

Carderock Division, Naval Surface Warfare Center

West Bethesda, Maryland 20817-5700

NSWCCD-50-TR—1999\075 Nov 1999
Hydromechanics Directorate
Research and Development Report

MASK Basin 'A' Bank Wave Survey

by
Timothy C. Smith

NSWCCD-50-TR—1999\075 MASK Basin 'A' Bank Wave Survey

20000207 148



Approved for Public Release, Distribution Unlimited.

MAJOR CARDEROCK DIVISION TECHNICAL COMPONENTS

CODE	011	Director of Technology
	10	Machinery Systems/Programs and Logistics Directorate
	20	Ship Systems & Programs Directorate
	50	Hydromechanics Directorate
	60	Survivability, Structures and Materials Directorate
	70	Signatures Directorate
	80	Machinery Research & Development Directorate
	90	Machinery In-Service Engineering Directorate

CARDEROCK DIVISION, NSWC, ISSUES THREE TYPES OF REPORTS:

- 1. CARDEROCKDIV reports, a formal series**, contain information of permanent technical value. They carry a consecutive numerical identification regardless of their classification or the originating directorate.
- 2. Directorate reports, a semiformal series**, contain information of a preliminary, temporary, or proprietary nature or of limited interest or significance. They carry an alpha numeric identification issued by the originating directorate.
- 3. Technical memoranda, an informal series**, contain technical documentation of limited use and interest. They are primarily working papers intended for internal use. They carry an identifying number which indicates their type and the numerical code of the originating directorate. Any distribution outside CARDEROCKDIV must be approved by the head of the originating directorate on a case-by-case basis.

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 26 November, 1999		3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE MASK Basin 'A' Bank Wave Survey				5. FUNDING NUMBERS PE 0603238N	
6. AUTHOR(S) TIMOTHY C. SMITH					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CARDEROCK DIVISION, NAVAL SURFACE WARFARE CENTER CODE 5500 9500 MACARTHUR BLVD WEST BETHESDA MD 20817-5700				8. PERFORMING ORGANIZATION REPORT NUMBER NSWCCD-50-TR--1999\075	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) CHIEF OF NAVAL RESEARCH (ONR 334) BALLSTON CENTRE TOWER ONE 800 NORTH QUNICY STREET ARLINGTON VA 22217-5660				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLIMENTARY NOTES					
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Pulic Release, Distribution Unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report describes and discusses the results from the Maneuvering and Seakeeping (MASK) Basin wave survey test conducted in May of 1999. The test deals exclusively with the 'A', or long bank of wave makers. The purpose of the test was to determine the uniformity, long crestedness, and repeatability of the waves in the MASK. Additionally, the test determined beach reflection and run length. The test were done using the test matrix for the follow on Mobile Offshore Base hydroelastic test, so the results could be used as incident wave data.					
14. SUBJECT TERMS wave measurements, mobile offshore base				15. NUMBER OF PAGES 37	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unclassified/Unlimited		

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only (Leave Blank).

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 10 Jun 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program elements number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract	PR - Project
G - Grant	TA - Task
PE - Program Element	WU - Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. (if known)

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Tran. of...; To be published in... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief (*Maximum 200 words*) factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code (*NTIS only*).

Block 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitations of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in the block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

CONTENTS

ABSTRACT	1
ADMINISTRATIVE INFORMATION	1
INTRODUCTION	1
TEST SETUP	2
WAVE PROBES	2
PRESSURE GAGES	2
VIDEO	3
INSTRUMENTATION	3
WAVE PROBES	3
PRESSURE GAGES	4
DATA COLLECTION	4
TEST METHODOLOGY	5
CREST AMPLITUDE UNIFORMITY	5
WAVE LONG CRESTEDNESS	6
REPEATABILITY	7
BEACH REFLECTION	8
RUN LENGTH	9
PRESSURE UNIFORMITY	9
HARMONIC CONTENT	10
PRESSURE LONG CRESTEDNESS	10
UNCERTAINTY DISCUSSION	10
CONCLUSIONS	11
REFERENCES	33

TABLES

1. English to metric units conversion factors.	13
2. Wire probe non-linear calibration coefficients.....	13
3. Test matrix showing desired wave slope over measured wave slope by period and nominal blower speed.....	13

FIGURES

1. Probe location (XY) for both carriage positions.....	14
2. Wave amplitude by probe location and blower speed (rpm) for 1.03 second period.	15
3. Wave amplitude by probe location and blower speed (rpm) for 1.16 second period.	15
4. Wave amplitude by probe location and blower speed (rpm) for 1.29 second period.	16
5. Wave amplitude by probe location and blower speed (rpm) for 1.55 second period.	16
6. Wave amplitude by probe location and blower speed (rpm) for 1.81 second period.	17
7. Wave amplitude by probe location and blower speed (rpm) for 2.06 second period.	17
8. Wave amplitude by probe location and blower speed (rpm) for 2.32 second period.	18
9. Wave amplitude by probe location and blower speed (rpm) for 2.58 second period.	18
10. Wave amplitude by probe location and blower speed (rpm) for 3.10 second period.	19
11. Wave amplitude by probe location and blower speed (rpm) for 3.61 second period.	19
12. Wave amplitude by probe location and blower speed (rpm) for 4.13 second period.	20
13. Wave phase angle by probe with wavelengths from wavemaker for 1.03 seconds..	21
14. Wave phase angle by probe with wavelengths from wavemaker for 1.16 seconds..	21
15. Wave phase angle by probe with wavelengths from wavemaker for 1.29 second period.....	22
16. Wave phase angle by probe with wavelengths from wavemaker for 1.55 second period.....	22
17. Wave phase angle by probe with wavelengths from wavemaker for 1.81 second period.....	23
18. Wave phase angle by probe with wavelengths from wavemaker for 2.06 second period.....	23
19. Wave phase angle by probe with wavelengths from wavemaker for 2.32 second period.....	24
20. Wave phase angle by probe with wavelengths from wavemaker for 2.58 second period.....	24
21. Wave phase angle by probe with wavelengths from wavemaker for 3.10 second period.....	25
22. Wave phase angle by probe with wavelengths from wavemaker for 3.61 second period.....	25
23. Wave phase angle by probe with wavelengths from wavemaker for 4.13 second period.....	26
24. Dome pressure by dome and blower speed (rpm) for 1.03 second period.....	27
25. Dome pressure by dome and blower speed (rpm) for 1.16 second period.....	27
26. Dome pressure by dome and blower speed (rpm) for 1.29 second period.....	28
27. Dome pressure by dome and blower speed (rpm) for 1.55 second period.....	28
28. Dome pressure by dome and blower speed (rpm) for 1.81 second period.....	29
29. Dome pressure by dome and blower speed (rpm) for 2.06 second period.....	29
30. Dome pressure by dome and blower speed (rpm) for 2.32 second period.....	30
31. Dome pressure by dome and blower speed (rpm) for 2.58 second period.....	30
32. Dome pressure by dome and blower speed (rpm) for 3.10 second period.....	31
33. Dome pressure by dome and blower speed (rpm) for 3.61 second period.....	31
34. Dome pressure by dome and blower speed (rpm) for 4.13 second period.....	32

ABSTRACT

This report describes and discusses the results from the Maneuvering and Seakeeping (MASK) Basin wave survey test conducted in May of 1999. The test deals exclusively with the 'A', or long, bank of wavemakers. The purpose of the test was to determine the uniformity, long crestedness, and repeatability of the waves in the MASK. Additionally, the test determined beach reflection and run length. The tests were done using the test matrix for the follow on Mobile Offshore Base hydroelastic test, so the results could be used as incident wave data.

