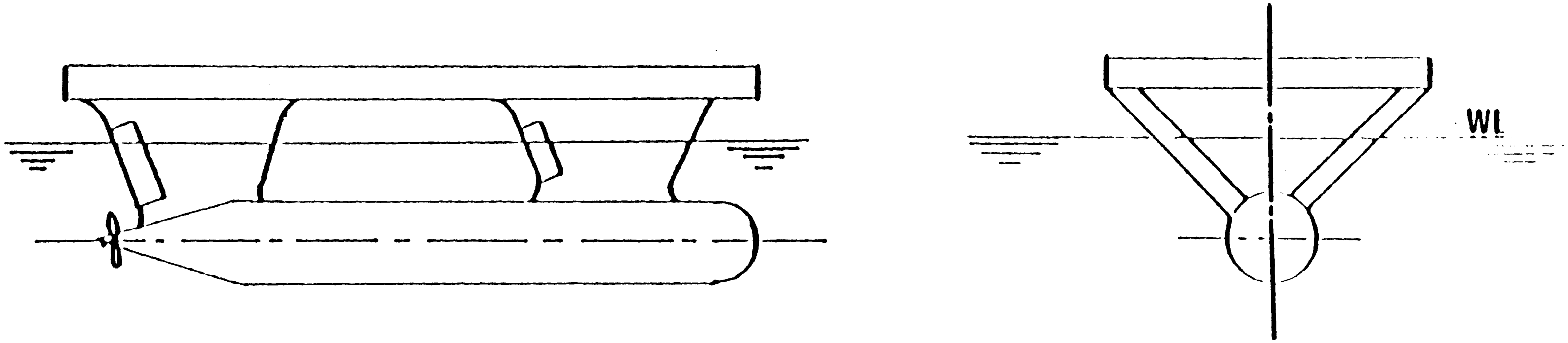


Figure 2.2 Sketch of the Monoform [2]

SWATH and Monoform take advantage of this phenomenon by placing the major part of their displacement well below the free surface. This leaves only the slender surface piercing struts to cause wave-making resistance. Since wave-making resistance is the dominant part of the drag at high speeds, the SWATH is capable of higher speeds than a conventional monohull of equal power and comparable size.

Improved Seakeeping

The reduced waterplane area of the SWATH tends to decouple its response to waves, allowing the SWATH to operate in high sea states without the severe motions of conventional vessels. Also, since the wetted surface area of the SWATH does not increase significantly as the SWATH enters a wave, its speed is not reduced as much as that of a monohull ship. The combination of these effects allows the SWATH to perform in high sea states like a conventional ship of much larger displacement.

Since the roll stability of a ship is based on the transverse moment of inertia of its waterplane area, the SWATH must place its struts far apart. This results in a large deck beam which is very useful for certain applications. There is no hydrodynamic reason against separating the struts as far as desired, but there are structural problems. Also, the beam might be limited by operational problems like the width of the Panama canal.

Disadvantages

There are two disadvantages of removing the ship's underwater hull from the vicinity of the waterplane. The first of these is an increase in wetted surface area which results in an increase in frictional drag. Since frictional drag is the largest component of drag at low speeds, the SWATH uses more power at low speeds than a monohull. The second drawback is an increase in the draft of the vessel. This should not hinder the open-ocean performance, but for larger SWATH designs the accessibility of ports might be limited.

2.3 COMPARISON OF THE SWATH AND MONOFORM

While the SWATH and Monoform both use the small waterplane area concept, there are some basic differences between the two. The two largest advantages of the Monoform over the SWATH are improved frictional resistance, and decreased structural weight. The Monoform's single underwater hull will have up to $1/\sqrt{2}$ times the wetted surface area of the SWATH's two cylindrical hulls. This reduction in wetted surface area will result in a reduction in frictional resistance which should decrease the low speed resistance of the Monoform as compared to the SWATH. The reduction in structural weight comes from the inherently stronger triangular structure of the Monoform compared to the inverted U-shape of the SWATH.

Other differences come from the Monoform's V-configured struts. The slope of the struts allows rudders placed on these struts to apply forces in the vertical as well as in the horizontal direction. This should facilitate control of pitch, roll, and heave without the addition of other control surfaces with their associated interference drag and flow noise. The damage stability of the Monoform should be superior to that of the SWATH. Any asymmetrical flooding would add weight close to the centerline of the Monoform instead of on the vessel's beam as in the SWATH. This reduces the roll moment caused by asymmetrical flooding. Another advantage to the V-shaped struts is the increased damping and added mass effects caused by their sloped sides. This should increase the Monoform's seakeeping ability by decreasing the amplitude in heave and reducing the risk of slamming.

A parametric study [2] was performed comparing the first SWATH vessel built, the SSP Kaimalino (described in the next section), with a Monoform. This study indicated that the Monoform had 17 percent less wetted surface area, a 13 percent increase in metacentric height, and a 37 percent increase in longitudinal metacentric height over the SSP Kaimalino. The study also showed that the Monoform had a greater waterplane area than the SSP. This increased waterplane area would harm both the wave-making resistance and the sea-keeping capability of the Monoform. It should be noted that one of the constraints of the study was that the two vessels were of equal beam. Since the struts on the Monoform angle in from the beam, the distance between the struts at the waterplane was much smaller on the Monoform than on the SSP. Thus, to achieve the same static stability, the Monoform needed thicker struts which lead to a larger waterplane area. This difficulty could be overcome by increasing the beam of the Monoform over the SSP for the same displacement. This would also increase the width of the deck and actually improve the usefulness of the above-water hull.

2.4 PRESENT AND POSSIBLE FUTURE MISSIONS OF THE SWATH

Present SWATH vessels

To date there have been three SWATH vessels built. The first of these was the SSP Kaimalino, which was designed by the Naval Undersea Center in San Diego, California [3]. SSP is the acronym for Semi-Submerged Platform, a name it was given to avoid calling it a ship, thus by-passing the necessary congressional ship-building approval. The Kaimalino was designed as a 190-ton work boat for the Naval Undersea Center in Hawaii. It was required to provide support for submersibles and various types of naval equipment, perform unimpeded operation in waves of up to about

2 meters (these are common near Hawaii), and be large enough to prove the concept in the open ocean. Later it was also used as a landing platform for a helicopter. It was built with a span of about 12 meters between the centers of the hulls and a length of 27 meters. This vessel was used to produce a wealth of information on the SWATH concept.

The two remaining SWATH-type vessels were built by Mitsui Engineering and Shipbuilding Co., Ltd. of Japan [4]. The first is the experimental vessel called the Semi-Submerged Catamaran (SSC) Marine Ace, which was completed in October of 1977. The SSC Marine Ace is 12 meters long and originally had two struts per side. After extensive sea trials the Marine Ace was converted to a single strut per side arrangement for performance comparison. The studies on the Marine Ace showed that the single strut per side design had less drag than the two strut per side design. They also indicated that the two strut per side configuration had the better natural periods of oscillation of the two. These studies led to the development of the first commercial SWATH design. In July of 1979 Mitsui launched a 36 meter ferry named the SSC MESA 80. It is capable of transporting 446 passengers with a maximum speed of about 50 km/hr (27 knots). It was designed to operate in seas with wave heights of up to 3.5 meters. This vessel was produced with one strut per side to decrease the resistance of the vessel.

Possible Future Missons of the SWATH Vessel

At present there are two missions which are most often mentioned for the SWATH [5]. The first is for a small 2000 to 5000-ton destroyer-escort type vessel. It would be used as an escort for larger vessels and would specialize in anti-submarine warfare. It would probably also serve as base for one or two helicopters or other VSTOL aircraft. The advantage of the SWATH over the conventional monohull in this type of application is primarily its improved sea-keeping ability. The SWATH also has improved sonar capabilities in higher sea states due to its near level flight, twin noses, and deep draft which allow many ways of mounting sonar. The SWATH's reduced motion would limit exposure and quenching of the sonar heads.

The other application which is most often mentioned is for a small aircraft carrier serving as a base for 15-25 VSTOL aircraft. This would give more flexibility to the Navy since more units could be purchased for the same total expenditure. It would also reduce the per unit target value. This mission could not be fulfilled by a conventional ship in the 10,000 to 20,000 ton range suggested by Childers [6], due to its small deck and excessive motion in high sea states.

Other possible missions mentioned in the literature include: search and rescue, ocean research, submarine support, surveillance, operation as missile platforms, command ships, and as floating hospitals.

3.0 INSTRUMENTATION AND PROCEDURES

This chapter discusses the equipment, instrumentation, and procedures used in this study. The discussion is divided into six parts. The first section, 3.1, describes the model used in this study. The towing tank and towing carriage are described in the next section, 3.2. This is followed, in section 3.3, by a discussion on the instrumentation used in the measurement of the forces and moments, and of the model velocity. Section 3.4 describes the calibration of the instrumentation. The data collection procedure is given in section 3.5. The final section contains a discussion of the advantages and disadvantages of the instrumentation used. An error analysis of the instrumentation system is presented in Appendix A, the computer codes used for data transmission and reduction are listed in Appendix B, and a list of the instrumentation used is given in Appendix C.

3.1 THE MONOFORM MODEL

A sketch of the model used is presented in Figure 3.1. It has an aluminum underwater hull which is 172 cm (68 inches) long, and 12 cm (4.75 inches) in diameter. The bow consists of a hemisphere while the stern is a cone 18 cm (7 inches) long. It has four identical struts which were attached to the hull at 45 degrees to the vertical. The struts have a thickness

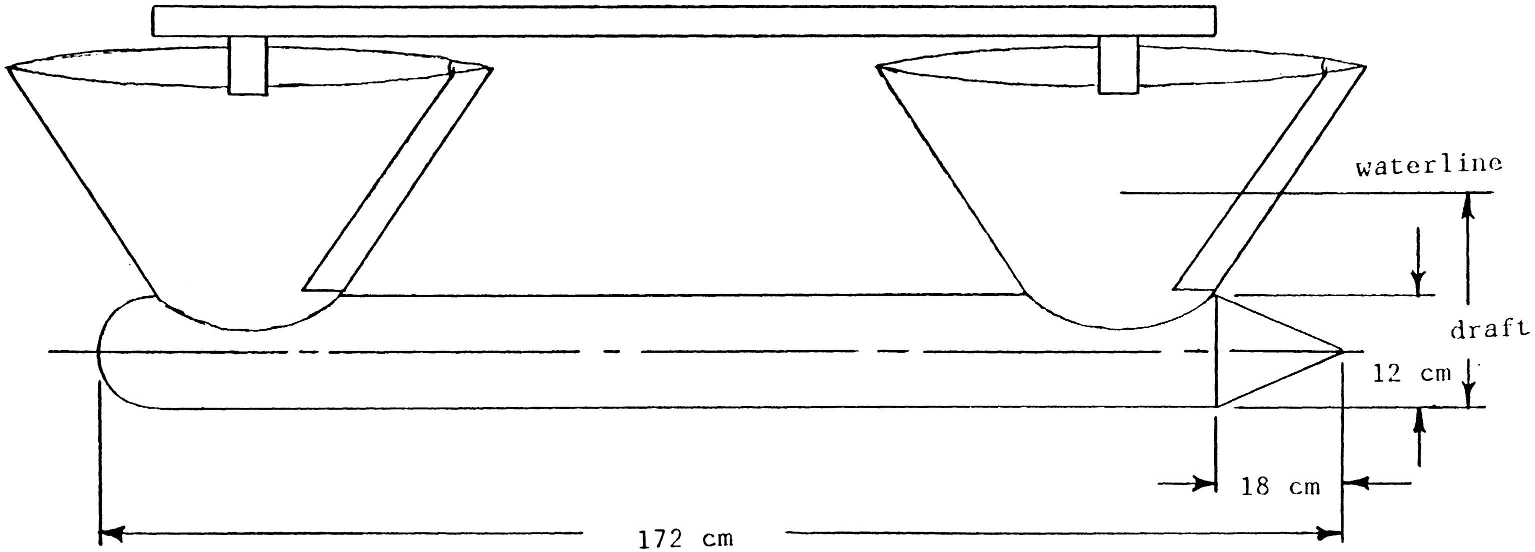


Figure 3.1 The Monoform Model used in this Investigation

of 5 cm (2 inches) at the base, and expand to a thickness of 7.5 cm (3 inches) at the top. The struts are symmetrical about the chord and were aligned parallel with the underwater hull. The struts have rounded leading edges below the design waterline with sharp leading edges at and above the waterline. The trailing edges are sharp at all drafts. The aft 25% of each strut is replaced by a wooden rudder which can be displaced fifteen degrees on either side of the center position.

Draft reference marks were placed on each strut for model leveling and to assist in repeating runs at the same draft. These marks start near where the struts meet with the hull and increase as the draft increases. Three different drafts were used in this study. These were drafts of 1.90, 2.21, and 2.42 hull diameters. The drafts were selected such that it was easy to return the model to the necessary draft. They corresponded to draft reference numbers of 15, 45, and 65. Later in this report the draft numbers are used as references instead of the actual drafts.

3.2 THE TOWING TANK AND CARRIAGE

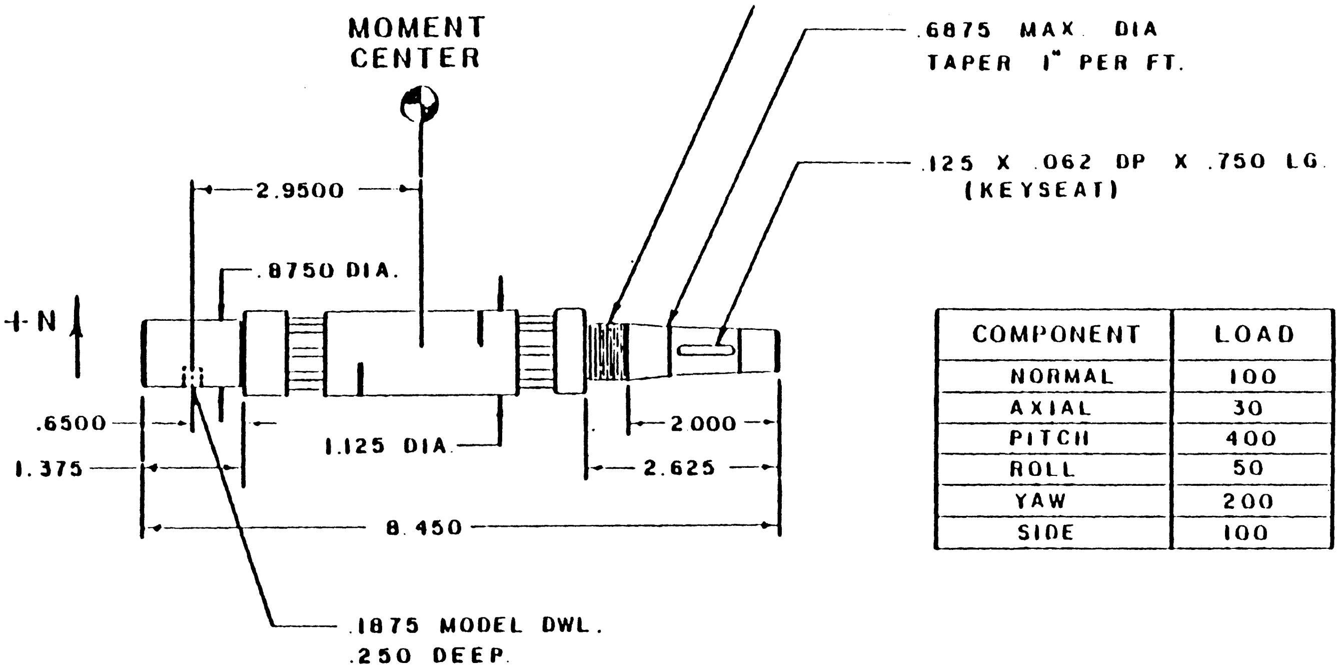
The towing tank used is located in Norris Hall on the campus of Virginia Polytechnic Institute and State University. The tank is 30.5 meters long, 1.8 meters wide, and the water is 1.2 meters deep. The useful length of the tank, however, is reduced to about 25 meters by a wave maker at one end of the tank and a wave absorber at the other end.

The towing carriage was built by Kemp and Remes of Hamburg, Germany around 1960. It is driven by a 400 volt DC electric motor which gets its power from a 220 volt AC motor-driven generator. The maximum speed which can be attained is about 3 meters per second.

3.3 INSTRUMENTATION

Measurement of Forces and Moments

The force/moment transducer used in this study is a strain-gage sting balance built by Modern Machine and Tool Co. of Newport News, VA. The manufacturer's drawing of the balance is presented in Figure 3.2. This balance can measure three mutually perpendicular forces and the associated moments. As shown in Figure 3.3, the balance was fixed to an aluminum strut (which projected down from the towing carriage) by clamping it into a cylindrical vise at the lower end of the strut. The other end of the sting balance was inserted into a closely fitting hole in an aluminum block bolted to the model. The alignment and position of the sting balance in the block was maintained by a screw inserted through the aluminum block into an alignment hole in the balance. Small wire cables were placed between the strut and the carriage to stiffen



COMPONENT	LOAD
NORMAL	100
AXIAL	30
PITCH	400
ROLL	50
YAW	200
SIDE	100

MODERN MACHINE & TOOL CO., INC.
NEWPORT NEWS, VA.

SCALE: HALF	APPROVED BY	DWN. BY:
DATE: 9-8-75	9-9-75	REV.

STING BALANCE SB-100
DWG. NO. M760071

Figure 3.2 Manufacturer's Drawing of the Sting Balance

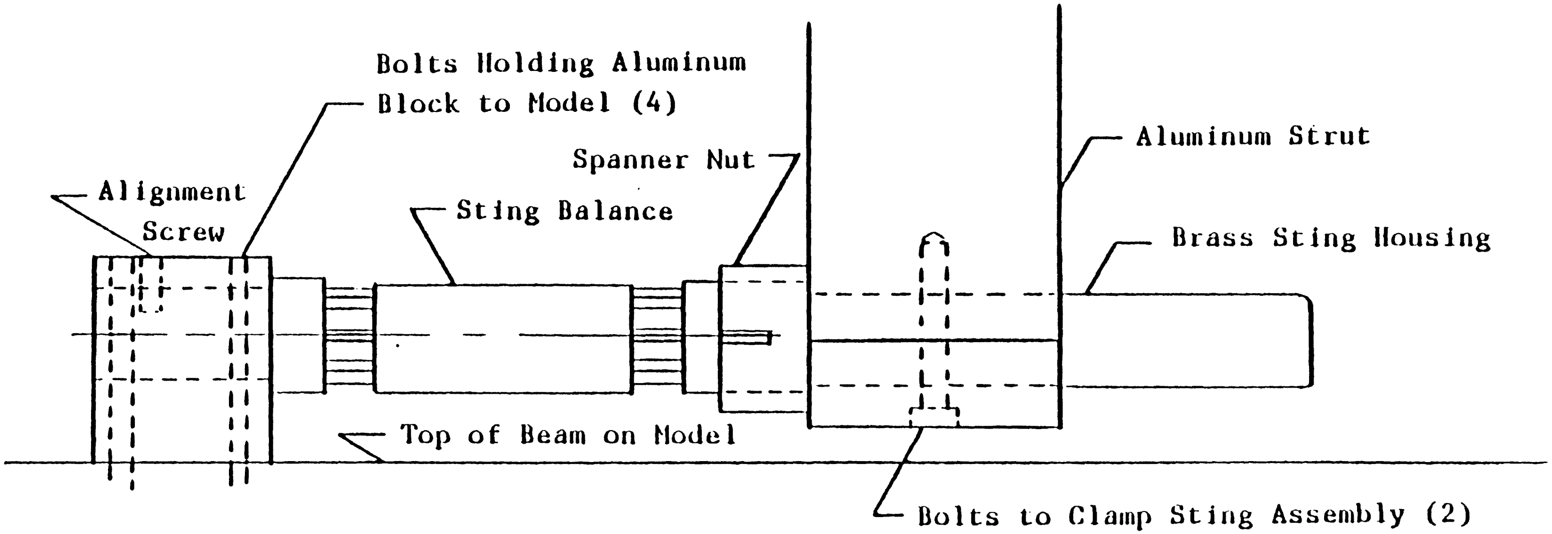


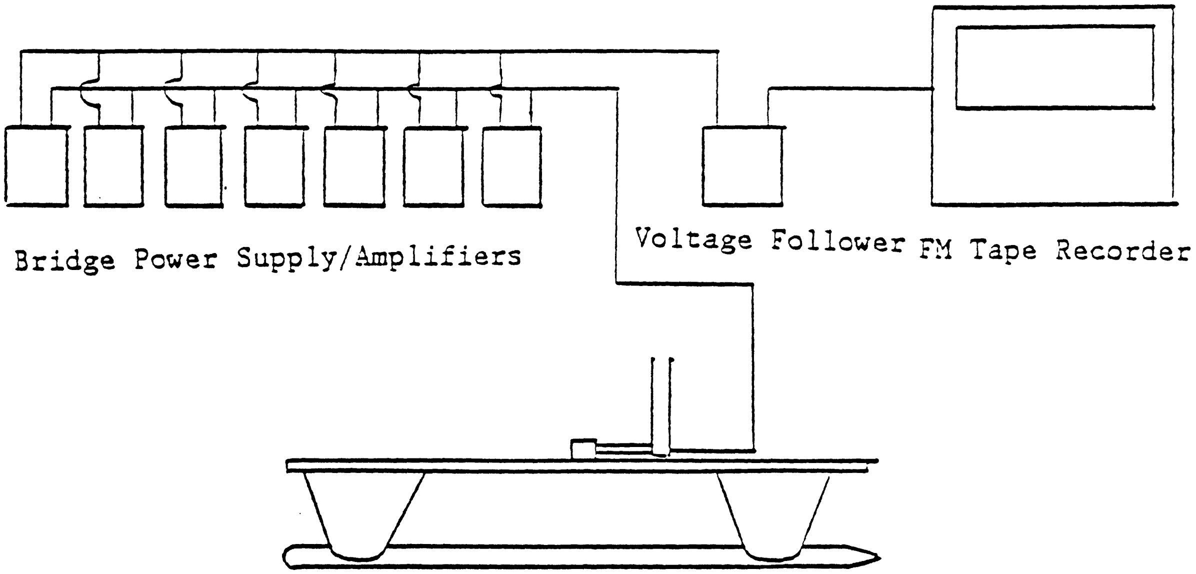
Figure 3.3 Sting Balance Installation

and thereby increase the natural frequency of the structure. This was done in an attempt to decrease the carriage noise transmitted to the model at low frequencies.

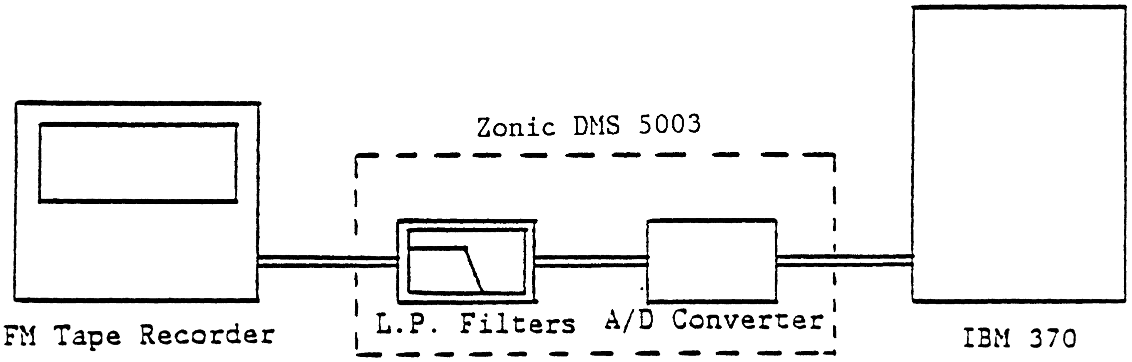
Figure 3.4 shows a schematic diagram of the instrumentation used in measuring the forces and moments applied to the strain gages. The equipment consisted of one on-carriage and one off-carriage group.

The first part of the equipment, shown as part A of Figure 3.4, was carried on the carriage during the experimental runs. The strain gage balance indicated the applied forces and moments as changes of resistance in opposite arms of resistance bridges. A set of six battery powered strain gage power supply/amplifiers converted these resistance changes into voltage signals. These amplifiers were connected to a set of six unity-gain voltage followers, which were needed for impedance matching. The outputs of these voltage followers were recorded by a seven-channel FM tape recorder. The tape recorder had a voltage range of -1.4 to +1.4 volts which was adequate to handle the -1.0 to +1.0 volt output of the amplifiers. A remote controller was used with the tape recorder so that one person could operate both the carriage and the tape recorder at the same time.

The second part of this instrumentation string, shown in Part B of Figure 3.4, read the data off the magnetic tape and did the actual data



Part A. On-Carriage Instrumentation



Part B. Off-Carriage Instrumentation

Figure 3.4 Schematic Diagram of the Force and Moment Measureing Instrumentation reduction. Here the tape recorder was connected to the anti-aliasing filters of a Data Memory System (DMS) built by Zonic Technical Laboratories. This DMS was connected to a model 5003 FFT processor for data processing and transmition. The anti-aliasing filters in the DMS are 10 pole active Butterworth filters with a -60 dB per octave drop-off after the cut off frequency. The output of these filters was digitized by the data acquisition stage of the DMS using a 9 bit plus sign analog to digital converter.

Since the A/D converter in the DMS is a 10 bit converter, the full range of allowed input voltages is divided into 1024, or 2^{10}, parts. The DMS 5003 uses ranges that went from positive to negative values such as from -100 to 100 mv. This particular type of A/D converter has an error of one half of the least significant bit. Therefore since the 1024 divisions are spread over twice the full scale, the converter accuracy is 1 part in 1024, or 0.098% of the full scale value. However, this value may not fully represent the actual error in the digitizing operation. If the input signal is small compared to full range, the error can be large when based on a percent of reading. For example, if the signal is near one half the smallest increment, or 1/1024 times the full scale value, then the error would approach 100 percent of the actual signal. In order to reduce this error, the input signal was amplified by 20 dB, a factor of 10, at the low-pass filters of the DMS 5003. This lessened the digitizing error of any small signal while it only placed larger signals into the next range. Signal amplification was not done for data that would exceed the 10 volt maximum range of the DMS. The gain factor was considered part of the calibration and was removed in later processing.

Since the DMS 5003 has only two channels, the data was digitized and transmitted one force or moment channel at a time. The other channel on the DMS 5003 was always used for the velocity data to facilitate correlating the forces to the velocity. After each batch of data was digitized, the DMS 5003 transferred it to a mainframe computer where it was stored for later reduction.

Velocity Measurement

The velocity signal was generated by an optical encoder. The encoder was driven by a 97 mm diameter aluminum disk coated on the outside edge with a hard rubber strip. As shown in Figure 3.5 the encoder was mounted on a hinged plate such that the weight of the encoder held the rubber coated wheel against the steel rear wheel of the towing carriage. When the encoder was not in use it was pulled away from the carriage wheel and secured in the up position to avoid creating a flat spot in the encoder drive wheel.

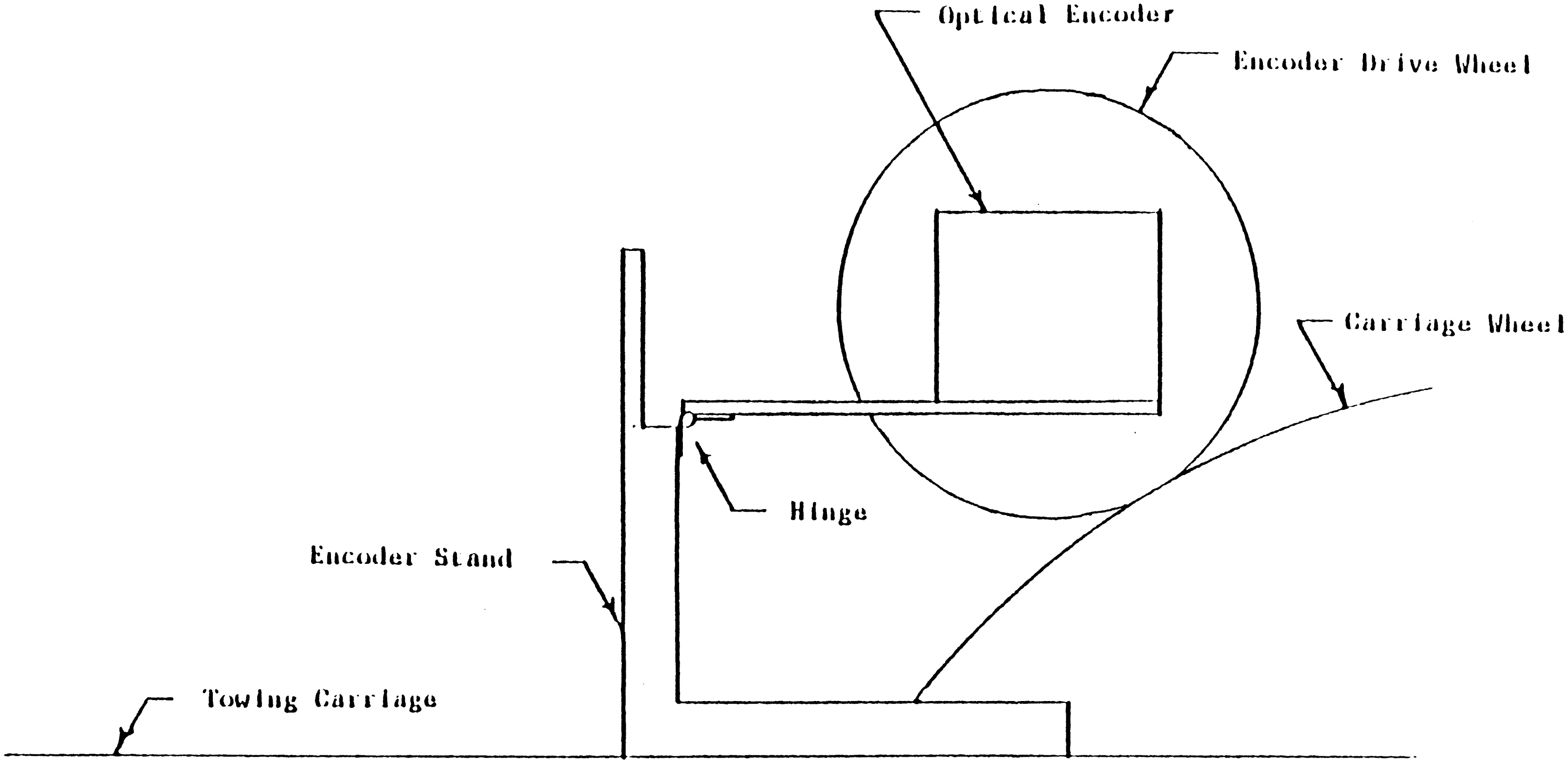
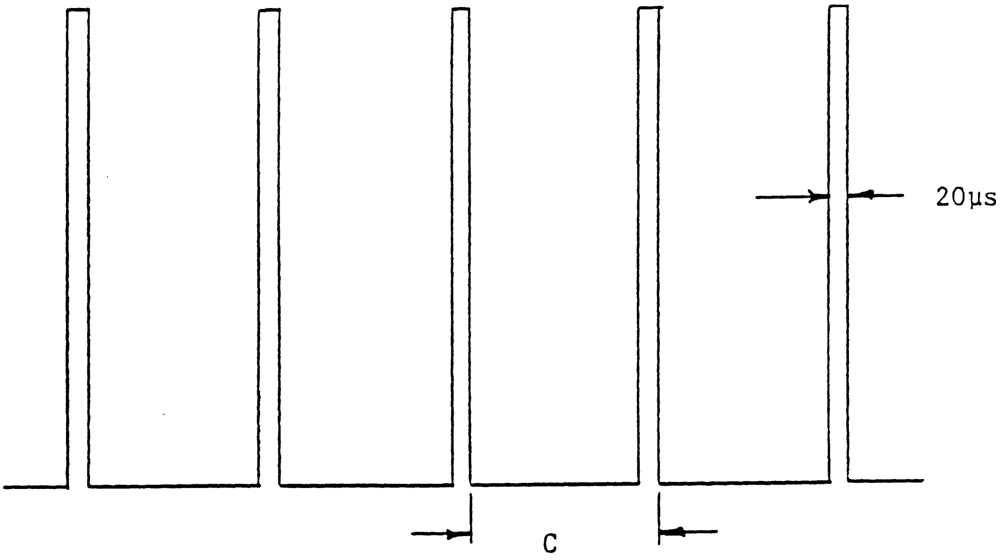


Figure 3.5 Diagram of the Encoder Placement and Mounting

The encoder produced six hundred 10 volt pulses per revolution. Each pulse had a duration of 20 μsec and a rise time of 1 μsec. Therefore, the output of this encoder was a rectangular wave with a 20 μsec 10 volt positive reference pulse followed by a variable length 0 volt base, as shown in Figure 3.6.

The encoder output was used in a manner similar to that of Robinson [7]. As the velocity of the encoder increases, the 0 volt base decreases in length, but the 20 μsec pulse does not. Hence, as the velocity of the encoder increases, the waveform of the encoder output changes. As seen in Figure 3.6 this causes the A_0 term of the Fourier series expansion of the waveform to change linearly with the velocity of the encoder. Therefore, if the encoder output is passed through a low-pass filter, which has a cut-off frequency far below the operating frequency of the encoder, the output will be a DC voltage which is linearly proportional to the velocity of the carriage. This voltage is equal to one half of A_0. In the speed range of the carriage the one half A_0 term ranged from about 0 to 0.1 volt DC.

In this study the cut-off frequency of the low-pass filter was set at 150 hz. At the slowest carriage speed used (0.25 meters per second) the optical encoder produced about 500 pulses per second. This placed the first harmonic of the Fourier series at 500 hz, which is 1.74 octaves above the cut-off frequency. Since the filter used has a drop of 60 dB



Waveform of the Optical Encoder in the Time Domain

$$f(t) = \frac{1}{2}(0.024R) + \sum_{n=1,\text{all}}^{\infty} \frac{2}{n\pi}\sin(0.12n\pi R) \quad \cos(n\pi 300R)$$

$$+ \sum_{n=1,\text{odd}}^{\infty} \frac{2}{n\pi}(\cos(0.12n\pi R) + 1) \sin(n\pi 300R)$$

R = Revolutions per Second

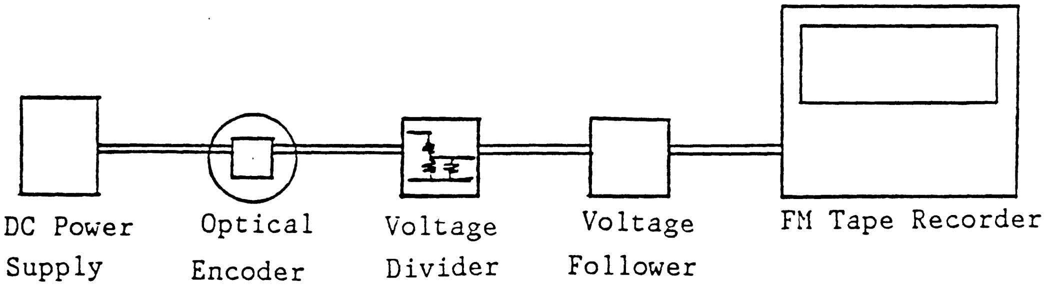
Fourier Series Expansion of the Optical Encoder Output

Figure 3.6 The Optical Encoder Output

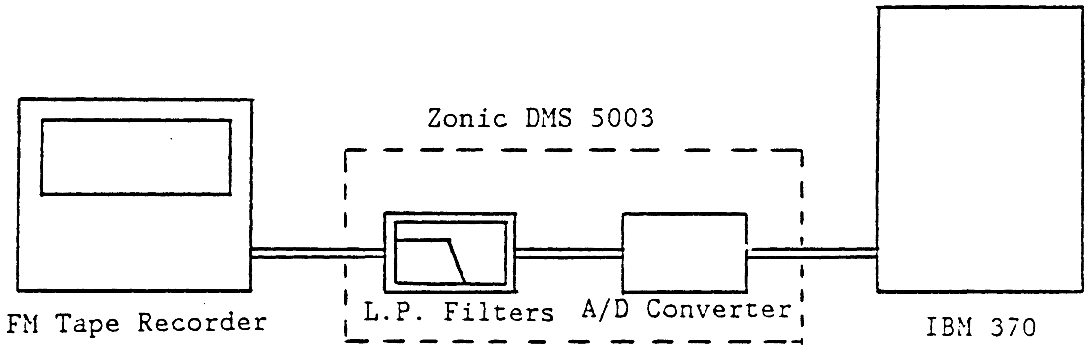
per octave, the first Fourier harmonic was reduced by about 105 dB. However, the DMS 5003 has a dynamic range of 58 dB. Hence, even at the slowest speed used, the first harmonic was below the range of the DMS 5003.

Figure 3.7 presents a diagram of the velocity measurement instrumentation. As shown in Part A, the on-carriage instrumentation, the output signal from the encoder was passed through a 10 to 1 voltage divider before it entered the seventh channel of the recorder. The 10 to 1 voltage division was necessary to reduce the 10 volt pulses into the -1.4 to +1.4 volt range of the tape recorder. Since only the low frequency components of the signal were needed, the tape recorder did not need to follow the 1 µsec rise time of the encoder.

As shown in Part B of Figure 3.7, the off-carriage portion of the instrumentation, the tape recorder was connected to one of the anti-aliasing filters of the Zonic DMS 5003. The cut-off frequency of the filter was set at 150 hz to reject any AC component of the signal. The velocity signal was amplified by 20 dB, a factor of 10, in the anti-aliasing filters to compensate for the 10 to 1 voltage divider used earlier.



Part A. On-Carriage Instrumentation



Part B. Off-Carriage Instrumentation

Figure 3.7 Schematic Diagram of the Velocity Measurement Instrumentation

3.4 CALIBRATION PROCEDURES

Since the data presented in this thesis was collected over a period of months, there was concern about drift in the characteristics of the voltage divider, the tape recorder's record and reproduce amplifiers, and the power supply/amplifiers. The data collection procedure was structured, as much as possible, to correct for any drift that might have occured. This was done with relative ease because all the signal conditioning equipment used treated the signals in a linear manner. If the characteristics of the instrumentation changed, only the gain and the DC bias would be affected. This allowed a procedure to be developed which calibrated the signals at two points, at no-load and at a known input signal. If it was known how the instrumentation string affected these two signals then all data signals could be corrected accordingly.

Obtaining the Balance Calibration Curves

In order to correctly interpret the output of the balance, six calibration curves were constructed. This was done by loading the balance with a known force or moment and measuring the output of the voltage follower with a digital voltmeter. This procedure was repeated with several forces or moments for all channels of the balance. The resulting calibration curves can be found in Figures 3.8-3.13. The slope of these curves were found by performing a linear regression for the data