ADMINISTRATIVE INFORMATION

The Naval Surface Warfare Center, Carderock Division (NSWCCD), Seakeeping Department (Code 5500) performed this work. The Office of Naval Research (ONR 334) funded this work under Mobile Offshore Basing (MOB) Project (R2266) of the Global Surveillance/Precision Strike and Air Defense Technology Program (PE 0603238N) for FY1999, authorized by Work Request N0001498WX20578. The Naval Facilities Engineering Service Center (NFESC ESC51) administered the MOB Project for ONR.

INTRODUCTION

The Maneuvering and Seakeeping (MASK) basin is 230 by 330 feet with a nominal 20 foot depth over much of its area¹. A 35-ft deep, 50-ft wide trench runs along its south wall, opposite the 'A', or long, bank of wavemakers, for the full basin length. A bridge spans the basin, resting on tracks at each end. The bridge can be rotated to 44.5 degrees and translate to the center of the basin. A self-propelled carriage is suspended below the bridge, which can travel the entire bridge length. The carriage supports test personnel, along with data collection, recording, and analysis equipment. See Table 1 for conversion factors for metric units.

Most models tested in the MASK are on the order of 20 feet long. As such, temporal and spatial variation of the wave field can be quantified by placing wave probes near the model. Typically, such variations, as well as, diffracted, radiated and reflected waves are ignored. The large Mobile Offshore Base (MOB) model interacts with a large portion of the wave field simultaneously. This requires a quantification of the temporal and spatial variation of the MASK wave field.

The MASK facility has pneumatic wavemakers with 21 domes spread along two perpendicular walls. The domes are numbered consecutively starting with the northwest end of the long bank to the northeast end of the short bank. Domes 1-13 on the 'A', or long, bank and Domes 14-21 on the 'B', or short, bank. There are beaches along the opposite walls to absorb the incoming waves and prevent reflection. The absorption properties are frequency dependent. An additional concern is repeatability of the wave field given changing environmental conditions, e.g., barometric pressure, and relative humidity.

The wave survey used an array of wave probes and pressure gages to measure the wave field and dome pressure. Measuring dome pressure is a means to determine whether the pressure in the domes is a source of wave field variability.

This test used the same regular waves as planned for the upcoming MOB hydroelastic test. The wave survey results are to be used as incident wave data. Other aspects of the wave survey addressed the issues of beach reflection and run length.

TEST SETUP

The test setup focused the sensors on the area in the center of the MASK basin where the MOB model will be located.

WAVE PROBES

The wave probe locations made use of existing rigging and booms. See Figure 1 for probe locations. The probe locations are referenced to an origin located at the corner of the basin wall behind the long bank and the starting edge of the beach facing the short bank, i.e., near the north east corner. The X-axis is positive along the long bank towards the east, i.e., short bank. The Y-axis is positive along the beach towards the long bank beach, i.e., the south.

A survey of possible bridge locations revealed on three more easily accessible spots. These spots would require fabrication of more booms and rigging. For this reason they were subsequently not considered.

The capacitance wire probes were mounted on the four bridge locations closest to the bridge center. The end locations were not outfitted at this time. Two additional wire probes were mounted on the carriage to compliment the existing three sonic probes.

The bridge probes were numbered 1, 3, 5, and 7. Probe 1 was on the wavemaker side of the bridge away to the short bank, i.e., the north east quadrant. The rest of the bridge probes are clockwise in numeric order from probe 1. The three sonic probes were designated bow, port, and starboard. These names reference the carriage assuming the "bow" points towards the short bank wavemakers. The bow probe was mounted on a boom. The port and starboard probes were inline near the center of the carriage. Wire probe 9 was mounted to the heave staff on the carriage. Wire probe 10 was mounted on a boom projecting from the stern of the carriage.

Two carriage positions were used to collect data over more of the MASK. The carriage positions were 29.5 feet apart. Carriage position 1 was closer to the short bank beach. Carriage position 2 was closer to the short bank wavemakers.

PRESSURE GAGES

Two different brands of differential pressure gages, Sensotec and Setra, were used to measure the dome pressures. Each pressure dome was tapped to install a pressure gage. The gages were located near the center of the dome longitudinally and on top closer to the wall side of the dome.

The Sensotec gages were located on Domes 3, 6, 8, 11, 16, and 19. The Setra gages were located on Domes 2, 4, 5, 7, 9, 10, 12, 14, 15, 17, 18, and 20.

Domes 1, 13, and 21 did not have gages installed because these domes are typically not operated. The submarine pier and punt obstruct Dome 1 for larger waves. Dome 13 was not run to avoid reflections from the short bank. Dome 14 is a short bank corner dome and is not run to avoid reflections from the long bank. Dome 21 is inoperable.

VIDEO

The wave pattern was recorded using two video cameras. One was located on a catwalk above the bridge to get a bird's eye view of the wave pattern. The other camera, on the shore, filmed along the crest to view the long crestedness of the wave patterns. There is video coverage of all the test conditions.

INSTRUMENTATION

The instrumentation for the wave survey consisted of wave probes, pressure gages, and video equipment. Separate data collection computers recorded the wave probe and pressure gage data. The videotapes of the waves provided qualitative data as to the wave field quality.

WAVE PROBES

The wave survey used a combination of capacitance wire probes and sonic probes. CDNSWC personnel made the capacitance wire probes following an in-house design. The probes are 36 inches long with a circuit box at one end. Two quarter inch threaded rods provide structural support. The wire probes were mounted to L-brackets that fit into the end of the long support poles.

The support poles are fiberglass, 16 feet long with a 2.0 inch outer diameter. Each pole had a three-foot extension added so the probe would contact the water. Cables connecting the probe to the data collection computer ran inside the pole and along the bridge to the carriage. The cables have connections at the top of the poles and at the carriage to allow movement of the pole and/or carriage.

The three sonic probes were attached to the carriage using existing mounts. The sonic probes are Westmar brand with 16-degree heads.

The wave probes were calibrated in place over ± 10 inches before and ± 12 inches after the test. The wire probes were weakly non-linear over this range, with the greatest deviation at the extremes. A 4th order polynomial calibration was used to decrease calibration error. The non-linear calibration coefficients were determined using the pre- and post-test calibrations. There was essentially no change during the test, except for probe 1. The zero value of probe 1 physically changed due to boom movement. The effect on the calibration was minimal. See Table 2 for calibration coefficients. The sonic probes were calibrated to 3 inches/volt.

PRESSURE GAGES

All pressure gages used are vented bi-directional differential gages with 4-20mA range. Six are Sensotec and twelve are Setra. The ranges on the Sensotec and Setra gages are ± 1 psig and ± 2.5 psig, respectively. The error is 0.1% and 0.2% full range for the Sensotec and Setra gages respectively. The gages were calibrated by the manufacture and came with National Institute of Standards and Technology (NIST) traceable calibrations.

The current loop was necessary to maintain signal strength over the long cable runs. The current was passed over a 250-ohm resistor to convert to current to a voltage. Tests indicated no signal loss over a 1000' cable. The maximum cable run was less than 400 feet. All the resistors were calibrated with a 250-ohm standard.

DATA COLLECTION

Dedicated computers collected the pressure and wave probe data. Both computers collected data on hard drives and backed up data to 100 Mb Iomega Zip drives. Digitization hardware in the collection computers consisted of Scientific Solutions, Inc. Lab Master AD-PGH analog-to-digital converter (ADC) expansion board with a 64 channel ADC expander multiplex board. The data are saved as two-byte integers. The resident in-house data acquisition software package, COLSEP95, was used to control the acquisition process.