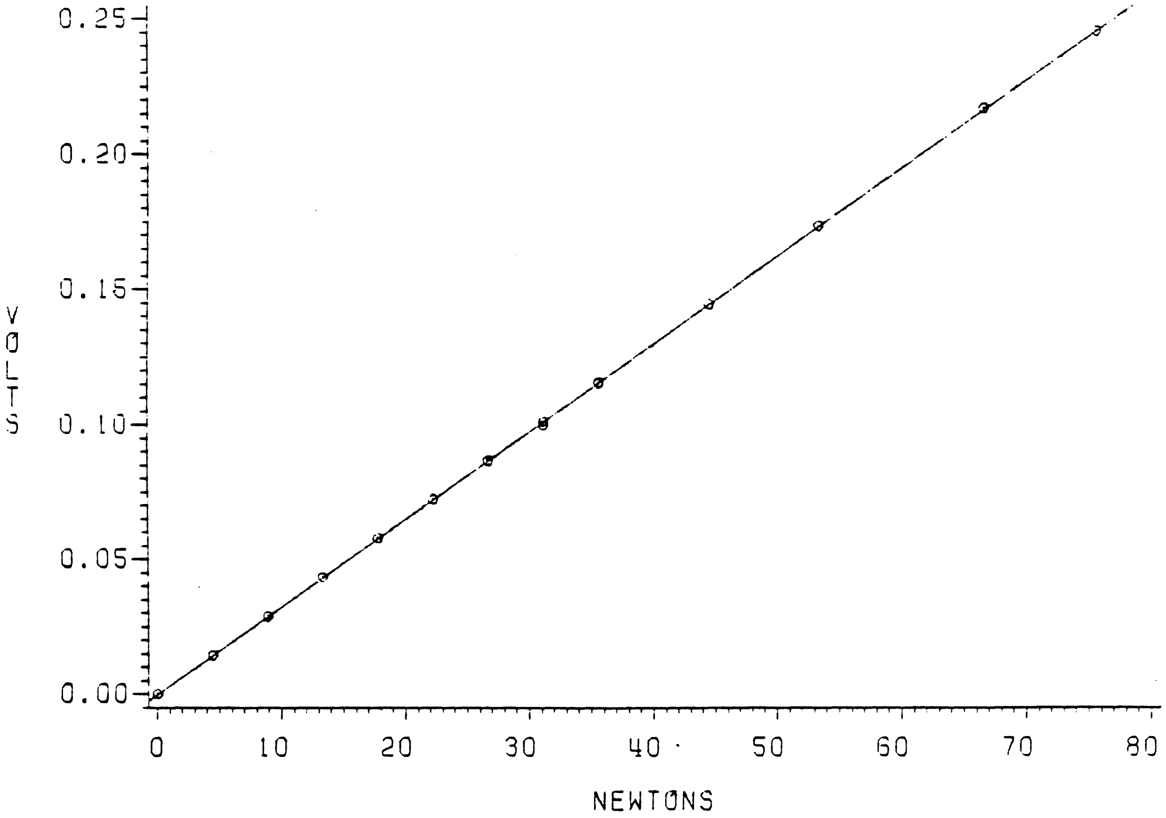


Figure 3.8 Drag Force Calibration Curve

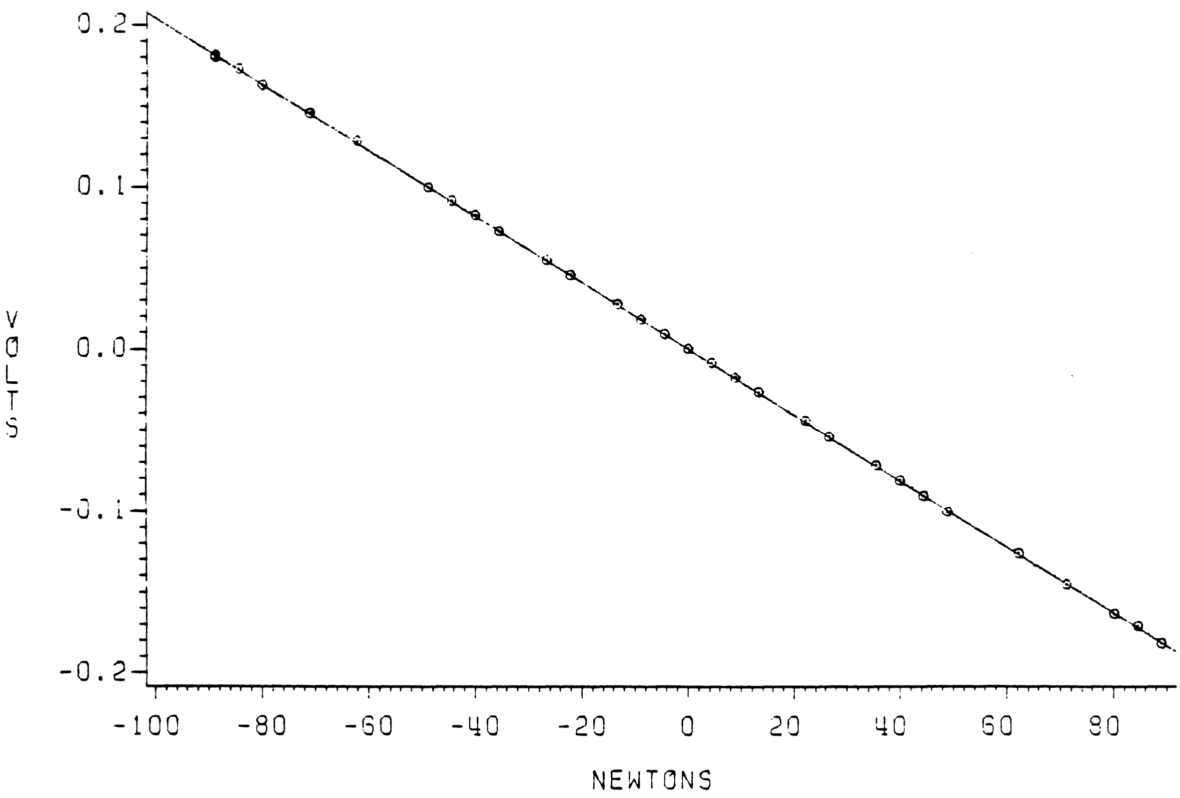


Figure 3.9 Lift Force Calibration Curve

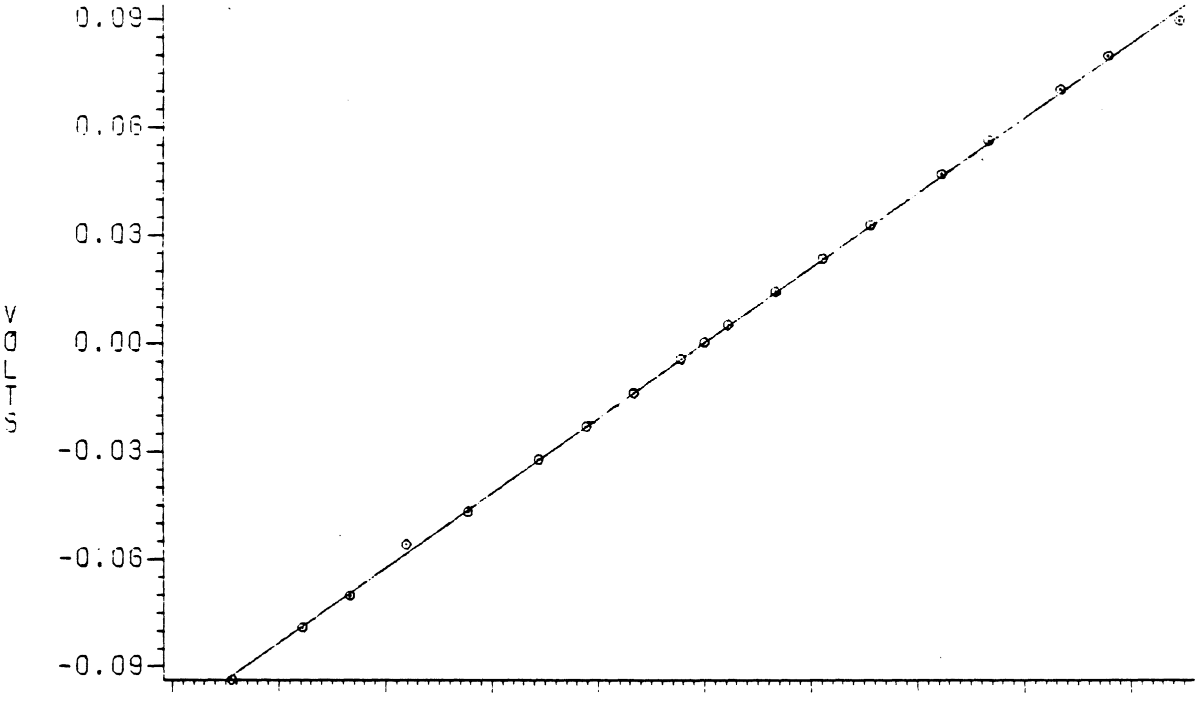


Figure 3.10 Side Force Calibration Curve

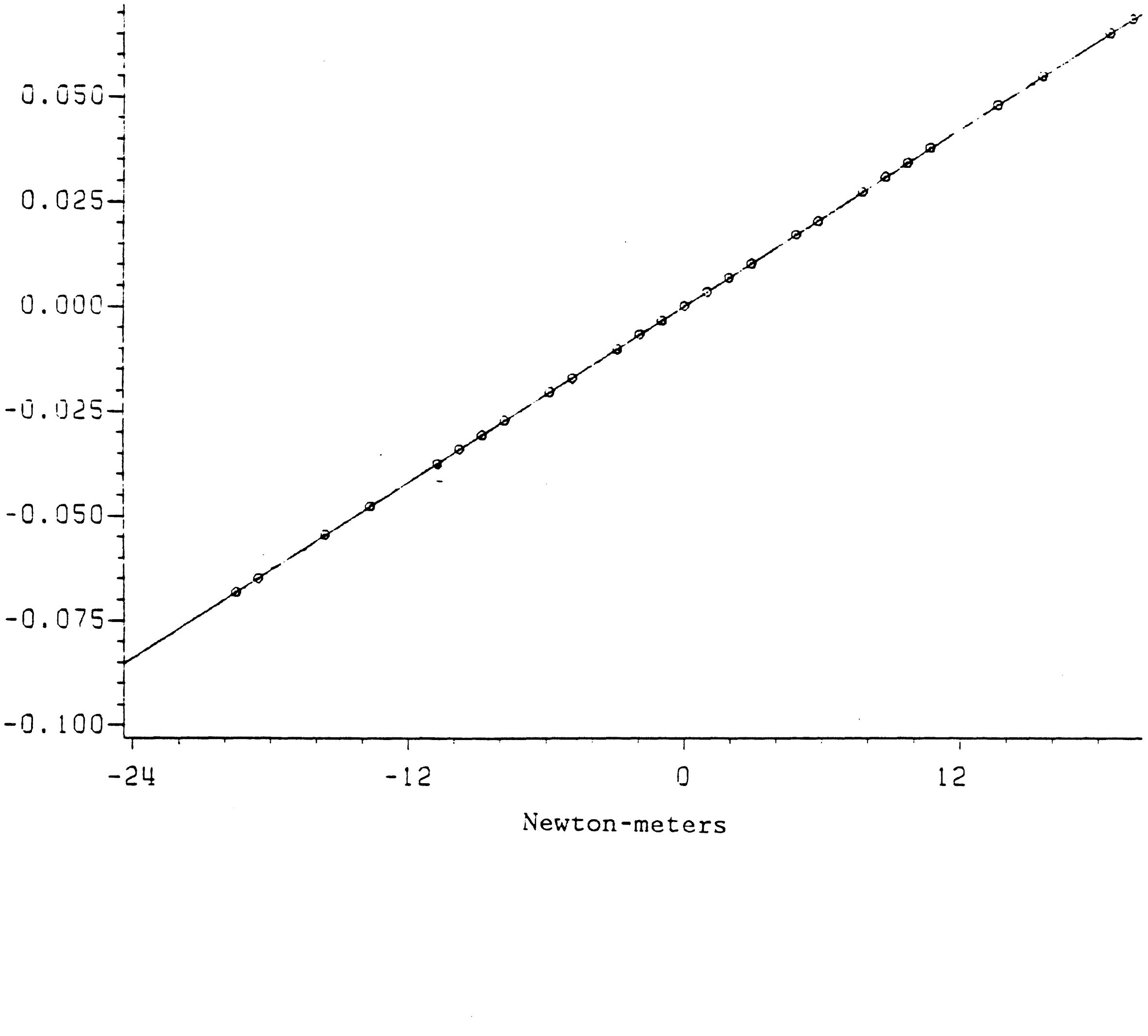


Figure 3.11 Pitching Moment Calibration Curve

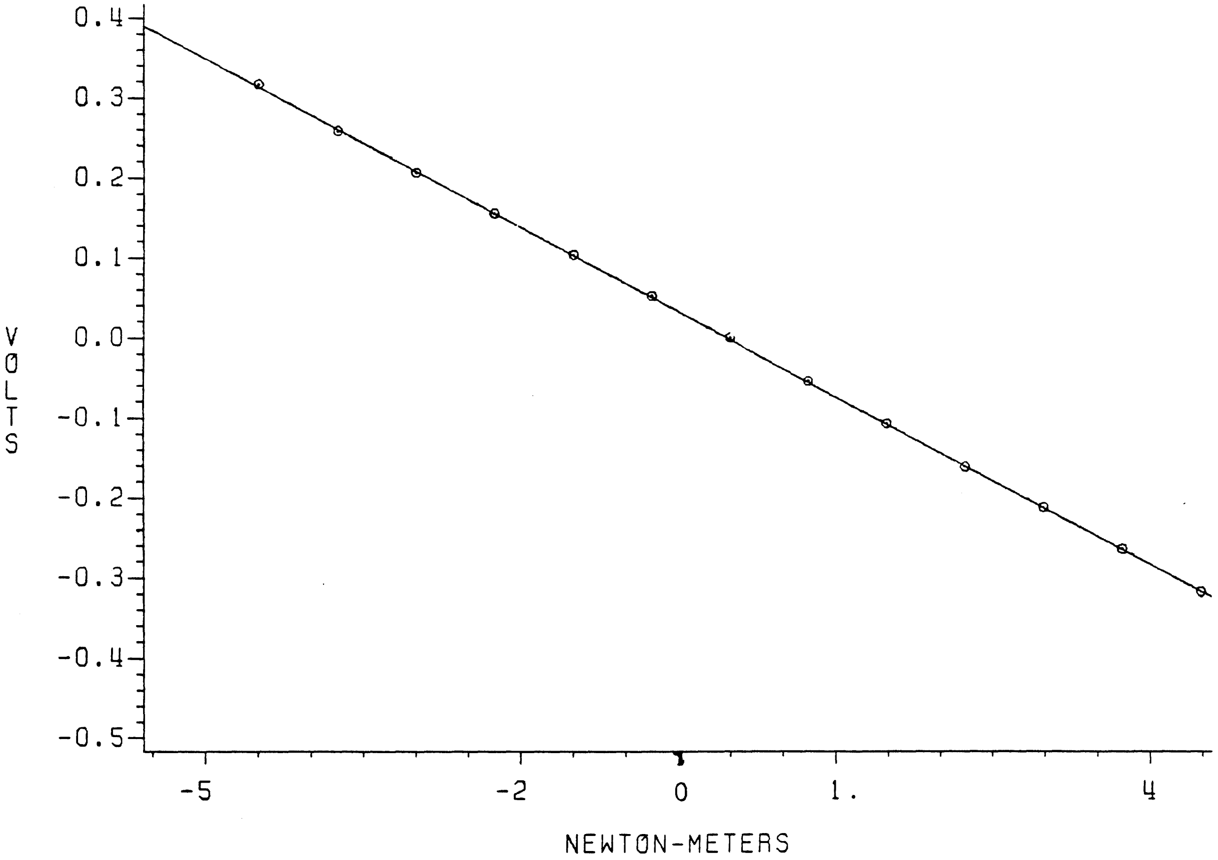


Figure 3.12 Roll Moment Calibration Curve

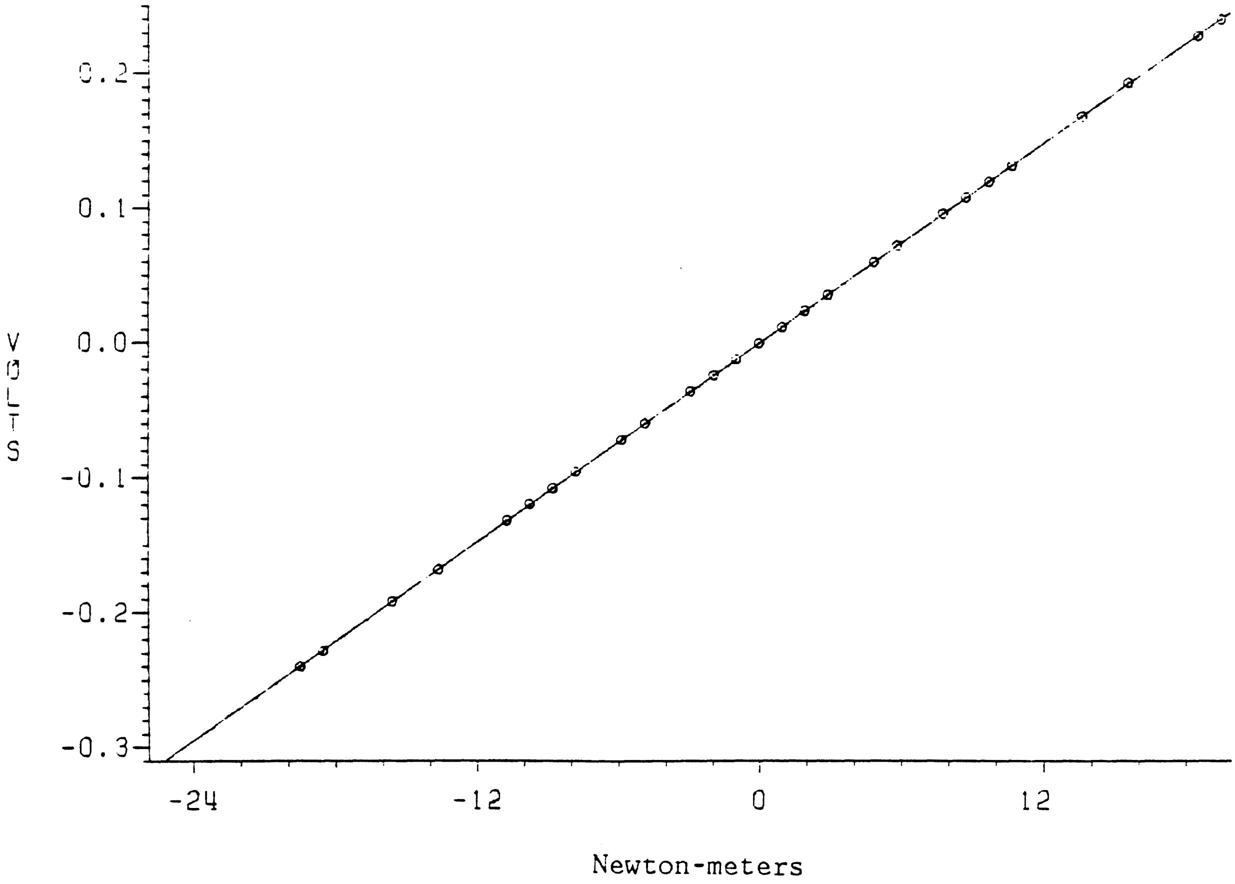


Figure 3.13 Yaw Moment Calibration Curve

of each channel. The coefficients of these curves are tabulated in Table 3.1 along with some of the statistical information generated.

As a part of the calibration process, six one-percent resistors were placed across one arm of each of the resistance bridges. The resulting outputs were later used as known signal inputs since the resistors caused bridge imbalances as if they were force inputs. Since precision resistors were used, these inputs were not expected to change significantly with time.

The seventh channel contained the velocity signal. It was calibrated by driving the optical encoder with a DC motor. The output of the encoder was sent into both a frequency counter and the low-pass filter of the DMS. The output of the low-pass filter was measured with a digital voltmeter. The encoder was driven at several rotational speeds, and a linear regression was performed on the data. The resulting calibration curve, Figure 3.14, shows voltage output as a function of the rotational speed of the encoder. Table 3.1 includes the values obtained from the regression. It should be noted that the output voltage was within one quarter of one percent of the expected theoretical value. In later calculations the experimental value was used.

Table 3.1 Results of the Linear Regression of Calibration Data

Channel	Units/volt		Std. Dev.	R-Square
Drag	308.	N	0.4313	0.999971
Lift	-491.	N	0.4773	0.999973
Side	960.	N	4.6064	0.999609
Pitch	285.	Nm	0.0854	0.999998
Roll	-14.3	Nm	0.0324	0.999943
Yaw	81.4	Nm	0.0408	0.999994
Velocity	8.28	m/s	0.0637	0.996587

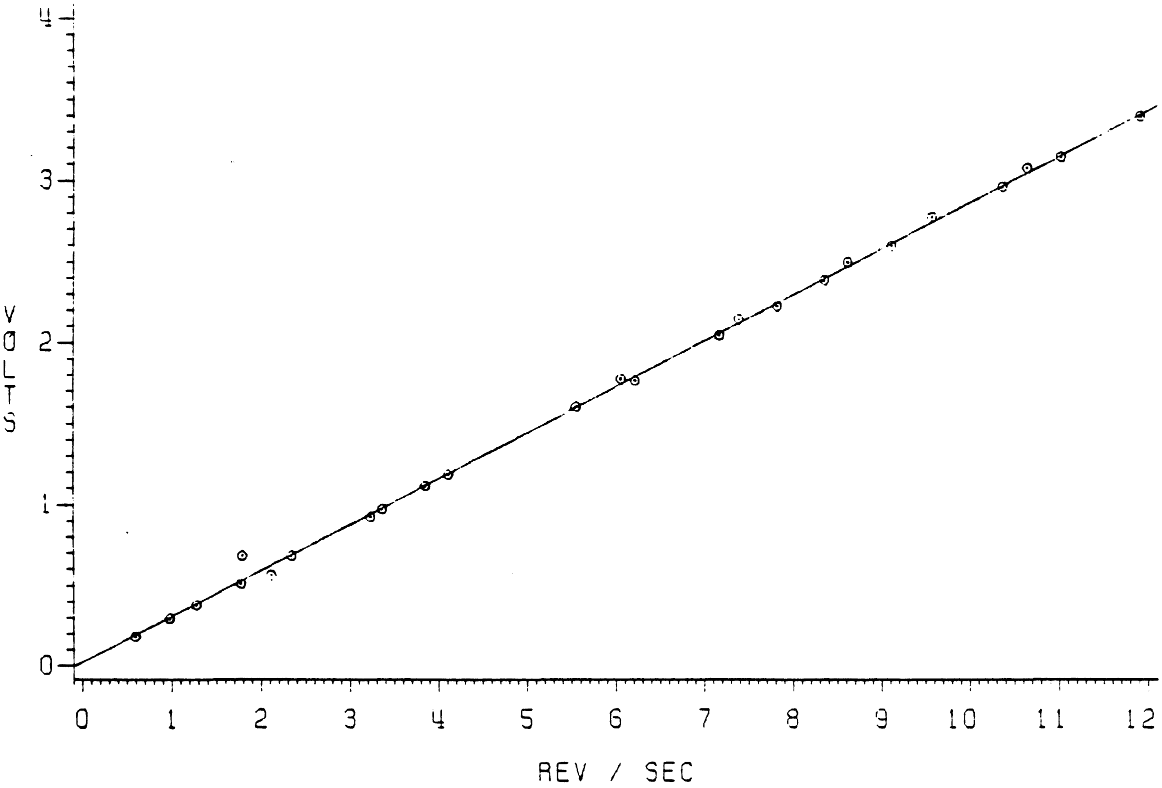


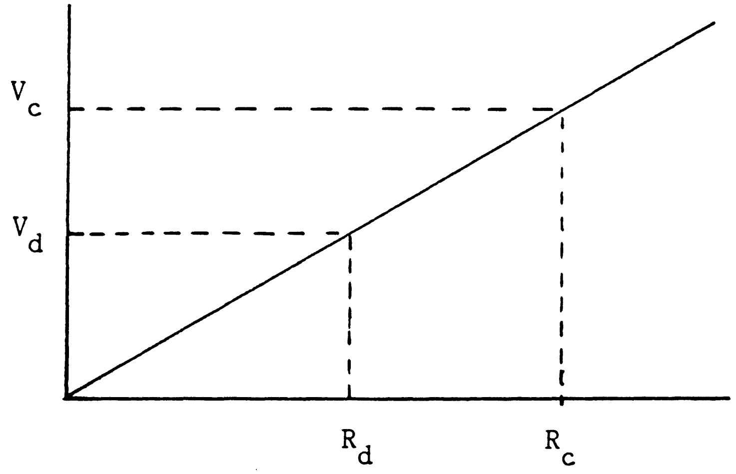
Figure 3.14 Calibration Curve for the Velocity Transducer

On-Line Calibration

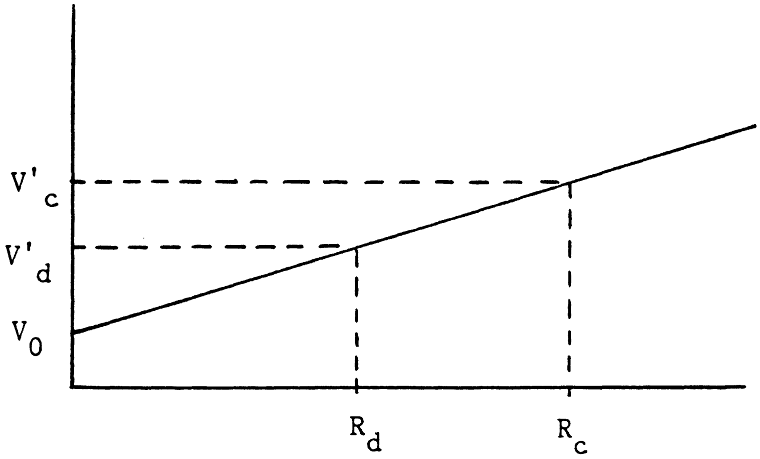
To compensate for the large amount of drift in the instrumentation which was expected, calibration signals were recorded before each run. These signals were used to correct any linear error of the signal conditioning equipment. Figure 3.15 illustrates the process used in this correction.

Part A of Figure 3.15 shows the original calibration curve for a strain gage balance. On this curve the resistance imbalances R_c and R_d are caused by the calibration resistor and an unknown load, respectively. V_c is the output voltage caused by R_c and V_d by R_d. Part B of Figure 3.15 shows the calibration curve after drift has caused both a DC bias and a change in the gain, or slope, of the curve. The output voltage caused by R_c is now V'_c and R_d now causes V'_d.

In the on-line calibration used in this study, V'_c, V'_d, and the no-load output voltage, V_0 are measured. The no-load output voltage is then subtracted from both V'_c and V'_d. This corrects for any DC bias in the instrumentation. The drift in the gain is corrected by multiplying the DC corrected data output by the ratio $(V'_c-V_0)/V_c$. This process is shown in Equation (1).



Part A. Original Calibration Curve



Part B. Drifted Calibration Curve

Figure 3.15 Illustration of the Calibration Procedure

$$V_{corrected} = \frac{(V'_d - V_0)\ \ (V_c{}' - V_0)}{V_c} \qquad (1)$$

3.5 DATA COLLECTION PROCEDURE

The data collection proceeded as followes. The model was placed in the water at the desired draft, and the rudder position and model alignment were checked. After all wave motion died down, the power supply/amplifiers were balanced so that the voltage follower outputs were as close to zero as possible. About three seconds of these signals, V_0, were then recorded. Then the calibration resistors were placed in the six amplifiers and a known voltage input was placed at the input to the voltage divider. This produced the signal V'_c in each of the seven channels. V'_c was used to correct for the drift in gain. Again, about three seconds of these signals were recorded. Once the calibration inputs were removed, a data run was made. The carriage was accelerated up to speed, the tape recorder was started, between one and three seconds of data was recorded, the tape recorder was stopped, and the carriage was decelerated. Three seconds of data was desired, but at the higher speeds the tank length would not all a constant speed to be maintained for this length of time. The calibration was repeated before each data run.

During the data reduction, the on-line calibration scheme mentioned in section 2.4 was used to correct the data. Thus, the original balance calibration curves could be used to obtain the numerical values for the forces, moments, and velocity.

3.6 STRENGTHS AND WEAKNESSES OF THE INSTRUMENTATION

The goal of this instrumentation system was to create a digital record of the carriage velocity and the forces and moments applied to the model during a run. This goal would normally imply the use of a computer placed on the carriage for data acquisition. This computer would have either seven channels for analog-to-digital conversion, or six channels for A/D and one digital frequency counter connected to the encoder. Since no appropriate computer was available, the instrumentation string described above was used.

A digital record of the signals allows a large amount of freedom in data reduction. This record can provide frequency information for the forces on the model, both those caused by the fluid flow and those caused by carriage noise. Spectral and cross-spectral analyses can be performed and a large amount of statistical information can be gained. Digital filtering is also a possiblity.

The advantage of the instrumentation system used in this study is its flexibility. If the electrical noise around the carriage had been as strong as was predicted early in the study, the DMS 5003 could have been used to find the signal power at DC. It also allowed the use of the excellent low-pass filters on the front end of the DMS 5003. The on-line calibration of the tape recorder was incorporated since it was originally believed that the recorder would not stay in calibration for more than one run due to carriage vibration.

The largest disadvantage of this instrumentation system was the amount of time required to transfer the data from the DMS 5003 to the mainframe. It required 4.5 minutes to transfer each file at 1200 baud, which was the fastest that the necessary commands would allow. Since 18 files were transferred for each run (zero pt., calibration pt., and data for each of 6 files), this resulted in a time expenditure of about one and a half hours per data run. This could have been reduced to one half hour if the calibration data were not needed for the tape recorder.

Since the data transmission time was so long, there was usually a time delay of about one week from when the data was collected until it was reduced to the final results. This lead to many problems in equipment availability and locating bugs in the instrumentation. It also resulted in the loss of some data due to subtle equipment problems which were not found until data reduction. Another difficulty caused by the long time delay was a reduction in the amount of data which could be collected. This loss of data harmed the resolution of some of the plots in the results section of this thesis.

The shortness of the tank also prevented the carriage from maintaining high speeds for a long enough time to insure either steady-state conditions for the model or a long enough sample interval. During part of this work the automatic brake on the carriage was not functioning. This limited the speed which could be safely used.

One final disadvantage of this instrumentation was that the operator had little time to watch the model during the data runs. The only time when it was possible to watch the model, and its associated wake, was when someone else operated the carriage.

4.0 RESULTS OF THE EXPERIMENT

This chapter presents the results of the Monoform investigation. The first section describes the conventions and procedures used in this presentation. They include the coordinate system used, the non-dimensional force and velocity coefficients, and the circumstances under which data points were considered erroneous and discarded. Section 4.2 presents the results obtained from towing the model at three different drafts with centered rudders. Drafts of 1.9, 2.21, and 2.42 hull diameters were tested. These drafts are referred to as draft numbers 15, 45, and 65 respectively. Section 4.3 discusses the results of tests with the rudders deflected to cause a yaw moment to port. The fourth section, 4.4, presents the results of runs with the rudders set to reduce the bow-down pitching moment caused by the underwater hull. The final section, 4.5, discusses what was learned about the instrumentation and equipment used. Appendix D contains the numerical data accumulated, and Appendix E contains some typical force/moment time recordes from a single data run.

4.1 CONVENTIONS AND PRESENTATION

Coordinate System

The conventional Cartesian coordinate system used is shown in Figure 4.1. Drag forces were considered positive toward the stern, lift forces positive upward, and side forces positive to port.

Drag and Velocity Non-Dimensional Coefficients

Two types of drag coefficients were used in this study. Both of these have the general form:

$$C_d = \frac{2 \text{ (Force)}}{\rho \text{ (Area) } V^2} \tag{1}$$

Where: C_d = drag coefficient (non-dimensional)

Area = reference area (square meters)

Force = drag force (Newtons)

V = model velocity (meters / second)

ρ = density of water (kilograms / meter^3)

The velocity coefficients used were two versions of the Froude number, which has the general form shown in Equation (2):

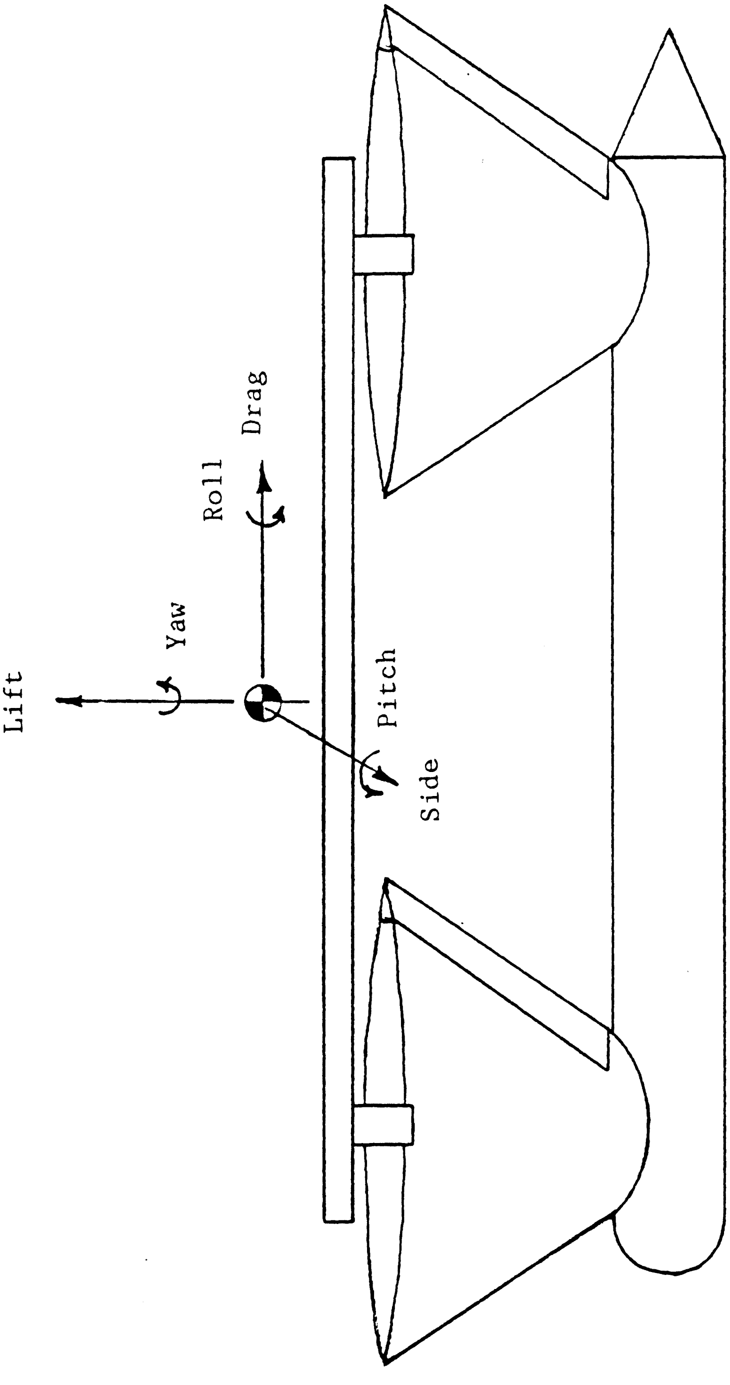


Figure 4.1 The Coordinate System Used in the Data Presentation

$$F = \frac{V}{\sqrt{g\ L}} \tag{2}$$

Where:

F = Froude number (non-dimensional)

g = acceleration due to gravity (meters/second^2)

L = characteristic length (meters)

V = velocity (meters/second)

The traditional reference area used in the resistance coefficient is the wetted surface area of the model. The traditional characteristic length of the model is the model's length at the waterline. With the development of non-conventional vessels like the hydrofoil, surface-effect ship, and the hover-craft, the use of the wetted surface area and the length of the waterline became impractical as a means of comparison. Hence, the cubic root of the vessel's displacement volume became the characteristic length for comparing vastly different hull-forms. The reference area became the characteristic length squared. In this study both types of the coefficients were calculated to present an easier method of comparison with other's work.

The displacement of the model was measured using the sting balance. The model was first weighed out of the water. It was then placed in the basin at the desired draft and the lift force on the balance was recorded.

The upward force was added to the weight of the model. This force was converted into an equivalent mass and finally the displacement volume of the model. This was repeated for each of the three drafts used.

The model's wetted surface area was calculated by integrating the length of the perimeter of a single strut from it's base to the waterline. This value was multiplied by four to account for all four struts and the surface area of the underwater hull was added. Table 4.1 contains the resulting displacement volumes and wetted surface areas.

Presentation of Data

A portion of each measured moment was caused by one or more of the forces generated by the flow on the underwater hull. This extra moment is equal to the force times the distance between the center of that force and the moment center of the transducer. For example, any side force caused a roll moment to be sensed which would not be present on the actual ship. If the longitudinal center of this side force was not at the moment center of the transducer, then it would also cause a yaw moment. In a similar manner, the pitching moment was affected by the drag and lift forces on the model.

In this study it was assumed that the side force and the drag force were applied at the vertical center of the wetted surface area. This allowed

Table 4.1 Wetted Surface Areas and Displacements of the Model

Draft No.	Wetted Surface Area	Displacement Volume
15	0.855 m^2	0.0389 m^3
45	1.056 m^2	0.0408 m^3
65	1.172 m^2	0.0421 m^3

the roll moment to be corrected for side force, and the pitching moment to be corrected for the drag force. Since the center of the lift force could not be determined, no correction was made for it in the pitching moment. Since the moment center of the sting balance was placed in the longitudinal center of the model, and side force was assumed to act through this center, it would create no additional yaw moment.

The moment arm was calculated by finding the vertical center of the wetted surface area of the model and then finding its distance from the moment center of the sting balance. These moment arms are presented in Table 4.2 for each of the drafts used in this study.

In any experimental work there are data points which simply do not seem to make sense. Some of these might be due to effects which are unexpected and subtle. Most are due to mistakes in equipment operation. In order to allow for unexpected results, no data points were removed from the data base unless they were physically impossible, or would unfairly distort the plot. Points considered physically impossible were, for example, negative velocities, or negative drag forces. Only two runs out of the 97 conducted were completely ignored for these reasons.

The lines drawn on the plots were not placed with any statistical assistance but were drawn by eye to fit the data. It was at times

Table 4.2 Moment Arms from Transducer to the Center of the Wetted Surface Area.

Draft Number	Moment Arm
15	0.3522 m
45	0.3335 m
65	0.3222 m

difficult to decide what points were good and what points could safely be neglected. For this reason, it was decided that the curves would be drawn point to point when the data permitted, excluding few points. Any doubt in the curve path is mentioned in the data presentation section.

4.2 STRAIGHT RUDDER RESULTS

Figure 4.2 presents the drag force of the model during the straight rudder runs at all three drafts. It can be seen from this figure that the set of runs at draft number 65 show at least three humps. These occur at about 1.6, 2.2, and 2.7 m/s. There is also a possibility of a small hump at about 0.7 m/s.

From visual observations during the data runs, two humps were expected. The first of these two was caused by water containing large-scale turbulence building-up between the front strut pair. This captured water increased both the frictional drag on the wetted surface and the wave-making drag. With a small increase in velocity, this build-up of water dissipated and was replaced by a depression of smooth fast moving flow. At a larger velocity the rear strut pair went through a similar flow transition. It was thought that this second hump would be smaller than the first, since it occured in the turbulent wake of the front strut pair.

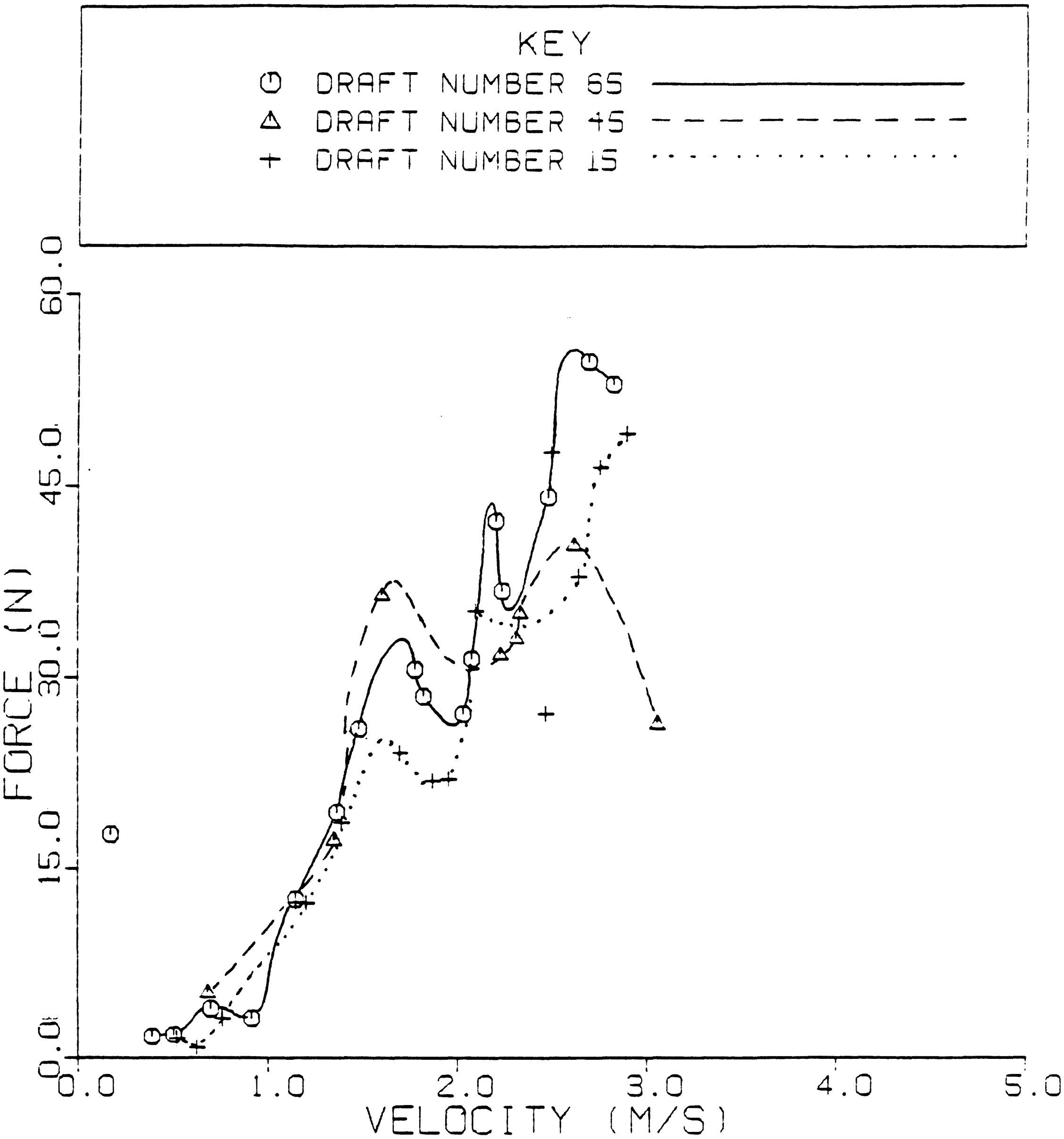


Figure 4.2 Straight Rudder Drag Forces

The third large hump might be explained by Figure 4.3. The front strut pair leaves an expanding V-shaped wake behind each strut. These two wakes meet in the middle causing a local disturbance of large-scale turbulent water. With an increase in velocity the point of this local disturbance moves further behind the front struts. At some speed the point of disturbance meets between the rear strut pair. Here the channeling effect of the struts and hull cause the disturbance to increase and absorb more energy. At a slightly larger speed the center part of this wake is hidden in the wake of the rear struts.

The results from draft number 15 show the same 1.6 and 2.2 m/s humps as draft number 65. The high speed hump does not show, although the slope of the curve indicates that it might exist above the highest speed data point. The 0.7 m/s hump is also evident in the results from draft number 15.

The data from draft 45 does show two of the four possible humps. The 0.7 m/s hump might be below the first data point. The 2.2 m/s hump might have been missed by the relatively sparse spread of data, although the hump would have to occur at a slightly lower speed than at draft 65.

It should be noted that there were three data points ignored when these curves were drawn. The first data point of draft number 65 was ignored since its magnitude is unreasonable at such a small velocity. The curve

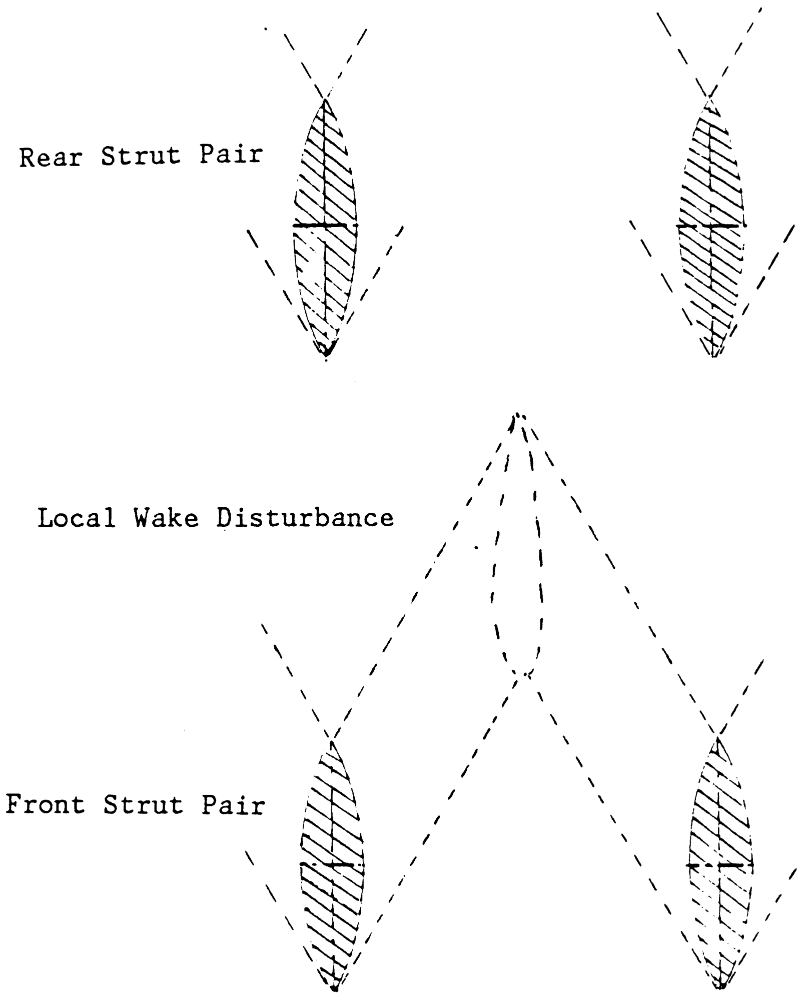


Figure 4.3 Front Strut Wake Interaction with Rear Struts

for draft number 15 was not fitted to two data points at a velocity of about 2.5 m/s since these points were so close in velocity. It seems unlikely the the second large hump would be that large or that sharp. For that reason the curve was drawn between the two points.

Figure 4.4 and 4.5 present, respectively, the displacement drag coefficient and the wetted surface drag coefficient. Since both of these curves present basically the same information, only Figure 4.5 is discussed. The most obvious feature of this plot is the oscillatory nature of the data. This is due to the wave-making resistance of the hull-strut combination. At larger drafts the wave-making resistance of the hull should decrease and the drag coefficient curve should smooth-out.

The downward slope at the lower speeds of the plot is caused by the $1/V^2$ term in the force coefficient data. The small 0.7 m/s hump which was evident in draft 65 and draft 15 of the force plot is now only evident in draft 65 data. The three large humps still appear as before.

There is some doubt whether the small hump at 0.7 m/s really exists. In this low-speed range force due to the vibration of the carriage was of a larger amplitude than the force due to the flow. This resulted in a standard deviation of the signal which was larger than the mean of the signal. If the system causing this vibration was linear, then the mean

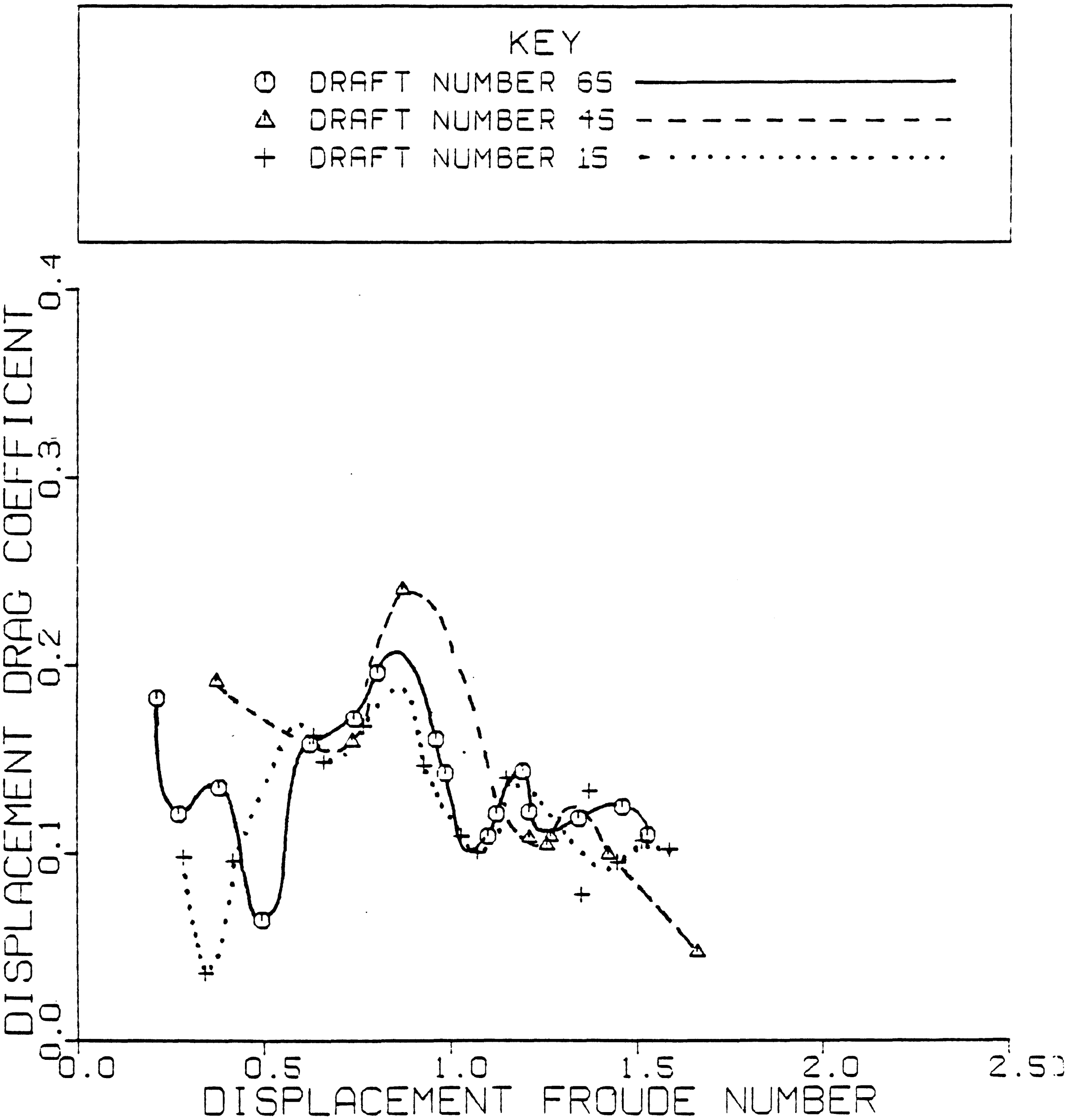


Figure 4.4 Straight Rudder Displacement Drag Coefficent

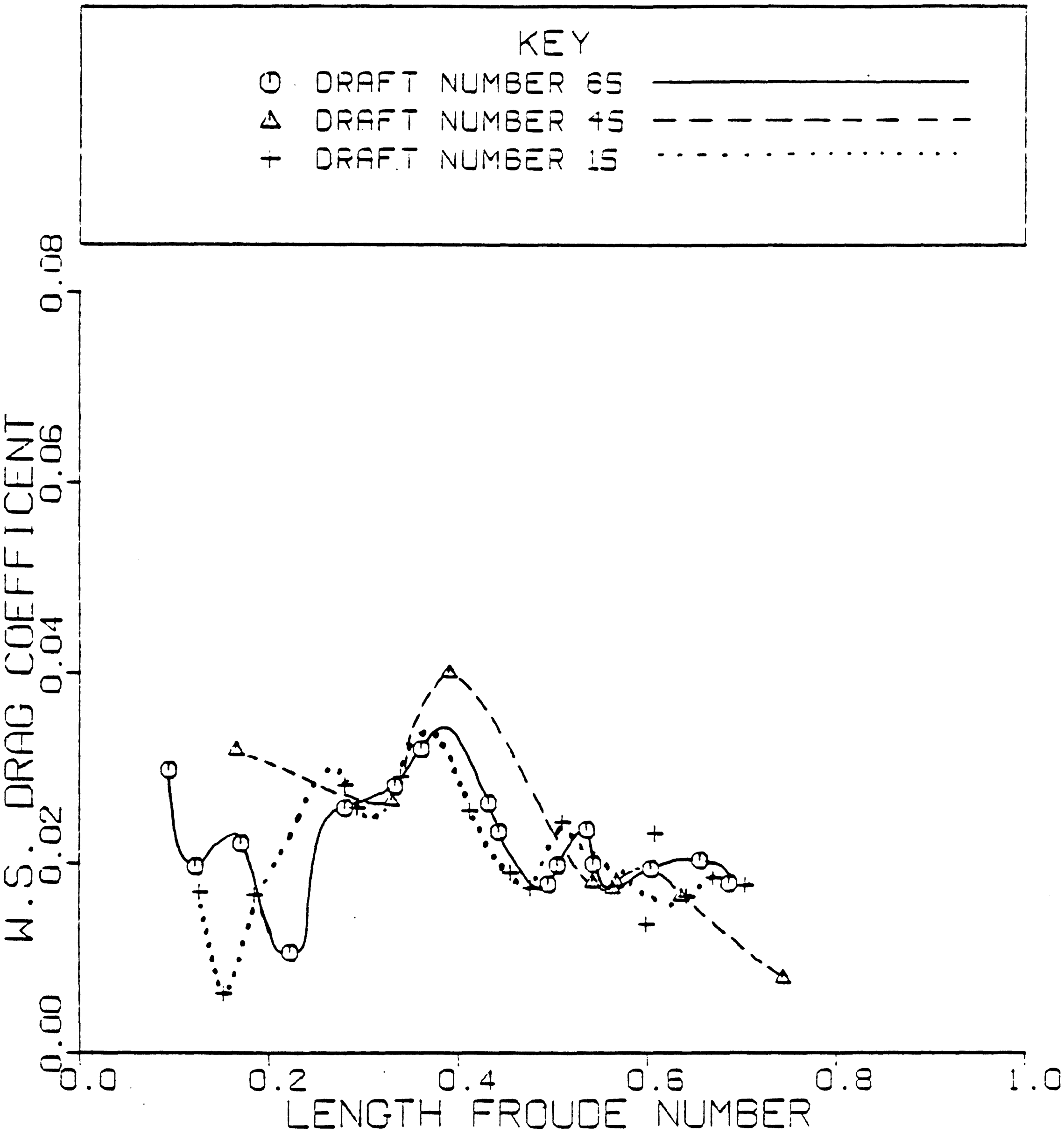


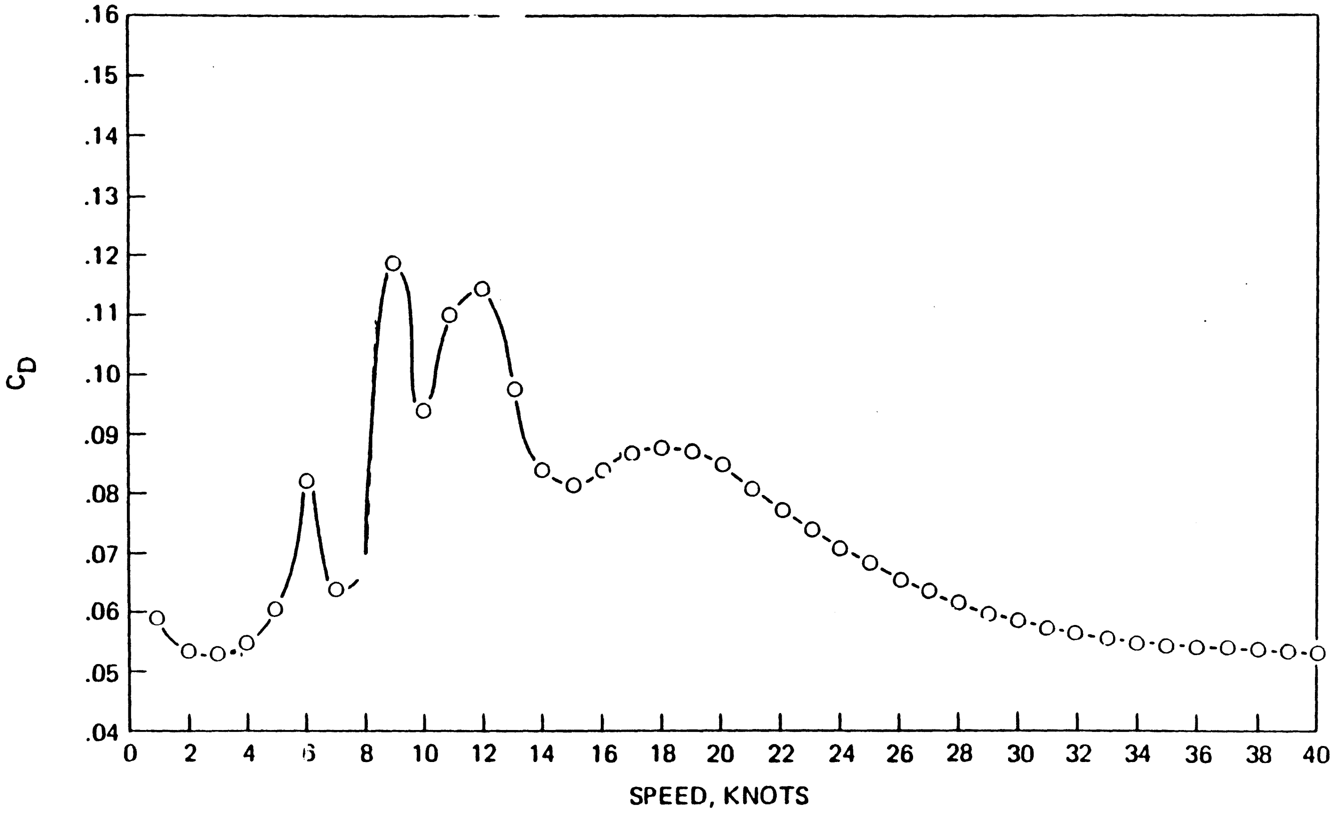
Figure 4.5 Straight Rudder W.S. Drag Coefficent

of this signal is still a good indication of the force on the model. While no experimental data on the SWATH seems to show this low speed hump, computer work done by Estabrook [8] indicates a small hump in the drag coefficient data at slow speeds. His work is presented in Figure 4.6. This might indicate that this slow speed hump is valid for the Monoform due to stronger interaction between struts.