The ADC is a single 12-bit successive approximation converter with a maximum throughput of 330 kHz. A programmable, precision gain amplifier in front of the ADC allows the input range to vary from ± 10 mV to ± 10 V. Wave data were collected at 20 Hz; and pressure data were collected at 50 Hz.

Due to the nature of the digitization process an upper limit must be placed on the frequency range of a measurement to avoid aliasing. Individual, Precision Incorporated 6604-B-TD2A-BCM constant time delay filters provided the electronic filtering for each channel prior to digitization by the data collection computer. The filters have a 6-pole Bessel with 6 zeros characteristic with a 3.97dB attenuation at the programmed cut-off frequency. The filter cut-off, f_c , was set at 4 Hz for the wave data and 10 Hz for the pressure data. Filter attenuation reaches the traditional cutoff specification of -3 dB at a frequency of $0.86f_c$. The -70 dB attenuation floor in the stop band is reached at $3.69f_c$.

The data collection computers were not specifically time synchronized. Run start and stop times are different between the two computers. A run log was used to keep track of the run numbers from each computer associated with a condition. Furthermore, pressure and wave data are stored in directories with different names.

The data were collected using linear calibrations. The non-linear calibrations of the wave probes were accounted for by post processing. The post processing took the collected voltages, removed the mean value, and calculated the correct engineering units using the 4th order polynomial calibration. The engineering units were converted back to voltages using a linear calibration consistent with current software.

TEST METHODOLOGY

The test used the same nominal test matrix of wave frequency and steepness as the MOB hydroelastic test. See Table 3 for the test matrix. The wave survey test matrix is entirely regular waves – 11 periods and 3 steepnesses per period. The MOB hydroelastic test matrix will have irregular waves as well.

The wave periods range from 1.03 to 4.13 seconds. The steepnesses are nominally 1/30, 1/50, and 1/100. The wave survey used short and long wave packets to measure reflection and stationarity. A short packet would have 4-10 wave cycles; whereas the long packets would have 25-50 wave cycles. Each condition was repeated three times, a long packet at each carriage position and a short packet at one position, to allow a measurement of uncertainty.

The dome lip immersion was set depending on the expected wave amplitude. The lip immersion was a nominal 9.5 in (full up) for wave amplitudes 5" or less; 15 in immersion for waves 5-15 inches; and 22 inches (full down) for waves greater than 15 inches. Some runs had spray from between the dome and stabilizer lip indicating potential non-uniformities. The log book shows lip height.

The beginning of the runs were harmonically analyzed to find amplitude and phase for the first three harmonics. The time chosen was the first 20-30 seconds of steady state data after the beginning transient. This time included reflected waves for the longer periods. In the long packets, different waves were examined on each channel due to the location difference between the probes. This is different than the short packet runs, where multiple time slices were taken to account for the phase different. It is possible to be analyzing waves on one channel and noise on another if this is not done. Using the same time window selection procedure on each run minimized the subjective part of picking the time window to analyze.

Values for all probes were calculated. Only values that were less than 5% distorted from pure sine waves were compared. The distortion was measured as the ratio of the first harmonic amplitude and 1.414 times the root mean squared of the signal. This term is designated A1/RQ0. Wave data that had an A1/RQ0 ratio less than 0.95 was ignored. The pressure data did not use this criterion due to the true presence of a third harmonic on shorter period runs.

The data were analyzed using a 95% confidence band (2σ) for determining bad data points. The 2σ band was applied twice to the data recalculating σ each time.

The comparison metric for most of data is the fraction the standard deviation (σ) is of the mean value. This is the coefficient of variation (COV).

CREST AMPLITUDE UNIFORMITY

The spatial and temporal uniformity of the waves was determined by examining the signals of the wave probes. The uniformity or constancy of the wave along the wave crest is important so each MOB section receives the same excitation during the model test. The uniformity of the crest is determined by comparing groups of probes.

The groups are: all the probes; four X groups; and three Y groups, where X is parallel to the long bank wavemaker. The X groups are #1, #3, and #10-1; 9-1, Starboard-1, Port-1, #10-2; Bow-1, #9-2, Starboard-2, and Port-2; and #5, Bow-2, and #7. The Y groups are: #1, #7, #9, and Starboard; #10 and Bow; and #3, #5, and Port. Carriage position is not an issue for the Y groups.

The average COV across all conditions for all the probes is 0.102 with a 0.029 standard deviation. The data COVs are spread between 0.056 and 0.173. Seventy-seven percent of the time COVs are less than 0.10; 90.1% of time less than 0.14. See Figures 2-12 for wave amplitude data and average values by X location.

For the 14 conditions with a COV greater than 0.1, a third had periods less than 3.1 seconds. These conditions have scatter throughout the test area on a whole, but less scatter when looking at the smaller X groups. The Y groups have the same or larger scatter than all the probes together. Furthermore, the Y group averages tend to have a dip near the center of the test area. Ignoring periods 3.1 seconds and greater, the average COV for all conditions is 0.089 ± 0.020 .

The results show that crest amplitude variation is a function of wave period. They show that there is more variation at the longer periods, i.e., above 3.1 seconds, and at higher blower speeds. As for spatial variation, the smaller X group COV indicate the amplitude is consistent over a normal test area. Because the X groups have less scatter within the group, there is a discernable pattern in the X direction. No Y direction pattern is visible because Y group COVs are of similar magnitude as the overall COV. This means for the test area, X location is more important than Y location for crest amplitude uniformity.

Of some concern is the port and starboard sonics measuring noticeably different amplitudes despite being virtually in-line. For example, at 3.61 second and 1230 rpm for carriage position 2, the port sonic had an average value of 5.99 inches and the starboard sonic measured 7.48 ± 0.13 inches.

WAVE LONG CRESTEDNESS

Long crestedness is a measure of how parallel the wave crest is to the wavemaker and basin. This can be determined by examining the wave phase angle between pairs of probes and comparing them with the linear wave dispersion relation including shallow water effects. Probe 1 was taken as the reference probe. Using any other probe as the reference probe did not affect the results. Comparing phase angles between the end and beginning of the run for 1.03 seconds showed variability usually less than sample rate error, but could reach 28.6 degrees. The results show little dependence on blower speed as expected.

The average phase angle for each probe followed the analytic prediction trend very well, as seen in Figures 13-23. The standard deviation of the measured phase angle averaged across all probes and periods is 10.9 degrees. Average standard deviation using only periods greater than or equal to 1.55 was 5.22 degrees.

The figures also show the measurements offset from the analytic predictions by a constant amount. For periods 1.55 seconds and greater, Figures 16-23, this offset is less

than 16 degrees, and less than 6 degrees at periods 2.32 seconds and greater. The offsets for periods 1.03, 1.16, and 1.29 seconds are 68, 68, and 49 degrees respectively. These periods also have a larger scatter in the run data. The standard deviation averaged across all probes for these conditions is 26.0 degrees.

Having a constant offset indicates the waves follow a linear dispersion relation between probes. Examination of the video record supports this. That the measurements do not agree well the analytic predictions is the result of the wavemakers producing a slightly different period than used for the analytic calculations. The average value for period as generated by the wavemakers is close to the selected, but individual cycle changes can be from 2-4%. Calculations show that variations in period of 2-4% can cause the phase difference seen. This variation in period is most noticeable at the shorter periods where the sensitivity is greatest due to the short periods and wavelengths. Using periods of 1.07, 1.19, and 1.33 rather than 1.03, 1.16, and 1.29 improve correlation for the three shortest periods.

The sample rate, 20 sample per second, accounts for an error of $1/20^{\text{th}}$ the wavelength. For periods 1.55 seconds and greater, this precision error is the predominant part of the constant offset to the average phase.