Estabrook's work also shows two of the three large humps. The third hump is missing since the SWATH does not constrain the flow between the rear struts as much as the Monoform does. If the Monoform is tested at larger drafts, this hump will probably disappear.

In Figures 4.4 and 4.5 the same three points were ignored as in the drag force plot above. In fact, it was necessary to remove the first data point for draft 65 from both drag coefficient curves since its large magnitude distorted the plots.

Figures 4.7-4.11 present the remainder of the straight rudder data. As seen in the figures, the pitching moment and the lift force both show the 1.6 m/s hump as in the drag force plot. It is caused by the water build-up between the front struts, which pushes the bow down. This causes both a negative lift force and a bow-down pitching moment. The hump, which should be caused by water build-up between the rear struts,



This figure is taken directly from Estabrook's [8] work which did not use the SI unit system.

Figure 4.6 Drag Coefficient for Standard Dimension 500-ton S^3 by Estabrook [8]

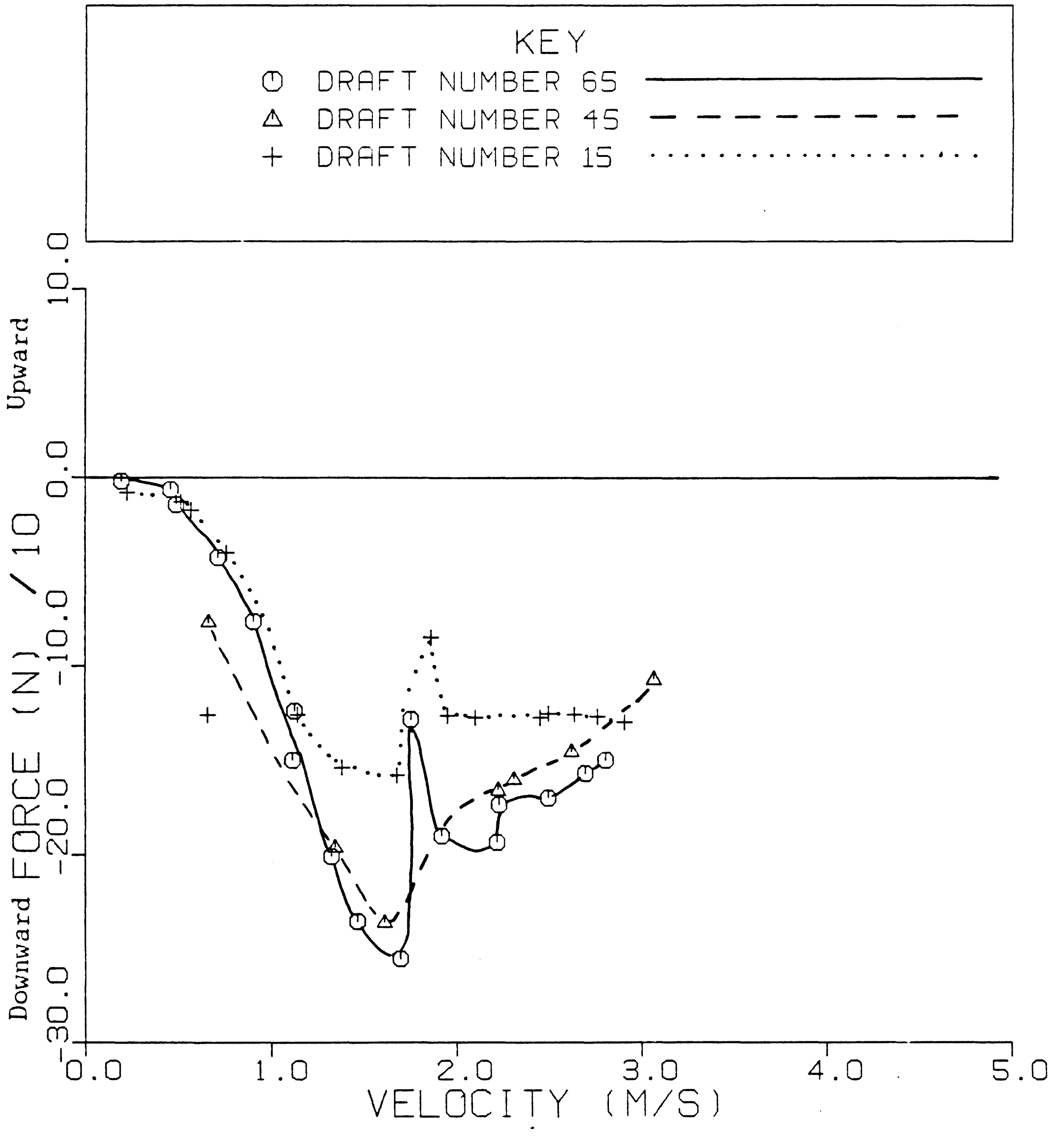


Figure 4.7 Straight Rudder Lift Forces

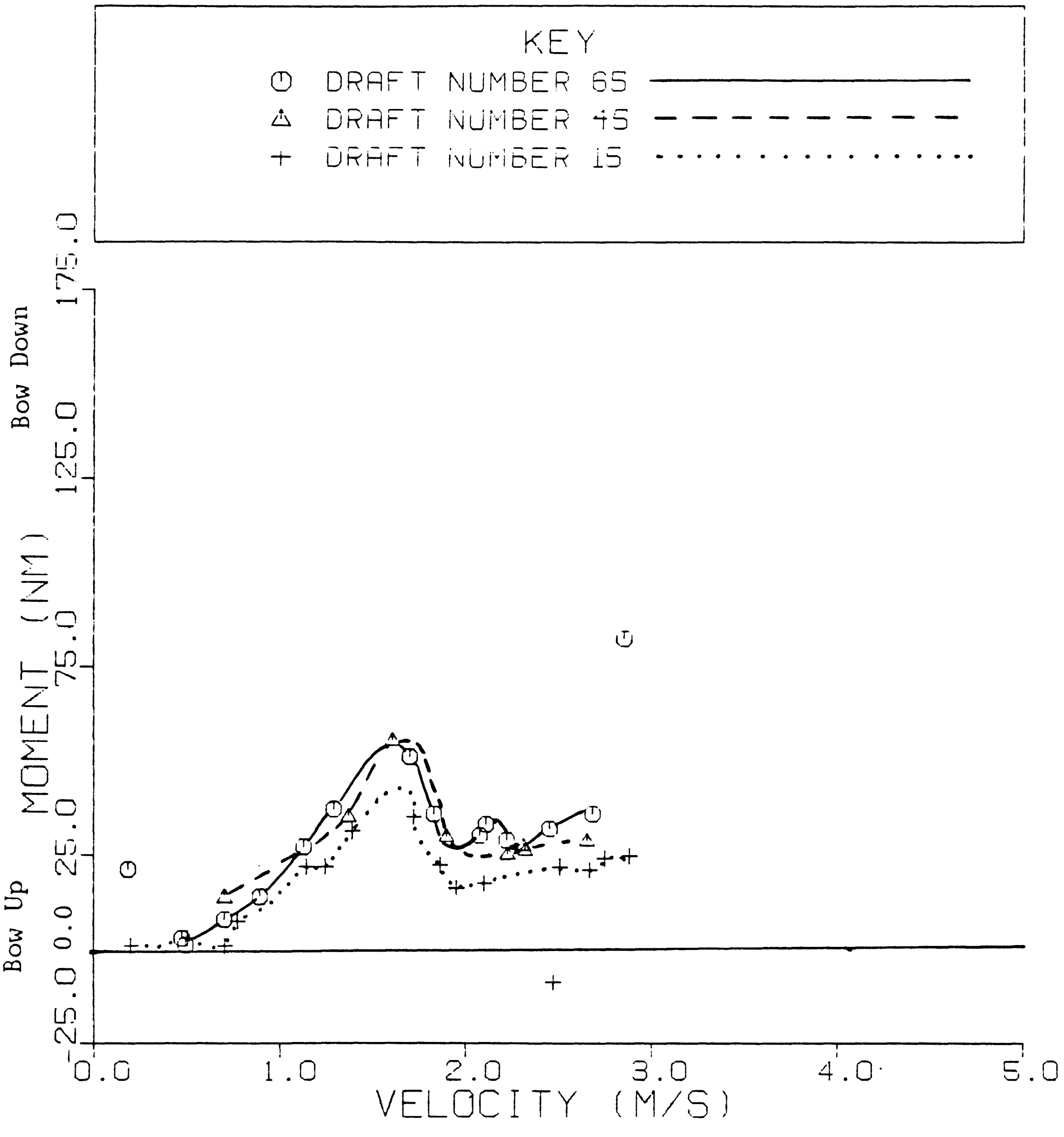


Figure 4.8 Straight Rudder Pitching Moments

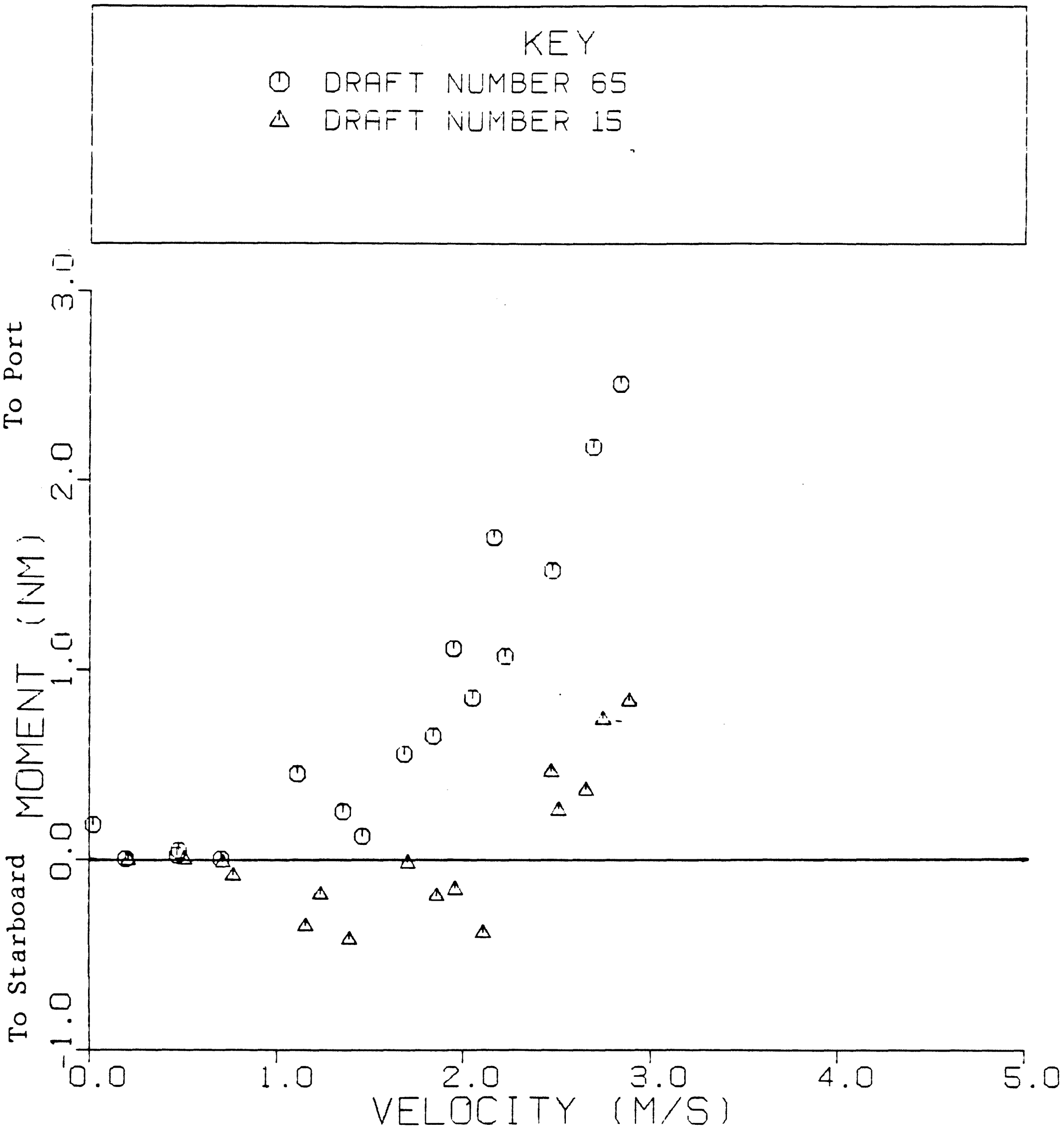


Figure 4.9 Straight Rudder Roll Moment

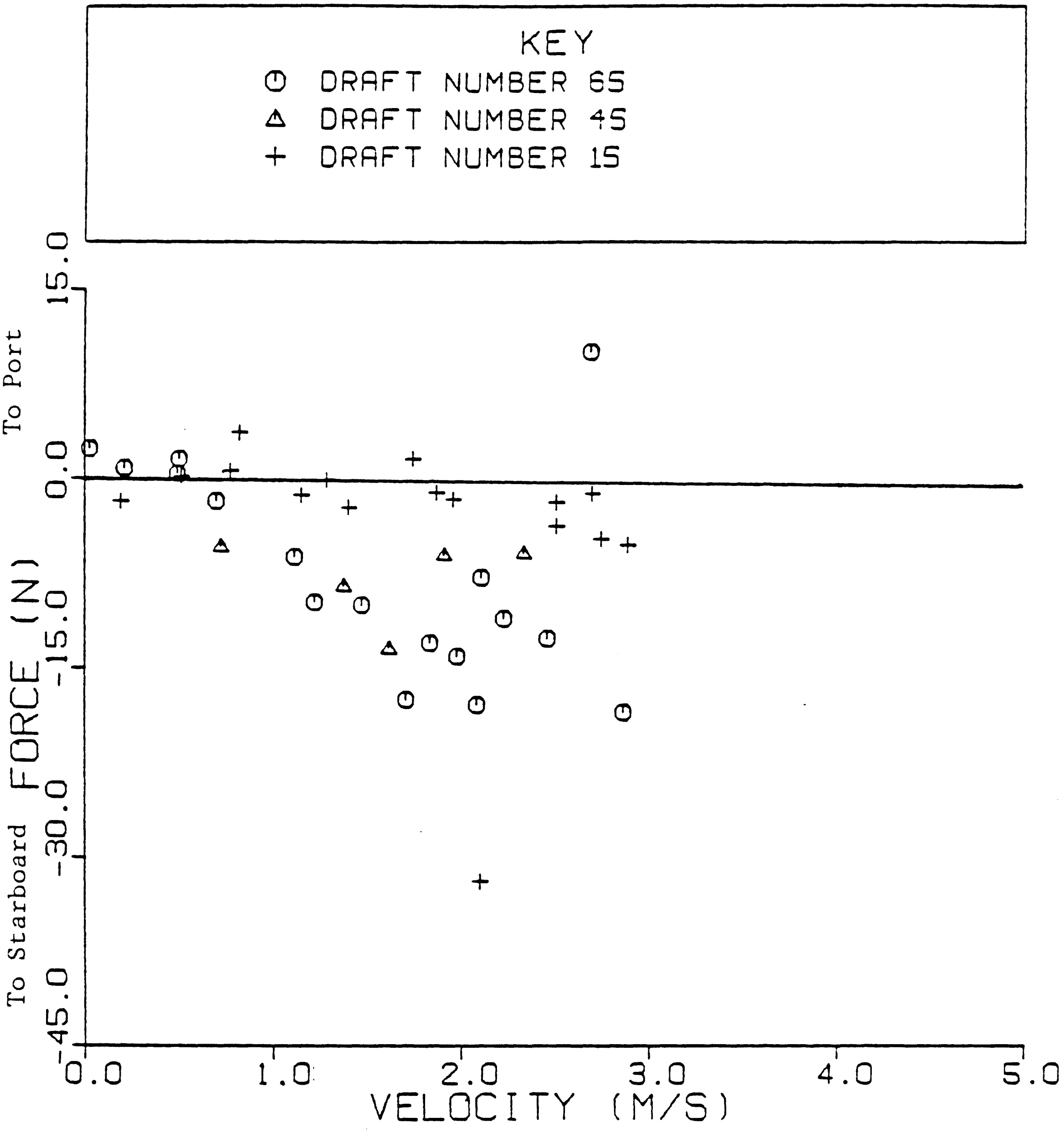


Figure 4.10 Straight Rudder Side Forces

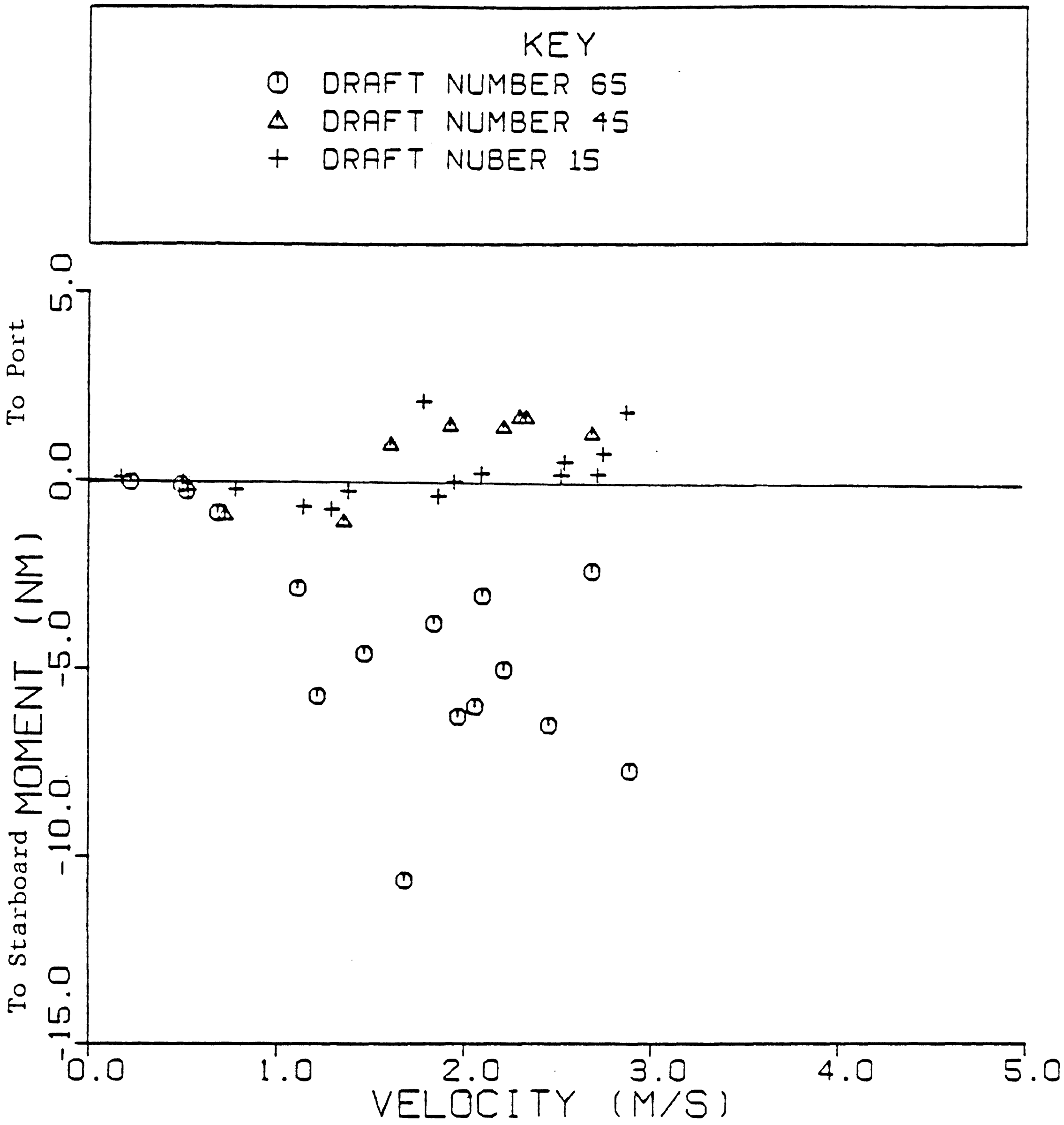


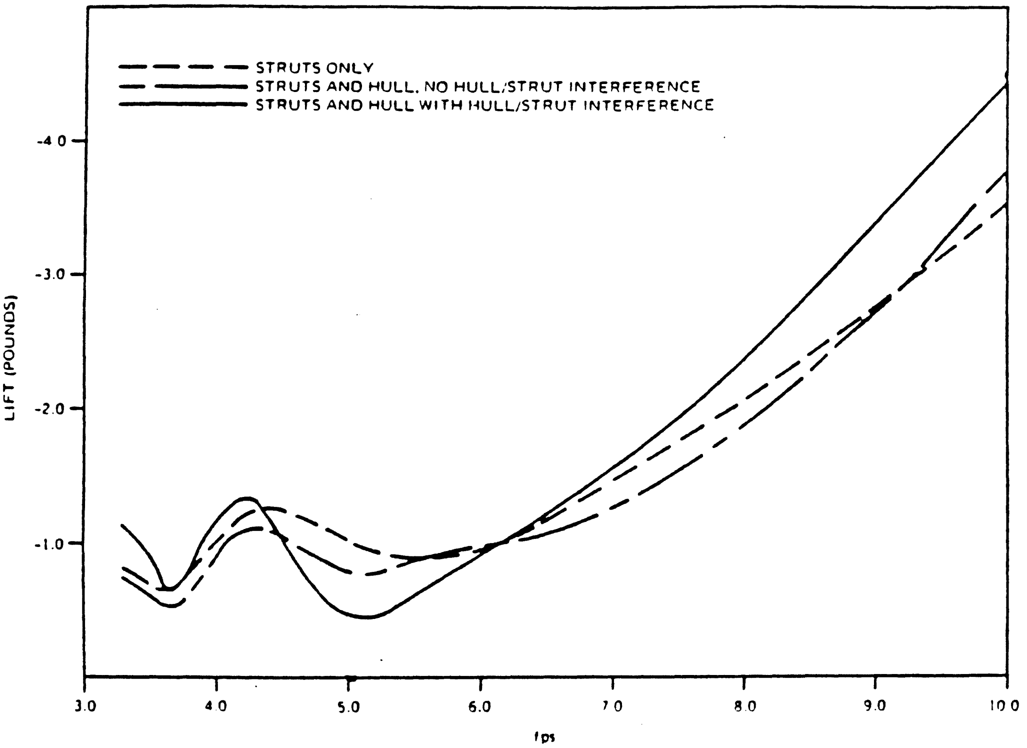
Figure 4.11 Straight Rudder Yaw Moment

does not show on these plots. This is probably due to the fact that the rear struts are in the wake of the front struts.

Theoretical work done by Chapman [9], Figure 4.12, shows two humps in the lift force for a SWATH model. The model used by Chapman is roughly the same length as the Monoform model, but the displacement of the two could not be compared. The two models show substantial differences between the two configurations. The largest difference is the magnitude of the lift forces. The Monoform model creates lift forces which are on the order of 35 times greater than the SWATH model. This is due to the greater flow constriction due to the V-configuration of the Monoform's struts. Another difference is the sharp spike which shows at drafts 15 and 65 for the Monoform model,but does not show with the SWATH. This spike is probably caused by the wake from the front struts interfering with the stern struts.

Although Figure 4.7 shows an increase of the lift force with draft, it is expected that once the draft is increased enough to reduce the effect of the constriction, the lift force will reduce with draft.

The roll data for draft 65 presented in Figure 4.9 shows a definite V^2-dependent rolling moment to port. This was caused by two small indentions on the inside of the forward port strut which were placed there by accident prior to this work. The smallest of these was at a



This figure is taken directly from Chapman's [9] work which did not use the SI unit system.

Figure 4.12 Theoretical Lift Characteristics of a SWATH model by Chapman [9] draft number of about 1 while the larger was at a draft number of about 5. The draft 15 roll data indicates that the port roll did not start until the model reached a velocity of about 2 meters per second. At this point the bow wave on the front strut was reaching above the second indentation. It is thought that these indentations slowed the water on the inside of the strut causing a higher pressure and thus a roll moment. The moments caused are small, which seems to indicate that the model is dynamically stable in roll. The draft number 45 roll data were not recorded due to an equipment failure.

The side force data presented in Figure 4.10 indicates a side force to starboard. This is caused by either the misalignment of the model with the basin, or by a small asymmetry in the model. Since the yaw data presented in Figure 4.11 shows a moment to starboard, it is safe to assume that the disturbing force is caused by the bow struts. While it is possible for the indentations found on the bow port strut to play a part, it would seem that these indentations would cause the opposite effect. Another reason for the side force might be that the port strut of the bow was angled more down toward the water than the other three struts were. This would seem to indicate a more serious problem with alignment than originally thought.

4.3 TURNING DATA

The turning data was taken with the bow rudders turned 15 degrees to the starboard while the stern rudders were turned 15 degrees to the port. This created a high-pressure region to the starboard of the bow struts and to the port of the stern struts, which resulted in a yaw moment to port. This configuration was tested at all three drafts.

Figures 4.13-4.15 show the straight rudder and the turning rudder yaw data for the model. These figures show a strong turning moment. The data for draft 65 shows an increase of around 75 Nm at 2.5 m/s, while even the data for draft 15 shows an increase of about 30 Nm. This would indicate that the rudders used work well for turning even with relatively small (15 degrees) rudder angles.

Figures 4.16-4.18 present a comparison of the drag forces measured while turning to the forces measured while the rudders were held straight. The draft 65 data, shown in Figure 4.16, shows a significant increase in drag at all speeds. At speeds higher than the first hump, it appears that the rudders cause the drag to increase with V^2 without any further humps. One data point at 1.3 m/s in the turning data was ignored since it is doubtful that the drag on the model would change magnitude so quickly and would be less than with straight rudders.

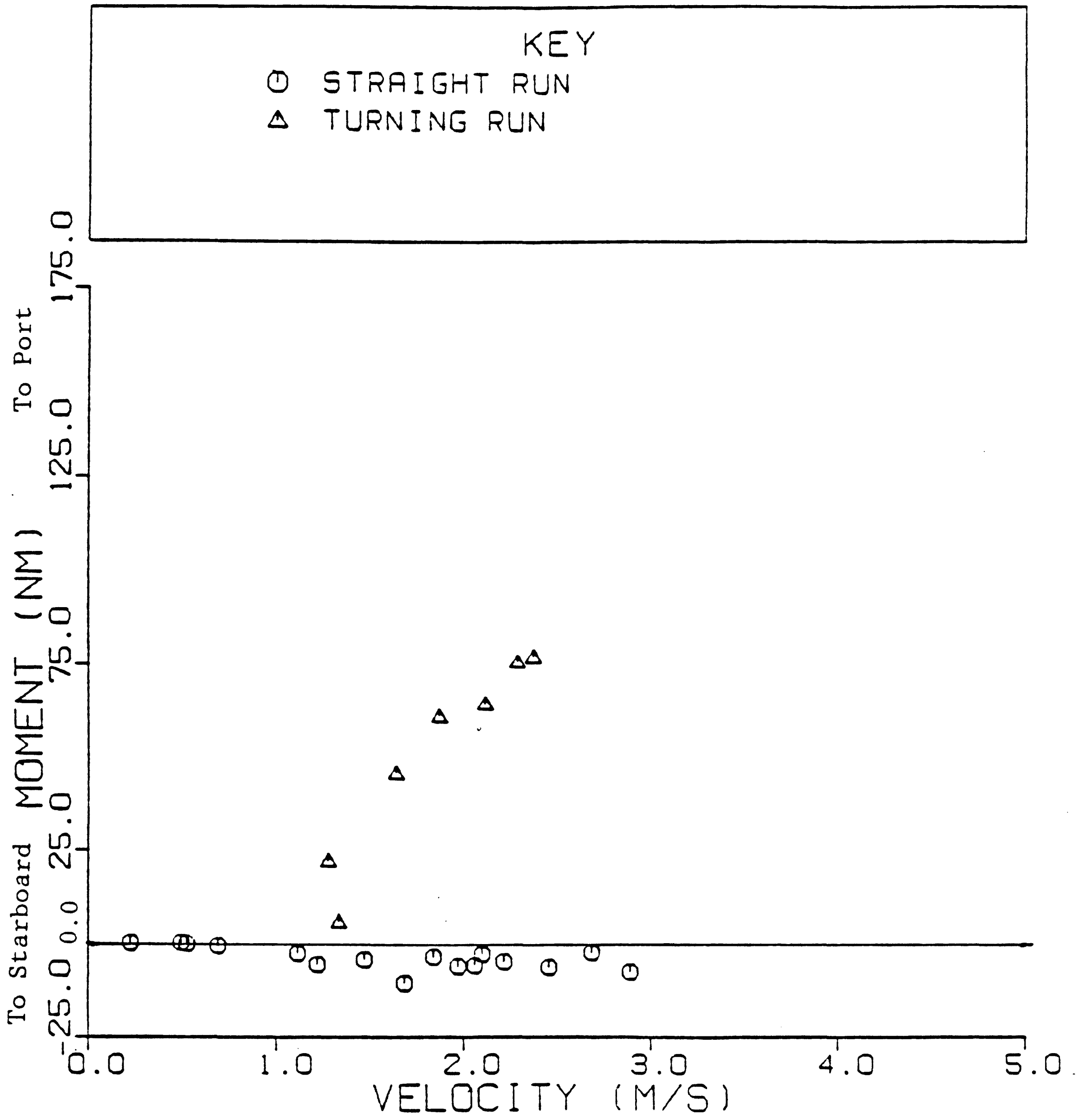


Figure 4.13 Yaw Moments for Straight and Turning Runs at Draft 65

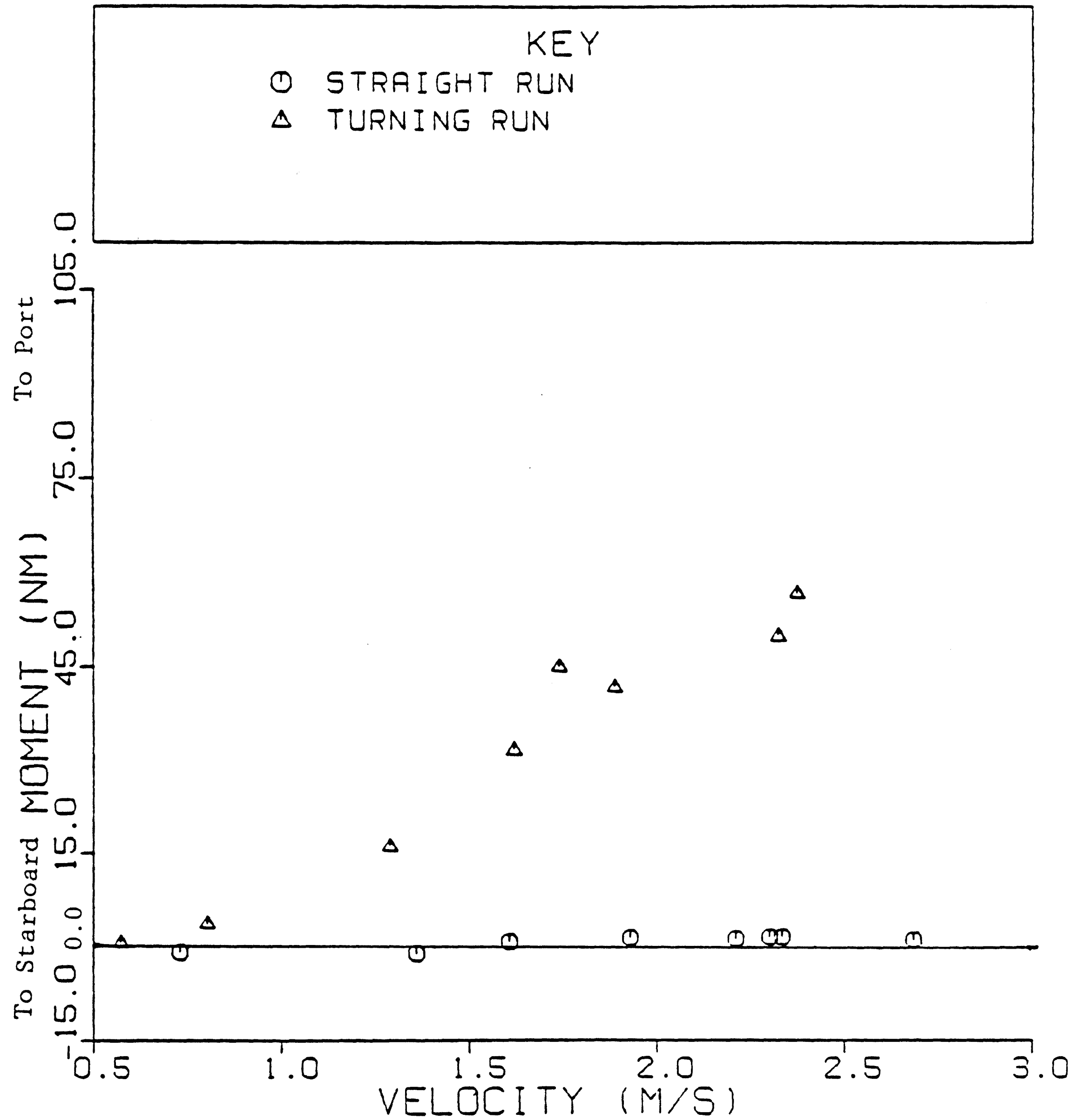


Figure 4.14 Yaw Moments for Straight and Turning Runs at Draft 45

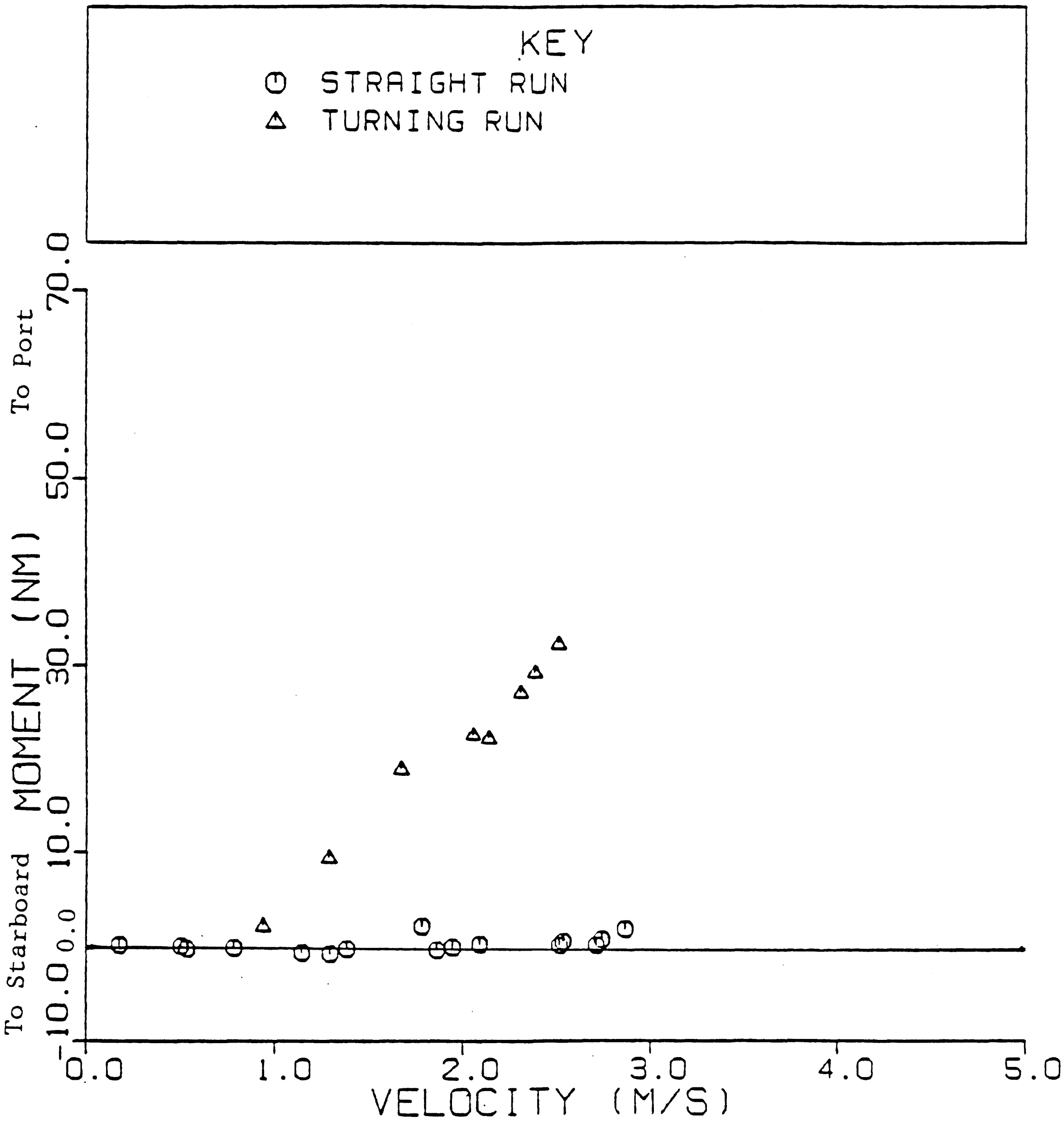


Figure 4.15 Yaw Moments for Straight and Turning Runs at Draft 15

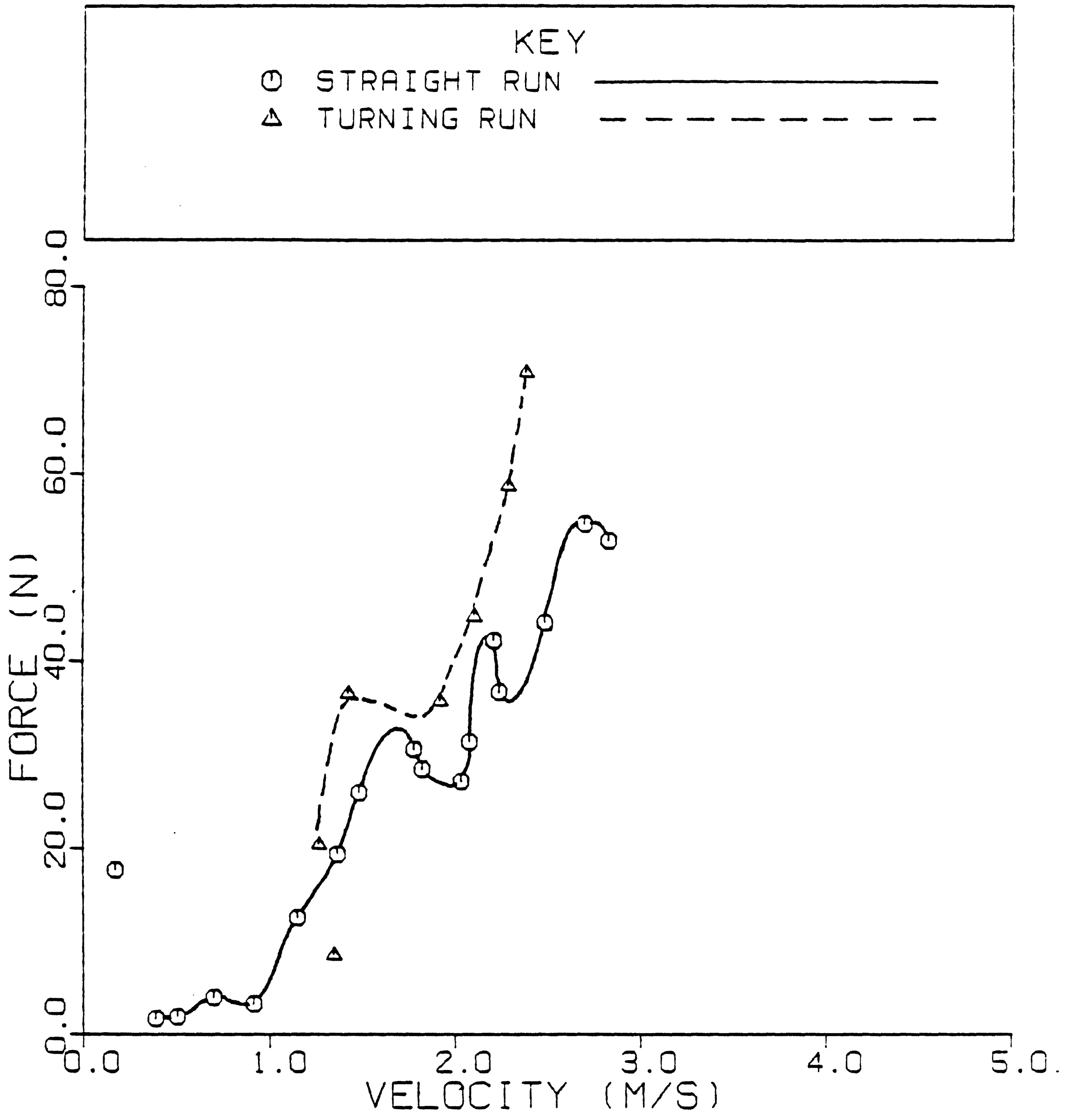


Figure 4.16 Drag Forces for Straight and Turning Runs at Draft 65

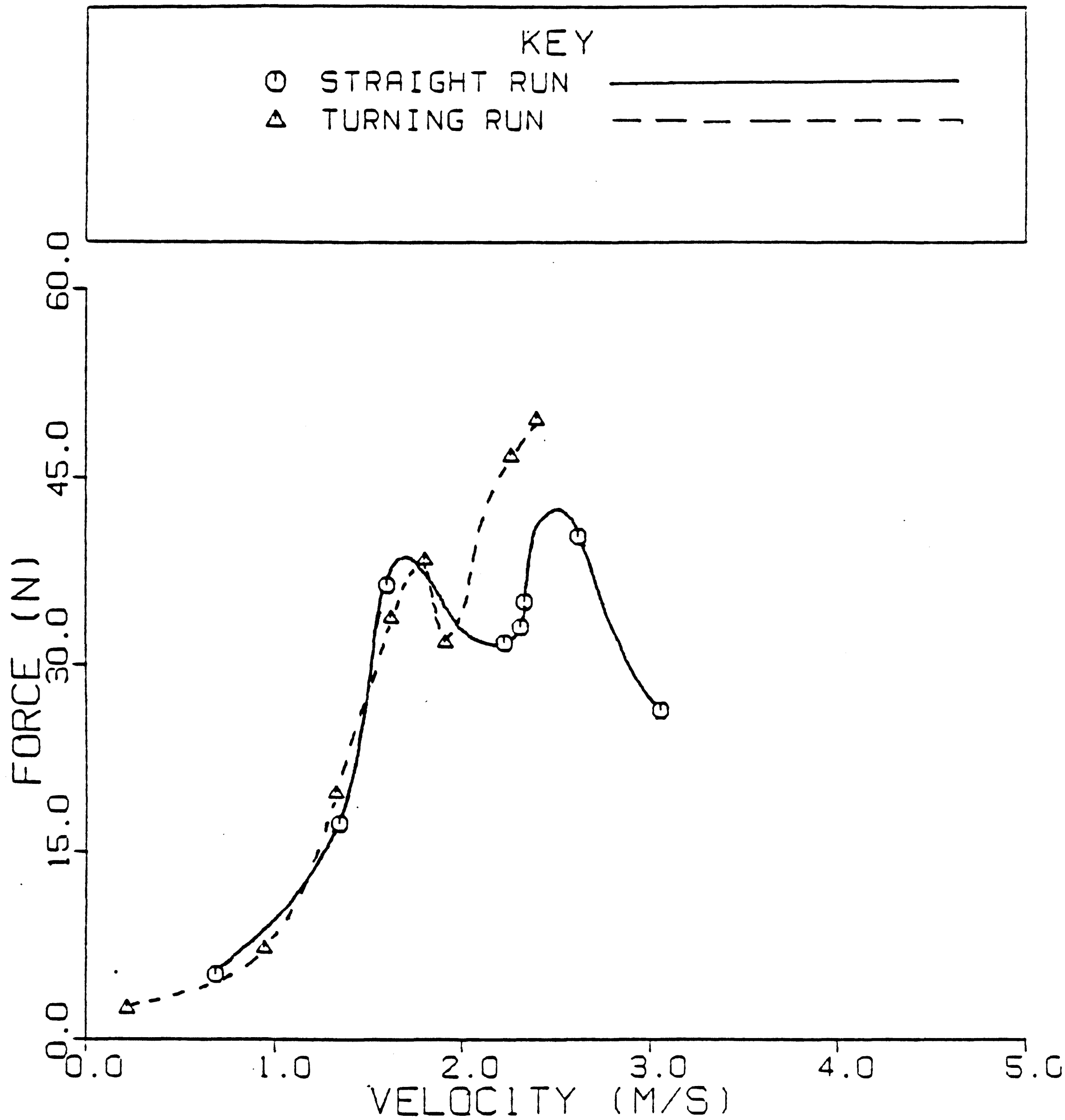


Figure 4.17 Drag Forces for Straight and Turning Runs at Draft 45

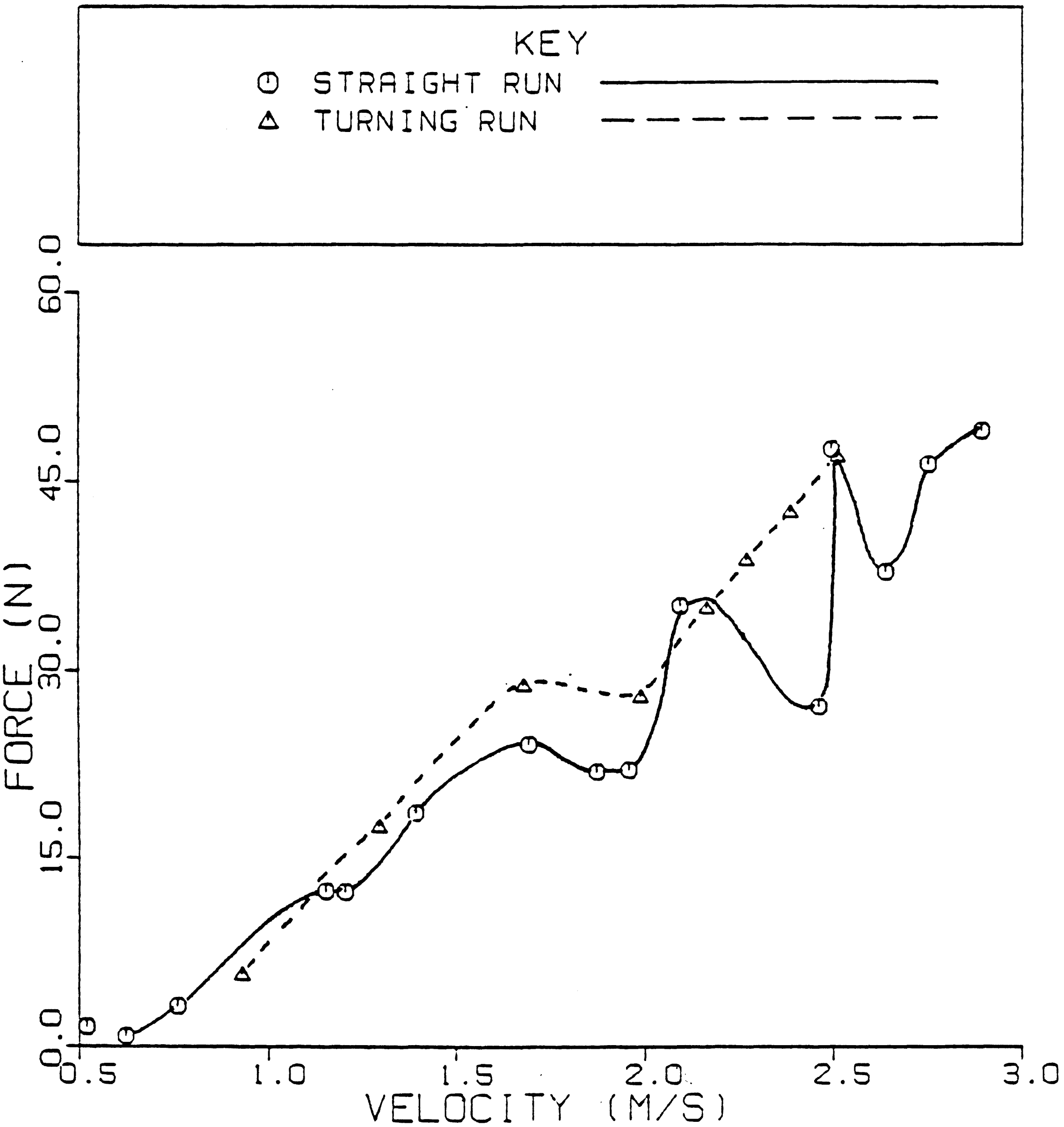


Figure 4.18 Drag Forces for Straight and Turning Runs at Draft 15

Draft 45 data, presented in Figure 4.17, shows a very small change in drag below the first hump, but a growing increase above it. It also shows a much sharper first hump than the straight rudder data allows. Like the draft 45 data, the draft 15 data shows a small increase in drag below the hump and an increasing drag after it.

The increase in drag is due to increased form drag caused by the rudder deflection. The dampening of the higher speed humps is probably caused by the increased wake of the forward strut pair which would hamper the development of the later humps.

Figures 4.19-4.21 show comparisons of the straight rudder and turning rudder pitching moment data. These plots generally show little or no change in the pitching moment before the hump, but an increase in the pitching moment after the hump. This additional pitching moment seems to increase with speed. Of the points ignored in Figure 4.19, only one of these seems possible in light of the pitching data at other drafts. This is the point at about 1.3 m/s and 65 Nm. It was ignored due to the large amount of scatter in the data at this speed.

Figures 4.22-4.24 present the lift data from the turning runs. Again, it can be seen that no change in the lift force occurs before the hump and that the lift decreases after the hump. The data presented for the turning case of draft 65 shows two data points which were presumed to

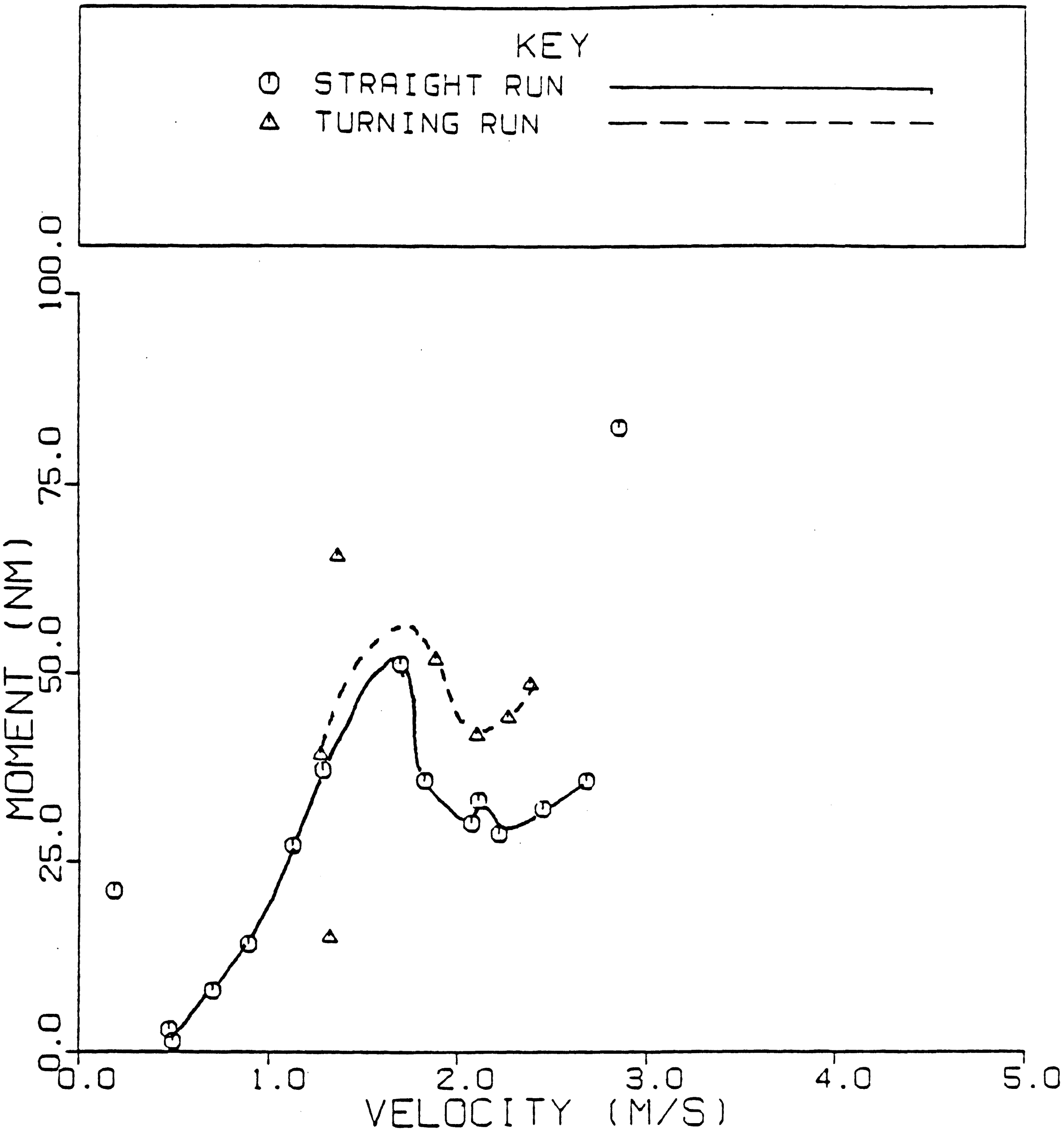


Figure 4.19
Pitching Moment for Straight and Turning Runs at Draft 65

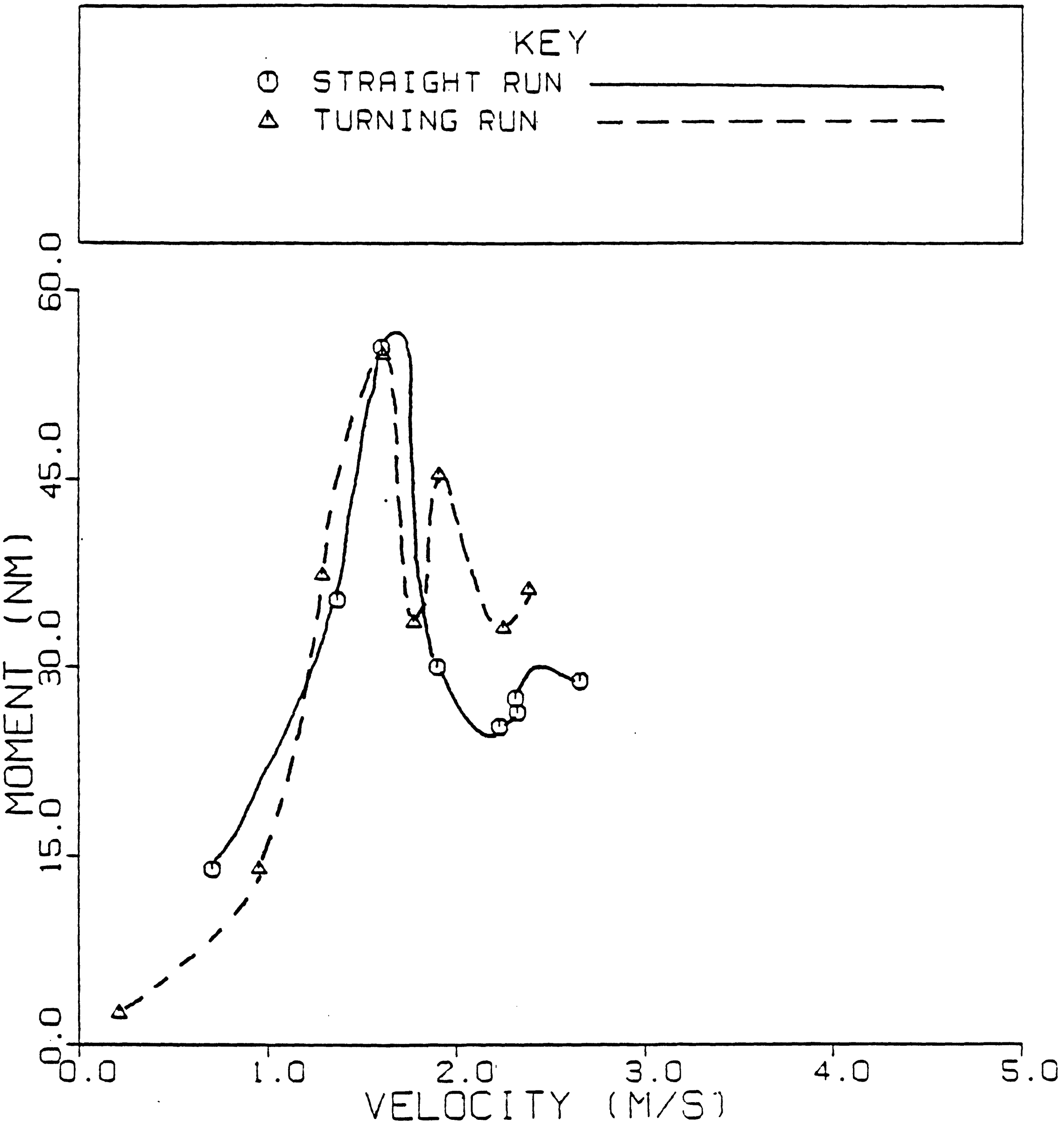


Figure 4.20
Pitching Moment for Straight and Turning Runs at Draft 45

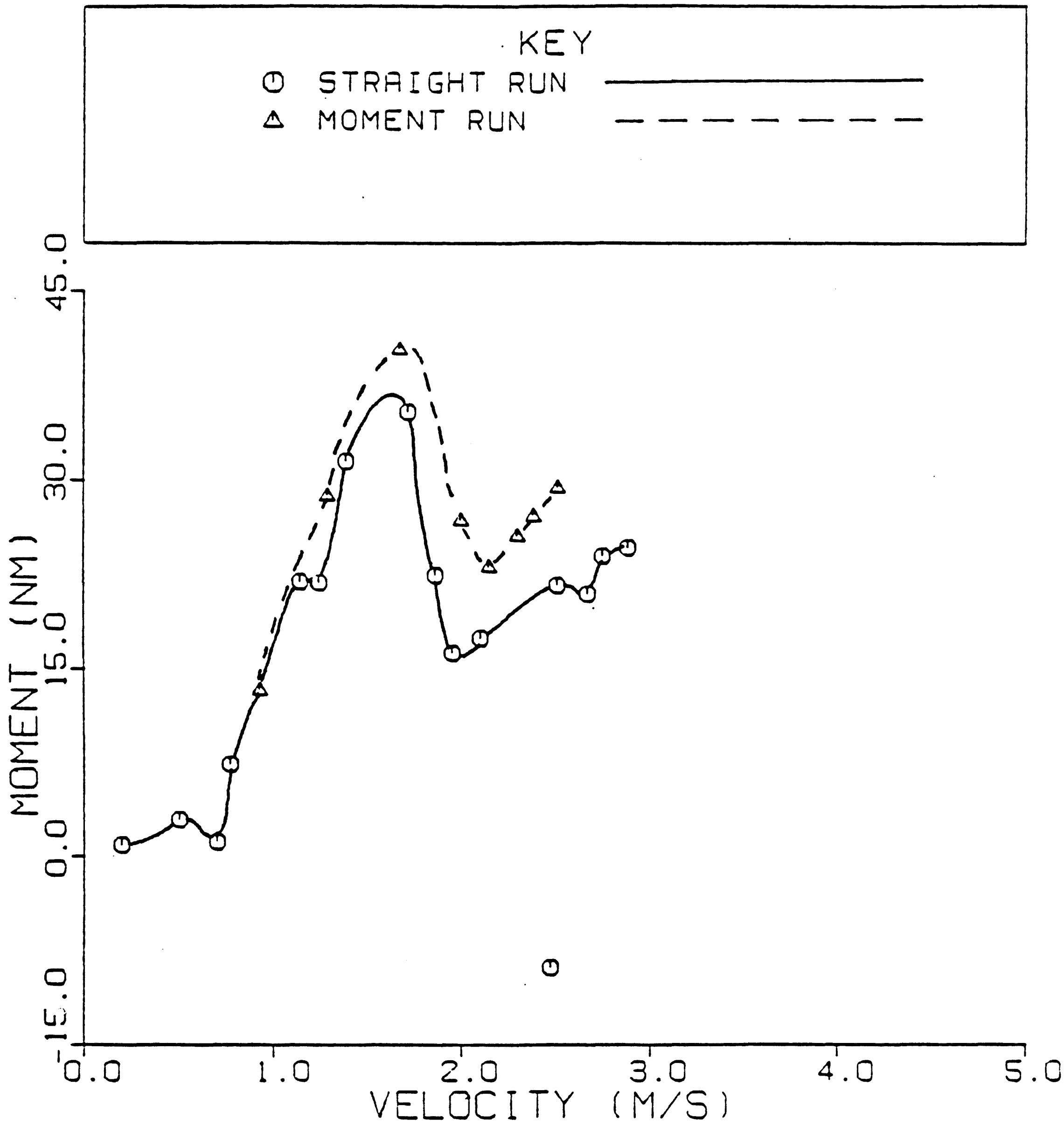


Figure 4.21
Pitching Moment for Straight and Turning Runs at Draft 15

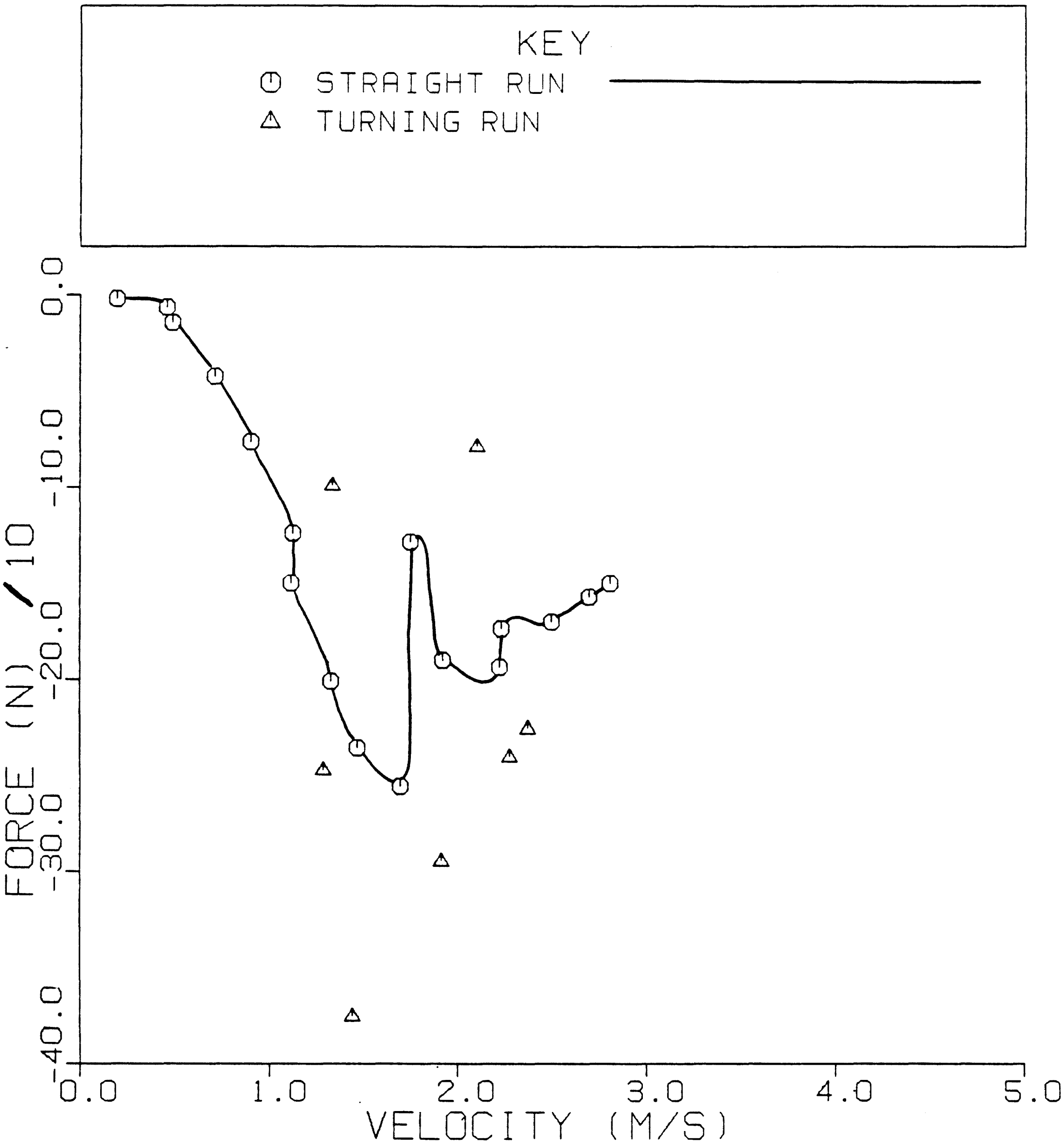


Figure 4.22 Lift Force for Straight and Turning Runs at Draft 65

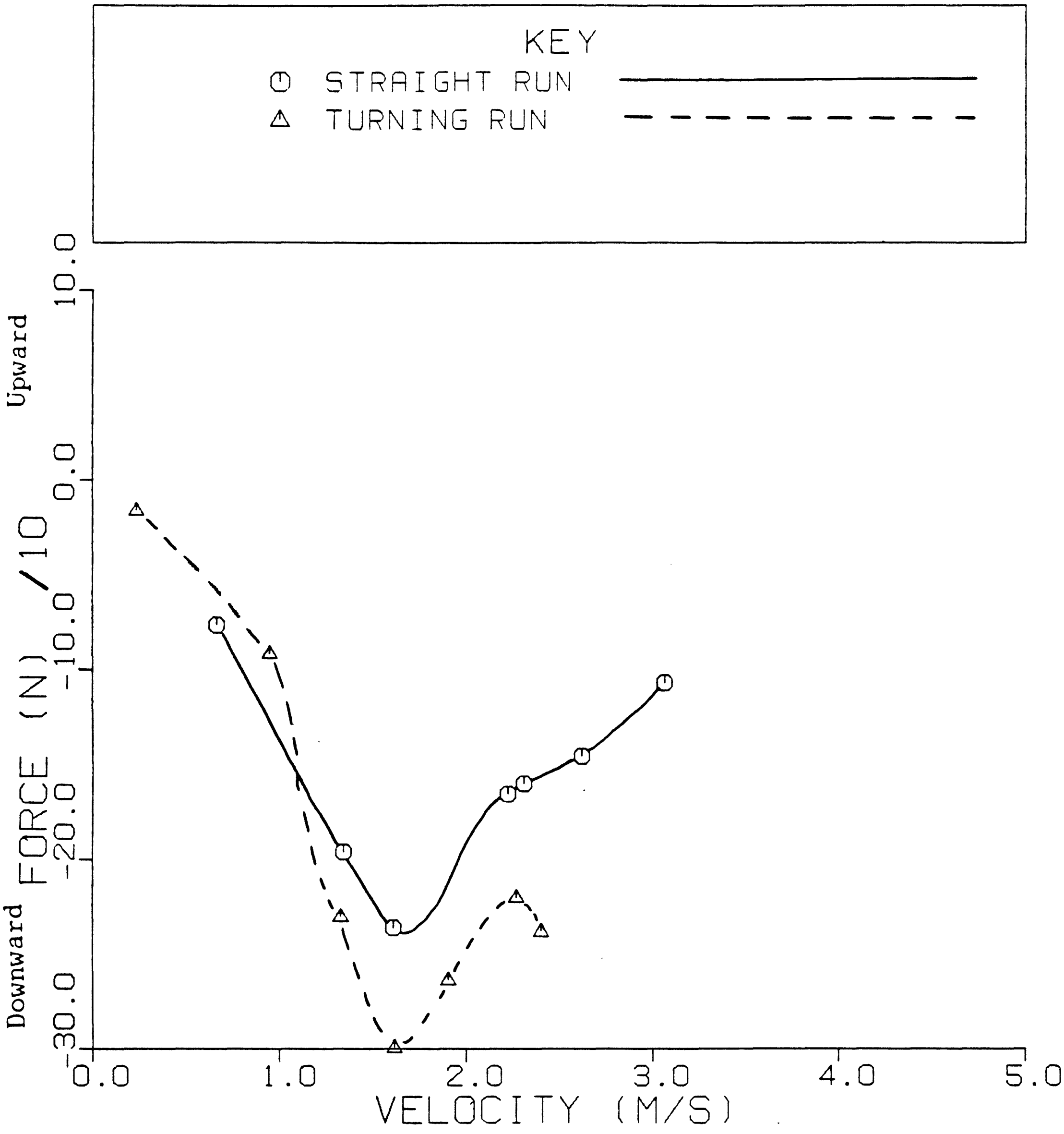


Figure 4.23 Lift Force for Straight and Turning Runs at Draft 45

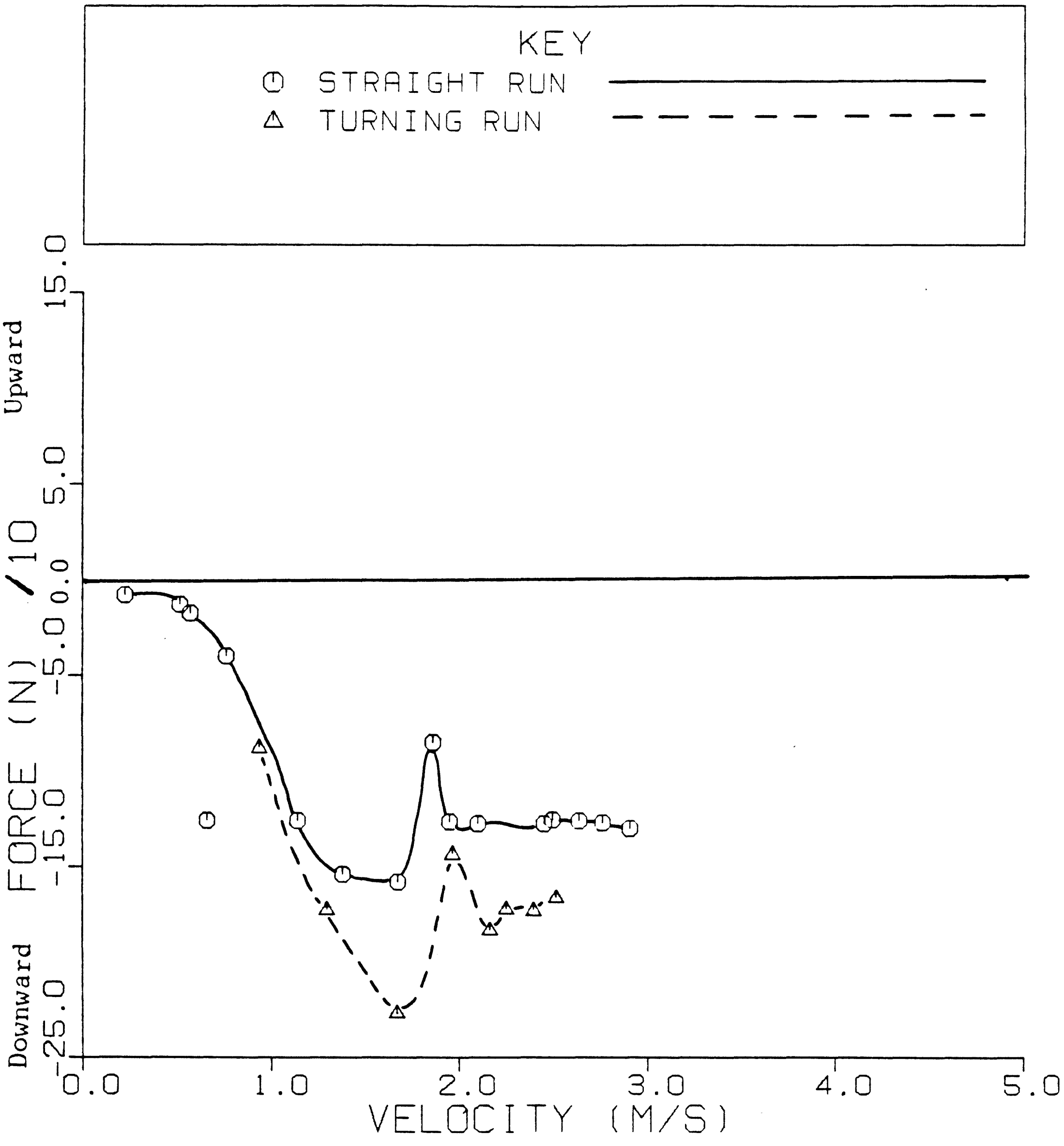


Figure 4.24 Lift Force for Straight and Turning Runs at Draft 15

be in error. These are the two points above the straight run data points. It seems inconceivable that the lift force follows these points. The data from drafts 45 and 15 seem to bear this out with the exception of one data point in Figure 4.24 which was also ignored.

Since there is an increase in the pitching moment above the hump and a decrease in the lift force it would seem that the decrease in lift is caused by the front strut pair. This cannot be determined for certain without an additional transducer to allow the locating of the longitudinal center of lift.

As can be seen in Figures 4.25 and 4.26, it is difficult to come to any conclusion about the side force data. Due to the spread of data in Figure 4.25, draft 65, there does not seem to be any coherent function followed by the side force data while turning. It is not certain whether this is due to experimental errors, instability in the model, or some other explanation. The data shown in Figure 4.26 for draft 45 shows a definite curve in the turning data. With the exception of one point, the magnitude of the side force increases with velocity. In fact, at the hump the side force is about 3 times larger than while rudders were straight. In light of this it can safely be said that the rudders cause a distinct force to starboard. This suggests that the forward rudders have less effect than the stern rudders, which is difficult to believe

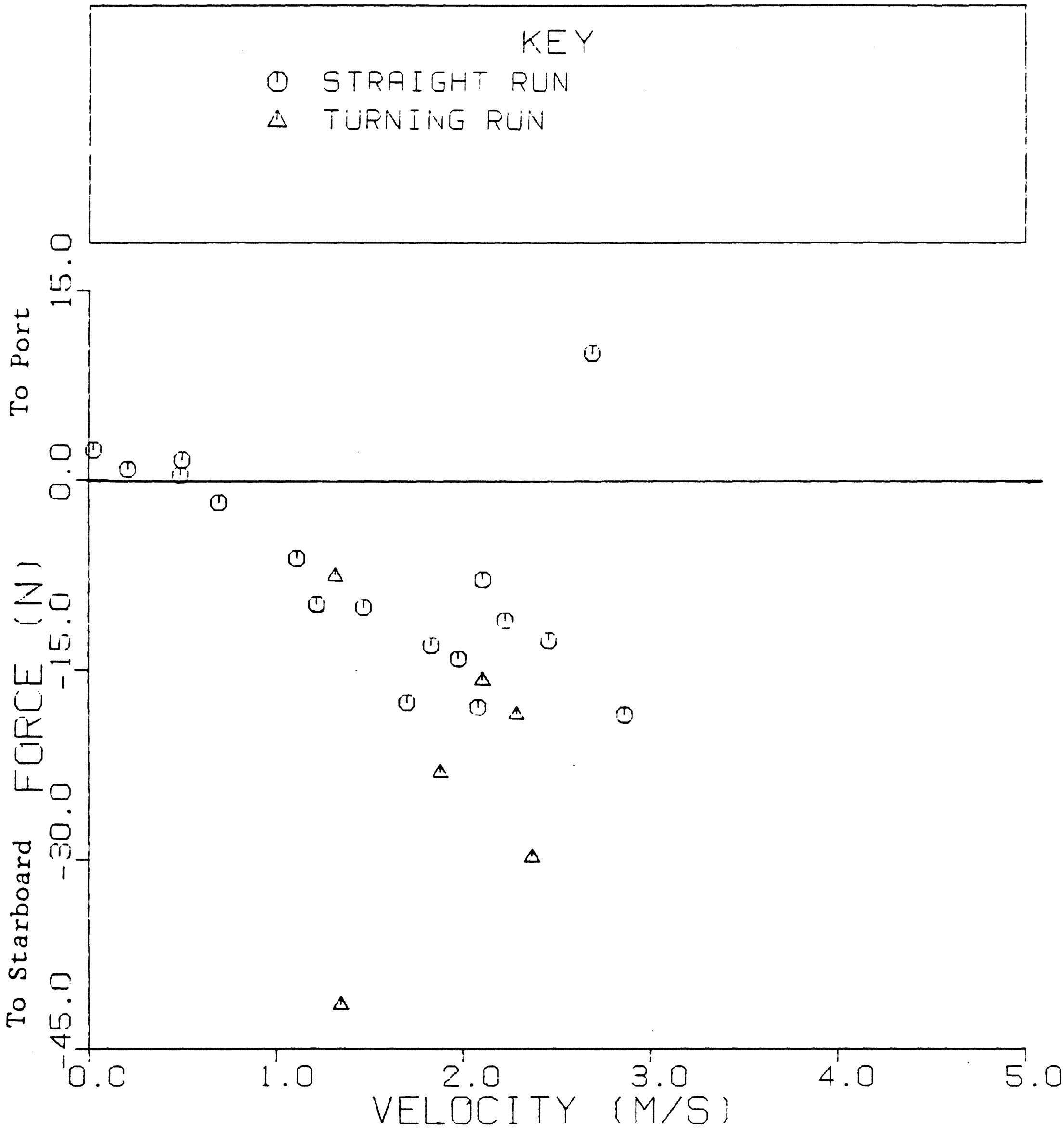


Figure 4.25 Side Force for Straight and Turning Runs at Draft 65

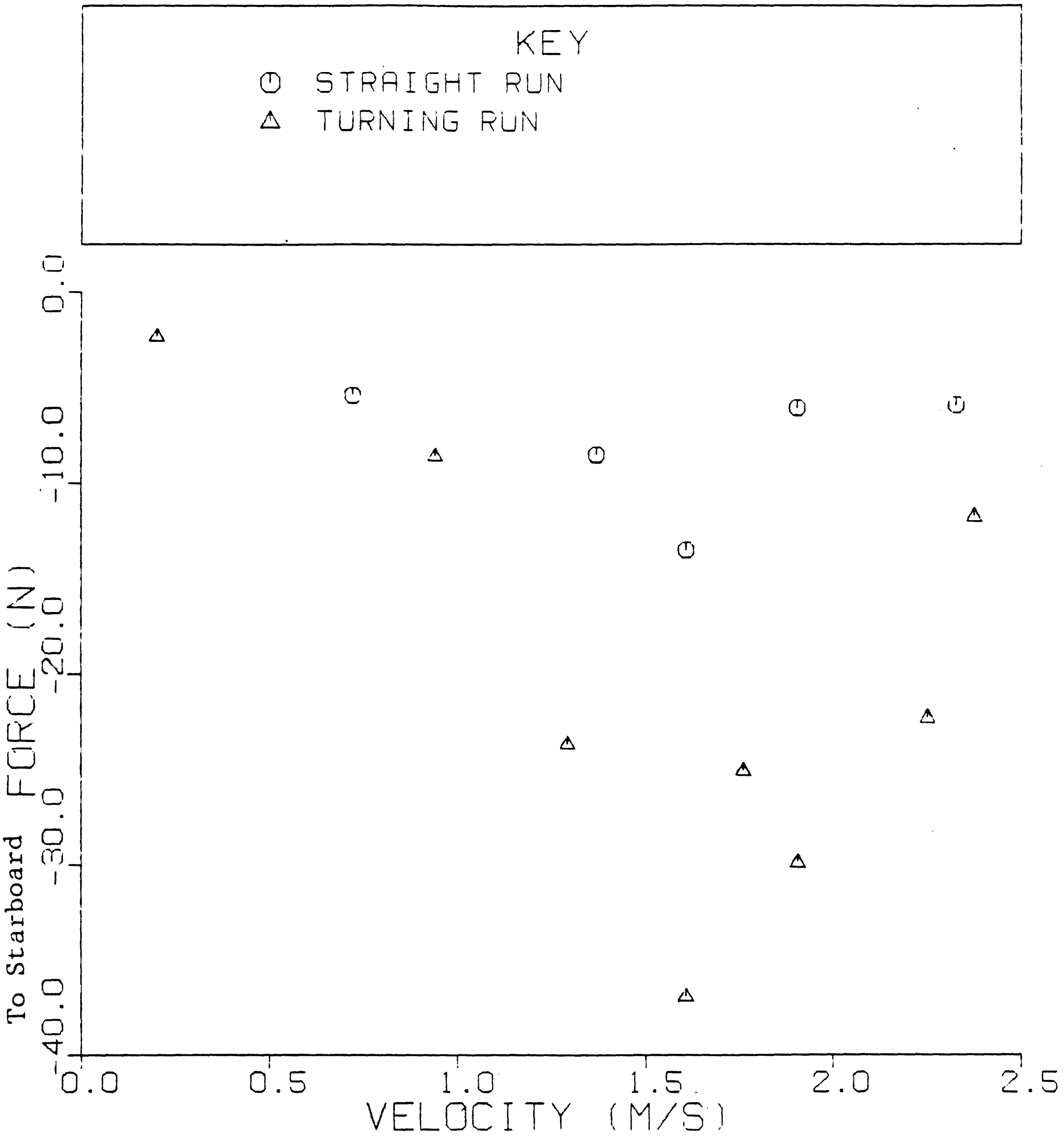


Figure 4.26 Side Force for Straight and Turning Runs at Draft 45

since the stern rudders are in the wake of the bow struts. It was expected that the model would have a side force into the turn.

There are two obvious possible causes of this side force. The first is that the model was improperly aligned in the basin during the draft 45 runs. The second is that the rudders were not adjusted properly. It is my opinion that the first of these is the probable cause.

4.4 PITCHING DATA

One of the problems that small waterplane area vessels contend with is a pitching moment caused by the underwater hull. When any cylindrical object passes underwater near the waterplane with an axial velocity, a bow-down pitching moment is created. This moment depends on the cylinder's velocity and distance from the waterplane. Both the SWATH and the Monoform suffer from this problem. The SWATH uses bow canards and a stern stabilizer to correct for the bow-down pitching moment. Since the Monoform's struts are angled toward the water from the vertical, it is hoped that the rudders can counter the pitching moment without the additional interference drag and flow noise of canards.

This section describes the results from deflecting the bow rudders out by 15 degrees and the stern rudders in by 15 degrees. This should cause high pressure regions on the bottom of the bow strut pair and on the top of the stern strut pair, thus countering the pitching of the underwater hull.

Figures 4.27-29 show the pitching moments measured from the model during these data runs. It can be seen that there is no detectable difference between the data taken with straight rudder configuration and the data taken with the pitching rudder configuration. Larger rudders or larger rudder angles would probably improve the control over the pitching moment.

Figures 4.30-32 present the drag forces measured with the rudders in their pitching position. These figures show an effect similar to that shown in the turning rudder data. There is a slight increase in the drag of the model, especially above the first hump, along with a loss of humps above this speed. This loss of the higher speed humps is again probably caused by the more turbulent wake of the bow strut pair striking the stern struts and disturbing the flow.

Figures 4.33-4.35 present a comparison between the lift forces measured with straight rudders with those measured with pitching rudders. From these plots it can be seen that the lift force on the model increases with the use of the rudders. The data presented earlier indicates no change in the pitching moment. Therefore, it seems that the bow rudders have more effect than the stern rudders. The reason for this is that