REPEATABILITY

Beyond the blower speed and frequency, pneumatic wavemakers are subject to changing environmental conditions. The environmental conditions are: barometric pressure, air temperature, relative humidity, water depth in the basin, and dome door and lip settings. All of these parameters were measured throughout the test to minimize and determine their effect. Water depth and dome settings were same as for the MOB hydroelastic model test.

The atmospheric conditions remained fairly constant during the test. Barometric pressure was 29.7 inches of mercury. Relative humidity changed from 34.2% to 51.2%, while air temperature changed from 78.5 to 83.8 degrees Fahrenheit. Water depth changed a quarter inch over the course of the test.

Repeatability was determined by examining standard deviation of repeated conditions looking at probes in the same XY position. Usually this means the bridge probes (#1,3,5,7) for every condition with the long packets. Occasionally a short packet could be analyzed for repeatability. Additional repeat runs provided repeat data for carriage locations.

The repeatability aspect of the wave survey used the same harmonic analysis results as the wave crest uniformity investigation. The metric used was the ratio of the standard deviation to the mean value, also known as, coefficient of variation (COV), for each individual probe.

With the 14 probe locations and multiple runs, there were 226 instances where repeatability can be assessed, about half with just 2 samples per instance. The variation decreased with increasing period. The average COV was around 0.07 and 0.06 for 1.03 and 1.16 seconds, respectively, and averaged 0.030 for the rest of the periods. The overall COV was 0.035 for the variability of measurements at a probe.

Of these 226 instances, 58.4% had COVs less than 0.035; 76.1% were less than 0.05; and 96.4% less than 0.10. This indicates a 95% confidence the spatial repeatability COV will be less than 0.088. This indicates the spatial wave pattern is repeatable from run-to-run.

BEACH REFLECTION

There are at least four ways to measure beach reflection. These four methods are: measuring return from a short packet, 3-5 wave cycles, of waves; running the carriage at the phase speed and using spectral analysis to separate the components; using in-line wave probes to separate components; and compare root mean square of incoming waves and what is left when waves are turned off.

This survey used the last method to estimate the reflection because the return from the beaches was hard to pick out with harmonic analysis. Rigging concerns prevented running the carriage. Variability amongst the probes and undesirable probe spacing made using in-line probes unfeasible.

Therefore beach reflection was estimated by comparing the standard deviation of the generated waves with the standard deviation of the noise in the tank shortly after turning off the wavemakers. The times selected avoided starting and stopping transients. The generated wave values are those used for the crest uniformity and long crestedness investigations.

Examining the reflection in an absolute sense shows the maximum reflection is less than 0.7 inches with an average value across all probes 0.65 inches. The mean COV across probes for all conditions is 0.28. This is higher than just the amplitudes, which indicates more scatter in the reflection than the incident wave. The reflection is not constant and does increase with blower speed, but does not increase in the same proportion as the wave amplitude. As a result, the reflection percentage decreases.

Also the beaches were transparent to the shorter waves as evidenced by a more sinusoidal return. It was thought that the longer waves would be less affected, but this was not the case. The larger reflections at the longer periods are more a function of a larger input rather than beach transparency.

The average percent of incident wave height reflected for all probes across all conditions is $12.2 \pm 6.0\%$. The minimum and maximum reflection of all conditions averaged across all probes is 4.2 and 28.1%, respectively.

The run-to-run scatter within a condition is relatively small, which is consistent with the repeatability of the wave amplitudes. The average standard deviation of the reflection for all the probes across all the runs was 3.2%. The maximum standard deviation was 10.0%; the minimum was 0.59%.

The reflection percentage decreases slightly with increasing period and decrease strongly with blower speed. Each period has a definite trend showing this decrease with increasing blower speed.

RUN LENGTH

To have statistically valid data requires long run lengths. If there are no reflected waves, it is possible to have infinite run length. The longer the run length, the more reflected waves contaminate the incident waves being generated. It is important to determine how long the run can last before the contamination level is unacceptable.

For long packet wave runs, data were collected for two to three minutes. This is enough time for even the shortest waves to reflect off the beach and return to the test area. The data at the end of the run will also contain reflections from the wavemaker side of the basin.

The runs were harmonically analyzed at the beginning and the end of the wave packet and compared for consistency. The starting and ending transients were ignored. The comparison metric is the percentage the difference of the beginning and end values is of their average. A negative number indicates the end is greater than the beginning. As expected, a positive number indicates the beginning is greater than the end.

Comparing values across periods for all blower speeds and probes shows the average values to be near zero with no real trend with respect to period. The averages range between 2.5 and -4.8, with 7 of 11 periods being less than 2 percentage points from zero. The standard deviation ranges from 3.7 to 13.2% and generally decreases with period.

These values indicate little consistent difference between the beginning and end of the wave packets. The difference is in the noise of the other measurements and on the order of other variability. Also the measured harmonic fitness, $A1/RQ0$, is still high, greater than 0.95, at the end of the run. Run lengths of two to three minutes of regular waves are not excessive.

The average value across all periods, blower speeds, and probes is $-0.68 \pm 7.99\%$. A histogram of all the differences shows 75.6% of the values within one standard deviation; and 95% of the values within 16.6 percentage points of zero. The values are symmetrically distributed about the mean with a skewness of 0.067. These values are similar to the crest uniformity average COV of 0.102.

PRESSURE UNIFORMITY

The pressure in the domes was harmonically analyzed to determine the first three harmonic amplitudes and phase angles. Dome 2 was the reference dome. This study compared the amplitude and phase of the first harmonic. This is consistent with the harmonic analysis of the wave data.

The pressure dome measurements provide a measure on the primary source of spatial non-uniformity in the wave field. Having a direct measure allows for the quick correction of the problems identified.

The time slice analyzed for most all of the runs was near the beginning of the run to correspond to the time slice used for the wave analysis and ensuring 8-10 cycles. A very few runs had spiky data or other difficulty during this time period requiring a later time slice.

The pressure uniformity across the domes for all the conditions followed very similar trends, see Figures 24-34. The coefficient of variation across all domes for all conditions ranged from 0.01 to 0.04. This indicates fairly uniform pressure across all the domes. Additionally there was very little scatter of the data between runs.

Examining each dome individually revealed very similar trends for all conditions. Domes 2, 10, and 12 had lower than average values, with Dome 10 being the most consistent. Domes 9 and 11 had higher than average values. The rest of the domes were nearly identical in pressure. The variation of Dome 10 from the mean value was consistently the largest of any dome, averaging 8%.

HARMONIC CONTENT

For the shorter periods tested, there was a third harmonic component of comparable magnitude to the first harmonic amplitude. This third harmonic component disappeared as the period increased, disappearing completely by 2.58 seconds. This higher harmonic was not noticeable in the wave signal as measured by the high A1/RQ0 ratio for these runs.

PRESSURE LONG CRESTEDNESS

The phase angles between the pressure domes should all be equal and near zero. Due to differences in gage polarity, there was a 180-degree phase shift between pressure gage brands. The author removed this phase shift for analysis. The metrics for comparison are the mean and standard deviation for each condition.

The mean phase angle for each dome ranged between ± 6 degrees for all conditions, with the exception of Dome 12. Dome 12's phase angle decreased with increasing period, starting at 9 degrees. It was less than 5 degrees for 1.55 seconds, and merged with the rest of the domes by 2.06 seconds. Domes 9 and 10 were also slightly separate from the rest of the domes over this period range.

The standard deviation of the phase angles was on the order of 0.5 degree for all conditions and domes, except 2.06 seconds at 700 rpm. There the standard deviation was 3.9 degrees.