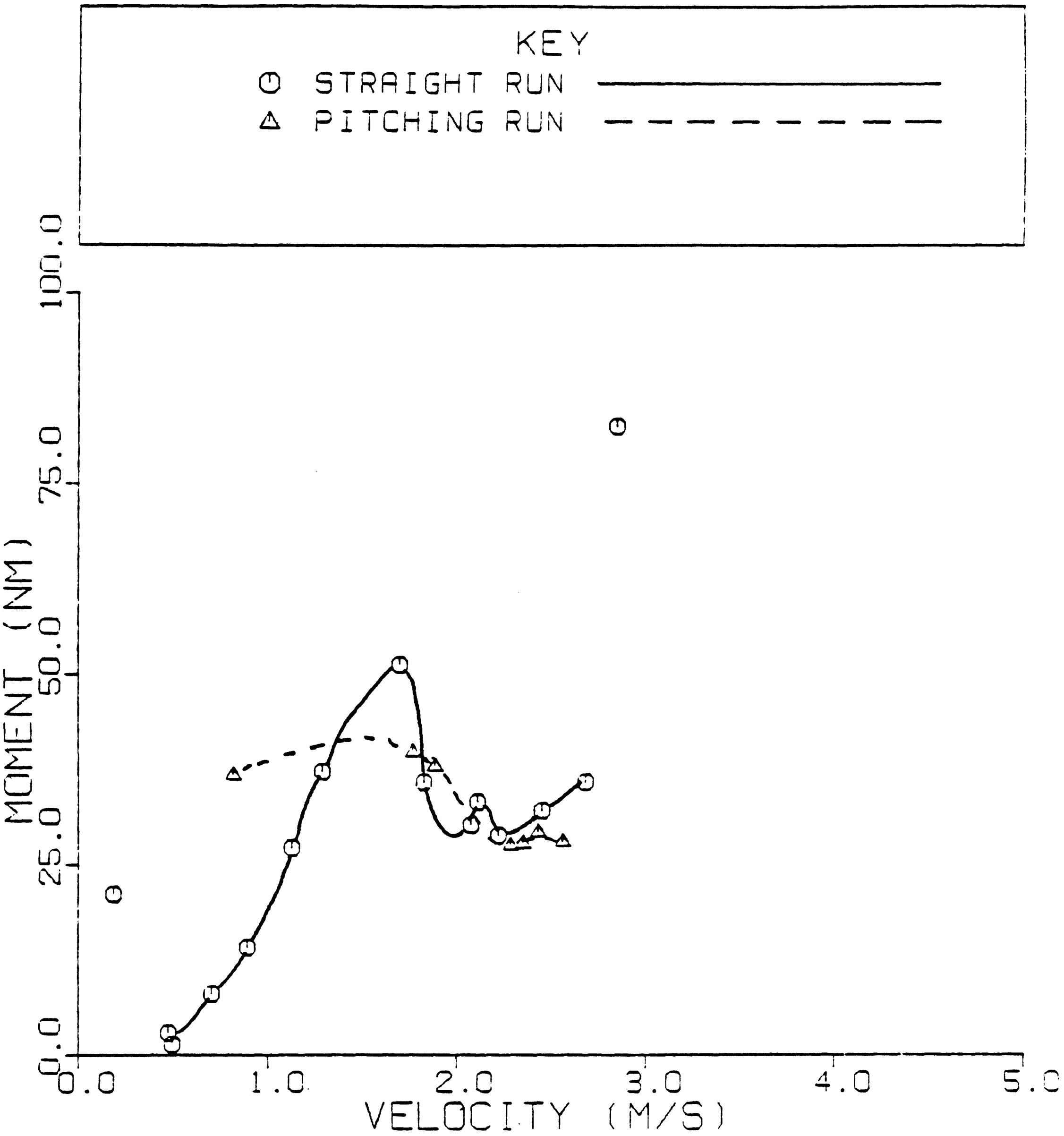


Figure 4.27
Pitching Moment for Straight and Pitching Runs at Draft 65

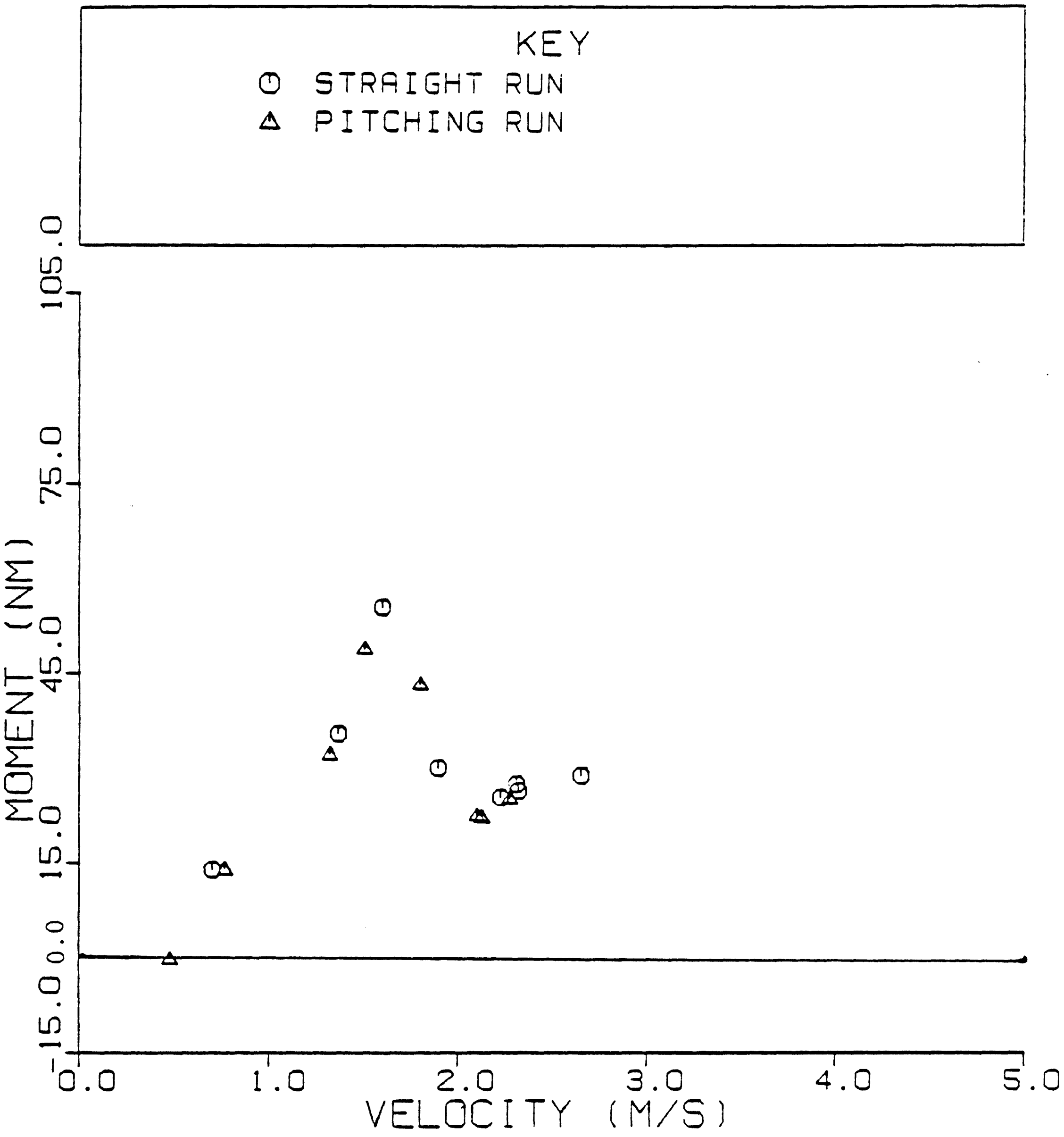


Figure 4.28
Pitching Moment for Straight and Pitching Runs at Draft 45

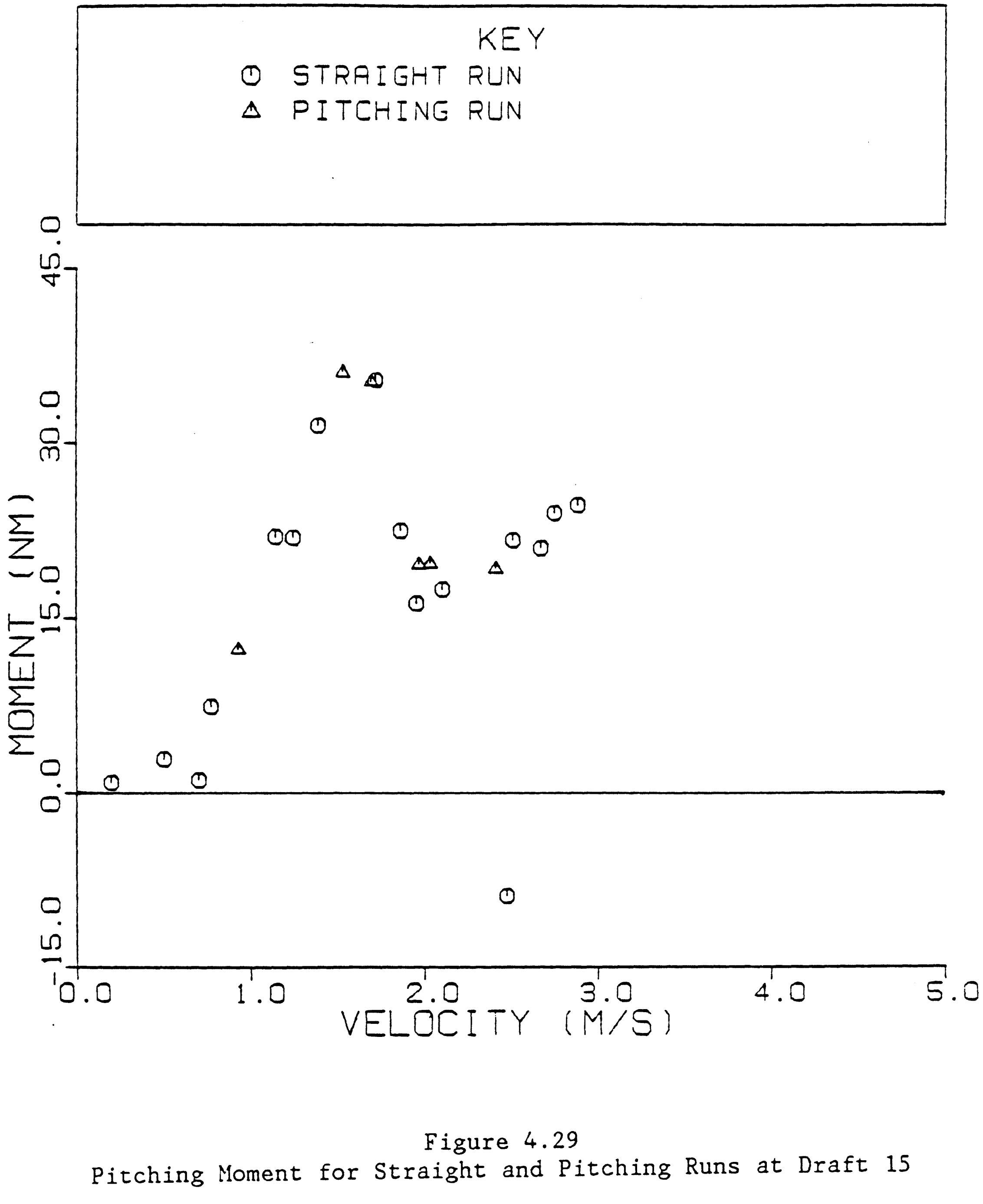


Figure 4.29
Pitching Moment for Straight and Pitching Runs at Draft 15

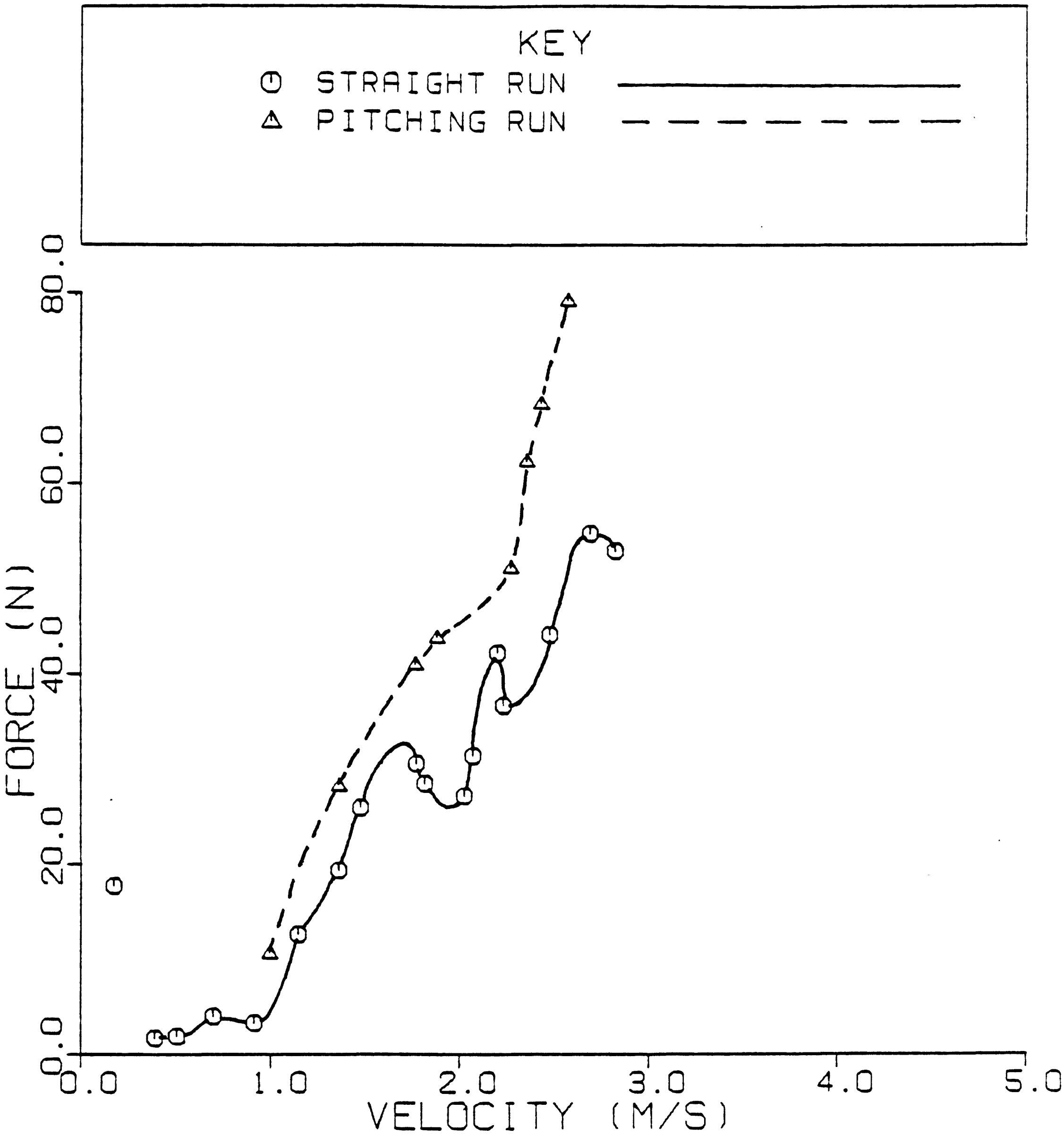


Figure 4.30 Drag Force for Straight and Pitching Runs at Draft 65

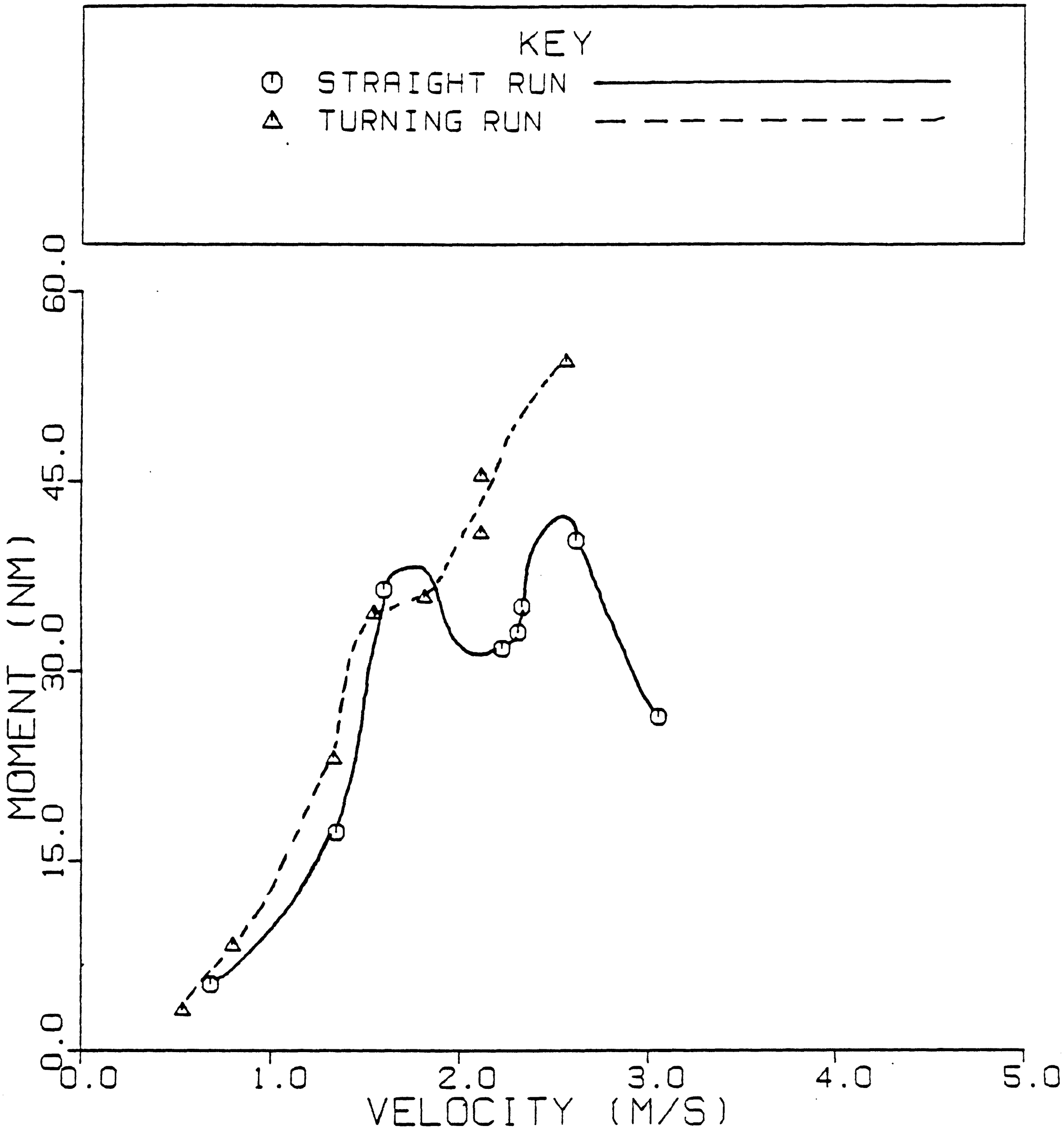


Figure 4.31 Drag Force for Straight and Pitching Runs at Draft 45

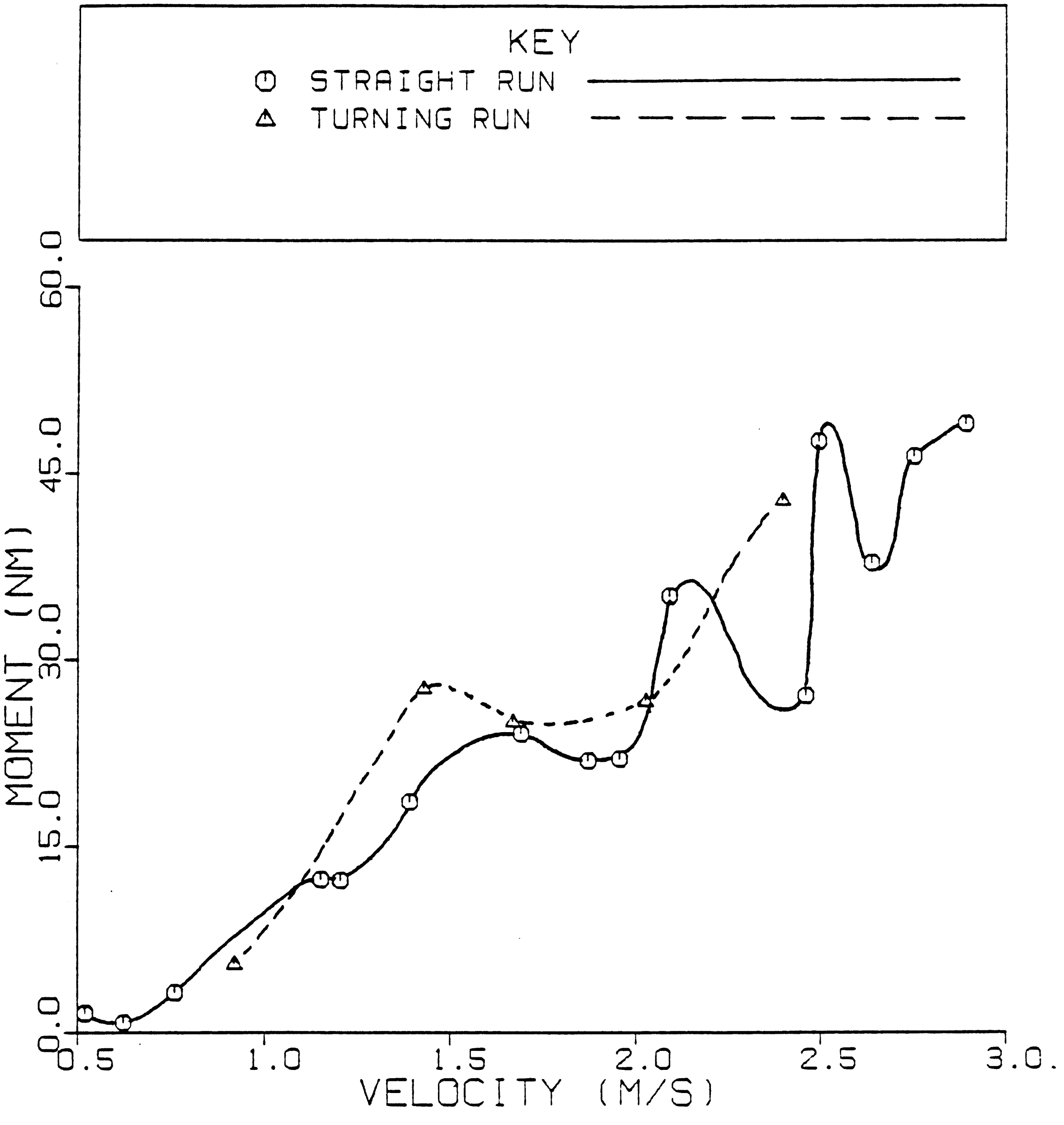


Figure 4.32 Drag Force for Straight and Pitching Runs at Draft 15

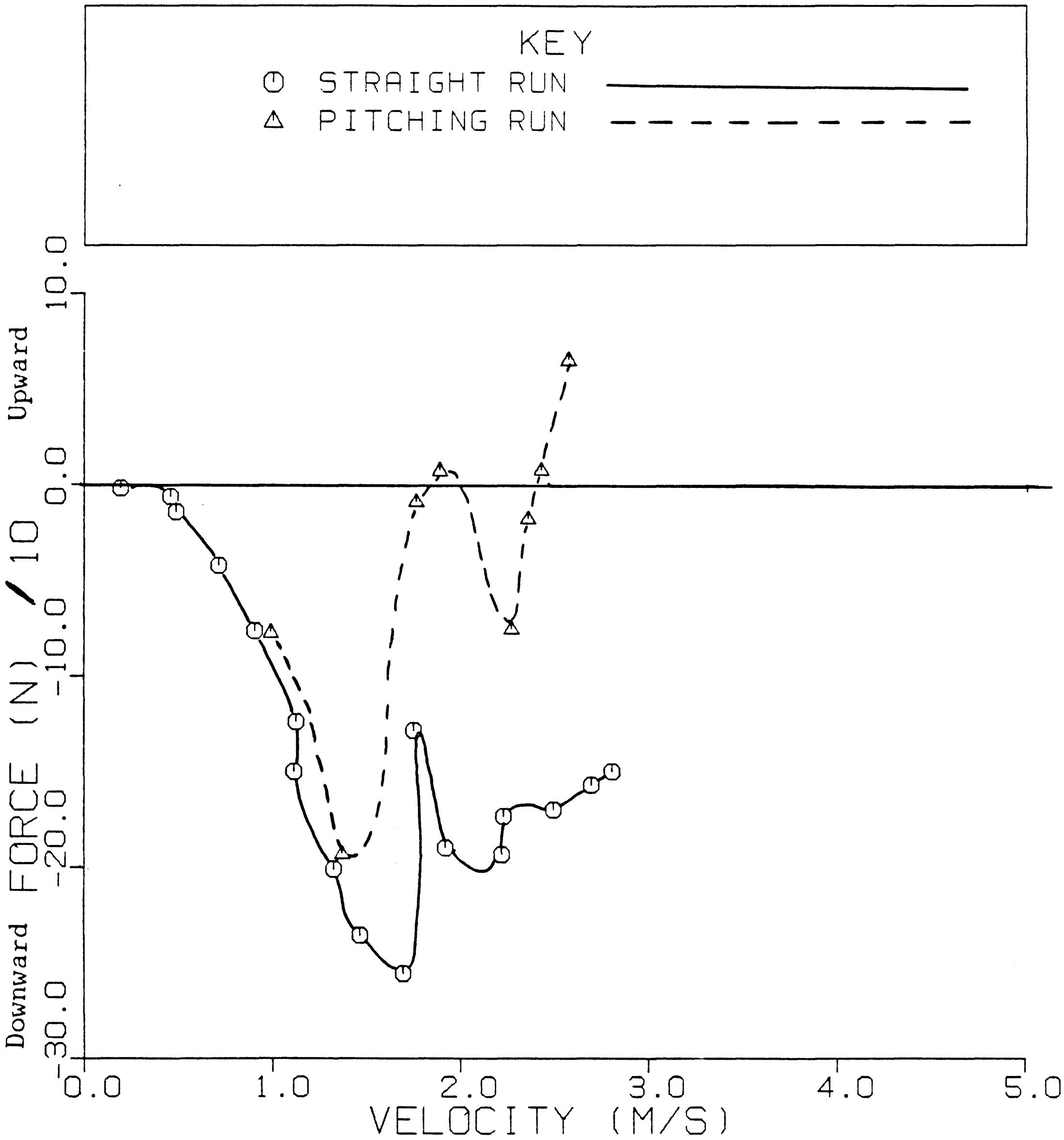


Figure 4.33 Lift Force for Straight and Pitching Runs at Draft 65

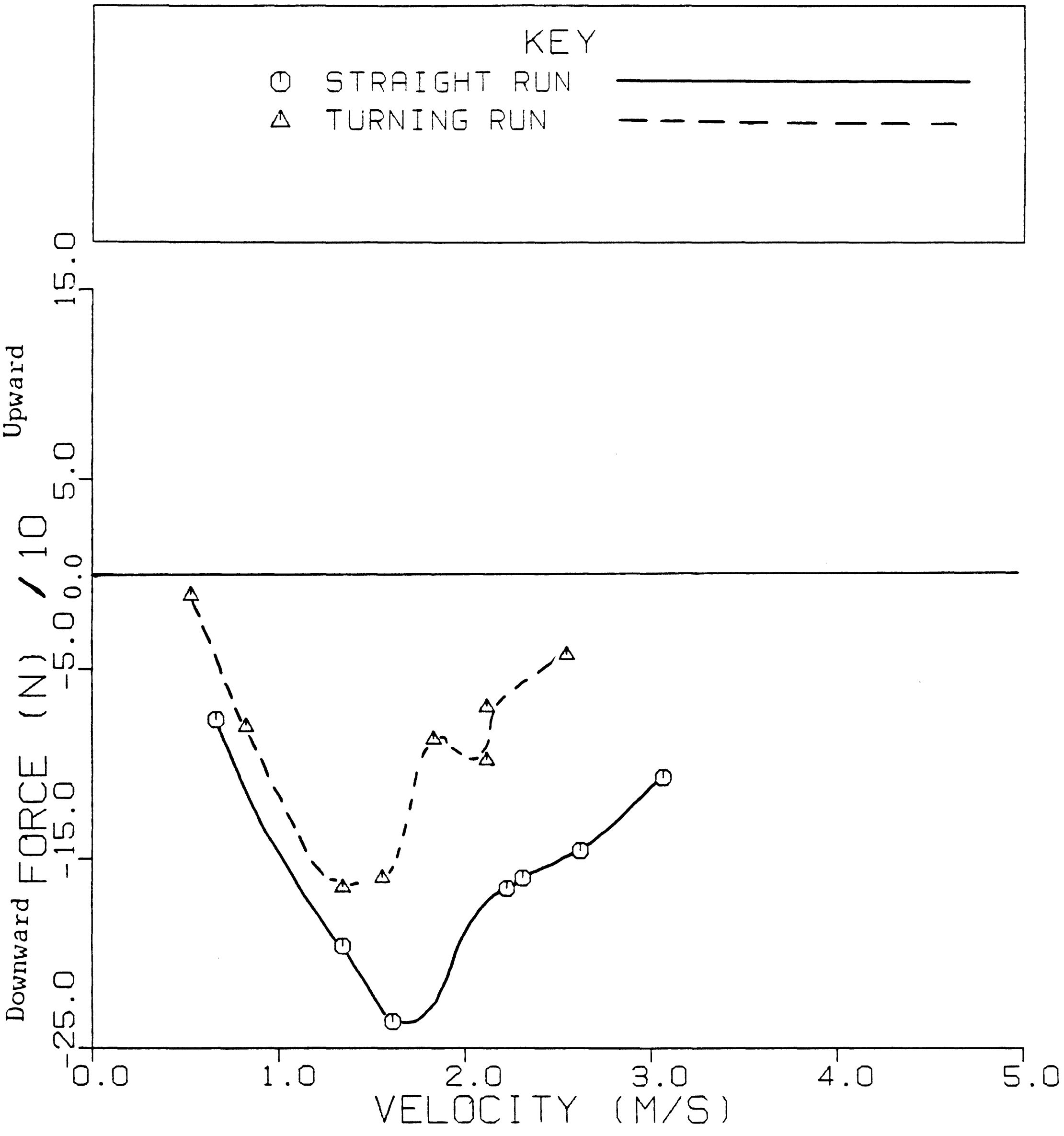


Figure 4.34 Lift Force for Straight and Pitching Runs at Draft 45

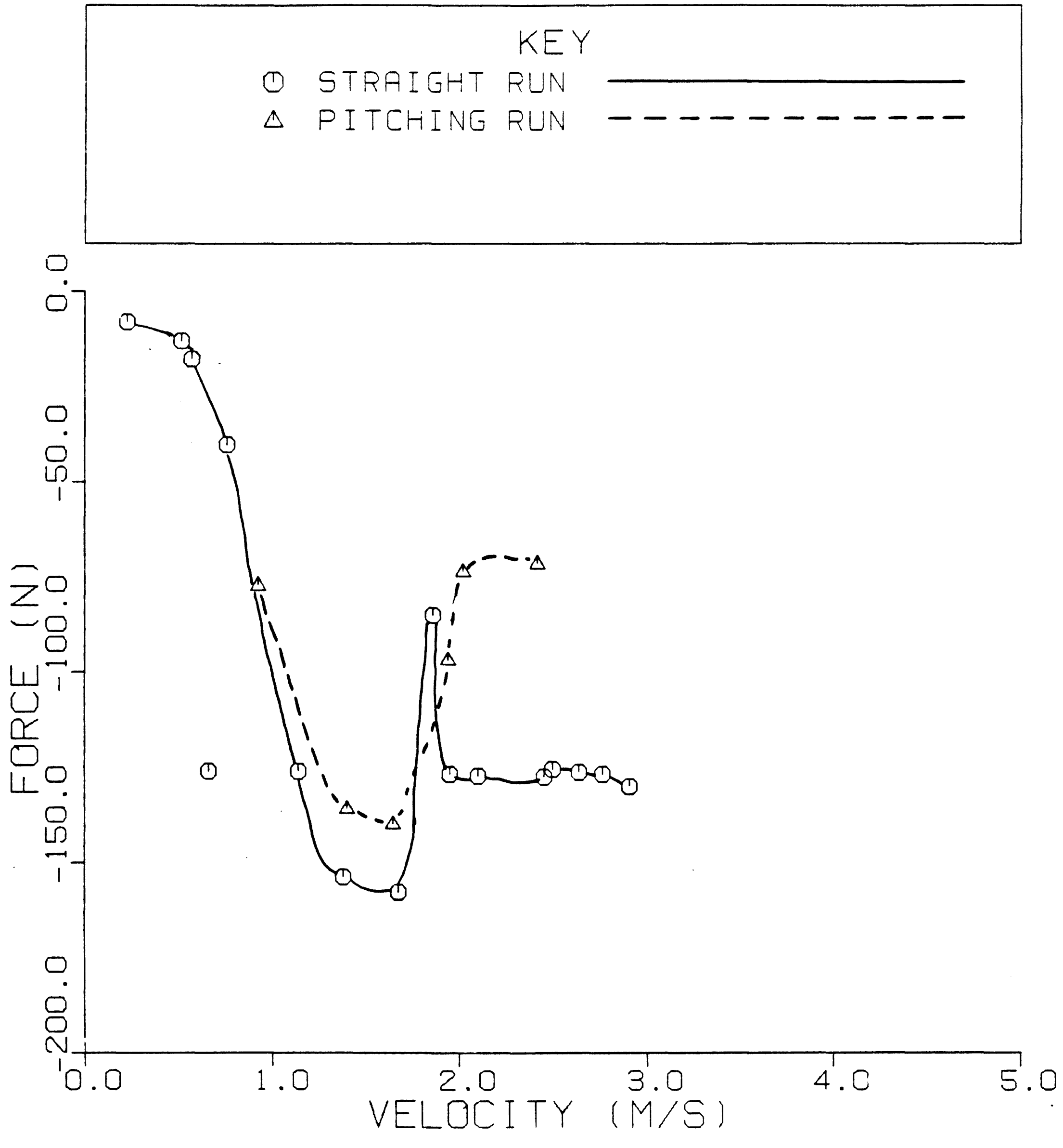


Figure 4.35 Lift Force for Straight and Pitching Runs at Draft 15

the stern rudders must operate in the wake of the bow rudders, and thus they lose efficiency. Since the bow struts are 0.6 meters ahead of the moment center, the lift force on them would still create a bow-up pitching moment. The reason this moment does not show in the figure remains unexplained.

The remainder of the data obtained during the pitching moment testing gives a feel for alignment and model inaccuracies. Figures 4.36 and 4.37 present a comparison of the side force with the rudders countering the pitching moment and the straight rudder runs. Figure 4.37 shows a decrease in side force while Figure 4.37 does not. This is probably due to misalignment of the model during the draft 45 data runs. As shown in Figures 4.38-4.40 the yaw moment shows a definite turning moment to port. This could be due to the misalignment of the port bow strut. Since it is angled closer to the water than the starboard strut, the port rudder has more surface area in the water than its starboard counterpart. This might cause a noticable yaw moment.

4.5 INSTRUMENTATION BEHAVIOR

This section presents some of the experience gained on the instrumentation, model, and carriage during this study. The main purpose behind the on-line calibration of the instrumentation was to avoid possible problems due to instrument drift caused by carriage vibration.

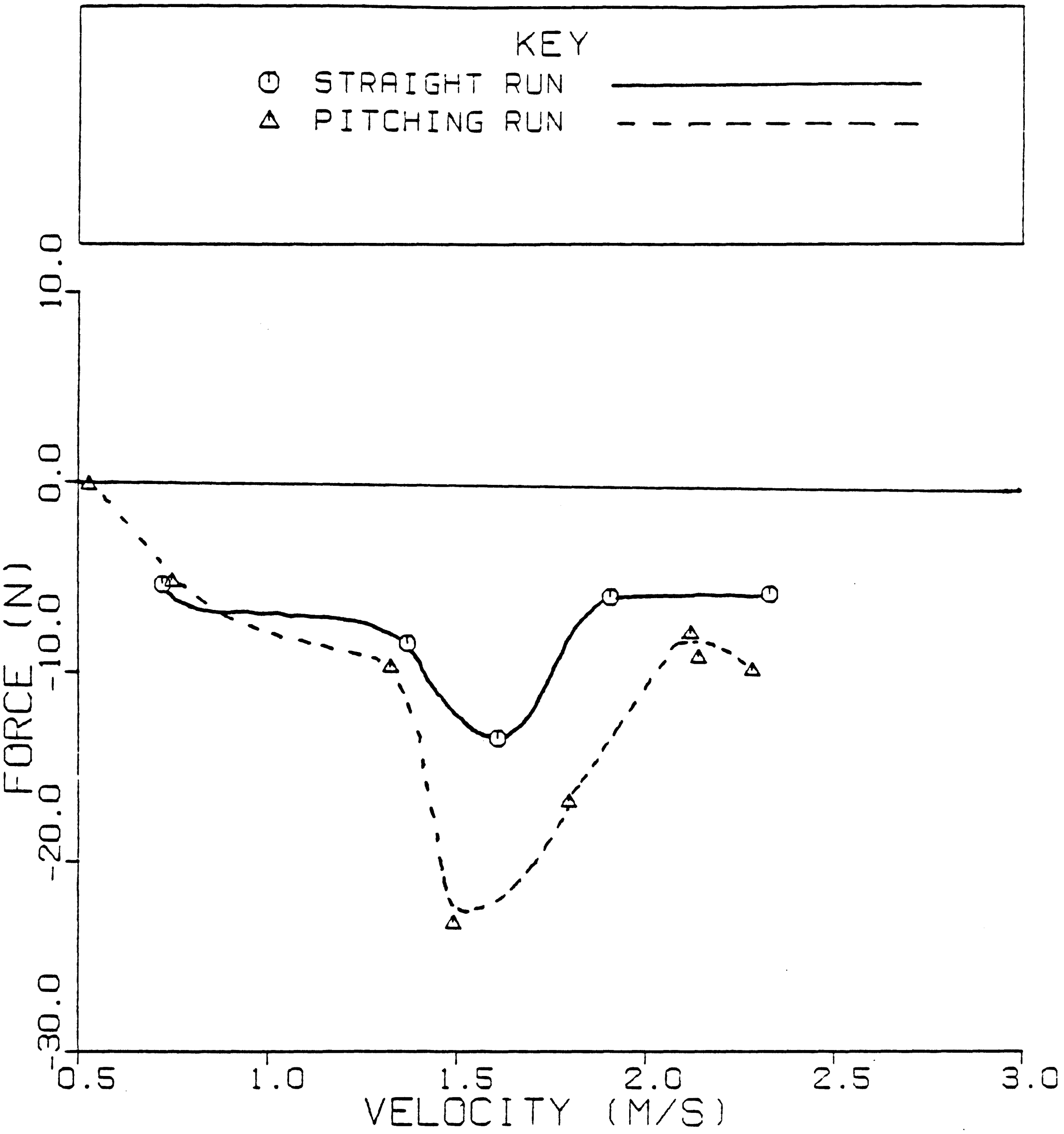


Figure 4.36 Side Force for Straight and Pitching Runs at Draft 45

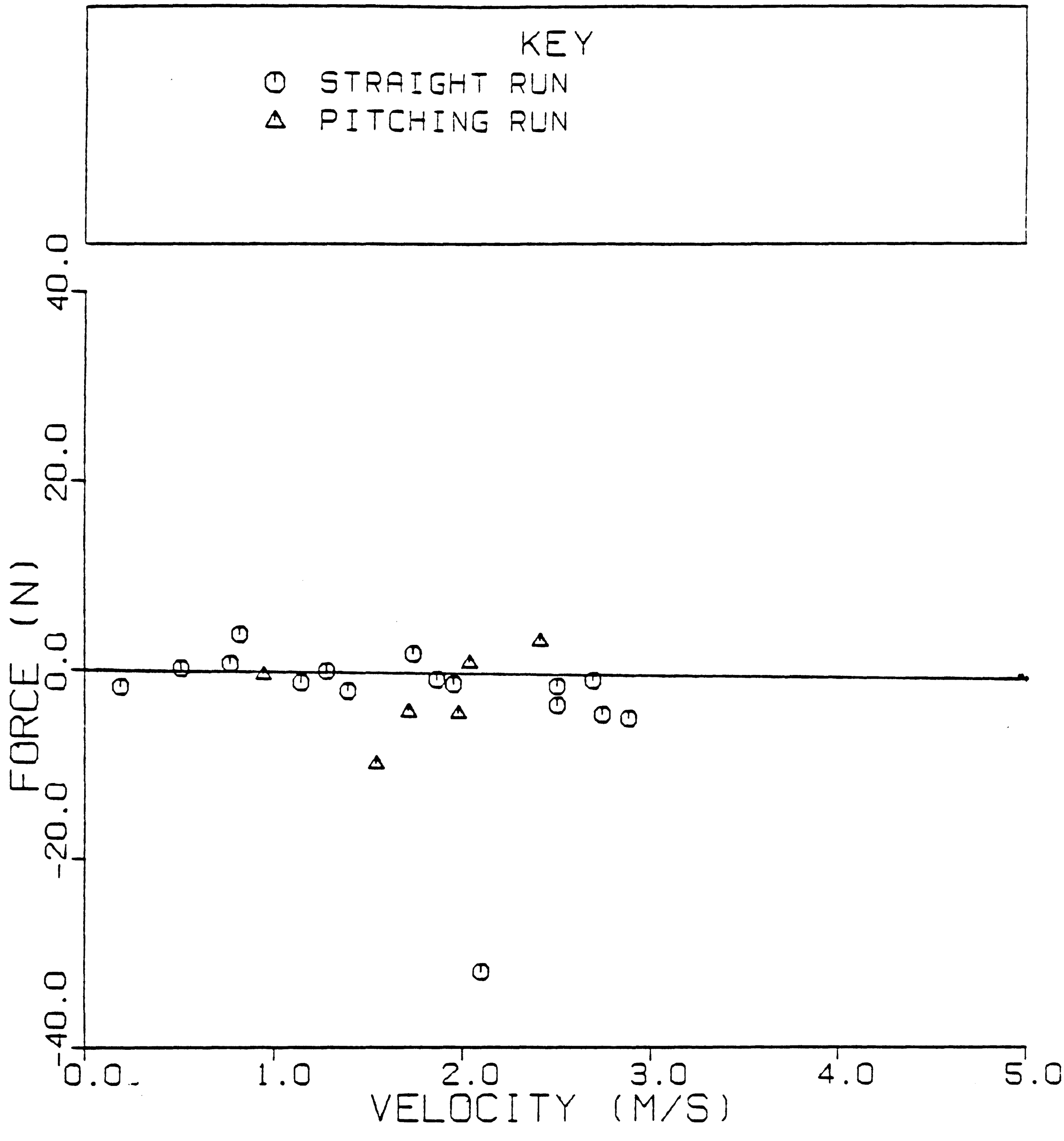


Figure 4.37 Side Force for Straight and Pitching Runs at Draft 15

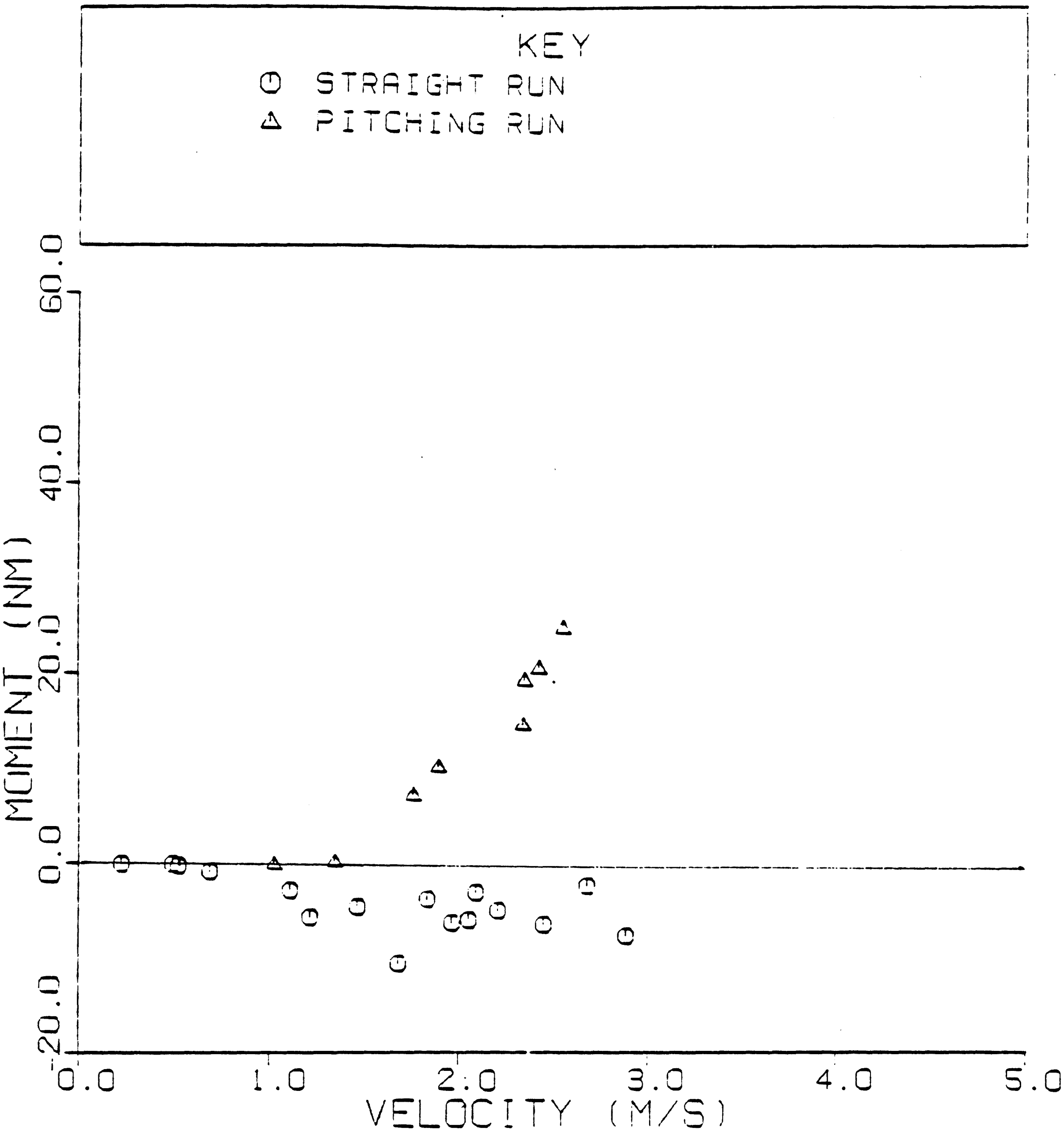


Figure 4.38 Yaw Moment for Straight and Pitching Runs at Draft 65

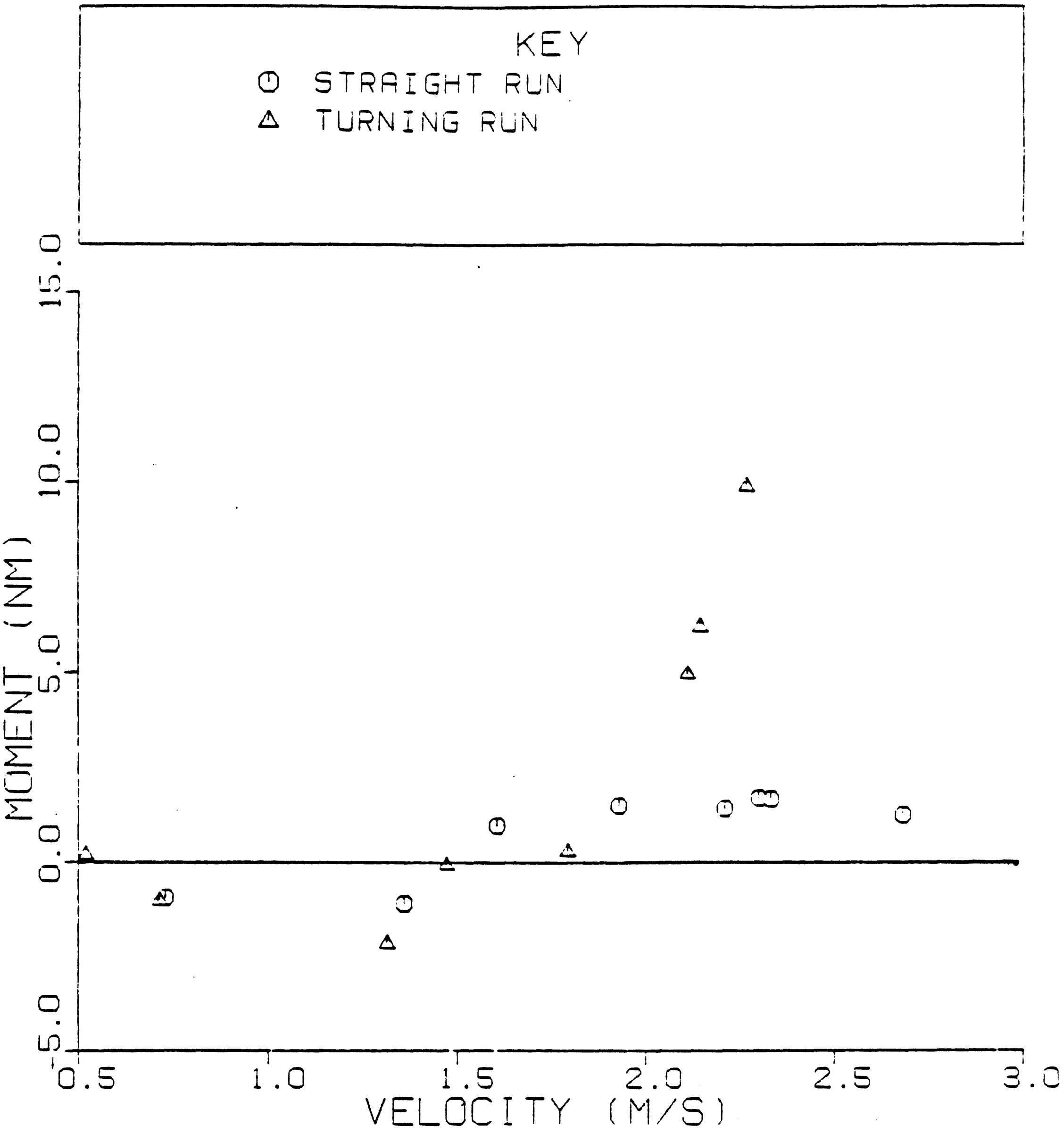


Figure 4.39 Yaw Moment for Straight and Pitching Runs at Draft 45

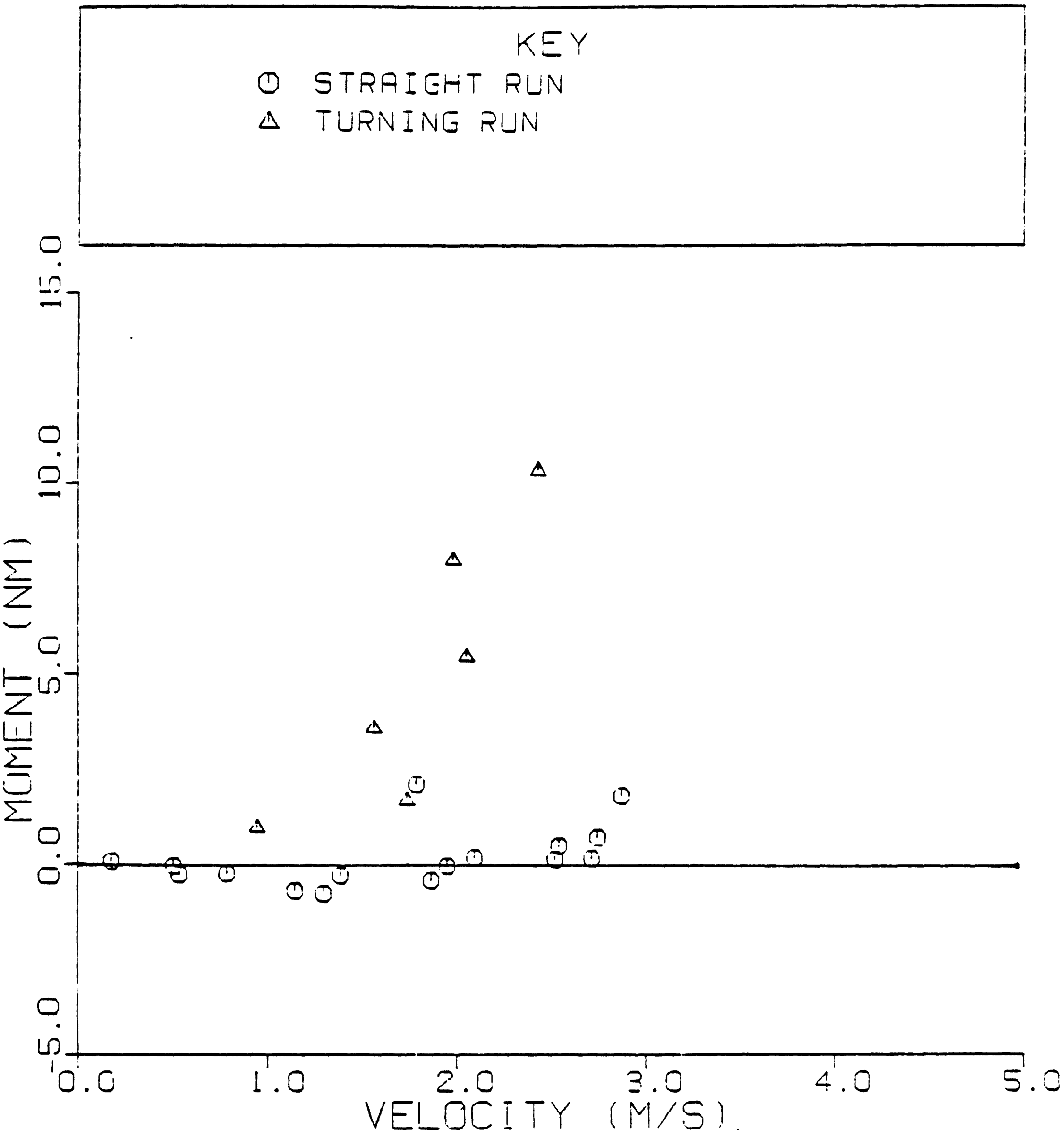


Figure 4.40 Yaw Moment for Straight and Pitching Runs at Draft 15

However, studying the calibration data revealed that instrument drift was not a problem. The instrumentation gain usually did not vary more than one to two percent over the course of a day. It cannot be stated how far the zero point changed throughout a day, since this was occasionally adjusted, but these adjustments were normally small. Overall, it is no longer felt that drift due to vibration is a problem.

Another concern was the amount of electronic noise due to the carriage motors. It cannot be absolutely determined if this was a source of signal noise or not. The instrumentation was grounded and shielded whenever possible, but the cables leading from the balance to the power supply/amplifiers were not.

The most probable source of signal noise was the vibration of the structure holding the model. There are several joints between the carriage and the model. These joints may have contributed some of the noise. In fact, any noise which they did contribute would probably be nonlinear due to a variable spring constant. This nonlinearity would introduce errors which would not average out.

5.0 CONCLUSIONS

This chapter presents the concluding comments of this thesis. The first section contains the comments dealing with the hydrodynamic forces on the model, while the second section presents the concluding comments on the instrumentation.

5.1 THE MONOFORM MODEL

The following is a summary of the results of the experimental analysis of the Monoform model:

- The hydrodynamic drag on the Monoform has several more humps than originally expected. This added complexity seems to be caused by increased wave-making resistance due to the flow restriction between the struts and the hull. The drag might be reduced by increasing the draft of the hull or by varying the distance between strut pairs. Increasing the draft would decrease the effect of the flow restriction, while varying the distance between strut pairs would effect the interaction between strut pairs.

- The Monoform has a strong tendency to pitch bow-down and to sink lower in the water, especially around a length Froude number of 0.9.

This seems to be caused by the flow restriction between the strut pairs. The lift force seems to create the worst problem, although this problem can be corrected with the existing rudders. The pitch portion will require either larger rudders or larger rudder angles. Part of the cause of poor pitch control seems to be that the stern strut pair looses efficiency since it operates in the wake of the bow strut pair.

- Deflecting the rudders increases the drag mostly at high speeds. The deflected rudders also dampen-out the higher speed humps caused by the rear strut pair.

- The existing rudders give excellent directional control. It might prove useful to have larger rudders in the stern than in the bow due to the turbulence coming from the bow rudders which decreases efficiency of the stern rudders.

- The Monoform has small roll moments, even while turning, since any force created by the rudders passes near the center of gravity of the model.

5.2 INSTRUMENTATION

The following can be said about the instrumentation used in this work:

- The most serious problem with the instrumentation was the time delay between data collection and reduction. This could be corrected with the use of a digital computer placed on the carriage during the data runs.

- The on-line calibration was unnecessary and resulted in a large waste of time. Even if the tape recorder is used in the future, the equipment should be calibrated only about once every ten runs; any more frequent calibration is unnecessary.

- Two transducers should be used in the future. This would decrease the forces and moments on each transducer, and also facilitate the determination of the location of the center of lift force and side force. The reduction in magnitude is especially necessary for the pitching moment since some of the pitching moments measured exceeded the transducer manufacturer's specifications. Two transducers would also increase the stiffness of the model supports and possibly increase the accuracy of the data.

- Vibration of the model support structure seems to be the cause of most of the noise in the data. In any future work the dynamics of the structure should be analized for natural frequencies. With this information it should be possible to filter out the force/moment contribution of the structure. It would also be profitable to measure the forces on a dead weight attached to the gages while the carriage is moving. Any force on the weight would be caused by either the carriage acceleration or vibration.

- Another source of possible noise is electro-magnetic noise from the electrical drive system of the carriage. The use of carrier amplifier systems instead of the DC power supplies used should decrease the noise picked-up in the strain-gages.

- This study did not account for model blockage effects. It would be helpful to study the size effect of the model in the Virginia Polytechnic Institute and State University basin. Since no analytical method is available, model series tests would be required.

REFERENCES

1. Lang, T. G., and R. B. Chapman, "Hydrodynamic Design of the SSP - A 190-ton High-Speed Stable Semisubmerged Platform of the S^3 Type", NUC TN 573, Naval Undersea Center, San Diego, California, July 1971.

2. Szeless, Adorjan G., and John D. C. Baldwin, "Hydrostatic and hydrodynamic characteristics of 'Monoform', a novel hull form", Final report prepared for the Office of Naval Research, December 1976.

3. Lang, T. G., "Hydrodynamic design of an S^3 semisubmerged ship", Ninth Symposium on Naval Hydrodynamics, Paris, France, August 1972.

4. Oshima, M. and Hitashi, N., "Development of the Semi-Submerged Catamaran (SSC)", Naval Architecture and Ocean Engineering, The Society of Naval Architects of Japan, Vol. 18, 1980, pp. 175-186.

5. Leopold R. et. al. "The Low Water Plane Multi-Hull Ship Principles, status, and Plans for Naval Development", AIAA/SNAME/USN Advanced Marine Vehicles Meeting, July 17-19, 1972.

6. Childers K. C., F. M. Gloeckler, R. M. Stevens, "SWATH - The VSTOL Aircraft Carrier for the Post-1990's", Presented at the Symposium "The Aircraft Carrier - Present and Future", San Diego, California. October 7-8, 1976.

7. Robinson, Charles H. "Measurement of Gear Transmission Error Using Optical Encoders." Masters Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, July 1981.

8. Estabrook, Norman B., "Effects of Variations in Hull Geometry on the Drag of a 500-ton S^3", Naval Undersea Center, NUC TN 1245, San Diego, California, not dated.

9. Chapman R. B., "Lift and Trim Acting on SWATH Demihulls", Naval Undersea Center, NUC TN 1275, San Diego, California, November, 1973.

APPENDIX A: INSTRUMENTATION ERROR ANALYSIS

In this section the error analysis of the instrumentation is described and the results are presented.

The error analysis of the instrumentation consisted of sending known inputs through the system and comparing them with the output. For the force/moment channels, this was done by placing weights on the sting balance in order to create the desired force or moment. Several different magnitudes were used throughout the range of the forces and moments experienced in the data runs. The signals from the balance were then recorded and processed in the same manner as were the actual experimental data.

The velocity channel was analized by driving the encoder with a speed controlled DC motor. The rotational speed of the DC motor was measured using a 1000 segment optical encoder. The output of the 600 segment optical encoder used in the data runs was treated in the same manner as the experimental signals.

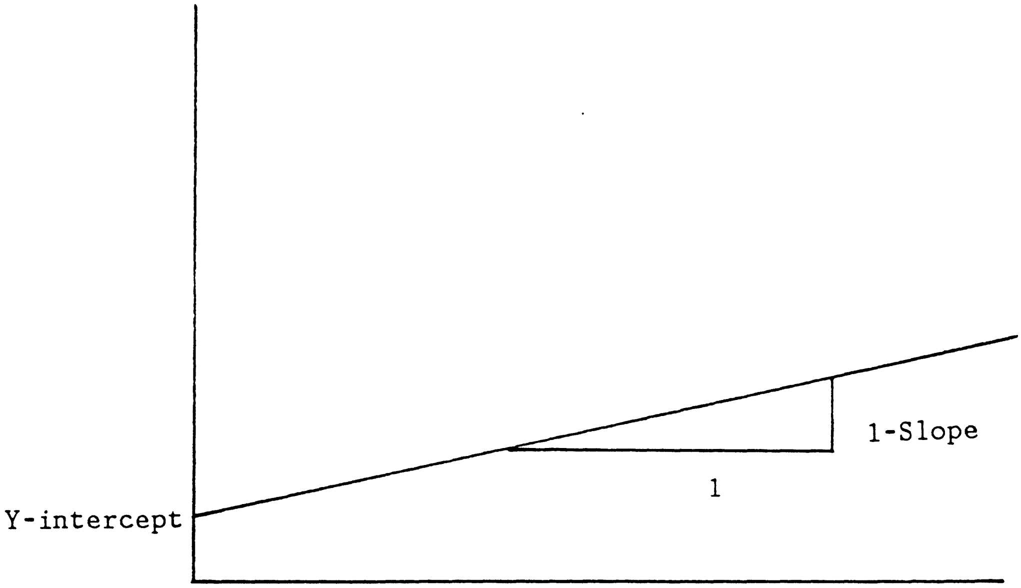
The reduced data was compared to the true input signals by performing a linear regression analysis. If the reduced data had been perfectly accurate, the output would equal the input and the linear regression would indicate a slope of 1 and a Y-intercept of 0.

Table A.1 presents the results of this analysis. The error can be divided into two parts; the steady-state or systematic error and the random error. A presentation of the systematic error can be seen in Part A of Figure A-1. The systematic error is a straight line with a Y-intercept equal to the Y-intercept found in Table A-1 and a slope equal to one minus the slope found in Table A-1.

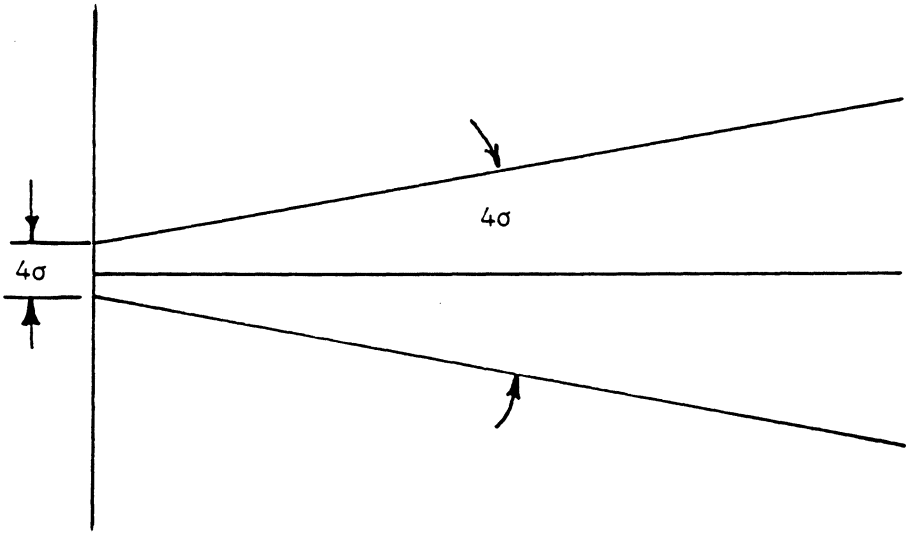
The schematic diagram of the random error is shown in Part B of Figure A-1. The random error is inside an envelop of the two lines found by taking twice the standard deviation of the intercept in Table A-1 for the intercept of the random error. The slope of this line is plus and minus twice the standard deviation of the slope found in Table A-1. This envelope is the 95% confidence envelope for the random error.

Table A-1 Results of the Error Analysis

Channel	Intercept	Std. Deviation	Slope	Std. Deviation
velocity	-0.003	0.009	1.011	0.005
lift	1.364	0.283	0.999	0.003
side	0.455	0.981	0.981	0.007
drag	-0.162	0.097	0.992	0.002
pitch	1.006	1.400	1.003	0.059
roll	0.006	0.008	1.005	0.003
yaw	0.068	0.064	0.994	0.003



Part A Systematic Error



Part B Random Error

Figure A-1 Schematic Diagram of Error Analysis

APPENDIX B: COMPUTER CODES USED

This appendix presents the computer codes developed and used in this study. They logically fall into three distinct sets of codes. The first is the code that was used to transfer data from the Zonic DMS FFT to the IBM 370 computer. The second set of codes is the one that was used to find the calibration constants of the data. The final set is the codes used in the actual data reduction. Because of the extremely large amount of data processed, only the files containing the raw statistics of each data file and the calibration information for each data file were kept on disk. The actual data files were kept on tape and recalled only as needed. In this way the amount of data which was actually kept on disk was minimized.

The documentation of the codes includes a discussion of the code, a list of variables, a list of file definitions, and a list of codes called by that particular code. This documentation can be found preceding each individual code.

All codes were written in either IBM EXEC or the FORTVS version of fortran-77.

```
&TRACE OFF
*
*
*  XT EXEC                              Written by:  S. G. Hittel
*                                       Version:  1-31-1985
*
*-----------------------------------------------------------------
*
*  This exec code causes the ZONIC 5003 FFT to transmit 2 channels of
*  time data to the users CMS VM.  The data is placed into a file of
*  the users choice. Default filetype and filemode is RDATA A.
*  The user is prompted for all input.
*
*  XT EXEC is specifically written for the Monoform project.  This means
*  that certain information is handled which would not be applicable to
*  other uses.  It should be obvious in the code which information is
*  only for the present study.
*
*  The ZONIC is set to interperet any command following the string VM.
*  This code uses the X command.  Therfore data transmision begins
*  with the string VMX.  The data is transferred in lines containing
*  eleven numbers seperated with commas.  The first ten numbers are the
*  voltage signals from the two channels of the 5003.  They are in
*  alternating order, channel 1 first.  The eleventh number is a three
*  digit check sum number.  The three exceptions to this are the first
*  line and the last two lines.  The first line contains 4 numbers
*  which contain scaling information which is not important for this
*  type of data transfer.  The last line contains a single dollar sign.
*  The next to the last line contains only four pairs of voltage signals.
*  These three lines are erased by this code since they are either of
*  no importance or can not be used in the later fortran codes.
*
*  This code also places both a header and the transfer date onto the
*  top of the file.  The transfer is recorded in two files. One FILE LIST
*  A, contains a record of all files transferred. The second file is
*  one of the following:  FILE CLIST A, FILE FLIST A, or FILE MLIST A.
*  Which file is used is dependent of whether the file
*  just transmitted is a file which contains zero point information,
*  calibration point information, force data information, or moment
*  data information.
*
*  Details of the data transfer commands can be seen below.
*----------------------------------------------------------------
*
*  LIST OF OTHER CODES CALLED:
*      NOYES EXEC   (a syn-type exec code. default=NO)
*
*-----------------------------------------------------------------
```

```
*
*  LIST OF VARIABLES:
*      &A,&B,&C,&D = Variables transmitted from the FFT which indicate
*                    input gains, sample rates ect.  These are not used.
*      &BLANK = A blank character
*      &DAY = Day of the month the data transfer occured
*      &END = Last memory location which is to be transferred
*      &FILE = The filetype of the file in which the transfer will be
*              recorded.
*      &FIRST = The first three letters of the output filename
*               This is used to determine the type of data being
*               transmitted.  Is it calibration data or not?
*      &FLAG1 = Temporary storage for a value to be passed to NOYES EXEC
*      &FM = Filemode of the output file
*      &FN = Name of output file
*      &FT = Filetype of the output file
*      &FUNCTION = 1, 2, or 3.  Function number of the Zonic which is to
*                  be transferred.  It is the same number as the DL
*                  command.
*      &HEADER = The Header which is to top the output file
*      &LETTER = First letter of the output filename.  Indicates
*                the type of data being transferred.
*      &MONTH = Month data transfer occured
*      &START = Starting memory location which is to be transferred
*      &SYN_VAL = The return variable from NOYES EXEC.
*      &TDATE = Date of data transfer  MM/DD/YY
*      &TEMP = The temperature of the water in the towing basin
*              during the data run.
*      &VOLTS = Input voltage of the tachometer channel during the
*               creation of the calibration data
*      &YEAR = Year data transfer occured
*
*---------------------------------------------------------------------
SET MSG OFF
CP TERM PROMPT ¢
CP CLEAR
*
*  Checking to see if the filename for the receiveing file has been
*  passed.
*
&IF &INDEX GT 1 &GOTO -ERR
&IF .&1 EQ .? &GOTO -ERR
*
*  Initailinzing variables
*
&FUNCTION = 3
&START = 1
&END = 1020
```

```
&FN = &1
&FT = RDATA
&FM = A
&IF &INDEX = 1 &GOTO -BYPASS
*
*  Asking what file the data is to be stored in, if it was not passed.
*
-ASKFILE
CP CLEAR
&TYPE
&TYPE What file do you wish the data to be stored in?
&TYPE The default filetype is RDATA.  The default filemode is A.
&READ VARS &FN &FT &FM
&IF .&FN EQ . &GOTO -ASKFILE
&IF &FN EQ QUIT &EXIT 0
&IF .&FT EQ . &FT = RDATA
&IF .&FM EQ . &FM = A
*
*  Checking to see if the data file already exists
*
-BYPASS
STATE &FN &FT &FM
&IF &RC NE 0 &GOTO -HEADER
*
*  Checking to see if the data file should be erased
*
&TYPE
&TYPE  Do you wish to erase the existing file &FN &FT &FM?
&TYPE  Default=NO.
&READ VARS &FLAG1
&IF .&FLAG1 EQ .QUIT &EXIT 0
EXEC NOYES &FLAG1
&READ VARS &SYN_VAL
&IF &SYN_VAL EQ NO &GOTO -ASKFILE
*
*  Erasing the old data file
*
ERASE &FN &FT &FM
*
*  Setting up a header in the data file
*
-HEADER
&HEADER =
&TYPE Enter a header of up to 80 characters
&READ ARGS
&IF .&1 =  . &GOTO -VOLTS
&I = 1
&HEADER =
```

```
-PEICE_IT
&LOOP -LOOP_A_END &N
&HEADER = &CONCAT OF &HEADER &BLANK &&I
&I = &I + 1
-LOOP_A_END
*
*  If the input file name has the first three letters CAL then it is
*  a calibration data file and the tachometer calibration voltage
*  must be entered for later use.
*
-VOLTS
&FIRST = &LEFT OF &FN 3
&IF &FIRST NE CAL &GOTO -BEGIN
&BEGTYPE 2

Enter the tachometer calibration voltage and water temp (F) for this run.
&READ VARS &VOLTS &TEMP
*
*  Data transmition begins
*
-BEGIN
CP TERM PROMPT $
&TYPE VMX &FUNCTION
&READ VARS &A &B &C &D
&STACK B
&STACK INPUT
&TYPE $&START &END
EDIT &FN &FT &FM (LRECL 130
CP TERM PROMPT OFF
*
*  Finding the transfer date
*
&YEAR = &LEFT OF &DATE 2
&DAY = &RIGHT OF &DATE 2
&MONTH = &RIGHT OF &DATE 5
&MONTH = &LEFT OF &MONTH 2
&TDATE = &CONCAT OF &MONTH / &DAY / &YEAR
*
*  Adding information banner on top of file and deleting useless lines
*
&STACK TOP
&STACK INPUT
&STACK &TDATE
&STACK &HEADER
&STACK
&STACK BOTTOM
&STACK UP 1
&STACK DEL 2
```

```
&STACK FILE
SET CMSTYPE HT
EDIT &FN &FT &FM
SET CMSTYPE RT
*
*  Finding the name of the file which this transfer should be recorded in.
*
&LETTER = &LEFT OF &FN 1
&FILE =
&IF &LETTER EQ C &FILE = CLIST
&IF &LETTER EQ D &FILE = FLIST
&IF &LETTER EQ L &FILE = FLIST
&IF &LETTER EQ S &FILE = FLIST
&IF &LETTER EQ R &FILE = MLIST
&IF &LETTER EQ P &FILE = MLIST
&IF &LETTER EQ Y &FILE = MLIST
&IF &LETTER EQ Z &GOTO -STATE_LIST
&IF .&FILE EQ . &TYPE  This transfer will not be recorded.
&IF .&FILE EQ . &EXIT
*
*  Checking to see if the transfer has been recorded earlier by mistake
*  Checking to see if FILE LIST exists
*
-STATE_LIST
STATE FILE LIST A
&IF &RC NE 0 &GOTO -RECORD
EXSERV STKFILE FILE LIST A
-TOPLOOP
SENTRIES
&IF &RC EQ 0 &GOTO -RECORD
&READ VARS &NAME &TYPE
&IF &NAME NE &FN  &GOTO -TOPLOOP
&TYPE The file &FN &FT already exists in FILE LIST.
&TYPE This transfer will not be re-recorded.
-SENTRY
SENTRIES
&IF &RC EQ 0 &EXIT
&READ VARS &DUMMY
&GOTO -SENTRY
*
*  Recording the transfer in the appropriate files
*
-RECORD
&IF .&FILE NE .CLIST &SKIP 2
EXECIO 1 DISKW FILE CLIST A ( STRING &FN DATA &FM &VOLTS &TEMP
&GOTO -FILE_LIST
&IF .&FILE EQ . &SKIP 1
EXECIO 1 DISKW FILE &FILE A ( STRING &FN DATA &FM
```

```
-FILE_LIST
EXECIO 1 DISKW FILE LIST A ( STRING &FN DATA &FM
*
*  TX EXEC ends.
*
SET MSGMODE ON
QUERY LASTMSG
&EXIT
-ERR
&BEGTYPE 6
Only the filename of the file to be transferred should be passed to XT
EXEC.  The default filetype and filemode is RDATA A.  If you wish to use
a filetype or filemode which is different from these, do not pass any
variables to XT EXEC.  You will be prompted for all input
&EXIT
```

```
&TRACE OFF
*  AVG EXEC                                  written by: S.G. Hittel
*                                            version: 12-14-1984
*
*  This code drives AVG FORTRAN which calculates the average and standard
*  deviations of input data files which were generated during the
*  monoform study.  These files contain numbers which represent voltages.
*  They are contained in two channels.  One of these channels contains
*  voltage signals for a tachometer used to measure velocity.  The other
*  channel contains strain-gage signals.
*
*  AVG EXEC allows the files to be input one at a time, or it excepts
*  a list of files to be reduced.  The user is prompted for all
*  choices.  If a list of file is to be used it must be contained in
*  a CMS file.  The list must have the format:
*
*  FILENAME1 FILETYPE1 FILEMODE1  ( other parameters not used by AVG EXEC
*  FILENAME2 FILETYPE2 FILEMODE2
*      .          .          .
*      .          .          .
*      .          .          .
*  FILENAMEn FILETYPEn FILEMODEm
*
*  There are not default values for FILENAME and FILETYPE, but of
*  course the CMS default for the FILEMODE is A.
*
*  AVG EXEC sets file definitions for AVG FORTRAN.  It then takes the
*  output of AVG FORTRAN from TRASH DATA A and creates an output line.
*  It then places  this output into a file called AVG DATA A.
*
*  The file definitions which AVG EXEC sets are:
*        03 DISK &FN &FT &FM
*        02 DISK TRASH DATA A
*
*   CODES CALLED:  AVG FORTRAN
*
*
*
*-----------------------------------------------------------------
*
*   LIST OF VARIABLES:
*       &FM = filemode of the input file
*       &FN = filename of the input file
*       &FT = filetype of the input file
*       &SDEV = the standard deviation of the strain gage channel signal
*       &SMEAN = the mean of the strain gage channel signal
*       &STKMOD = mode of the file which contains the list of files
*       &STKNAM = name of the file which contains the list of files
```

```
*       &STKTYP = type of the file which contains the list of files
*       &VDEV = the standard deviation of the velocity channel signal
*       &VMEAN = the mean of the velocity channel signal
*       &WHAT = flag indicating type of data entry
*
*-------------------------------------------------------------------
SET BLIP working
*
*  checking for the existance of AVG DATA A
*
STATE AVG DATA A
&IF &RC EQ 0 &GOTO -HOWFILE
*
*  the file AVG DATA A does not exist so I create it here
*
&STACK INPUT
&STACK FILENAME.FILETYPE.VMEAN.......VDEV...........SMEAN...........SDEV
&STACK
&STACK FILE
SET CMSTYPE HT
EDIT AVG DATA A
SET CMSTYPE RT
*
*   finding how the user wants to enter the files
*
-HOWFILE
CLEAR
CP SLEEP 1 SEC
&BEGTYPE 6
Would you like to:
     1) enter files individually
     2) have AVG read them from a file
     3) Quit

enter 1, 2, or 3
&READ VARS &WHAT
&IF .&WHAT EQ .1 &GOTO -STARTLOOP
&IF .&WHAT EQ .2 &GOTO -STKFILE
&IF .&WHAT EQ .3 &GOTO -EXIT
&GOTO -HOWFILE
-STKFILE
*
*  a list of files will be used
*
&TYPE Enter the FN FT FM of the file holding all the files to be averaged.
&READ VARS &STKNAM &STKTYP &STKMOD
&IF .&STKMOD EQ . &STKMOD = A
&IF .&STKNAM EQ . &GOTO -STKFILE
```

```
&IF STKNAM EQ QUIT &GOTO -EXIT
*
*  checking for the existance of &STKNAM &STKTYP &STKMOD
*
STATE &STKNAM &STKTYP &STKMOD
&IF &RC EQ 0 &GOTO -GOODFILE
*
*   file does not exist
*
&TYPE The file &STKNAM &STKTYP &STKMOD does not exist
&TYPE
&GOTO -HOWFILE
*
*   the file does exist
*
-GOODFILE
EXSERV STKFILE &STKNAM &STKTYP &STKMOD
*
* Either the filenames will be entered individually or
* the filenames have now been stacked onto the console stack
*
CLEAR
&TYPE Execution begins on &STKNAM &STKTYP &STKMOD
-STARTLOOP
SENTRIES
&IF &RC NE 0 &SKIP 2
&BEGTYPE 1
Enter FN FT FM of the input file or null line to exit
&READ VARS &FN &FT &FM
&IF .&FN EQ .QUIT &GOTO -EXIT
&IF .&FN EQ . &GOTO -EXIT
*
*  checking for the existance of the input files
*
STATE &FN &FT &FM
&IF &RC NE 0 &TYPE the file &FN &FT &FM does not exist
&IF &RC NE 0 &GOTO -STARTLOOP
*
*  setting up for AVG FORTRAN run then executing
*
FI 03 DISK &FN &FT &FM
FI 02 DISK TRASH DATA A (LRECL 80
SET CMSTYPE HT
LOAD AVG (NOMAP START
SET CMSTYPE RT
*
*  writing to the contents of TRASH DATA A to AVG DATA A
*
```

```
EXECIO 1 DISKR TRASH DATA A ( LIFO
&READ VARS &VMEAN &VDEV &SMEAN &SDEV
EXECIO 1 DISKW AVG DATA A (STRING &FN &FT &VMEAN &VDEV &SMEAN &SDEV
*
*  clean-up
*
FINIS AVG DATA A
ERASE TRASH DATA
*
*  looping back
*
&GOTO -STARTLOOP
*
* AVG EXEC ends
*
-EXIT
SET BLIP OFF
&EXIT
```

```
C--------------------------------------------------------------------
C  AVG FORTRAN                            written by: S.G. Hittel
C                                         version :  12-14-1984
C
C     This code calculates the mean and standard deviations of
C     ZONIC 5003 FFT generated files.  It is driven by AVG EXEC.
C     It Writes to file 02.
C     See AVG EXEC for more detail.
C--------------------------------------------------------------------
C
C
      COMMON VELDAT,STRNDT
      REAL*8 VELDAT,STRNDT,VMEAN,SMEAN,VDEV,SDEV
      DIMENSION VELDAT(1025), STRNDT(1025)
C
C-----------------------------------------------------------
C     READING VALUES OF 'VELOCITY DATA' AND 'STRAIN-GAGE' DATA
C-----------------------------------------------------------
      CALL INPUT(ICOUNT)
C
C----------------------------------------------------------
C     CALCULATING MEAN AND STANDARD DEVIATIONS OF INPUT DATA
C----------------------------------------------------------
      CALL STAT(ICOUNT,VMEAN,SMEAN,VDEV,SDEV)
C
C----------------------------------------------------------
C     OUTPUT AREA
C----------------------------------------------------------
      WRITE(2,90)VMEAN,VDEV,SMEAN,SDEV
90    FORMAT(4E20.8)
      END
```

```
C-----------------------------------------------------------------
C  SUBROUTINE INPUT                        written by: S.G. Hittel
C                                          version :  3-11-1985
C
C     This subroutine inputs the velocity and strain information
C     from file 03.  File 03 is assumed to be a file generated by the
C     XT EXEC.
C-------------------------------------------------------------------
C
C     VARIABLES RECEIVED FROM CALLING ROUTINE:  NONE
C
C     VARIABLES RETURNED TO CALLING ROUTINE: ICOUNT
C
C     VARIABLES IN AN UNNAMED COMMON BLOCK: VELDAT,STRNDT
C
C     LIST OF VARIABLES:
C
C     A       real array;  temporary storage of velocity channel values
C                          during the read operation
C     B       real array;  temporary storage of strain channel values
C                          during the read operation
C     DUMMY   character ;  dummy string to align first read from file
C     ICOUNT  integer   ;  the length of VELDAT and STRNDT
C     STRNDT  real array;  values of the strain channel
C     VELDAT  real array;  values of the velocity channel
C
C-----------------------------------------------------------------
C
C
      SUBROUTINE INPUT(ICOUNT)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON VELDAT(1025),STRNDT(1025)
      DIMENSION A(5),B(5)
      CHARACTER DUMMY*12
C--------------------------------------------------------
C     READING VALUES OF 'VELOCITY DATA' AND 'STRAIN-GAGE' DATA
C--------------------------------------------------------
      ICOUNT = 0
      READ(3,10)DUMMY
 10   FORMAT(/,A12)
      DO 30 I=1,1000,1
         READ(3,*,END=40) ( A(L),B(L) ,L=1,5 )
         ICOUNT = ICOUNT + 5
         DO 20 K=1,5,1
         VELDAT(5*I+K-5)= A(K)
         STRNDT(5*I+K-5)= B(K)
 20      CONTINUE
 30   CONTINUE
```

```
40    RETURN
      END
```

```
C-------------------------------------------------------------------
C  SUBROUTINE STAT                            written by: S.G. Hittel
C                                             version :  3-11-1985
C
C     This code calculates the mean and standard deviations of
C     two double dimension real arrays.
C     The input values are not distroyed in this code.
C     The two input arrays must be the same length
C-------------------------------------------------------------------
C
C    VARIABLES PASSED FROM CALLING ROUTINE: ICOUNT
C
C    VARIABLES RETURNED TO CALLING ROUTINE: VMEAN,SMEAN,VDEV,SDEV
C
C    VARIABLES IN AN UNNAMED COMMON BLOCK: VELDAT,STRNDT
C
C    LIST OF VARIABLES:
C
C    ICOUNT   integer    ;  length of the arrays VELDAT and STRNDT
C    SDEV     real       ;  standard deviation of STRNDT
C    SMEAN    real       ;  mean of strndt
C    STRNDT   real array;  input form calling routine
C    VDEV     real       ;  standard deviation of VELDAT
C    VELDAT   real array;  input from calling routine
C    VMEAN    real       ;  mean of VELDAT
C
C---------------------------------------------------------------------
C
      SUBROUTINE STAT(ICOUNT,VMEAN,SMEAN,VDEV,SDEV)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON VELDAT(1025),STRNDT(1025)
C-------------------------------------------------------
C     CALCULATING MEAN OF VARIABLES
C-------------------------------------------------------
      VMEAN=0.0D00
      SMEAN=0.0D00
      DO 10 I=1,ICOUNT,1
         VMEAN=VMEAN+VELDAT(I)
         SMEAN=SMEAN+STRNDT(I)
 10   CONTINUE
      VMEAN=VMEAN/FLOAT(ICOUNT)
      SMEAN=SMEAN/FLOAT(ICOUNT)
C-------------------------------------------------------
C     CALCULATING STANDARD DEVIATIONS
C-------------------------------------------------------
      VDEV=0.0D00
      SDEV=0.0D00
      DO 20 I=1,ICOUNT,1
```

```
         VDEV= VDEV + ( VELDAT(I) -  VMEAN )**2
         SDEV= SDEV + ( STRNDT(I) -  SMEAN )**2
 20   CONTINUE
      VDEV= SQRT( VDEV/FLOAT( ICOUNT - 1 ))
      SDEV= SQRT( SDEV/FLOAT( ICOUNT - 1 ))
C---------------------------------------------------------
C     RETURNING TO CALLING ROUTINE
C---------------------------------------------------------
      RETURN
      END
```

```
&TRACE OFF
*  CAL EXEC                                      written by: S.G. Hittel
*                                                version: 12-14-1984
*
*---------------------------------------------------------------------
* List of codes called:  CAL FORTRAN
*
* List of files used: AVG DATA A
*                     input file
*                     CALIBRAT DATA A
*                     TRASH DATA A (temporary ony)
*----------------------------------------------------------------------
*
* This exec drives CAL FORTRAN.  It was written for the Monoform
* project.  In this project data was contained in three files.  The
* first of these files was a zero pt. file.  It contained a time signal
* which represented the at-rest, no-load voltages.  The second file
* contained calibration data in the form of a time signal created by a
* known input to the system.  The third file contained the actual run
* data.  See AVG EXEC for more detail on the format of the files.
* Each file contains data from two channels.  Channel one is the velocity
* channel and channel two is a force or moment data channel.
*
* The purpose of these two codes is to create factors to correct for any
* inaccuracies in the gain of the signal conditioning instrumentation.
*
* AVG EXEC and AVG FORTRAN averaged each of the two channels and also
* calculated their standard deviations.  This information was stored in
* the file AVG DATA A.  This was done for all three file types.
*
* This code retrieves the average of the zero point file.
* It then passes this information to CAL FORTRAN.
* CAL FORTRAN reads the calibration data from the input file and
* subtracts the average of the zero pt file from each of the two
* channels.  The resulting number is compared to the value of the
* known input and a calibration gain factor is calculated for each of
* the two channels.  CAL FORTRAN then writes
* these factors into a temporary file named TRASH DATA A.  CAL EXEC
* reads this file and transfers the information to CALIBRAT DATA A.
*
* CAL EXEC allows the input to occur from either the terminal or from
* a file which contians the nessacary information.  The file is much
* easier to use if a large number of files are to be calibrated.
* The user will be prompted for all nessacary input.
*
* The input file must contain the following information in this form:
*
* FILENAME1 FILETYPE1 FILEMODE1 VOLTS1 TEMP1
```

```
* FILENAME2 FILETYPE2 FILEMODE2 VOLTS2 TEMP2
* FILENAME3 FILETYPE3 FILEMODE3 VOLTS3 TEMP3
*     .         .         .         .     .
*     .         .         .         .     .
*     .         .         .         .     .
* FILENAMEN FILETYPEN FILEMODEN VOLTSN TEMPN
*
* Where FILENAME FILETYPE FILEMODE identifies the input calibration
* file.  VOLTS is the input voltage to the velocity channel during the
* calibration.  TEMP is the temperature of the water during the run.
* Temp is not used in this set of codes but it is placed in CALIBRAT
* DATA for future use.
*
* During the Monoform study there was a standard way to name files.
* This code makes use of this convention to save the user time.
* When CAL EXEC searches AVG DATA A for the data on the input files
* it searches for files named with this convention.
* Zero pt. files where named ZEROXXXG where XXX is the number of the
* data run and G is the initial of the strain gage who's data the file
* contains.  The calibration information is stored in a file named
* CALXXXG. The strian gage initials are:  L=lift, S=side, D=drag, R=roll
* P=pitch, Y=yaw.
*
* CAL EXEC sets the following file definitions :
*    FI 12 TRASH DATA A(LRECL 90
*
*---------------------------------------------------------------------
*  List of variables:
*     &CM =  filemode of the input calibration file (FILEMODE)
*     &CN =  filename of the input calibration file (FILENAME)
*     &CSDEV = standard deviation of the calibration signal on the strain
*              gage channel
*     &CT =  filetype of the input calibration file (FILETYPE)
*     &CVDEV = standard deviation of the calibration signal on the
*              velocity channel
*     &D1 =  dummy variable to align read (not used)
*     &D2 =  dummy variable to align read (not used)
*     &DTYPE = initial of the strain gage which created the strain signal
*     &RUN = run number of the data run
*     &SCAL = mean of the calibration signal on the strain gage channel
*     &STKMOD =  filemode of the input file which contains the list of
*                files to be calibrated
*     &STKNAM =  filename of the input file which contains the list of
*                files to be calibrated
*     &STKTYP =  filetype of the input file which contains the list of
*                files to be calibrated
*     &SZERO =  mean of the zero pt file strain gage channel
*     &TEMP =  basin water temperature during data run
```

```
*     &TEST =  first three letters in the input calibration filename
*     &VCAL =  mean of the calibration file velocity channel
*     &VOLTS =  input calibration voltage to the velocity channel
*     &VZERO =  mean of the zero pt file velocity channel
*     &WHAT =  variable indicating choice of data entry
*     &ZN =  filename of the zero point file
*     &ZSDEV =  standard deviation of the zero pt file strain gage chl.
*     &ZVDEV =  standard deviation of the zero pt file velocity channel
*
*-----------------------------------------------------------------
SET BLIP working
*
*  checking for the existance of CALIBRAT DATA A
*
STATE CALIBRAT DATA A
&IF &RC EQ 0 &GOTO -HOWFILE
*
*  the file CALIBRAT DAT A does not exist so I create it here
*
&STACK INPUT
&STACK FILENAME.VFACT.......SFACT...........VOLTS.....TEMP (F)
&STACK
&STACK FILE
SET CMSTYPE HT
EDIT CALIBRAT DATA A
SET CMSTYPE RT
*
*   finding how the user wants to enter the files
*
-HOWFILE
CLEAR
&BEGTYPE 6
Would you like to:
     1) enter files individually
     2) have CAL read them from a file
     3) Quit

      enter 1, 2, or 3
&READ VARS &WHAT
&IF .&WHAT EQ .1 &GOTO -STARTLOOP
&IF .&WHAT EQ .2 &GOTO -STKFILE
&IF .&WHAT EQ .3 &GOTO -EXIT
&GOTO -HOWFILE
-STKFILE
&TYPE Enter the FN FM FT of the file containing the names of the file
&TYPE to be calibrated.
&READ VARS &STKNAM &STKTYP &STKMOD
&IF .&STKMOD EQ . &STKMOD = A
```

```
&IF .&STKNAM EQ . &GOTO -STKFILE
&IF STKNAM EQ QUIT &GOTO -EXIT
*
*  checking for the existance of &STKNAM &STKTYP &STKMOD
*
STATE &STKNAM &STKTYP &STKMOD
&IF &RC EQ 0 &GOTO -GOODFILE
*
*   file does not exist
*
&TYPE The file &STKNAM &STKTYP &STKMOD does not exist
&TYPE
&GOTO -HOWFILE
*
*   the file does exist
*
-GOODFILE
EXSERV STKFILE &STKNAM &STKTYP &STKMOD
*
* Either the filenames will be entered individually or
* the filenames have now been stacked onto the console stack
*
CLEAR
&TYPE Execution begins on &STKNAM &STKTYP &STKMOD ....
-STARTLOOP
SENTRIES
&IF &RC NE 0 &SKIP 3
&BEGTYPE 2
 Enter FN FT FM,and input tachometer calibration voltage, and the
 water temp. for the next run, or enter a null line to exit.
-READ
&READ VARS &CN &CT &CM &VOLTS &TEMP
&IF .&CN EQ .QUIT &GOTO -EXIT
&IF .&CN EQ . &GOTO -EXIT
*
*  determining if the file &CN &CT &CM is a legal calibration
*  file
*
&TEST = &LEFT OF &CN 3
&IF &TEST EQ CAL &GOTO -CHECKVOLTS
&TYPE NOT A CALIBRATION DATA FILE.  This run ( &CN &CT ) failed.
&GOTO -STARTLOOP
*
*  Checking the input voltage.
*
-CHECKVOLTS
&IF .&VOLTS NE . &SKIP 2
&TYPE NO VOLTAGE ENTERED.  This run ( &CN &CT ) failed.
```

```
&GOTO -STARTLOOP
*
*  Checking the water temp
*
&IF .&TEMP NE . &SKIP 2
&TYPE NO WATER TEMP ENTERED.  This run ( &CN &CT ) failed.
&GOTO -STARTLOOP
*
*  determining the name of the input zero pt file
*
-INNAME
&DTYPE = &RIGHT OF &CN 1
&RUN = &RIGHT OF &CN 4
&RUN = &LEFT OF &RUN 3
&ZN = &CONCAT OF ZERO &RUN &DTYPE
*
*  modifying &DTYPE for transfer to CAL FORTRAN
*
&QUOTE = '
&DTYPE = &CONCAT OF &QUOTE &DTYPE &QUOTE
*
*  retrieving the zero pt information from the file AVG DATA A
*
EXECIO * DISKR AVG DATA A (FINIS LOCATE /&ZN &CT / LIFO
&IF &RC EQ 0 &GOTO -READDATA
&TYPE The file &ZN &CT is not in AVG DATA A.
&GOTO -STARTLOOP
-READDATA
&READ ARGS
&READ VARS &D1 &D2 &VZERO &ZVDEV &SZERO &ZSDEV
*
*  setting up for cal fortran run the executing
*
&STACK LIFO &VZERO &SZERO
&STACK LIFO &DTYPE
&STACK LIFO &VOLTS
FI 03 DISK &CN &CT &CM
FI 12 AISK TRASH DATA A (LRECL 80
SET CMSTYPE HT
LOAD CAL (NOMAP START
SET CMSTYPE RT
*
*  writing to the contents of TRASH DATA A to CALIBRAT DATA A
*
EXECIO 1 DISKR TRASH DATA A ( LIFO
&READ VARS &VMEAN &SMEAN
EXECIO 1 DISKW CALIBRAT DATA A (STRING &CN &VMEAN &SMEAN &VOLTS &TEMP
*
```

```
*  clean-up
*
FINIS AVG DATA A
ERASE TRASH DATA
*
*  looping back
*
&GOTO -STARTLOOP
*
*  CAL EXEC ends
*
-EXIT
SET BLIP OFF
&EXIT
```

```
C
C   CAL FORTRAN    Written By: S.G. Hittel
C                  Version: 10-25-84
C
C     This code reads a ZONIC data file and claculates the mean of the
C     Channel one is assumed to carry velocity signals while
C     channel two is assumed to carry strain-gage signals.
C
C     This code is called by CAL EXEC.
C
C-------------------------------------------------------------
C
C     File Definitions:
C          03  input calibration file
C          12  TRASH DATA A (LRECL 90
C
C
C     CODES CALLED:   INPUT FORTRAN (reads input file)
C                     STAT FORTRAN (computes the standard deviation and
C                                   mean of the output variables)
C
C     VARIABLES IN AN UNNAMMED COMMON:  VELDAT, STRNDT
C
C-------------------------------------------------------------
C
C     LIST OF VARIABLES:
C        GAGE   character ; indicates the force/moment type of the input
C                           file
C        ICOUNT integer   ; number of elements actually in VELDAT and
C                           STRNDT
C        SDEV   real      ; standard deviation of SFACT
C        SFACT  real      ; output calibration factor for the
C                           force/moment channel
C        STRNDT real array; contains input and, later, the output
C                           values of the force/moment channel
C        SVOLTS real      ; The know input to the force/moment channel
C                           (dependent on input channel)
C        SZERO  real      ; mean of the force/moment channel of the zero
C                           pt. file
C        VDEV   real      ; standard deviation of VFACT
C        VELDAT real array; contains input and, later, the output
C                           values of the velocity channel
C        VFACT  real      ; output calibration factor for the velocity
C                           channel
C        VVOLTS real      ; The know input to the velocity channel
C        VZERO  real      ; mean of the velocity channel of the zero pt.
C                           file
```

```
C
C======================================================================
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER*1 GAGE
      COMMON VELDAT(1025),STRNDT(1025)
C-----------------------------------------------------------
C     READING FROM THE CONSOLE STACK
C-----------------------------------------------------------
C     READING THE INPUT CALIBRATION VOLTAGE
      READ(5,*) VVOLTS
C     READING WHICH STRAIN GAGE IS BEING CALIBRATED
      READ(5,*) GAGE
C     READING THE ZERO PT CALIBRATION DATA
      READ(5,*) VZERO,SZERO
C
C---------------------------------------------------------
C     READING THE INPUT CALIBRATION FILE
C---------------------------------------------------------
      CALL INPUT(ICOUNT)
C---------------------------------------------------------
C     DETERMINING THE STRAIN GAUGE CALIBRATION VOLTAGE FROM GAGE
C---------------------------------------------------------
      IF(GAGE.EQ.'Y') SVOLTS = 0.660D00
      IF(GAGE.EQ.'S') SVOLTS = 0.965D00
      IF(GAGE.EQ.'P') SVOLTS = 0.801D00
      IF(GAGE.EQ.'R') SVOLTS = 0.930D00
      IF(GAGE.EQ.'D') SVOLTS = 0.902D00
      IF(GAGE.EQ.'L') SVOLTS = 0.794D00
C----------------------------------------------------------
C     CALCULATING THE CALIBRATION FACTORS
C----------------------------------------------------------
      SFACT = 0.00D00
      VFACT = 0.00D00
      DO 80 I=1,ICOUNT,1
      STRNDT(I) = SVOLTS/(STRNDT(I) - SZERO)
      VELDAT(I) = VVOLTS/(VELDAT(I) - VZERO)
 80   CONTINUE
C
C---------------------------------------------------------
C     CALLING STATISTICAL ROUTINE
C---------------------------------------------------------
      CALL STAT(ICOUNT,VFACT,SFACT,VDEV,SDEV)
C---------------------------------------------------------
C     OUTPUT AREA
C---------------------------------------------------------
      WRITE(12,90)VFACT,SFACT
90    FORMAT(2E15.7)
      END
```

```
&TRACE OFF
*
*   Exec code MANIP (manipulate data)
*   Written by: Steven Hittel
*   version: 1-4-85
*
*  This exec code sets up the virtual machine for MANIP FORTRAN.
*  It also passes nessacary information to MANIP FORTRAN.
*
*  This code assumes that the input file, file 11, is named with the
*  following format:   GXXYYY .
*  where:      G is the first initial of the tape recorder channel
*                (D for drag,  L for lift, R for roll, ect.)
*              XX  is the draft number of the model
*              YYY is the run number of the data (as shown in the lab
*                  book.
*
*  This code either adds data to an already existing output file or
*  creates the output file GXX PDATA A if force data is requested or
*  GCXX PDATA A if force coefficent data is requested.
*
*  Codes called:  MANIP FORTRAN
*                 YESNO EXEC    (syn-type EXEC   yes=default)
*                 NOYES EXEC    (syn-type EXEC   no=default)
*
*  Data files used:    AVG DATA
*                      CALIBRAT DATA
*
***********************************************************************
-TOP
SET BLIP working
*
*  Determining what type of output is requested.
CLEAR
-DATA_REQUEST
&BEGTYPE 6
What type of output do you want?
     1) force/moment vs. velocity
     2) force coefficent vs. Froude number (displacement)
     3) force coefficent vs. Froude number (length)

Enter 1, 2, or 3.
&READ VARS &DATA_REQUEST
&IF .&DATA_REQUEST EQ .1 &SKIP 3
&IF .&DATA_REQUEST EQ .2 &SKIP 2
&IF .&DATA_REQUEST EQ .3 &SKIP 1
&GOTO -DATA_REQUEST
*
```

```
* Finding whether the user wants to by-pass the moment correction
-SKIP
&TYPE If Pitch or Roll data is evaluated, do you wish to BY-PASS the
&TYPE correction for Drag force and Side force respectively? (Y/N)
&READ VARS &PAS
CLEAR
&IF .&PAS EQ .Y &SKIP 2
&IF .&PAS EQ .N &SKIP 1
&GOTO -SKIP
&QUOTE = '
&PAS = &CONCAT OF &QUOTE &PAS &QUOTE
*
*  Finding how the user wants to enter the files
-HOWFILE
&BEGTYPE 6
Would you like to:
     1) enter files individually
     2) have MANIP read them from a file
     3) quit

Enter 1,2, or 3
&READ VARS &WHAT
&IF .&WHAT EQ .1 &GOTO -STARTLOOP
&IF .&WHAT EQ .2 &GOTO -STKFILE
&IF .&WHAT EQ .3 &GOTO -EXIT
&GOTO -HOWFILE
-STKFILE
*
*  The files will be entered using a file containing
*  a list of file names.
*  Determining the name of the file containing the file names.
*  The format of the file is assumed to be:
*  filename filetype filemode <other parameters which are not used>
*  filename filetype filemode <  "      "         "    "    "    "
*    .          .        .       .      .         .    .    .    .
*    .          .        .       .      .         .    .    .    .
*    .          .        .       .      .         .    .    .    .
*  filename  filemode filetype <                                 >
&TYPE What is the FN FT FM of the file which contains the filenames of
&TYPE the files which MANIP is to reduce?  The default filemode is A.
&TYPE
&READ VARS &STKNAM &STKTYP &STKMOD
&IF .&STKNAM EQ . &GOTO -STKFILE
&IF .&STKNAM EQ .QUIT &GOTO -EXIT
&IF .&STKTYP EQ . &GOTO -STKFILE
&IF .&STKMOD EQ . &STKMODE = A
*
*  Checking for the existence of &STKNAM &STKTYP &STKMOD
```

```
STATE &STKNAM &STKTYP &STKMOD
&IF &RC EQ 0 &GOTO -GOODFILE
*
*  The file does not exist
&TYPE The file &STKNAM &STKTYP &STKMOD does not exist.
&GOTO -HOWFILE
*
*  The file does exist
*  Stacking the file &STKNAM &STKTYP &STKMOD.
-GOODFILE
EXSERV STKFILE &STKNAM &STKTYP &STKMOD
CLEAR
&TYPE Execution begins on &STKNAM &STKTYP &STKMOD
*
*  At this point either the files will be entered individually or
*  a list of files is already in the console stack.
-STARTLOOP
SENTRIES
&IF &RC NE 0 &SKIP 3
&TYPE
&TYPE Enter the FN FT FM of the file which MANIP is to reduce,
&TYPE or enter a null line to exit. The default FT is DATA.  The default FM is *.
&READ VARS &FN &FT &FM
&IF .&FN EQ . &GOTO -EXIT
&IF .&FM EQ . &FM = *
&IF .&FT EQ . &FT = DATA
*
*  Checking the validity of the input filename
STATE &FN &FT &FM
&IF &RC EQ 0 &SKIP 2
&TYPE THE FILE &FN &FT &FM DOES NOT EXIST.
&GOTO -STARTLOOP
&GAGE = &LEFT OF &FN 1
&IF &GAGE EQ D &GOTO -GOODNAME
&IF &GAGE EQ L &GOTO -GOODNAME
&IF &GAGE EQ S &GOTO -GOODNAME
&IF &GAGE EQ P &GOTO -GOODNAME
&IF &GAGE EQ Y &GOTO -GOODNAME
&IF &GAGE EQ R &GOTO -GOODNAME
&TYPE INVALID GAGE TYPE.  This run ( &FN &FT &FM ) failed.
&GOTO -STARTLOOP
*
*  The input filename is valid.
*  Creating the filenames of the calibration data file and the zero pt.
*  data file.
-GOODNAME
&RUN = &RIGHT OF &FN 3
&DRAFT = &RIGHT OF &FN 5
```

```
&DRAFT = &LEFT OF &DRAFT 2
&ZN = &CONCAT OF ZERO &RUN &GAGE
&CN = &CONCAT OF CAL &RUN &GAGE
*
*  Checking the validity of the draft number
&IF &DRAFT EQ 15 &SKIP 6
&IF &DRAFT EQ 45 &SKIP 5
&IF &DRAFT EQ 65 &SKIP 4
&TYPE
&TYPE INVALID DRAFT NUMBER.  This run fails ( &FN &FT &FM )
&GOTO -STARTLOOP
*
*  Retrieving the calibration data from CALIBRAT DATA.
EXECIO * DISKR CALIBRAT DATA A 1 (FIND /&CN / LIFO
&IF &RC EQ 0 &SKIP 3
&TYPE  THE FILE &CN IS NOT IN CALIBRAT DATA.
&TYPE  This run ( &FN &FT &FM ) fails.
&GOTO -STARTLOOP
&READ VARS &D1 &D2
&READ VARS &D1 &VFACT &SFACT &D2 &TEMP
&IF .&TEMP EQ . &TYPE NO INPUT TEMP. This run (&FN &FT &FM ) fails.
&IF .&TEMP EQ . &GOTO -STARTLOOP
*
*  Retriving the zero pt data from AVG DATA.
EXECIO * DISKR AVG DATA A 1 (FIND /&ZN / LIFO
&IF &RC EQ 0 &SKIP 2
&TYPE  THE FILE &ZN IS NOT IN AVG DATA.  This run ( &FN &FT &FM ) fails.
&GOTO -STARTLOOP
&READ VARS &D1 &D2
&READ VARS &D1 &D2 &VZERO &D3 &SZERO &D4
*
* At this point the code seperates the Roll and Pitch moments from the
* other data types.  If the data to be reduced is Roll or Pitch
* then other values are read from CALIBRAT DATA and AVG DATA
* to allow the moments to be corrected by the forces applied at a
* distance. Drag force causing Pitching moment and Side force causing
* Roll moment.  This section can be by-passed.
-SEPERATE
&IF &PAS EQ 'Y' &GOTO -OUTFILE
&IF &GAGE EQ P &SKIP 2
&IF &GAGE EQ R &SKIP 1
&GOTO -OUTFILE
-OTHERS
&IF &GAGE EQ R &FORCE = S
&IF &GAGE EQ P &FORCE = D
*
* Retrieving the zero point data for the force from AVG DATA A
&ZRNAME = &CONCAT OF ZERO &RUN &FORCE
```

```
EXECIO * DISKR AVG DATA A 1 (FIND /&ZRNAME / LIFO
&IF &RC EQ 0 &SKIP 3
&TYPE THE ZERO POINT INFORMATION FOR THE CORRECTION CANNOT BE FOUND.
&TYPE This run ( &FN &FT &FM ) fails.
&GOTO -STARTLOOP
&READ VARS &D1 &D2
&READ VARS &D1 &D2 &D3 &D4 &ZCOR &D5
*
* Retrieving the caibration information from CALIBRAT DATA for the
* correcting force.
&CLNAME = &CONCAT OF CAL &RUN &FORCE
EXECIO * DISKR CALIBRAT DATA A 1 (FIND /&CLNAME / LIFO
&IF &RC EQ 0 &SKIP 3
&TYPE THE CAL POINT INFORMATION FOR THE CORRECTION CANNOT BE FOUND
&TYPE This run ( &FN &FT &FM ) fails.
&GOTO -STARTLOOP
&READ VARS &D1 &D2
&READ VARS &D1 &D2 &CALCOR &D3 &D4
*
* Retrieving the run data from AVG DATA for the correcting force.
&DNAME = &CONCAT OF &GAGE &DRAFT &RUN
EXECIO * DISKR AVG DATA A 1 (FIND /&DNAME / LIFO
&IF &RC EQ 0 &SKIP 3
&TYPE THE DATA VOLTAGE FOR THE CORRECTING FORCE CANNOT BE FOUND IN AVG DATA
&TYPE This run (&FN &FT &FM ) fails.
&GOTO -STARTLOOP
&READ VARS &D1 &D2
&READ VARS &D1 &D2 &D3 &D4 &DATCOR &D5
*
*  Checking for the existence of the output file.
*  The output file is named GZZXX PDATA A.  Where G is the initial of the
*  strain gage which produced the signal, ZZ is null if force data is
*  requested or is CD if displacement force coefficient and displacement
*  Foude number are requested.  ZZ is CL if wetted surface force
*  coefficent and length Froude number should be used.
*  XX is the draft number of the file being reduced.
-OUTFILE
&IF &DATA_REQUEST EQ 1 &Z =
&IF &DATA_REQUEST EQ 2 &Z = CD
&IF &DATA_REQUEST EQ 3 &Z = CL
&OUTNAME = &CONCAT OF &GAGE &Z &DRAFT
STATE &OUTNAME PDATA A
&IF &RC EQ 0 &GOTO -RUNIT
&HEADERC = &STRING OF RUN...FROUDE NUM....DEV...........COEFF.........DEV
&HEADERN = &STRING OF RUN...VELOCITY(M/S)...DEV.........FORCE/MOMENT......DEV
&HEADER =
&IF .&Z EQ . &HEADER = &HEADERN
&IF .&Z EQ .CD &HEADER = &HEADERC
```

```
&IF .&Z EQ .CL &HEADER = &HEADERC
*
*  Creating the output file
&STACK LIFO FILE
&STACK LIFO
&STACK LIFO &HEADER
&STACK LIFO INPUT
SET CMSTYPE HT
EDIT &OUTNAME PDATA A ( LRECL 90
SET CMSTYPE RT
*
*  Setting up for MANIP FORTRAN run.
-RUNIT
&QUOTE = '
&GAGE = &CONCAT OF &QUOTE &GAGE &QUOTE
&IF &PAS EQ 'Y' &SKIP 2
&IF &GAGE EQ 'P' &STACK LIFO &DATCOR &CALCOR &ZCOR
&IF &GAGE EQ 'R' &STACK LIFO &DATCOR &CALCOR &ZCOR
&STACK LIFO &VZERO &SZERO &TEMP &PAS
&STACK LIFO &GAGE &DATA_REQUEST &DRAFT &VFACT &SFACT
FI 03 DISK &FN &FT &FM
FI 05 TERMINAL
FI 12 DISK TRASH DATA A ( LRECL 90
*
* Checking for a compiled version of MANIP
STATE MANIP TEXT *
&IF &RC EQ 0 &SKIP 1
FORTVS MANIP
*
*  Running MANIP FORTRAN.
SET CMSTYPE HT
LOAD MANIP ( NOMAP START
SET CMSTYPE RT
*
*  At this point MANIP FORTRAN has written its output to the file
*  TRASH DATA A.  Here we read TRASH DATA A and then write the
*  information to the output file &OUTNAME PDATA A.
EXECIO * DISKR TRASH DATA A 1 ( LIFO
&READ VARS &VEL &VELDEV &STRN &STRNDEV
EXECIO 1 DISKW &OUTNAME PDATA A ( STRING &RUN &VEL &VELDEV &STRN &STRNDEV
*
*  clean-up
FINIS AVG DATA A
FINIS CALIBRAT DATA A
ERASE TRASH DATA A
*
*  looping back
&GOTO -STARTLOOP
```

```
*
*  MANIP EXEC ends
-EXIT
SET BLIP OFF
&EXIT
```

```
C
C     MANIP FORTRAN  (MANIPULATE DATA)      Written by S. G. Hittel
C                                           Version: 12-14-84
C
C     This code is driven by MANIP EXEC.  It reads strain gage signals
C     and velocity signals from file 3 and outputs to file 12.
C
C     MANIP FORTRAN calibrates the input signals using data passed
C     from MANIP EXEC and then calculates the mean and standard
C     deviation of the force and velocity, displacement force
C     coefficent vs. displacement Froude no., or Wetted Surface area
C     force coefficent vs. length Froude no.  If moment data is input
C     only the moment vs. velocity calculation will be allowed.
C
C     If the input file contains Pitch data MANIP FORTRAN will
C     subtract the moment caused by drag.  If the input file contains
C     Roll data MANIP FORTRAN will subtract the moment caused
C     by side force.
C
C     It is assumed that the input file was created by transferring
C     data from the ZONIC 5003 signal processor to the mainframe using
C     the XT EXEC.
C
C     MANIP FORTRAN does not communicate with the user.  MANIP EXEC
C     handles all I/O to the user.
C
C     CODES CALLED:   INPUT FORTRAN  (reads input file)
C                     STAT  FORTRAN  (computes the standard deviation
C                                     and mean of the output variables)
C
C     VARIABLES IN AN UNNAMMED COMMON:  VELDAT, STRNDT
C
C     LIST OF VARIABLES:
C        CALCOR real      ; calibration factor for the correcting force
C                           (only used for Roll and Pitch moments)
C        DATCOR real      ; data pt. voltage for the correcting force
C                           (only used for Roll and Pitch moments)
C        DISPL  integer   ; model draft number of model displacement
C                           depending on position in code
C        DTYPE  alfa      ; type of force/moment information contained
C                           in the input file
C        SFACT  real      ; calibration factor for the strain channel
C        SLOPE  real      ; same as *mult
C        STRNDT real array; input strain gage voltage data or output
C                           variable dependent on location in code.
C        VELDAT real array; input tachometer voltage data or actual
C                           model velocity dependent on position in code
C        VFACT  real      ; calibration factor for the velocity channel
```

```
C        RQUEST integer   ; what type of output file is desired
C        *MULT  real      ; slope of the calibration line used to
C                           change the strain gage voltage into a
C                           force/moment
C              D = drag force
C              L = lift force
C              R = roll moment
C              S = side force
C              P = pitch moment
C              Y = yaw moment
C
C        ZCOR   real      ; zero pt. data for the correcting force
C                           (only used for Roll and Pitch moments)
C-----------------------------------------------------------------------
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON VELDAT(1025),STRNDT(1025)
      REAL*8 INTERC,LINT,LMULT,LENGTH
      INTEGER*4 RQUEST,DISPL
      CHARACTER DTYPE*1,PAS
      LOGICAL PASS
C
C-----------------------------------------------------------
C     Initializing calibration constants
C-----------------------------------------------------------
      DATA DMULT/308.196022D00/LMULT/-491.0086547D00/
      DATA SMULT/959.924944D00/PMULT/285.403332D00/
      DATA YMULT/81.42538221D00/RMULT/-14.2613365D00/
      DATA VSLOPE/8.33333333D00/MARM15/0.3522D00/
      DATA MARM45/0.3335D00/MARM65/0.3222D00/
C
C-----------------------------------------------------------
C     Reading values from the console stack
C     VFACT, SFACT, VZERO, and SZERO are used for calibration
C     of data.
C     TEMP is used to determine the water density.
C     DTYPE, RQUEST, and DISPL are used for branching and information
C-----------------------------------------------------------
      PASS = .FALSE.
      READ(5,*) DTYPE,RQUEST,DISPL,VFACT,SFACT
      READ(5,*) VZERO,SZERO,TEMP,PAS
      IF (PAS .EQ. 'Y' ) PASS = .TRUE.
      IF (PASS) GOTO 5
      IF ( DTYPE .EQ.'R'.OR. DTYPE .EQ.'P') READ(5,*) DATCOR,CALCOR,ZCOR
C
C----------------------------------------------------------
C     Reading in values from the input file
C----------------------------------------------------------
```

```
 5    CALL INPUT (ICOUNT)
C
C------------------------------------------------------------
C     using calibration factors to correct values of VELDAT and STRNDT
C------------------------------------------------------------
      DO 10 I=1,ICOUNT,1
      VELDAT(I) = ( VELDAT(I) - VZERO ) * VFACT
      STRNDT(I) = ( STRNDT(I) - SZERO ) * SFACT
 10   CONTINUE
C
C------------------------------------------------------------
C     Modifying STRNDT to represent force in Newtons or moment in
C       Newton-meters.  This is dependent on 'DTYPE' (input file type)
C------------------------------------------------------------
      IF(DTYPE.EQ.'D') SLOPE = DMULT
      IF(DTYPE.EQ.'L') SLOPE = LMULT
      IF(DTYPE.EQ.'S') SLOPE = SMULT
      IF(DTYPE.EQ.'R') SLOPE = RMULT
      IF(DTYPE.EQ.'Y') SLOPE = YMULT
      IF(DTYPE.EQ.'P') SLOPE = PMULT
C
C------------------------------------------------------------
C     Preparing the values of the correcting force
C------------------------------------------------------------
      CORT = 0.0D00
      IF (PASS) GOTO 15
      IF (DTYPE .EQ.'P' .OR. DTYPE .EQ. 'R') THEN
         IF (DTYPE .EQ. 'P') THEN
             CORT = ( DATCOR - ZCOR ) * CALCOR * DMULT
             ELSE
             CORT = ( DATCOR - ZCOR ) * CALCOR * SMULT
         END IF
      END IF
 15   CONTINUE
      IF (DISPL .EQ. 15) MARM = MARM15
      IF (DISPL .EQ. 45) MARM = MARM45
      IF (DISPL .EQ. 65) MARM = MARM65
C
C-------------------------------------------------------------
C     Modifying STRNDT to represent its equivalent force/moment
C-------------------------------------------------------------
      CORRCT = CORT * MARM
      DO 20 I=1,ICOUNT,1
      STRNDT(I) = STRNDT(I) * SLOPE  - CORRCT
 20   CONTINUE
C
C------------------------------------------------------------
C     Modifying VELDAT to represent meters per second.
```

```
C     The factor of 3.298 converts revolutions per second into
C     meters per second.  This comes from the diameter of the
C     tachometer drive wheel.  ( 0.0965*PI = 1/3.298 )
C-----------------------------------------------------------
      DO 30 I=1,ICOUNT,1
      VELDAT(I) =  VELDAT(I) * VSLOPE  / 3.298D0
 30   CONTINUE
C
C-----------------------------------------------------------
C     Determining whether STRNDT represents a force or a
C     moment.  If STRNDT represents moment information then
C     force coefficent information will not be generated.
C-----------------------------------------------------------
      IF (DTYPE.EQ.'R' .OR. DTYPE.EQ.'P' .OR. DTYPE.EQ.'Y') GOTO 60
C
C-----------------------------------------------------------
C     If force/moment vs. velocity is requested then goto the
C     call of the statistical routine
C-----------------------------------------------------------
      IF(RQUEST.EQ.1) GOTO 60
C
C-------------------------------------------------------------
C     Calculating water density.  Formula taken from the CRC Handbook
C     of Chemistry and Physics  64TH Edition,  page F-6
C     units are kg/m**3
C     This is a very small correction--Negligible
C-------------------------------------------------------------
      TEMP = (TEMP -32.0) * 5.0/9.0
      ROE = (999.83952 + 16.945176 * TEMP - 7.9870401D-03 * TEMP*TEMP
     $-46.170461D-06 *TEMP**3 + 105.56302D-09 *TEMP**4 - 208.54253D-12
     $*TEMP**5)/(1 + 16.879850D-03*TEMP)
C
C-------------------------------------------------------------
C     Determining the displacement of the model in cubic meters
C-------------------------------------------------------------
      IF(DISPL.EQ.65) DPLACE =  42.07D-03
      IF(DISPL.EQ.45) DPLACE =  40.813D-03
      IF(DISPL.EQ.15) DPLACE =  38.870D-03
C
C-------------------------------------------------------------
C     Determining the wetted surface area of the model in sq. meters
C-------------------------------------------------------------
      IF(DISPL.EQ.65) WSAREA =  1.172D00
      IF(DISPL.EQ.45) WSAREA =  1.056D00
      IF(DISPL.EQ.15) WSAREA =  0.855D00
C
C-------------------------------------------------------------
C     Determining what area to use for the force coefficent data
```

```
C     and what length to use for the Froude number
C-----------------------------------------------------------
      IF ( RQUEST.EQ.2 ) THEN
         AREA = DPLACE ** (2./3.)
         LENGTH = DPLACE ** (1./3.)
      ELSE
         AREA = WSAREA
         LENGTH = 1.721D00
      END IF
      DO 40 I=1,ICOUNT,1
      STRNDT(I) = STRNDT(I)*2.0D0/(ROE * AREA * VELDAT(I)**2)
 40   CONTINUE
C
C----------------------------------------------------------
C     Modifying VELDAT to represent Froude number
C----------------------------------------------------------
      FACT = 1/(DSQRT( 9.81D0 * LENGTH ))
      DO 50 I=1,ICOUNT
      VELDAT(I) = VELDAT(I) * FACT
 50   CONTINUE
C
C----------------------------------------------------------
C     Calculating the mean and standard deviations of the output data
C----------------------------------------------------------
 60   CALL STAT(ICOUNT,VMEAN,SMEAN,VDEV,SDEV)
C
C----------------------------------------------------------
C     output area
C----------------------------------------------------------
      WRITE(12,80)VMEAN,VDEV,SMEAN,SDEV
 80   FORMAT(F5.3,8X,F5.3,9X,F8.3,7X,F8.3)
C---------------------------------------------------------
C     on end, execution returns to MANIP EXEC
C---------------------------------------------------------
      END
```