The pressures were sampled at 50 Hz. This gives a precision error of 7.2 degrees which spans all the data except dome 12 for short periods. This means the wavemakers are producing a repeatable long crested wave front. Wave crest distortion is a result of interaction in the basin.

UNCERTAINTY DISCUSSION

The uncertainty of the wave measurements results from variation between runs, variation in the wave amplitude from cycle to cycle, calibration curve fit accuracy, probe movement in waves, meniscus effects on the wire, data collection and sampling error. The between runs variation of measurements at a probe is the repeatability COV of 3.53 and 3.43% for wire and sonic probes, respectively.

The 4th order calibration polynomial had an average standard error estimate² of 0.15 inches. This is the error due to using a curve fit of the calibration rather than actual

data for the measurement. The average percent error for the curve fit is 2.0%. Movement of the wire probes due to waves during testing produced a change no greater than 5mV as determined by shaking the probe on the calibration stand. This corresponds to an average change of 0.021 inches. The average percent error due to probe movement is 0.47%. It is assumed meniscus effects are of similar magnitude. The acoustic probes are accurate to 0.01 inches over their entire range.

The other precision error comes from data acquisition and sample rate. The test used a 12 bit analog-to-digital converter and saved the data as 2 byte integers. This gave the data a resolution of 0.01 inches (0.23%), and 0.0005 psi and 0.001 psi for the Sensotec and Setra gages, respectively.

The phase angles are subject to a precision error due to sampling rate. The sample rate, 20 sample per second, accounts for an error of $1/20^{\text{th}}$ the wavelength. For periods 1.55 seconds and greater, this precision error is the predominant part of the constant offset to the average phase.

The wave amplitude uncertainty is 6.3 and 5.9% for the wire and sonic probes, respectively. For wire probe, the majority of the uncertainty comes from the calibration curve fit error. The majority of the uncertainty comes from variation of the wave amplitude within the analysis time window, 4.8%, for the sonic probe. The uncertainty was found taking the square root of the sum of the squares following Reference 2.

The **INSTRUMENTATION PRESSURGE GAGES** section discusses the uncertainty associated with the pressure gages.

The Setra gages had non-zero mean values. The wave probes also had non-zero mean values either due to changing water level and/or boom movement. This bias error does not affect the harmonic analysis which removes the mean values.

SUMMARY OF CONCLUSIONS

This test surveyed the wave quality of the 'A' bank wavemakers in the MASK at the expected test location for the MOB model. The test evaluated the wave quality in terms of repeatability, crest uniformity, long crestedness, beach reflection, and run length. Additionally, the dome pressures were measured to help reveal disturbance sources.

This wave survey helped determine areas of high and lesser quality waves. There is some variation in wave amplitude at all periods and blower speeds. The amplitude variation is less for periods between 1.29-3.1 seconds and below the over pressure speed of 1100 rpm. The upper end of this range, 1.55 seconds and above, is long crested in the center of the tank.

The average standard deviation of the wave amplitude along the crest is 10% of the mean value for all conditions tested. Considering only conditions with periods less than 3.1 seconds results in an average COV of 8.9%. There is pattern in wave amplitude with respect to X location, but not with Y location. This is visible despite the uncertainty in the measurements.

The phase angles reveal long crested waves for periods above 1.55 seconds to within the accuracy of the measurement. Examining of the video confirmed that waves

are long crested for the shorter periods. Run lengths of 2-3 minutes did not significantly change the amplitude, phase, or harmonic content of the waves. Beach reflection averaged 12.2% of the incoming waves for all conditions.

The pressure measurements reveal a consistent value in dome pressure and phase angle between domes. Dome 10 is consistently low by 8 percent of the average value. Surrounding domes, 9, 11, and 12 also show more deviation from the mean than the other domes. But variation between runs was small.

Another follow on wave survey would provide data for a wider range of atmospheric conditions. With the dome pressure measurements, it may be possible to tune the blower speed to repeat the same pressures and wave field. Repetition of test conditions with high variability would be beneficial. It would also allow further exploration of the large wave amplitude difference between in-line probes.

Table 1 English to metric units conversion factors.

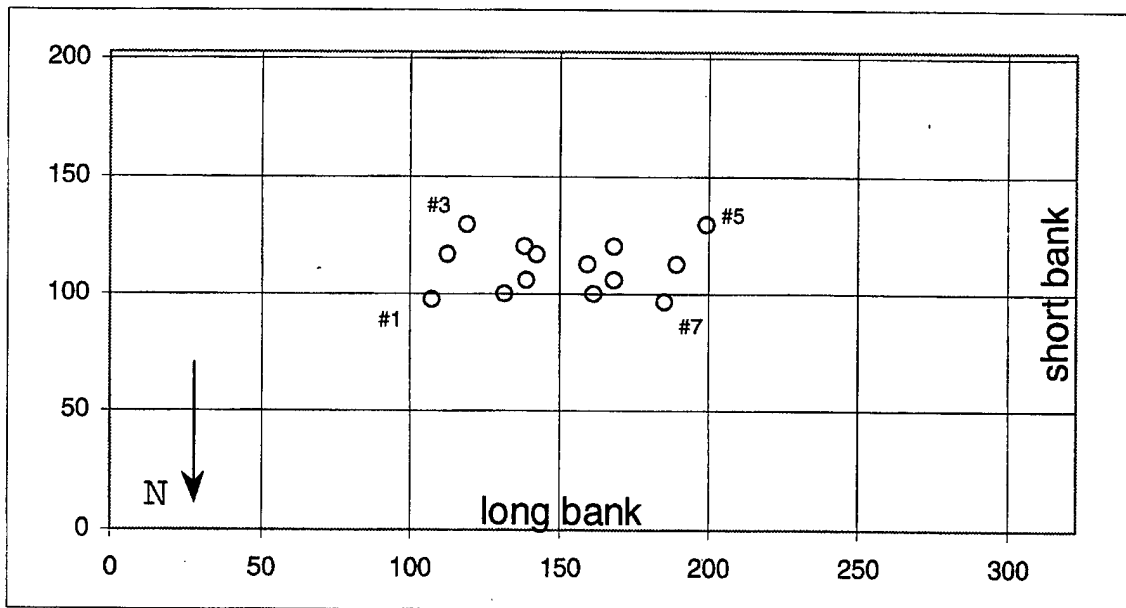
1 inch (in)	=	2.54 cm
1 foot (ft)	=	30.48 cm = 0.3048 m
1 pound/square inch (psi)	=	6.89 kPascals (kPa)

Table 2 Wire probe non-linear calibration coefficients.

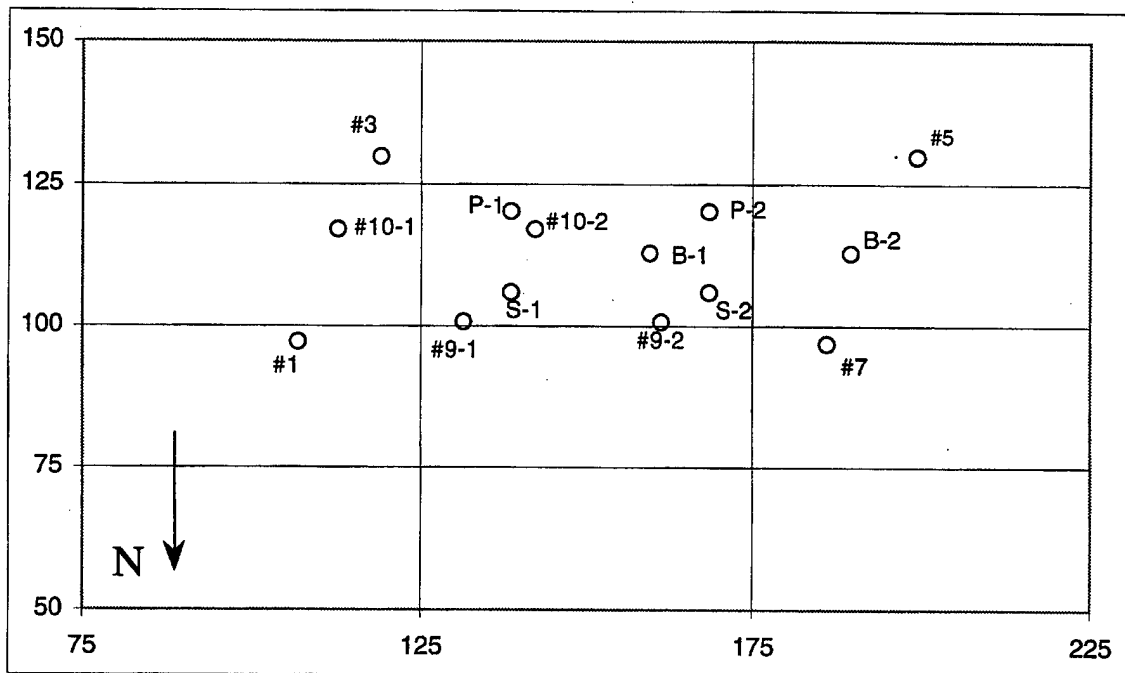
Probe	C0 (in)	C1 (in/volt)	C2 (in/volt ²)	C3 (in/volt ³)	C4 (in/volt ⁴)
1	0.1294	-4.7302	0.5775	-0.0460	-0.0017
3	-0.0202	-3.7096	0.3488	-0.0396	0.0036
5	-0.0062	-4.4316	0.4634	-0.0136	-0.0029
7	0.0541	-4.0965	0.6321	-0.1410	0.0158
9	-0.0112	-4.5809	0.4991	-0.0187	-0.0032
10	0.1331	-4.6292	0.5125	-0.0208	-0.0034

Table 3 Test matrix showing desired wave slope over measured wave slope by period and nominal blower speed.

Period (sec)	Blower speed		
	Low	Medium	High
1.03	80/36.6	50/20.4	
1.16	100/31.6	50/14.8	30/
1.29	100/32.8	50/18.8	25/
1.55	100/54.3	50/34.4	25/17.0
1.81	100/124.0	50/47.0	25/15.0
2.06	100/139.3	50/51.8	25/21.1
2.32	100/90.3	50/41.5	25/21.8
2.58	80/79.3	50/46.7	25/20.8
3.10	100/131.2	50/50.4	30/29.4
3.61	100/109.2	80/	50/46.2
4.13	100/97.4	80/58.7	50/55.2



(a) Wide view of probes in whole basin.



(b) Close up view with probes labeled.

Figure 1. Probe location (XY) for both carriage positions.

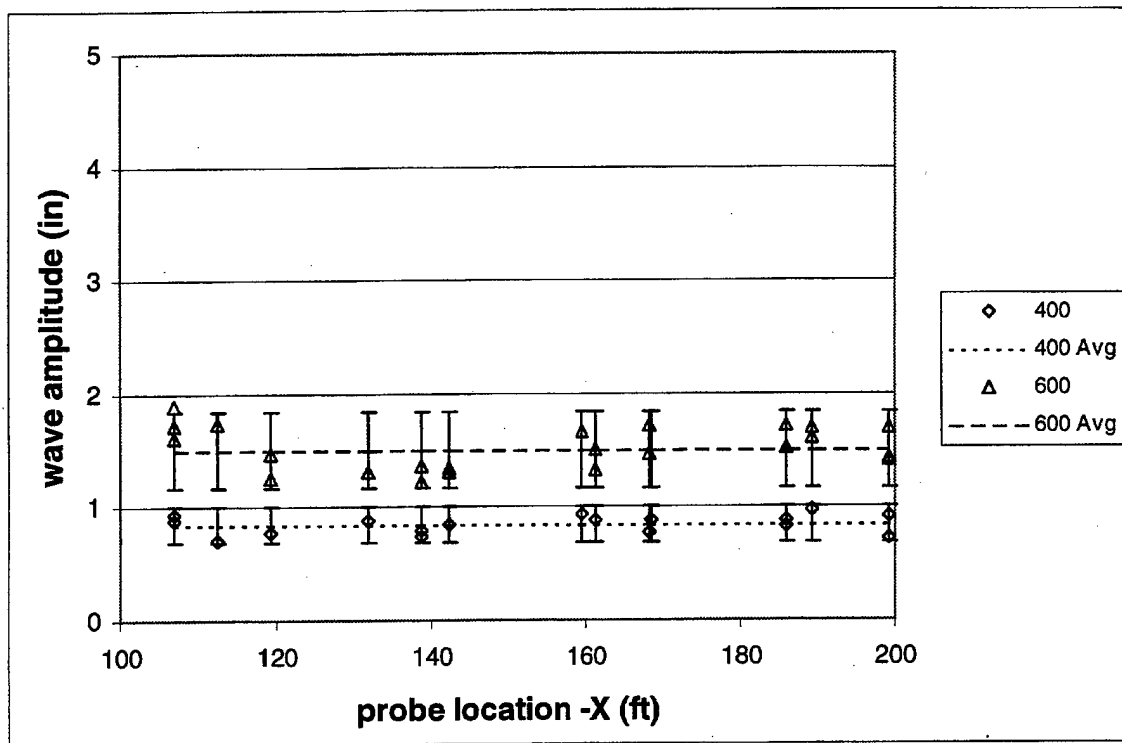


Figure 2. Wave amplitude by probe location and blower speed (rpm) for 1.03 second period.

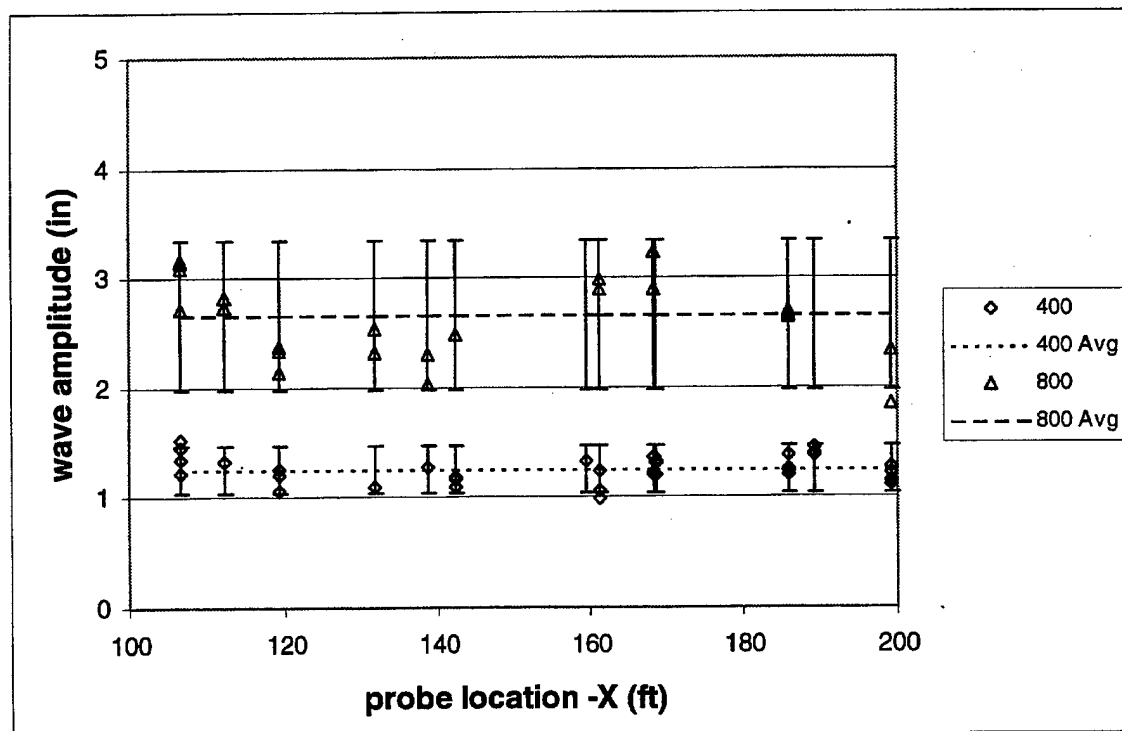


Figure 3. Wave amplitude by probe location and blower speed (rpm) for 1.16 second period.