APPENDIX C. LIST OF EQUIPMENT USED

Dual Channel Low Pass Filters
Zonic Technical Laboratories, Inc.
Model AE-104

Memory Control
Zonic Technical Laboratories, Inc.
Model AE-101

Data Memory
Zonic Technical Laboratories, Inc.
Model AE-102

Optical Encoder
Accu-coder
Model 714
Serial Number 48071

Tape Recorder
Honeywell
Model 5600e

D.C. Power Supply
Hewlet Packard
Model 6226B
serial number 1104A01959

Digital Multimeter
Flute
Model 8050A
VPI&SU Inventory No. 69031

Strain-Gage Power-Supplies/Amplifiers
Vishay-Ellis
Model V/E-11

serial number	strain-gage channel
027487	drag force
027485	lift force
027482	side force
027484	pitch moment
032466	roll moment
027481	yaw moment

Sting Balance

channel	maximum force/moment
drag force	30 pounds
lift force	100 pounds
side force	100 pounds
pitch moment	400 inch-pounds
roll moment	50 inch-pounds
yaw moment	200 inch-pounds

APPENDIX D. NUMERICAL EXPERIMENTAL DATA

This appendix presents the numerical data obtained during this research. The data shown has been reduced to obtain the average and standard deviation of the data taken during each run. It should be noted that the coefficient data was obtained by calculating a drag coefficient for each of the 1000 to 2000 data points taken during the run then averaging them. This means that the standard deviations shown are the standard deviations of the variables presented and not necessarily those calculated from the standard deviations of the primary forces, moments, and velocity.

Drag Force and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
001	0.714	0.015	2.29	2.81
002	0.918	0.019	3.25	2.26
003	1.38	0.021	19.4	6.02
004	1.79	0.021	30.6	6.87
005	0.393	0.021	1.70	2.54
006	0.508	0.023	1.89	3.51
007	1.16	0.022	12.6	4.84
008	1.49	0.024	26.0	6.61
009	2.09	0.033	31.4	5.59
010	0.177	0.023	17.7	4.60
011	0.705	0.023	4.00	4.17
012	1.83	0.025	28.5	6.62
013	2.04	0.026	27.2	7.62
014	2.25	0.024	36.7	6.20
015	2.22	0.026	42.2	6.16

016	2.50	0.027	44.1	5.13
017	2.84	0.023	52.9	6.24
018	2.71	0.025	54.7	6.83

Lift Force and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
002	0.911	0.020	-76.4	4.53
003	1.33	0.024	-201.	3.30
004	1.71	0.024	-256.	14.1
005	0.461	0.019	-6.39	1.55
006	0.495	0.022	-14.5	2.64
007	1.12	0.023	-150.	4.55
008	1.47	0.026	-236.	8.81
009	1.93	0.999	-190.	113.
010	0.197	0.022	-1.86	1.18
011	0.719	0.024	-42.4	4.67
012	1.13	0.013	-124.	9.20
013	1.76	0.966	-129.	98.9
014	2.24	0.024	-190.	4.31
015	2.25	0.025	-174.	3.23
016	2.51	0.026	-170.	3.14
017	2.82	0.024	-150.	2.18
018	2.71	0.025	-157.	4.73

Side Force and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
001	0.708	0.019	3.91	2.03
002	0.024	0.020	2.42	1.37
003	1.22	0.024	-9.82	3.01
004	1.71	0.021	-17.5	4.16
005	0.503	0.020	1.55	1.90
006	0.493	0.021	0.359	2.84
007	1.12	0.025	-6.24	3.20
008	1.47	0.026	-10.1	3.47
009	1.99	0.989	-14.1	14.4
010	0.209	0.021	0.798	2.48
011	0.698	0.024	-1.77	3.32
012	1.84	0.026	-13.03	4.02
013	2.12	0.024	-7.90	3.30
014	2.24	0.024	-11.1	3.76
015	2.09	0.029	-17.9	3.75
016	2.47	0.027	-12.6	3.52

017	2.88	0.023	-18.5	3.70
018	2.71	0.026	10.1	2.13

Yaw Moment and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
2	0.007	0.019	-0.018	0.081
3	1.22	0.022	-5.72	0.884
4	1.69	0.021	-10.6	1.09
5	0.526	0.019	-0.304	0.137
6	0.494	0.020	-0.124	0.569
7	1.12	0.024	-2.86	0.640
8	1.47	0.025	-4.61	0.907
9	1.97	0.955	-6.27	1.28
10	0.223	0.020	-0.053	0.154
11	0.688	0.023	-0.869	0.490
12	1.84	0.024	-3.79	1.87
13	2.10	0.025	-3.07	0.530
14	2.22	0.024	-5.02	1.13
15	2.06	0.029	-5.99	0.544
16	2.45	0.027	-6.50	0.649
17	2.89	0.023	-7.71	0.703
18	2.69	0.026	-2.42	0.311

Pitching Moment and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
001	0.733	0.017	3.67	0.503
002	0.902	0.021	14.1	0.788
003	1.30	0.020	37.2	1.22
004	1.71	0.025	51.3	2.55
005	0.497	0.023	1.35	0.536
006	0.479	0.023	2.91	0.671
007	1.14	0.025	27.2	1.57
010	0.187	0.021	21.1	0.429
011	0.711	0.024	7.95	0.914
012	1.84	0.024	35.9	2.26
013	2.09	0.024	30.2	3.18
014	2.24	0.026	28.9	1.51
015	2.13	0.028	33.3	1.39
016	2.47	0.026	32.1	1.27
017	2.87	0.023	82.5	3.50
018	2.70	0.026	35.9	1.31

Roll Moment and Velocity Data for Draft 65 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
001	0.616	0.017	0.113	0.113
002	0.022	0.020	0.183	0.022
003	1.36	0.025	0.257	0.601
004	1.70	0.023	0.561	0.564
005	0.475	0.019	0.023	0.044
006	0.483	0.022	0.049	0.252
007	1.12	0.025	0.456	0.276
008	1.47	0.026	0.125	0.558
009	1.96	0.993	1.12	1.54
010	0.196	0.022	0.003	0.052
011	0.712	0.024	0.007	0.195
012	1.85	0.025	0.654	0.743
013	2.06	0.025	0.856	0.337
014	2.24	0.023	1.08	0.720
015	2.18	0.027	1.70	0.369
016	2.49	0.026	1.53	0.645
017	2.86	0.023	2.51	0.181
018	2.71	0.026	2.17	0.297

Wetted Surface Drag Coefficient and Length Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
001	0.174	0.004	0.008	0.009
002	0.223	0.005	0.007	0.005
003	0.335	0.005	0.018	0.005
004	0.435	0.005	0.016	0.004
005	0.096	0.005	0.019	0.029
006	0.124	0.006	0.012	0.023
007	0.282	0.005	0.016	0.006
008	0.363	0.006	0.020	0.005
009	0.508	0.008	0.012	0.002
010	0.043	0.006	1.01	0.392
011	0.172	0.006	0.014	0.014
012	0.445	0.006	0.015	0.003
013	0.497	0.006	0.011	0.003
014	0.547	0.006	0.012	0.002
015	0.540	0.006	0.015	0.002
016	0.608	0.007	0.012	0.001
017	0.691	0.006	0.011	0.001
018	0.660	0.006	0.013	0.002

Wetted Surface Lift Coefficient and Length Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
086	0.569	0.012	-0.049	0.002
002	0.222	0.005	-0.157	0.011
003	0.325	0.006	-0.193	0.007
004	0.415	0.006	-0.150	0.010
005	0.112	0.005	-0.051	0.012
006	0.120	0.005	-0.102	0.020
007	0.273	0.006	-0.204	0.010
008	0.359	0.006	-0.185	0.010
009	0.470	0.243	-0.076	0.326
010	0.048	0.005	-0.080	0.051
011	0.175	0.006	-0.140	0.016
012	0.276	0.003	-0.165	0.013
013	0.428	0.235	-0.054	0.043
014	0.544	0.006	-0.066	0.002
015	0.546	0.006	-0.059	0.002
016	0.610	0.006	-0.046	0.001
017	0.687	0.006	-0.032	0.001
018	0.660	0.006	-0.036	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
001	0.172	0.005	0.013	0.007
003	0.297	0.006	-0.011	0.004
004	0.417	0.005	-0.010	0.002
005	0.122	0.005	0.010	0.013
006	0.120	0.005	0.002	0.020
007	0.272	0.006	-0.009	0.005
008	0.359	0.006	-0.008	0.003
009	0.483	0.241	-0.006	0.008
010	0.051	0.005	0.024	0.103
011	0.170	0.006	-0.006	0.012
012	0.448	0.006	-0.007	0.002
013	0.516	0.006	-0.003	0.001
014	0.545	0.006	-0.004	0.001
015	0.510	0.007	-0.007	0.002
016	0.601	0.007	-0.004	0.001

017	0.701	0.006	-0.004	0.001
018	0.659	0.006	0.002	0.000

Displacement Drag Coefficient and Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
001	0.387	0.008	0.074	0.091
002	0.497	0.010	0.064	0.045
003	0.745	0.011	0.170	0.053
004	0.967	0.011	0.159	0.036
005	0.213	0.011	0.180	0.277
006	0.275	0.013	0.119	0.227
007	0.627	0.012	0.156	0.060
008	0.807	0.013	0.194	0.050
009	1.13	0.018	0.119	0.022
010	0.096	0.013	9.86	3.800
011	0.382	0.013	0.133	0.139
012	0.991	0.014	0.141	0.033
013	1.11	0.014	0.108	0.030
014	1.22	0.013	0.120	0.020
015	1.20	0.014	0.142	0.020
016	1.35	0.015	0.117	0.013
017	1.54	0.012	0.108	0.013
018	1.47	0.013	0.123	0.015

Displacement Side Coefficient and Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
001	0.383	0.011	0.128	0.065
003	0.661	0.013	-0.109	0.035
004	0.927	0.011	-0.099	0.024
005	0.272	0.011	0.097	0.124
006	0.267	0.012	0.018	0.197
007	0.606	0.014	-0.083	0.044
008	0.798	0.014	-0.077	0.027
009	1.08	0.535	-0.054	0.075
010	0.113	0.012	0.230	0.994
011	0.378	0.013	-0.062	0.115
012	0.998	0.014	-0.064	0.020
013	1.15	0.013	-0.029	0.012
014	1.21	0.013	-0.037	0.012
015	1.13	0.016	-0.068	0.015

016	1.34	0.014	-0.034	0.010
017	1.56	0.012	-0.037	0.008
018	1.47	0.014	0.023	0.005

Displacement Lift Coefficient and Froude number for Draft 65 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
086	1.27	0.026	-0.471	0.019
002	0.493	0.011	-1.53	0.111
003	0.722	0.013	-1.87	0.071
004	0.923	0.013	-1.46	0.092
005	0.249	0.010	-0.498	0.119
006	0.268	0.012	-0.986	0.190
007	0.607	0.012	-1.97	0.094
008	0.798	0.014	-1.79	0.092
009	1.05	0.541	-0.740	3.16
010	0.107	0.012	-0.774	0.496
011	0.389	0.013	-1.36	0.160
012	0.613	0.007	-1.60	0.126
013	0.953	0.523	-0.525	0.417
014	1.21	0.013	-0.640	0.017
015	1.22	0.014	-0.570	0.017
016	1.36	0.014	-0.447	0.012
017	1.53	0.013	-0.311	0.006
018	1.47	0.014	-0.353	0.014

Drag Force and Velocity Data for Draft number 45 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
080	0.501	0.015	1.41	3.16
081	0.688	0.019	5.29	4.65
082	1.36	0.019	17.3	5.36
083	1.61	0.026	36.5	6.01
084	3.07	0.043	26.4	5.26
085	2.24	0.023	31.8	5.33
086	2.35	0.049	35.1	5.92
087	2.33	0.029	33.1	6.50
088	2.63	0.027	40.4	5.93

Lift Force and Velocity Data for Draft number 45 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
080	0.498	0.017	-16.8	2.02
081	0.669	0.020	-76.3	4.25
082	1.35	0.018	-196.	7.35
083	1.62	0.026	-236.	12.2
084	3.08	0.042	-107.	6.91
085	2.24	0.023	-166.	2.58
087	2.33	0.029	-160.	5.32
088	2.63	0.027	-145.	5.77

Side Force and Velocity Data for Draft number 45 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
080	0.493	0.016	-0.090	1.70
081	0.726	0.018	-5.38	2.37
082	1.38	0.018	-8.51	3.10
083	1.62	0.026	-13.5	3.20
084	1.92	0.022	-6.07	4.54
086	2.34	0.047	-5.90	5.73

Pitching Moment and Velocity Data for Draft number 45 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
080	0.490	0.015	2.29	0.476
081	0.710	0.019	13.9	0.973
082	1.38	0.019	35.4	1.86
083	1.62	0.025	55.6	2.12
084	1.91	0.022	30.0	1.57
085	2.24	0.022	25.3	1.09
086	2.34	0.049	26.4	1.27
087	2.33	0.029	27.5	1.17
088	2.67	0.029	28.9	1.43

Yaw Moment and Velocity Data for Draft number 45 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
80	0.485	0.015	-0.271	0.284
81	0.731	0.018	-0.922	0.704
82	1.36	0.019	-1.09	0.627

83	1.61	0.025	0.946	1.23
84	1.93	0.022	1.47	0.860
85	2.21	0.022	1.40	0.610
86	2.34	0.048	1.65	0.569
87	2.30	0.029	1.67	0.833
88	2.69	0.028	1.23	0.868

Wetted Surface Drag Coefficient and Length Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.122	0.004	0.011	0.024
081	0.167	0.005	0.021	0.019
082	0.331	0.005	0.018	0.006
083	0.392	0.006	0.027	0.004
084	0.748	0.010	0.005	0.001
085	0.545	0.006	0.012	0.002
086	0.571	0.012	0.012	0.002
087	0.566	0.007	0.012	0.002
088	0.640	0.007	0.011	0.002

Wetted Surface Lift Coefficient and Length Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.121	0.004	-0.129	0.018
081	0.163	0.005	-0.324	0.025
082	0.329	0.004	-0.203	0.009
083	0.394	0.006	-0.170	0.008
084	0.751	0.010	-0.021	0.002
085	0.545	0.006	-0.063	0.002
087	0.566	0.007	-0.056	0.002
088	0.641	0.007	-0.040	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.120	0.004	-0.001	0.013
081	0.177	0.004	-0.019	0.009
082	0.335	0.004	-0.009	0.003
083	0.394	0.006	-0.010	0.002

084	0.467	0.005	-0.003	0.002
086	0.570	0.012	-0.002	0.002

Displacement Drag Coefficient and Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.273	0.008	0.094	0.213
081	0.374	0.011	0.190	0.167
082	0.740	0.011	0.158	0.049
083	0.876	0.014	0.238	0.039
084	1.67	0.023	0.047	0.010
085	1.22	0.012	0.107	0.018
086	1.28	0.027	0.108	0.018
087	1.27	0.016	0.103	0.020
088	1.43	0.015	0.099	0.015

Displacement Lift Coefficient and Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.271	0.009	-1.15	0.158
081	0.364	0.011	-2.89	0.218
082	0.736	0.010	-1.81	0.080
083	0.882	0.014	-1.52	0.076
084	1.68	0.023	-0.190	0.014
085	1.22	0.013	-0.558	0.014
087	1.27	0.016	-0.499	0.019
088	1.43	0.015	-0.354	0.013

Displacement Side Coefficient and Froude number for Draft 45 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
080	0.268	0.009	-0.008	0.119
081	0.395	0.010	-0.174	0.078
082	0.750	0.010	-0.076	0.028
083	0.881	0.014	-0.087	0.021
084	1.04	0.012	-0.028	0.021
086	1.28	0.026	-0.018	0.017

Drag Force and Velocity Data for Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
019	0.236	0.019	0.269	3.26
021	0.524	0.023	1.54	3.70
022	0.627	0.019	0.803	4.14
023	0.765	0.022	3.19	3.94
025	1.21	0.021	12.3	4.91
026	1.16	0.022	12.3	4.89
027	1.40	0.020	18.6	4.46
028	1.70	0.022	24.1	6.32
029	1.88	0.021	21.9	6.34
030	1.97	0.022	22.1	7.05
031	2.11	0.024	35.2	5.99
032	2.48	0.024	27.2	5.57
033	2.66	0.019	37.9	5.72
034	2.77	0.023	46.4	5.77
035	2.51	0.041	47.6	5.02
036	2.91	0.024	49.1	7.91

Lift Force and Velocity Data for Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
019	0.244	0.019	-2.81	1.49
020	0.228	0.022	-7.98	1.38
021	0.517	0.023	-13.1	2.18
022	0.571	0.019	-17.6	2.28
023	0.763	0.022	-40.2	2.37
025	0.665	0.021	-126.	3.02
026	1.15	0.023	-126.	3.91
027	1.39	0.020	-154.	4.57
028	1.69	0.022	-158.	4.77
029	1.87	0.022	-85.0	4.14
030	1.96	0.022	-127.	16.5
031	2.11	0.024	-127.	3.17
032	2.46	0.023	-128.	3.18
033	2.65	0.019	-126.	2.61
034	2.78	0.023	-127.	4.24
035	2.51	0.033	-125.	3.61
036	2.92	0.024	-130.	5.84

Side Force and Velocity Data for Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
019	0.215	0.017	-0.168	2.86
020	0.193	0.021	-1.79	2.00
021	0.511	0.024	0.115	3.98
022	0.824	0.020	3.70	3.12
023	0.777	0.022	0.615	3.76
025	1.29	0.021	-0.167	1.98
026	1.15	0.021	-1.36	2.59
027	1.40	0.021	-2.32	3.26
028	1.75	0.021	1.60	4.12
029	1.88	0.021	-1.13	3.49
030	1.97	0.022	-1.62	2.60
031	2.11	0.024	-32.0	2.86
032	2.52	0.024	-1.84	5.28
033	2.71	0.019	-1.19	4.23
034	2.76	0.023	-4.80	3.61
035	2.52	0.035	-3.76	3.08
036	2.90	0.023	-5.23	4.90

Pitching Moment and Velocity Data For Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
019	0.221	0.018	0.428	0.506
020	0.202	0.022	0.880	0.577
021	0.506	0.023	2.90	0.904
022	0.710	0.020	1.10	0.828
023	0.779	0.021	7.43	0.780
025	1.25	0.020	21.9	0.906
026	1.15	0.021	22.0	0.999
027	1.40	0.021	31.5	1.02
028	1.73	0.021	35.4	1.32
029	1.88	0.021	22.5	1.08
030	1.97	0.021	16.3	1.96
031	2.12	0.024	17.5	1.28
033	2.69	0.021	21.0	1.07
034	2.77	0.022	24.0	1.16
035	2.52	0.053	21.7	1.46
036	2.90	0.022	24.7	1.02
032	2.49	0.024	-8.86	1.44

Roll Moment and Velocity Data For Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
019	0.227	0.018	-0.012	0.079
020	0.211	0.021	0.003	0.069
021	0.511	0.024	0.008	0.131
022	0.719	0.021	-0.010	0.152
023	0.77	0.022	-0.080	0.105
025	1.24	0.021	-0.178	0.155
026	1.16	0.022	-0.345	0.311
027	1.40	0.020	-0.414	0.495
028	1.71	0.022	-0.012	0.265
029	1.87	0.057	-0.185	0.374
030	1.97	0.022	-0.152	0.170
031	2.12	0.024	-0.380	0.241
032	2.48	0.024	0.470	0.277
033	2.67	0.020	0.373	0.280
034	2.76	0.023	0.746	0.235
035	2.52	0.034	0.269	0.368
036	2.90	0.023	0.844	0.373

Yaw Moment and Velocity Data For Draft 15 with Straight Rudders

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
19	0.216	0.018	-0.051	0.178
20	0.176	0.021	0.078	0.161
21	0.506	0.022	-0.043	0.376
22	0.535	0.022	-0.286	0.340
23	0.783	0.022	-0.246	0.348
25	1.30	0.022	-0.782	0.529
26	1.15	0.020	-0.697	0.760
27	1.39	0.021	-0.292	0.991
28	1.79	0.022	2.11	0.594
29	1.87	0.020	-0.436	0.534
30	1.95	0.022	-0.051	0.468
31	2.09	0.024	0.169	0.785
32	2.52	0.024	0.131	0.843
33	2.72	0.020	0.141	0.725
34	2.75	0.021	0.707	0.597
35	2.54	0.034	0.463	0.841
36	2.87	0.023	1.81	0.735

Wetted Surface Drag Coefficient and Length Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.057	0.005	0.010	0.143
021	0.128	0.006	0.013	0.032
022	0.152	0.005	0.005	0.025
023	0.186	0.005	0.013	0.016
025	0.295	0.005	0.020	0.008
026	0.282	0.005	0.022	0.009
027	0.341	0.005	0.022	0.005
028	0.414	0.005	0.019	0.005
029	0.458	0.005	0.014	0.004
030	0.479	0.005	0.013	0.004
031	0.513	0.006	0.019	0.003
032	0.603	0.006	0.010	0.002
033	0.646	0.005	0.013	0.002
034	0.674	0.005	0.014	0.002
035	0.611	0.010	0.018	0.002
036	0.709	0.006	0.014	0.002

Wetted Surface Lift Coefficient and Length Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.059	0.005	-0.109	0.058
020	0.056	0.005	-0.364	0.075
021	0.126	0.006	-0.115	0.020
022	0.139	0.005	-0.127	0.017
023	0.186	0.005	-0.162	0.014
025	0.162	0.005	-0.668	0.040
026	0.279	0.006	-0.224	0.011
027	0.338	0.005	-0.187	0.007
028	0.410	0.005	-0.130	0.005
029	0.456	0.005	-0.057	0.003
030	0.478	0.005	-0.077	0.010
031	0.514	0.006	-0.067	0.002
032	0.600	0.006	-0.049	0.001
033	0.645	0.005	-0.042	0.001
034	0.676	0.005	-0.038	0.001
035	0.610	0.008	-0.047	0.001
036	0.711	0.006	-0.036	0.002

Wetted Surface Side Coefficient and Length Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.052	0.004	-0.015	0.154
020	0.047	0.005	-0.128	0.148
021	0.124	0.006	0.000	0.036
022	0.200	0.005	0.013	0.011
023	0.189	0.005	0.002	0.015
025	0.313	0.005	0.000	0.003
026	0.281	0.005	-0.002	0.005
027	0.341	0.005	-0.003	0.004
028	0.426	0.005	0.001	0.003
029	0.457	0.005	-0.001	0.002
030	0.478	0.005	-0.001	0.002
031	0.514	0.006	-0.017	0.002
032	0.613	0.006	-0.001	0.002
033	0.660	0.005	0.000	0.001
034	0.672	0.006	-0.001	0.001
035	0.614	0.009	-0.001	0.001
036	0.706	0.006	-0.001	0.001

Displacement Drag Coefficient and Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.129	0.010	0.073	1.06
021	0.288	0.013	0.097	0.237
022	0.344	0.011	0.036	0.185
023	0.420	0.012	0.095	0.117
025	0.665	0.011	0.147	0.059
026	0.636	0.012	0.161	0.064
027	0.768	0.011	0.165	0.040
028	0.934	0.012	0.145	0.038
029	1.03	0.012	0.108	0.031
030	1.08	0.012	0.099	0.032
031	1.16	0.013	0.138	0.024
032	1.36	0.013	0.077	0.016
033	1.46	0.011	0.094	0.014
034	1.52	0.012	0.105	0.013
035	1.38	0.022	0.132	0.014
036	1.60	0.013	0.101	0.016

Displacement Lift Coefficient and Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.134	0.010	-0.813	0.434
020	0.125	0.012	-2.71	0.557
021	0.284	0.013	-0.859	0.148
022	0.313	0.010	-0.945	0.128
023	0.419	0.012	-1.21	0.101
025	0.365	0.011	-4.98	0.301
026	0.629	0.013	-1.67	0.081
027	0.761	0.011	-1.39	0.052
028	0.925	0.012	-0.968	0.037
029	1.03	0.012	-0.423	0.022
030	1.08	0.012	-0.573	0.071
031	1.16	0.013	-0.498	0.018
032	1.35	0.013	-0.366	0.011
033	1.45	0.011	-0.313	0.009
034	1.52	0.012	-0.287	0.010
035	1.38	0.018	-0.348	0.011
036	1.60	0.013	-0.266	0.012

Displacement Side Coefficient and Froude number for Draft 15 with Straight Rudders

RUN	FROUDE NUM	DEV	COEFF	DEV
019	0.118	0.009	-0.113	1.15
020	0.106	0.012	-0.956	1.10
021	0.280	0.013	0.001	0.267
022	0.452	0.011	0.094	0.079
023	0.426	0.012	0.017	0.110
025	0.705	0.011	-0.002	0.021
026	0.633	0.011	-0.018	0.034
027	0.769	0.012	-0.021	0.029
028	0.959	0.012	0.009	0.024
029	1.03	0.012	-0.006	0.017
030	1.08	0.012	-0.007	0.012
031	1.16	0.013	-0.125	0.012
032	1.38	0.013	-0.005	0.015
033	1.49	0.011	-0.003	0.010
034	1.52	0.012	-0.011	0.008
035	1.38	0.019	-0.010	0.008
036	1.59	0.013	-0.011	0.010

Drag Force and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
072	0.629	0.017	3.43	3.08
073	1.35	0.050	8.58	6.38
074	1.27	0.021	20.5	4.41
075	1.43	0.019	36.6	5.90
076	1.93	0.021	35.8	7.12
077	2.12	0.022	44.9	5.47
078	2.30	0.019	58.8	4.93
079	2.39	0.023	70.9	4.32

Lift Force and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
072	0.683	0.019	-28.1	1.43
073	1.34	0.048	-99.1	3.44
074	1.29	0.022	-247.	10.1
075	1.45	0.020	-375.	8.03
076	1.93	0.021	-294.	17.9
077	2.12	0.023	-78.5	0.567
078	2.29	0.020	-240.	2.41
079	2.39	0.082	-225.	1.98

Side Force and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
072	0.595	0.020	0.035	4.07
073	1.32	0.052	-7.54	5.12
075	1.36	0.020	-41.4	6.61
076	1.89	0.021	-23.0	8.95
077	2.12	0.023	-15.8	7.24
078	2.30	0.019	-18.4	6.99
079	2.39	0.023	-29.7	9.08

Pitching Moment and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
072	0.608	0.020	1.77	0.515
073	1.34	0.049	15.1	0.811
074	1.28	0.021	39.3	1.47
075	1.37	0.020	65.6	2.09

076	1.90	0.021	52.0	3.01
077	2.12	0.022	42.0	0.952
078	2.29	0.018	44.2	1.57
079	2.40	0.023	48.7	1.32

Roll Moment and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
072	0.624	0.020	0.114	0.135
073	1.36	0.049	0.701	0.184
075	1.39	0.020	1.52	0.182
076	1.90	0.022	5.55	0.499
077	2.12	0.023	3.95	0.523
078	2.30	0.019	1.83	0.240
079	2.40	0.023	1.15	0.340

Yaw Moment and Velocity data for Draft 65 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
72	0.576	0.019	1.605	0.349
73	1.34	0.051	5.651	0.709
74	1.28	0.023	22.2	1.06
75	1.64	0.022	45.7	1.54
76	1.87	0.021	60.9	0.928
77	2.11	0.021	64.2	0.741
78	2.28	0.020	75.5	0.626
79	2.37	0.024	76.9	0.555

Wetted Surface Drag Coefficient and Length Froude number for Draft 65 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.153	0.004	0.015	0.013
073	0.329	0.012	0.008	0.006
074	0.310	0.005	0.022	0.005
075	0.348	0.005	0.031	0.005
076	0.469	0.005	0.017	0.003
077	0.515	0.005	0.017	0.002
078	0.559	0.005	0.019	0.002
079	0.582	0.006	0.021	0.001

Wetted Surface Lift Coefficient and Length Froude number for Draft 65 While Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.166	0.005	-0.103	0.007
073	0.326	0.012	-0.094	0.007
074	0.314	0.005	-0.253	0.009
075	0.352	0.005	-0.306	0.010
076	0.469	0.005	-0.136	0.010
077	0.516	0.006	-0.030	0.001
078	0.556	0.005	-0.078	0.001
079	0.581	0.020	-0.069	0.024

Wetted Surface Side Coefficient and Length Froude number for Draft 65 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.145	0.005	0.000	0.020
073	0.322	0.013	-0.007	0.005
075	0.330	0.005	-0.039	0.006
076	0.460	0.005	-0.011	0.004
077	0.516	0.006	-0.006	0.003
078	0.559	0.005	-0.006	0.002
079	0.581	0.006	-0.009	0.003