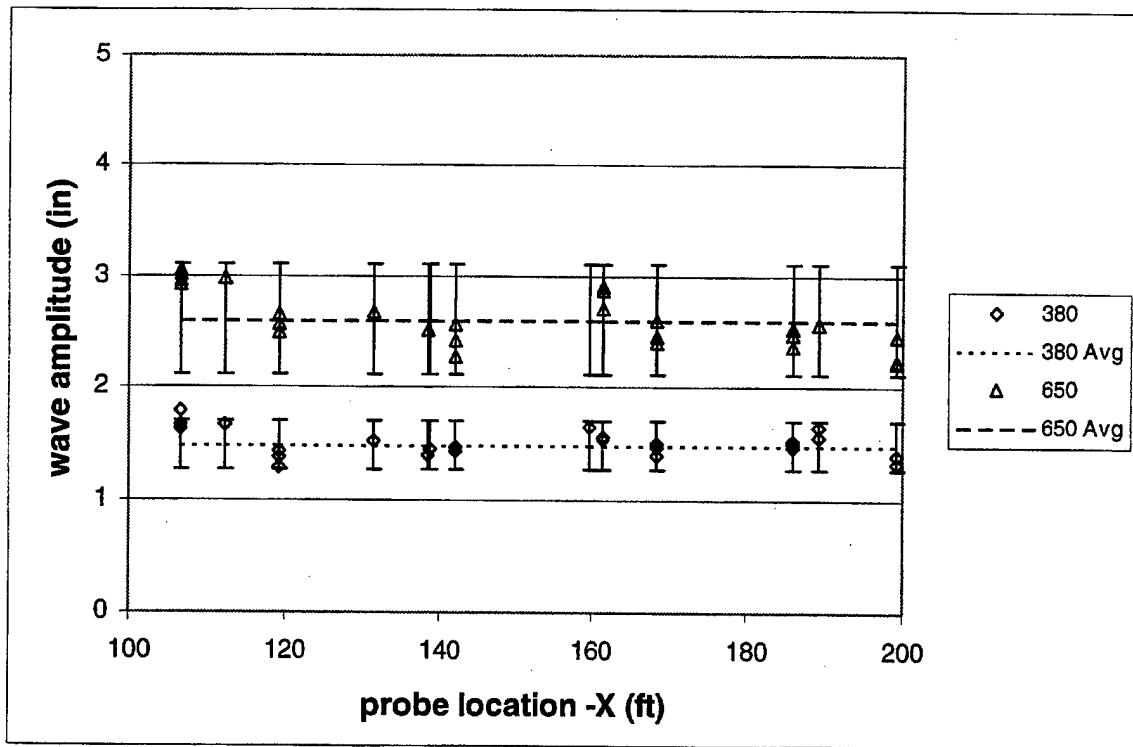


Figure 4. Wave amplitude by probe location and blower speed (rpm) for 1.29 second period.

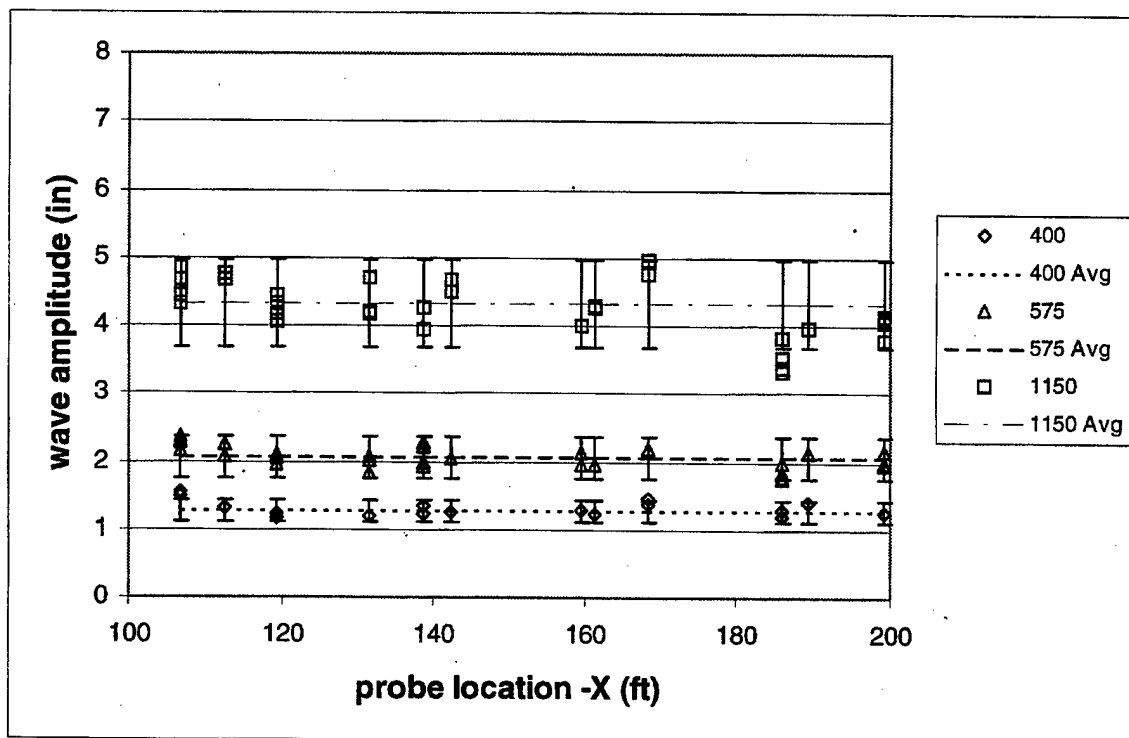


Figure 5. Wave amplitude by probe location and blower speed (rpm) for 1.55 second period.