Displacement Drag Coefficient and Froude number for Draft 65 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.340	0.009	0.143	0.129
073	0.732	0.027	0.078	0.059
074	0.690	0.011	0.209	0.045
075	0.774	0.011	0.296	0.048
076	1.04	0.011	0.160	0.032
077	1.15	0.012	0.166	0.020
078	1.24	0.010	0.184	0.016
079	1.30	0.012	0.205	0.013

Displacement Lift Coefficient and Froude number for Draft 65 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.370	0.010	-1.00	0.065
073	0.726	0.026	-0.915	0.066
074	0.699	0.012	-2.46	0.088
075	0.784	0.011	-2.96	0.095
076	1.04	0.011	-1.32	0.095
077	1.15	0.012	-0.289	0.006
078	1.24	0.011	-0.760	0.014
079	1.29	0.044	-0.664	0.228

Displacement Side Coefficient and Froude number for Draft 65 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
072	0.322	0.011	-0.001	0.191
073	0.716	0.028	-0.072	0.050
075	0.733	0.011	-0.374	0.060
076	1.02	0.011	-0.107	0.041
077	1.15	0.013	-0.058	0.027
078	1.24	0.010	-0.058	0.022
079	1.29	0.013	-0.087	0.027

Drag Force and Velocity Data for Draft 45 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
054	0.387	0.019	1.14	2.58
055	0.216	0.047	2.61	3.20
056	0.948	0.022	7.34	6.82
057	1.34	0.020	19.8	4.63
058	1.63	0.034	33.8	6.04
059	1.81	0.024	38.6	7.20
060	2.41	0.024	49.8	6.39
061	1.92	0.029	31.9	6.41
062	2.27	0.075	46.9	5.73

Lift Force and Velocity Data for Draft 45 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
054	0.395	0.021	-3.79	1.59
055	0.235	0.044	-15.9	1.77
056	0.954	0.022	-91.4	2.83
057	1.34	0.021	-230.	5.01
058	1.63	0.032	-299.	15.5
059	1.81	0.248	-126.	8.53
060	2.41	0.024	-238.	3.16
061	1.92	0.029	-264.	40.1
062	2.28	0.074	-220.	2.69

Side Force and Velocity Data for Draft 45 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
054	0.358	0.018	-0.359	1.37
055	0.201	0.046	-2.29	1.88
056	0.949	0.020	-8.54	2.96
057	1.30	0.021	-23.6	2.15
058	1.62	0.032	-36.9	3.97
059	1.77	0.026	-25.0	6.11
060	2.39	0.025	-11.7	6.32
061	1.92	0.030	-29.8	6.02
062	2.27	0.106	-22.3	7.10

Pitching Moment and Velocity Data for Draft 45 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
054	0.355	0.017	0.931	0.326
055	0.213	0.043	2.59	0.463
056	0.954	0.023	14.1	0.857
057	1.30	0.020	37.4	0.957
058	1.62	0.033	55.1	1.28
059	1.79	0.025	33.6	1.80
060	2.40	0.024	36.3	1.65
061	1.92	0.029	45.4	5.10
062	2.27	0.100	33.2	1.68

Yaw Moment and Velocity Data for Draft 45 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
54	0.362	0.019	0.421	0.140
55	0.574	12.3	0.811	0.366
56	0.803	0.018	3.75	0.340
57	1.29	0.021	16.2	0.722
58	1.62	0.032	31.9	1.21
59	1.74	0.025	45.1	1.57
60	2.37	0.025	56.9	0.676
61	1.89	0.029	41.8	0.933
62	2.33	0.299	50.1	5.81

Wetted Surface Drag Coefficient and Length Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.094	0.005	0.014	0.033
055	0.052	0.011	0.120	0.190
056	0.231	0.005	0.015	0.014
057	0.325	0.005	0.021	0.005
058	0.396	0.008	0.024	0.004
059	0.441	0.006	0.022	0.004
060	0.587	0.006	0.016	0.002
061	0.468	0.007	0.016	0.003
062	0.553	0.018	0.017	0.004

Wetted Surface Lift Coefficient and Length Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.096	0.005	-0.046	0.019
055	0.057	0.011	-0.612	0.290
056	0.232	0.005	-0.191	0.010
057	0.326	0.005	-0.243	0.007
058	0.396	0.008	-0.215	0.008
059	3.011	0.060	-0.002	0.000
060	0.588	0.006	-0.077	0.002
061	0.467	0.007	-0.136	0.023
062	0.555	0.018	-0.081	0.021

Wetted Surface Side Coefficient and Length Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.087	0.004	-0.006	0.021
055	0.049	0.011	-0.152	0.188
056	0.231	0.005	-0.018	0.007
057	0.316	0.005	-0.027	0.003
058	0.394	0.008	-0.027	0.003
059	0.432	0.006	-0.015	0.004
060	0.582	0.006	-0.004	0.002
061	0.467	0.007	-0.015	0.003
062	0.552	0.026	-0.009	0.013

Displacement Drag Coefficient and Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.211	0.010	0.127	0.292
055	0.117	0.026	1.07	1.69
056	0.516	0.012	0.138	0.128
057	0.727	0.011	0.187	0.044
058	0.886	0.019	0.216	0.039
059	0.987	0.013	0.198	0.037
060	1.31	0.013	0.145	0.019
061	1.05	0.016	0.146	0.030
062	1.24	0.041	0.154	0.036

Displacement Lift Coefficient and Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.215	0.011	-0.410	0.169
055	0.128	0.024	-5.45	2.59
056	0.519	0.012	-1.70	0.087
057	0.729	0.011	-2.17	0.066
058	0.885	0.018	-1.91	0.073
059	6.73	0.135	-0.014	0.001
060	1.31	0.013	-0.689	0.017
061	1.04	0.016	-1.21	0.204
062	1.24	0.040	-0.720	0.186

Displacement Side Coefficient and Froude number for Draft 45 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
054	0.195	0.010	-0.057	0.186
055	0.110	0.025	-1.35	1.67
056	0.516	0.011	-0.161	0.058
057	0.707	0.012	-0.237	0.025
058	0.880	0.017	-0.239	0.029
059	0.965	0.014	-0.135	0.034
060	1.30	0.013	-0.035	0.018
061	1.04	0.016	-0.137	0.029
062	1.23	0.058	-0.080	0.119

Drag Force and Velocity Data for Draft 15 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
063	0.520	0.017	2.19	4.43
064	0.935	0.022	5.74	5.41
065	1.30	0.026	17.5	5.37
066	1.69	0.024	28.8	6.12
067	2.00	0.021	27.9	5.28
068	2.18	0.021	35.0	5.77
069	2.28	0.019	38.8	5.79
070	2.40	0.022	42.6	4.26
071	2.53	0.024	47.0	7.75

Lift Force and Velocity Data for Draft 15 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
063	0.508	0.018	-16.5	2.85
064	0.941	0.021	-87.6	2.59
065	1.30	0.024	-172.	4.38
066	1.68	0.024	-226.	10.2
067	1.98	0.020	-143.	7.75
068	2.18	0.020	-183.	2.64
069	2.26	0.101	-172.	4.26
070	2.41	0.023	-173.	3.24
071	2.53	0.025	-166.	2.78

Side Force and Velocity Data for Draft 15 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
063	0.519	0.018	-0.965	3.41
064	0.945	0.021	-6.35	3.09
066	1.69	0.023	-28.2	3.59
067	2.02	0.021	-21.5	7.00
068	2.16	0.020	-12.6	3.41
069	2.32	0.021	-14.3	7.01
070	2.41	0.021	-15.3	5.77
071	2.53	0.024	-19.0	7.31

Pitching Moment and Velocity Data for Draft 15 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
063	0.510	0.017	2.63	0.490
064	0.937	0.022	13.4	0.692
065	1.30	0.025	28.8	0.938
066	1.69	0.024	40.4	1.40
067	2.01	0.022	26.9	2.71
068	2.16	0.020	23.2	0.959
069	2.31	0.019	25.7	1.03
070	2.40	0.022	27.2	1.29
071	2.53	0.024	29.4	1.19

Yaw Moment and Velocity Data for Draft 15 while Turning

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
63	0.500	0.016	0.331	0.333
64	0.942	0.022	2.16	0.346
65	1.29	0.024	9.47	0.671
66	1.68	0.022	19.1	1.26
67	2.06	0.020	22.7	1.59
68	2.15	0.019	22.4	0.741
69	2.32	0.022	27.2	0.741
70	2.39	0.019	29.3	0.453
71	2.52	0.026	32.4	0.979

Wetted Surface Drag Coefficient and Length Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.127	0.004	0.019	0.038
064	0.228	0.005	0.015	0.014
065	0.317	0.006	0.024	0.007
066	0.410	0.006	0.024	0.005
067	0.486	0.005	0.016	0.003
068	0.529	0.005	0.017	0.003
069	0.556	0.005	0.017	0.003
070	0.585	0.005	0.017	0.002
071	0.615	0.006	0.017	0.003

Wetted Surface Lift Coefficient and Length Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.124	0.004	-0.150	0.027
064	0.229	0.005	-0.232	0.013
065	0.317	0.006	-0.239	0.009
066	0.409	0.006	-0.188	0.007
067	0.481	0.005	-0.086	0.005
068	0.530	0.005	-0.090	0.002
069	0.550	0.025	-0.080	0.026
070	0.586	0.006	-0.070	0.001
071	0.616	0.006	-0.061	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.126	0.004	-0.009	0.030
064	0.230	0.005	-0.017	0.008
066	0.410	0.006	-0.023	0.003
067	0.491	0.005	-0.012	0.004
068	0.526	0.005	-0.006	0.002
069	0.565	0.005	-0.006	0.003
070	0.586	0.005	-0.006	0.002
071	0.616	0.006	-0.007	0.003

Displacement Drag Coefficient and Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.286	0.009	0.140	0.287
064	0.513	0.012	0.114	0.108
065	0.714	0.014	0.181	0.055
066	0.925	0.013	0.177	0.038
067	1.10	0.011	0.122	0.023
068	1.19	0.011	0.129	0.021
069	1.25	0.010	0.130	0.019
070	1.32	0.012	0.129	0.013
071	1.39	0.013	0.129	0.021

Displacement Lift Coefficient and Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.279	0.010	-1.12	0.199
064	0.516	0.012	-1.73	0.095
065	0.714	0.013	-1.78	0.065
066	0.921	0.013	-1.40	0.055
067	1.08	0.011	-0.641	0.035
068	1.20	0.011	-0.672	0.014
069	1.24	0.055	-0.597	0.197
070	1.32	0.012	-0.519	0.010
071	1.39	0.014	-0.452	0.008

Displacement Side Coefficient and Froude number for Draft 15 while Turning

RUN	FROUDE NUM	DEV	COEFF	DEV
063	0.285	0.010	-0.066	0.222
064	0.518	0.012	-0.125	0.062
066	0.924	0.013	-0.174	0.024
067	1.11	0.012	-0.092	0.030
068	1.19	0.011	-0.047	0.013
069	1.27	0.011	-0.046	0.023
070	1.32	0.011	-0.046	0.018
071	1.39	0.013	-0.052	0.020

Drag Force and Velocity Data for Draft 65 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
089	0.559	0.020	3.90	1.19
090	1.01	0.024	10.7	5.46
091	1.37	0.021	28.3	5.51
092	1.78	0.022	41.0	6.88
093	1.90	0.023	43.8	6.10
094	2.29	0.020	51.1	7.12
095	2.38	0.023	62.3	6.71
096	2.45	0.023	68.4	7.06
097	2.59	0.023	79.2	6.04

Lift Force and Velocity Data for Draft 65 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
089	0.551	0.021	-13.4	2.88
090	0.994	0.024	-77.1	2.18
091	1.38	0.021	-193.	5.86
092	1.78	0.021	-8.76	7.16
093	1.90	0.022	7.32	11.4
094	2.29	0.020	-75.5	4.14
095	2.37	0.023	-18.1	6.68
096	2.44	0.025	7.42	3.07
097	2.59	0.021	65.4	2.76

Side Force and Velocity Data for Draft 65 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
091	1.37	0.021	-32.2	5.11
094	1.89	0.023	-0.521	4.53
096	2.44	0.024	-1.16	5.27

Pitching Moment and Velocity Data for Draft 65 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
090	1.02	0.024	13.3	0.987
091	0.826	0.022	36.9	1.46
092	1.78	0.021	39.9	1.88
093	1.90	0.022	38.0	2.44
094	2.30	0.023	27.6	1.12
095	2.37	0.023	28.0	1.34

096	2.45	0.024	29.4	1.25
097	2.58	0.023	28.2	1.29

Yaw Moment and Velocity Data for Draft 65 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
89	0.549	0.020	0.939	0.334
90	1.03	0.024	-0.105	0.845
91	1.35	0.020	0.227	1.09
92	1.77	0.021	7.27	1.16
93	1.90	0.022	10.2	0.766
94	2.35	0.022	14.6	0.828
95	2.36	0.024	19.3	0.738
96	2.43	0.025	20.6	0.473
97	2.56	0.022	24.8	0.986

Wetted Surface Drag Coefficient and Length Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
089	0.136	0.005	0.021	0.007
090	0.245	0.006	0.018	0.009
091	0.334	0.005	0.026	0.005
092	0.433	0.005	0.022	0.004
093	0.462	0.005	0.021	0.003
094	0.557	0.005	0.017	0.002
095	0.578	0.006	0.019	0.002
096	0.596	0.006	0.019	0.002
097	0.631	0.006	0.020	0.002

Wetted Surface Lift Coefficient and Length Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
089	0.134	0.005	-0.075	0.016
090	0.242	0.006	-0.134	0.007
091	0.335	0.005	-0.174	0.008
092	0.432	0.005	-0.005	0.004
093	0.462	0.005	0.004	0.005
094	0.556	0.005	-0.025	0.001
095	0.578	0.006	-0.005	0.002

096	0.595	0.006	0.002	0.001
097	0.630	0.005	0.017	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
091	0.333	0.005	-0.029	0.005
094	0.460	0.006	0.000	0.002
096	0.594	0.006	0.000	0.002

Displacement Drag Coefficient and Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
089	0.303	0.011	0.207	0.064
090	0.546	0.013	0.174	0.089
091	0.742	0.011	0.249	0.049
092	0.963	0.012	0.215	0.036
093	1.03	0.012	0.202	0.029
094	1.24	0.011	0.162	0.023
095	1.29	0.013	0.183	0.020
096	1.33	0.012	0.189	0.020
097	1.40	0.013	0.195	0.015

Displacement Lift Coefficient and Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
089	0.298	0.011	-0.730	0.158
090	0.538	0.013	-1.294	0.066
091	0.745	0.011	-1.687	0.074
092	0.962	0.011	-0.046	0.037
093	1.03	0.012	0.034	0.052
094	1.24	0.011	-0.239	0.013
095	1.29	0.013	-0.053	0.019
096	1.32	0.013	0.021	0.008
097	1.40	0.012	0.161	0.007

Displacement Side Coefficient and Froude number for Draft 65 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
091	0.741	0.011	-0.284	0.047
094	1.02	0.012	-0.002	0.021
096	1.32	0.013	-0.003	0.015

Drag Force and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
045	0.453	0.019	1.22	4.17
046	0.536	0.023	3.23	3.81
047	0.806	0.019	8.39	5.86
048	1.34	0.022	23.19	6.08
049	1.55	0.024	34.63	7.19
050	1.83	0.028	35.84	7.20
051	2.13	0.023	40.95	6.42
052	2.13	0.026	45.49	6.98
053	2.58	0.025	54.53	5.68

Lift Force and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
045	0.441	0.017	0.048	1.57
046	0.534	0.019	-10.7	1.50
047	0.831	0.018	-79.7	2.45
048	1.35	0.021	-165.	3.15
049	1.57	0.023	-159.	10.9
050	1.84	0.029	-86.4	29.6
051	2.13	0.020	-97.5	4.83
052	2.13	0.026	-69.5	10.3
053	2.56	0.026	-41.8	3.16

Side Force and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
045	0.508	0.024	2.37	2.95
046	0.530	0.020	-0.118	1.94
047	0.753	0.020	-5.22	2.65
048	1.33	0.028	-9.75	3.12
049	1.50	0.023	-23.2	4.44

050	1.81	0.031	-16.8	3.86
051	2.13	0.022	-7.95	3.05
052	2.15	0.029	-9.21	4.02
053	2.30	0.027	-9.88	4.92

Pitching Moment and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
046	0.536	0.020	2.46	0.551
045	0.485	0.020	-0.150	0.468
047	0.775	0.021	14.1	0.856
048	1.33	0.025	32.2	1.48
049	1.52	0.026	49.0	3.08
050	1.81	0.030	43.2	4.01
051	2.12	0.021	22.5	1.11
052	2.14	0.027	22.2	1.09
053	2.29	0.028	25.3	1.34

Roll Moment and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
045	0.473	0.019	-0.017	0.072
046	0.530	0.023	0.006	0.117
047	0.798	0.019	-0.033	0.223
048	1.34	0.023	-0.237	0.149
049	1.54	0.041	0.555	0.537
050	1.82	0.027	0.480	0.423
051	2.13	0.022	0.386	0.229
052	2.14	0.027	0.547	0.240
053	1.29	0.024	0.429	0.440

Yaw Moment and Velocity Data for Draft 45 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
45	0.553	0.022	-0.157	0.184
46	0.520	0.019	0.214	0.318
47	0.715	0.025	-0.987	0.523
48	1.32	0.022	-2.14	1.03
49	1.47	0.021	-0.074	1.30
50	1.79	0.031	0.271	0.683
51	2.11	0.023	4.99	0.569
52	2.15	0.032	6.22	0.622

53	2.27	0.028	9.92	0.685

Wetted Surface Drag Coefficient and Length Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.110	0.005	0.011	0.039
046	0.131	0.006	0.021	0.025
047	0.196	0.005	0.024	0.017
048	0.326	0.005	0.024	0.006
049	0.378	0.006	0.027	0.006
050	0.444	0.007	0.020	0.004
051	0.518	0.006	0.017	0.003
052	0.517	0.006	0.019	0.003
053	0.628	0.006	0.016	0.002

Wetted Surface Lift Coefficient and Length Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.107	0.004	0.001	0.015
046	0.130	0.005	-0.071	0.010
047	0.202	0.004	-0.219	0.011
048	0.330	0.005	-0.170	0.006
049	0.381	0.005	-0.123	0.008
050	0.447	0.007	-0.049	0.017
051	0.517	0.005	-0.041	0.002
052	0.518	0.006	-0.029	0.004
053	0.623	0.006	-0.012	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.124	0.006	0.017	0.021
046	0.129	0.005	-0.001	0.014
047	0.183	0.005	-0.018	0.009
048	0.324	0.007	-0.010	0.003
049	0.366	0.006	-0.020	0.004
050	0.440	0.008	-0.010	0.002
051	0.519	0.005	-0.003	0.001

052	0.524	0.007	-0.004	0.002
053	0.559	0.007	-0.004	0.002

Displacement Drag Coefficient and Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.246	0.010	0.100	0.346
046	0.292	0.012	0.189	0.226
047	0.439	0.010	0.218	0.152
048	0.729	0.012	0.218	0.057
049	0.845	0.013	0.243	0.052
050	0.993	0.016	0.182	0.037
051	1.16	0.013	0.153	0.024
052	1.16	0.014	0.170	0.026
053	1.40	0.014	0.138	0.015

Displacement Lift Coefficient and Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.240	0.009	0.006	0.136
046	0.291	0.011	-0.634	0.086
047	0.452	0.010	-1.95	0.095
048	0.737	0.012	-1.52	0.051
049	0.852	0.012	-1.10	0.072
050	1.00	0.016	-0.434	0.152
051	1.16	0.011	-0.365	0.018
052	1.16	0.014	-0.259	0.036
053	1.39	0.014	-0.108	0.007

Displacement Side Coefficient and Froude number for Draft 45 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
045	0.277	0.013	0.149	0.191
046	0.288	0.011	-0.011	0.121
047	0.410	0.011	-0.157	0.082
048	0.725	0.015	-0.093	0.031
049	0.817	0.013	-0.174	0.035
050	0.980	0.017	-0.087	0.022
051	1.16	0.012	-0.030	0.012

052	1.17	0.016	-0.034	0.015
053	1.25	0.015	-0.032	0.016

Drag Force and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
038	0.558	0.019	1.47	3.93
039	0.924	0.019	5.59	4.75
040	1.68	0.018	25.1	6.91
041	1.44	0.016	27.8	5.91
042	2.04	0.019	26.7	7.06
044	2.42	0.041	42.9	7.81

Lift Force and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
038	0.582	0.020	-13.8	1.49
039	0.929	0.019	-77.1	2.68
040	1.65	0.019	-140.	10.21
041	1.41	0.018	-136.	10.48
042	2.03	0.018	-73.4	19.05
043	1.95	0.019	-96.7	2.70
044	2.43	0.030	-71.3	3.02

Side Force and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
038	0.539	0.019	-1.92	2.07
039	0.949	0.017	-0.514	2.97
040	1.73	0.017	-4.45	3.03
041	1.55	0.019	-9.89	3.86
042	2.05	0.019	0.721	4.38
043	1.99	0.018	-4.56	30.9
044	2.43	0.029	3.03	3.91

Pitching Moment and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
038	0.538	0.019	2.13	0.495
039	0.936	0.018	12.4	0.784
040	1.71	0.018	35.3	1.31
041	1.54	0.019	36.1	2.02
042	2.05	0.019	19.7	2.45
043	1.98	0.018	19.7	1.17
044	2.42	0.030	19.3	1.14

Roll Moment and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
038	0.548	0.019	-0.073	0.084
039	0.932	0.018	-0.540	0.244
040	1.68	0.017	-0.311	0.438
041	1.52	0.020	0.202	0.653
042	2.04	0.018	-1.08	0.253
043	1.97	0.018	-1.41	0.250
044	2.43	0.030	-1.48	0.125

Yaw Moment and Velocity Data for Draft 15 while Pitching

RUN	VELOCITY(M/S)	DEV	FORCE/MOMENT	DEV
38	0.511	0.019	0.392	0.267
39	0.946	0.017	0.978	0.793
40	1.74	0.018	1.71	0.913
41	1.56	0.020	3.60	0.934
42	2.05	0.019	5.48	0.978
43	1.98	0.024	8.01	0.646
44	2.43	0.030	10.37	0.584

Wetted Surface Drag Coefficient and Length Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.136	0.005	0.011	0.030
039	0.225	0.005	0.015	0.013
040	0.409	0.004	0.021	0.006
041	0.350	0.004	0.031	0.007

042	0.496	0.005	0.015	0.004
044	0.588	0.010	0.017	0.003

Wetted Surface Lift Coefficient and Length Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.142	0.005	-0.095	0.010
039	0.226	0.005	-0.209	0.011
040	0.402	0.005	-0.120	0.009
041	0.342	0.004	-0.161	0.013
042	0.495	0.004	-0.042	0.011
043	0.475	0.005	-0.059	0.002
044	0.592	0.007	-0.028	0.001

Wetted Surface Side Coefficient and Length Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.131	0.005	-0.015	0.017
039	0.231	0.004	-0.001	0.008
040	0.420	0.004	-0.004	0.002
041	0.378	0.005	-0.010	0.004
042	0.500	0.005	0.000	0.002
043	0.485	0.004	-0.003	0.018
044	0.591	0.007	0.001	0.002

Displacement Drag Coefficient and Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.306	0.011	0.084	0.223
039	0.507	0.010	0.114	0.097
040	0.922	0.010	0.155	0.043
041	0.790	0.009	0.234	0.050
042	1.12	0.010	0.112	0.030
044	1.33	0.022	0.128	0.023

Displacement Lift Coefficient and Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.319	0.011	-0.711	0.078
039	0.510	0.010	-1.56	0.084
040	0.907	0.010	-0.892	0.065
041	0.772	0.010	-1.20	0.098
042	1.12	0.010	-0.310	0.080
043	1.07	0.010	-0.443	0.015
044	1.33	0.017	-0.211	0.011

Displacement Side Coefficient and Froude number for Draft 15 while Pitching

RUN	FROUDE NUM	DEV	COEFF	DEV
038	0.296	0.010	-0.112	0.123
039	0.520	0.009	-0.010	0.058
040	0.947	0.009	-0.026	0.018
041	0.852	0.010	-0.072	0.028
042	1.13	0.010	0.003	0.018
043	1.09	0.010	-0.020	0.136
044	1.33	0.016	0.009	0.012

APPENDIX E EXAMPLE TIME RECORDS

This Appendix presents one set of example time records for the forces and moments for the Monoform project. This is done to demonstrate the noise problems encountered and to show some typical for the data recordes obtained. The records shown are for a run with straight rudders and at a draft of 15.

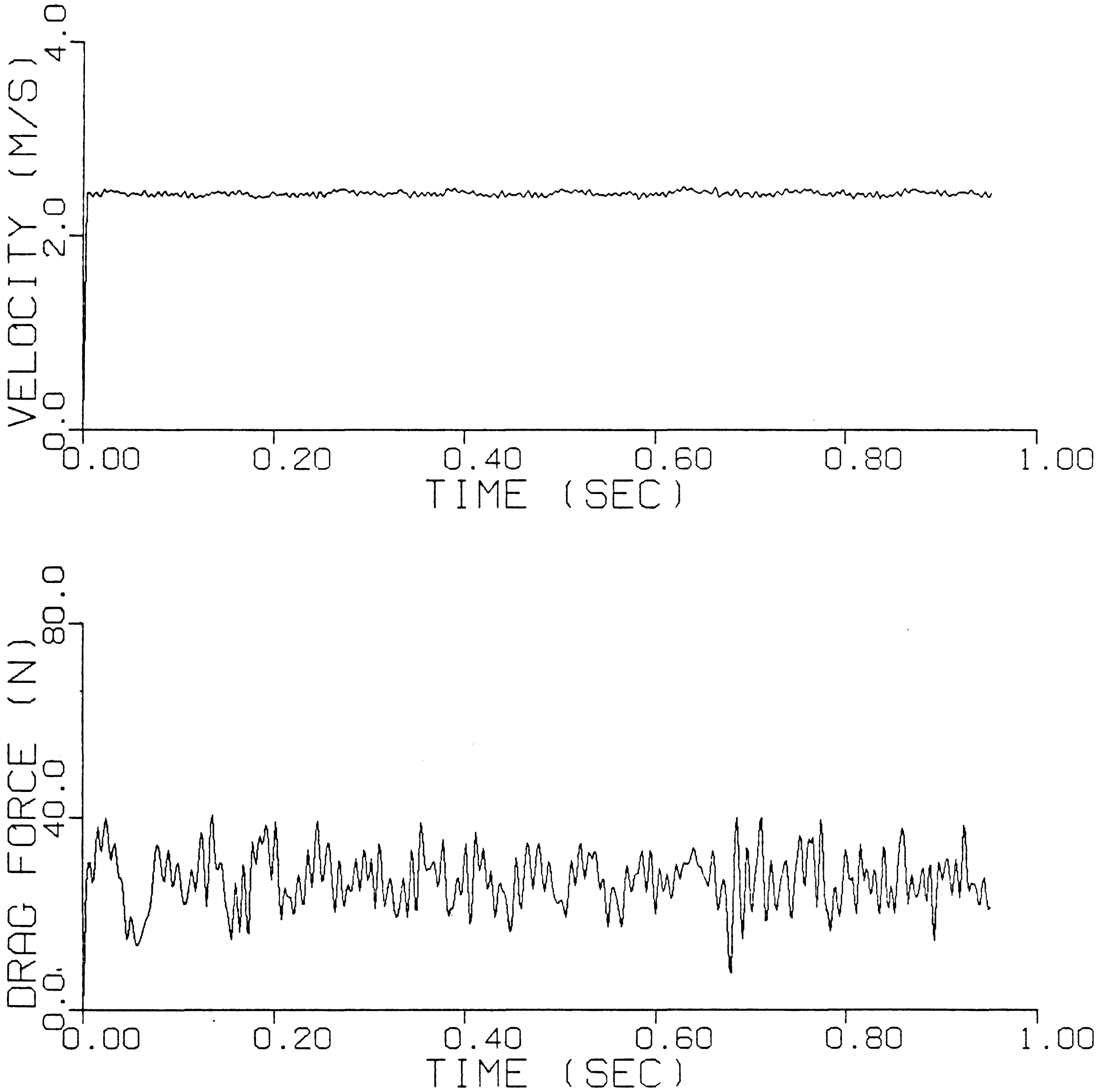


Figure E.1 Drag Force and Velocity for Run no. 32

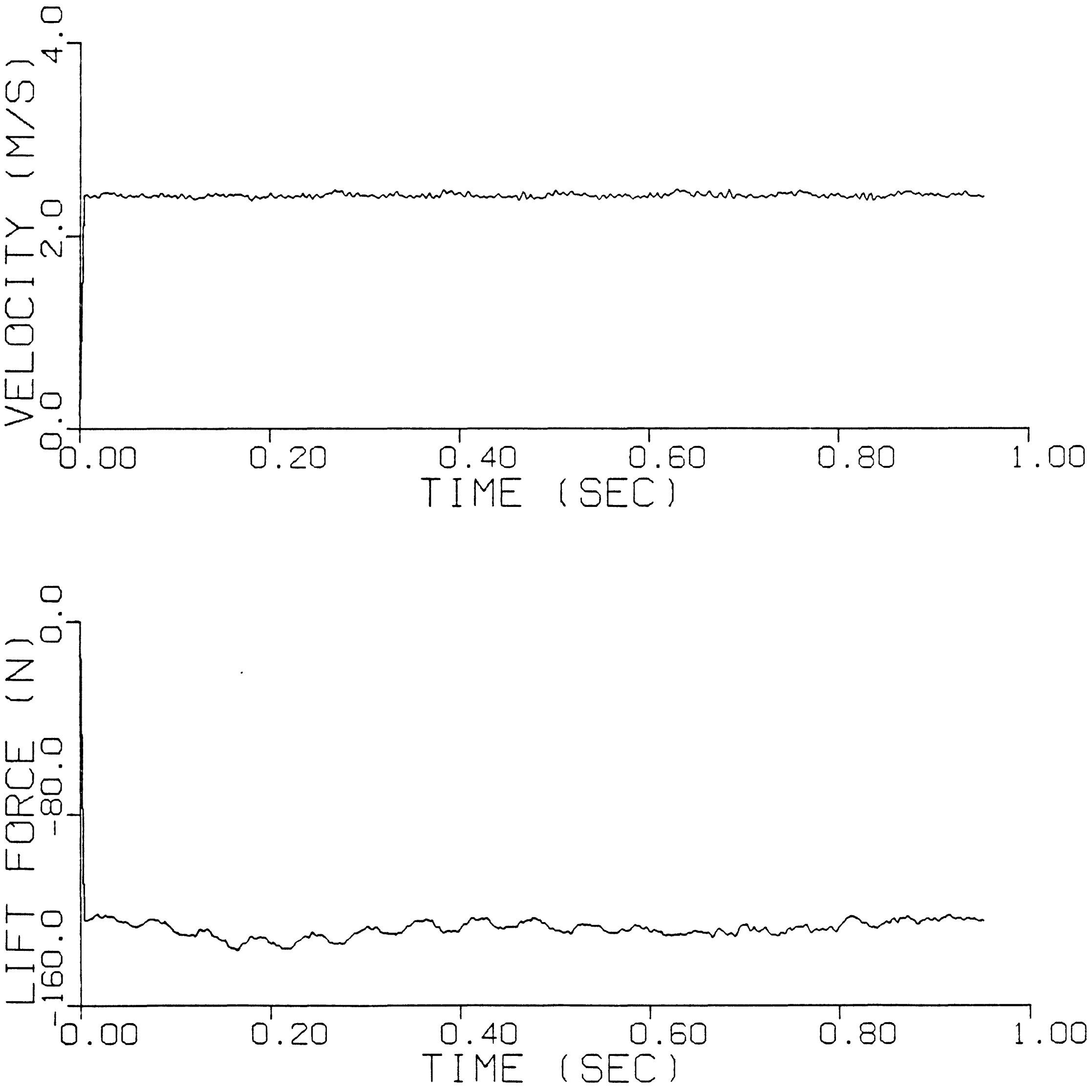


Figure E.2 Lift Force and Velocity for Run no. 32

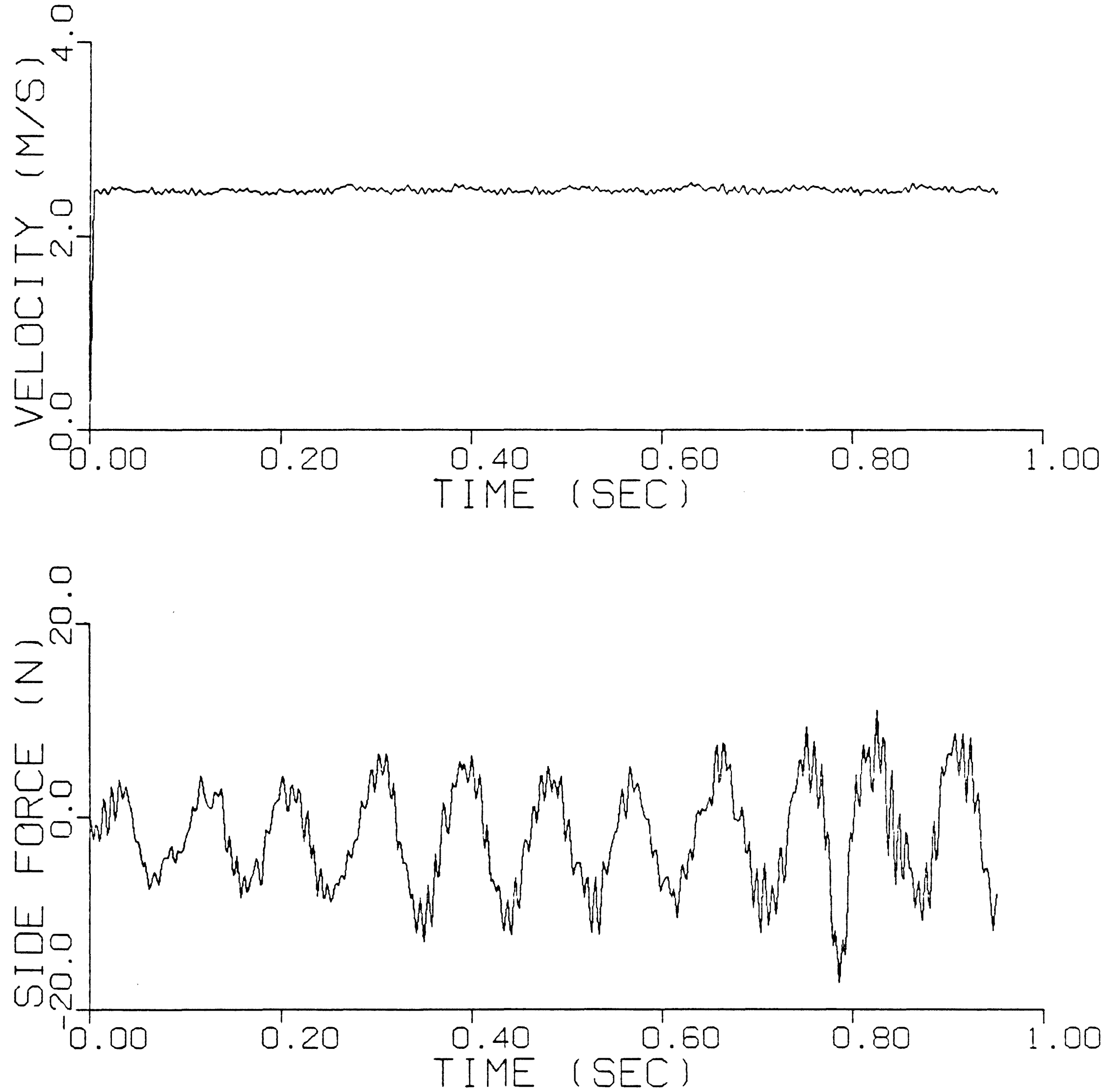


Figure E.3 Side Force and Velocity for Run no. 32

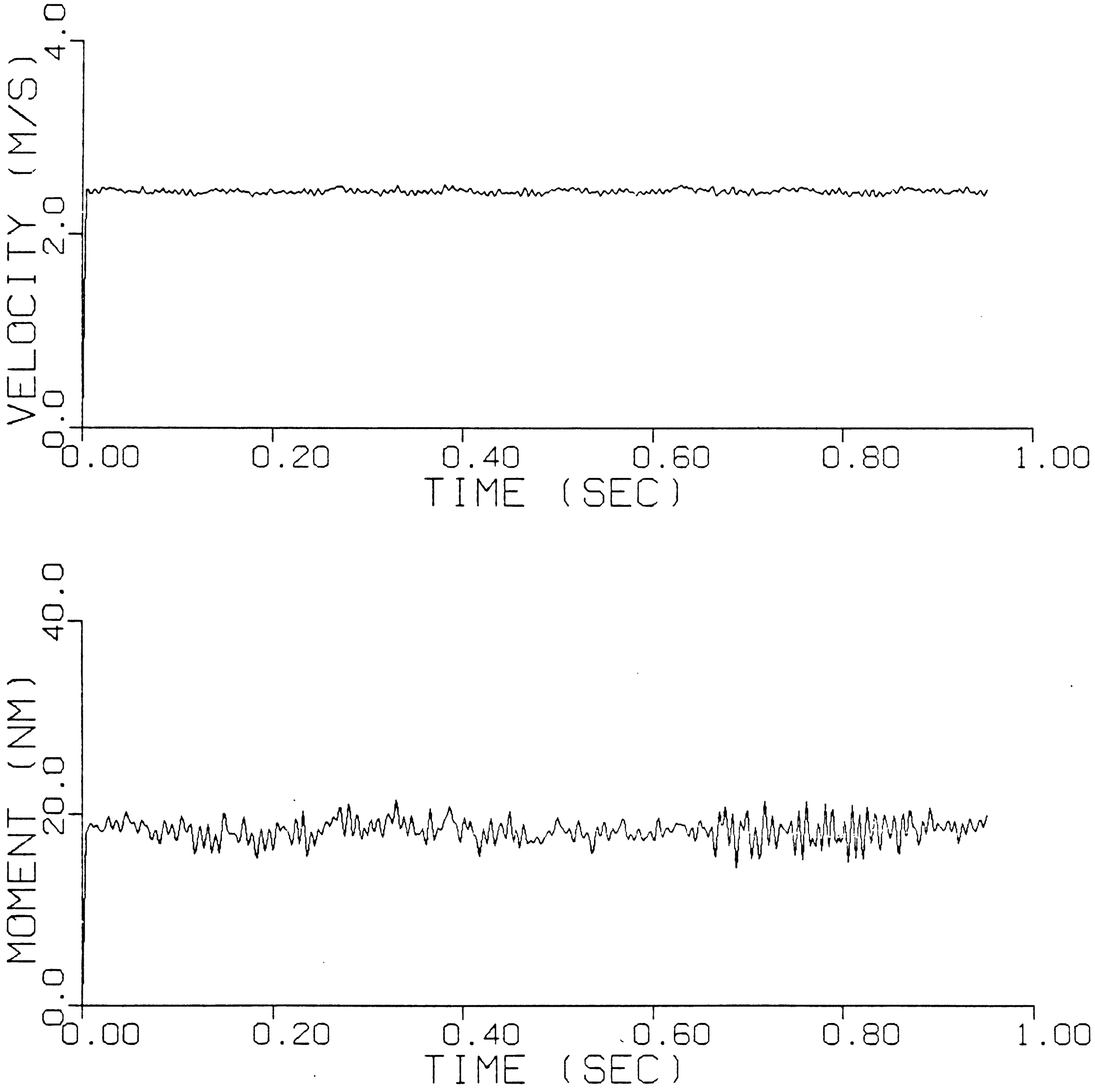


Figure E.4 Pitching Moment and Velocity for Run no. 32

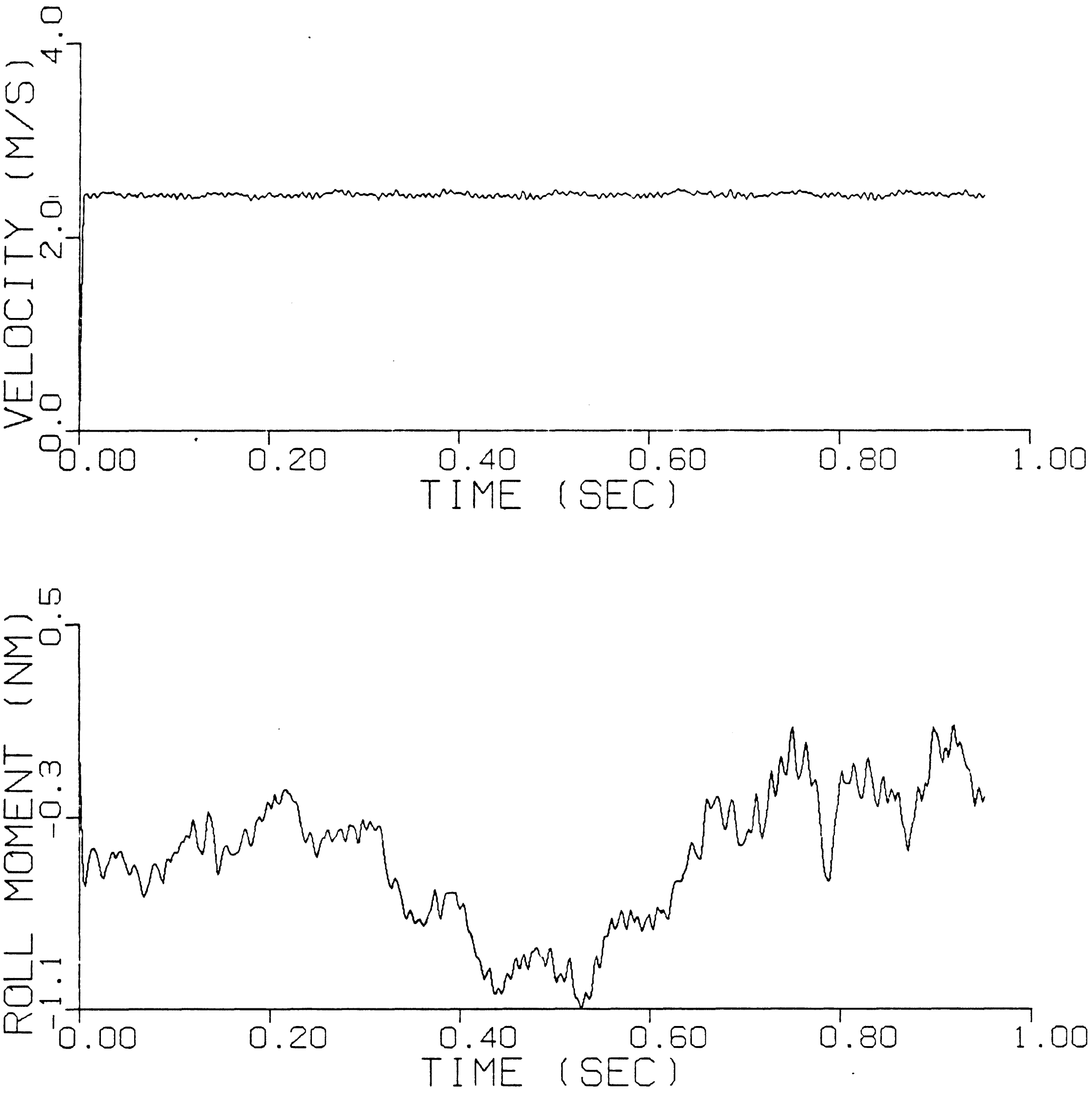


Figure E.5 Roll Moment and Velocity for Run no. 32

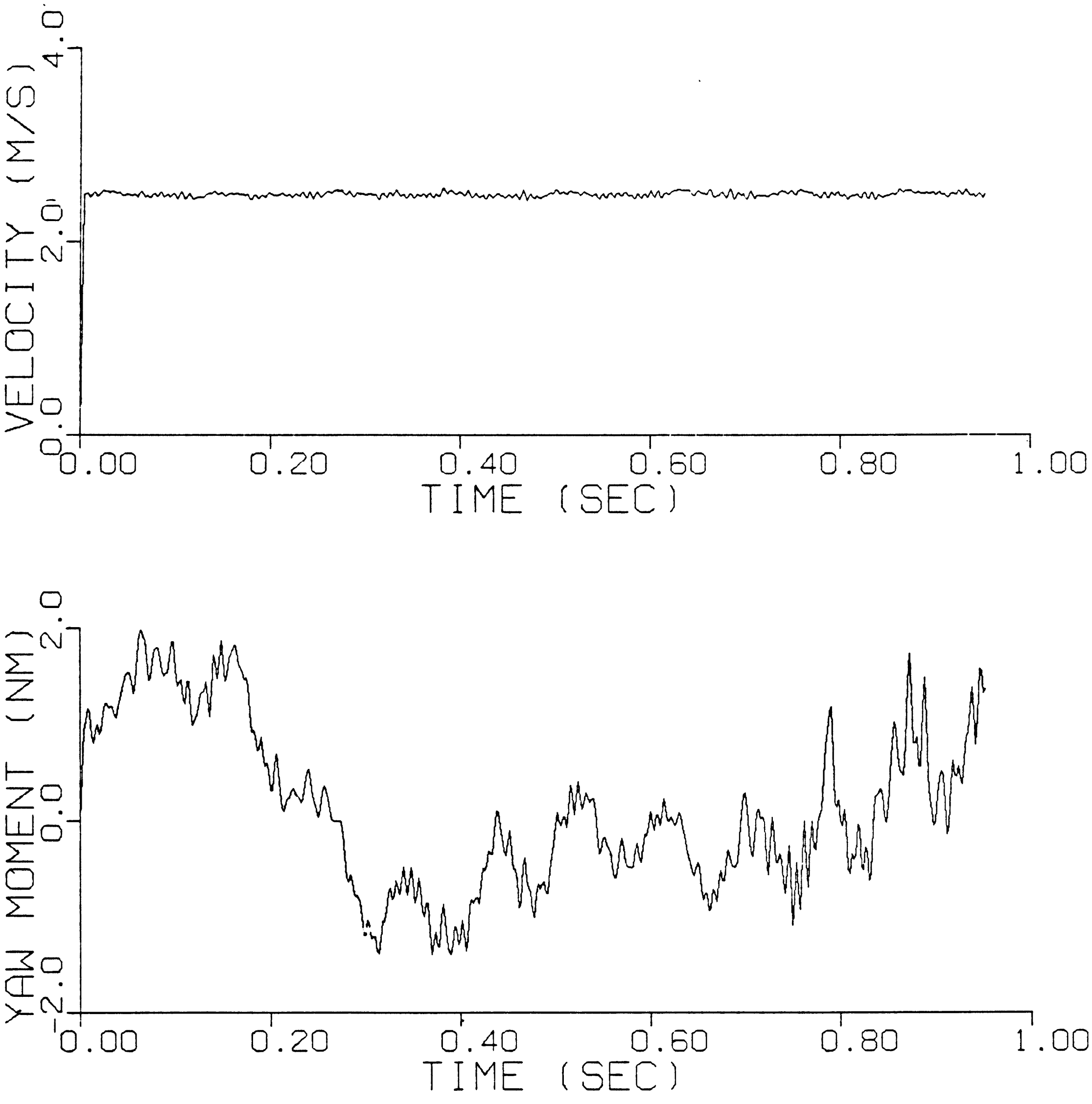


Figure E.6 Yaw Moment and Velocity for Run no. 32