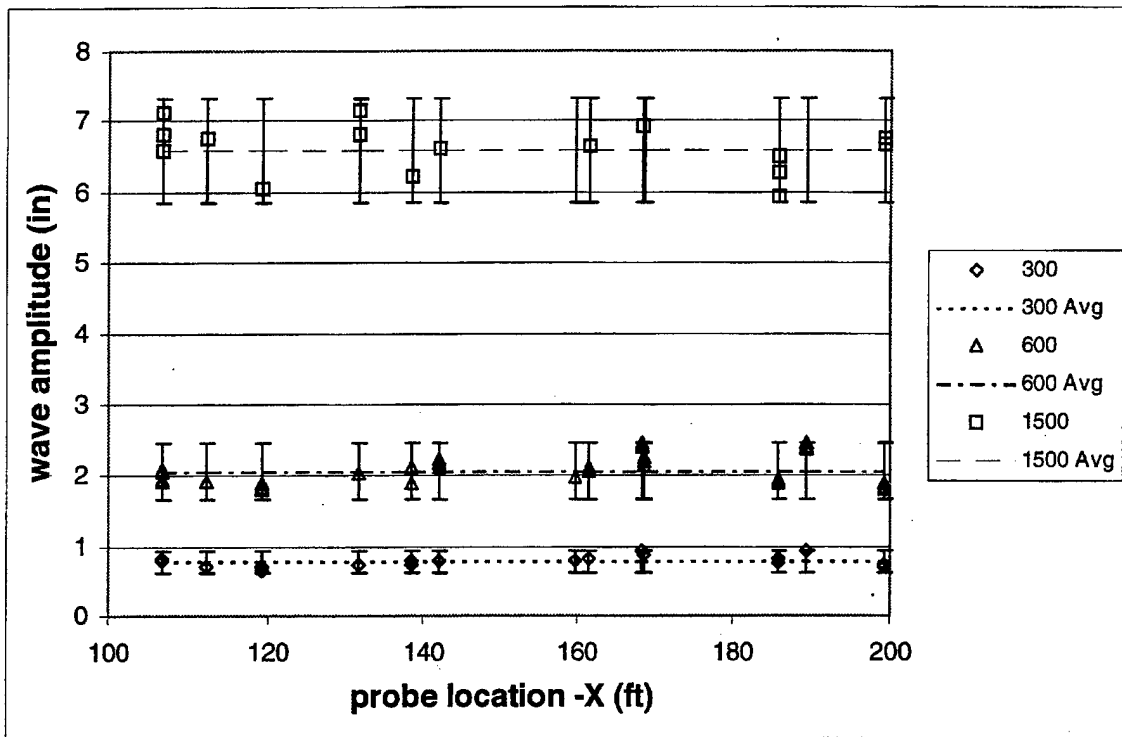


Figure 6. Wave amplitude by probe location and blower speed (rpm) for 1.81 second period.

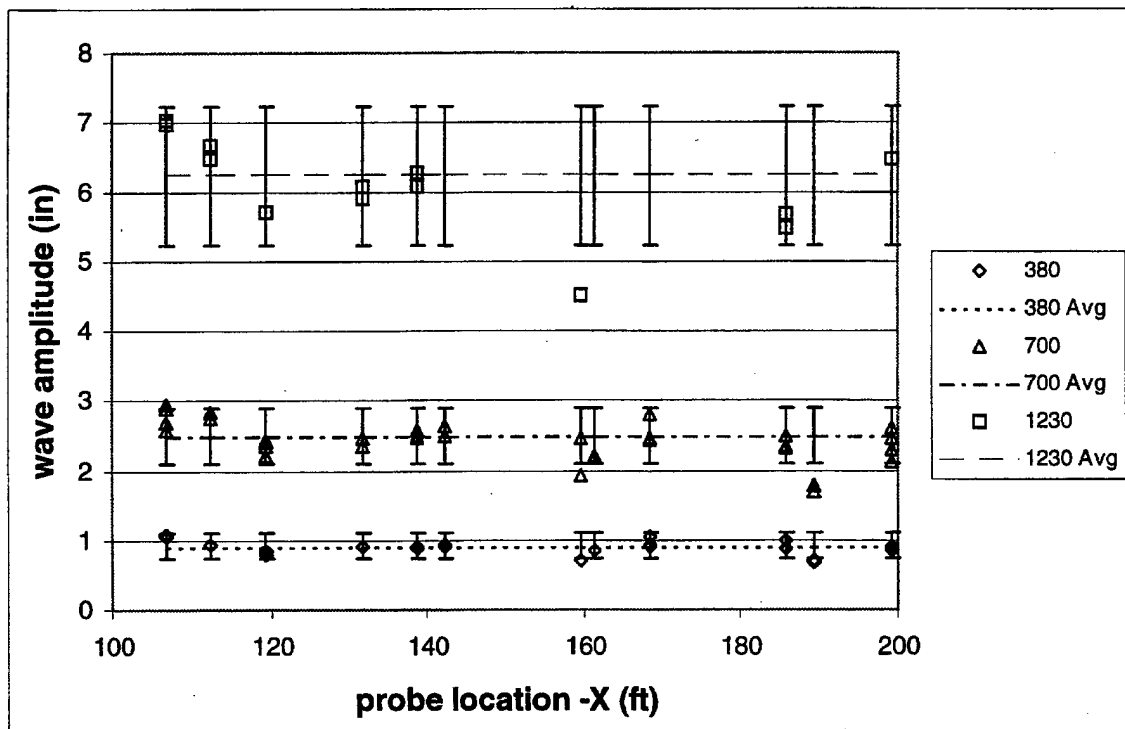


Figure 7. Wave amplitude by probe location and blower speed (rpm) for 2.06 second period.

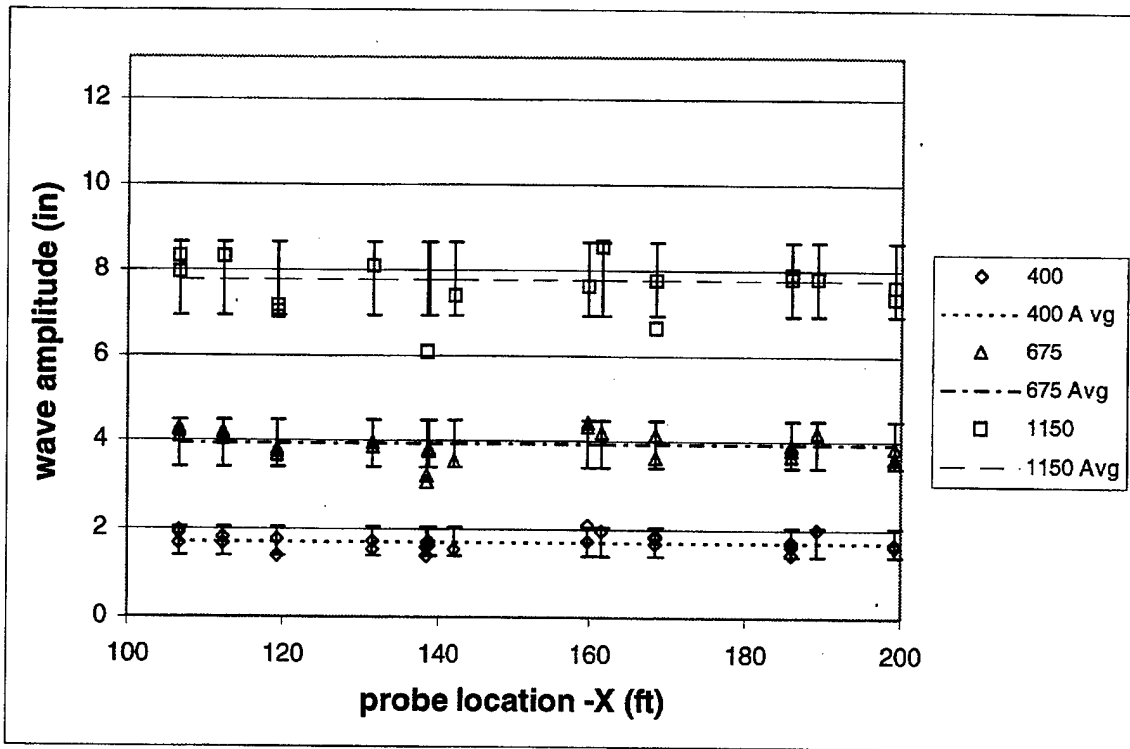


Figure 8. Wave amplitude by probe location and blower speed (rpm) for 2.32 second period.

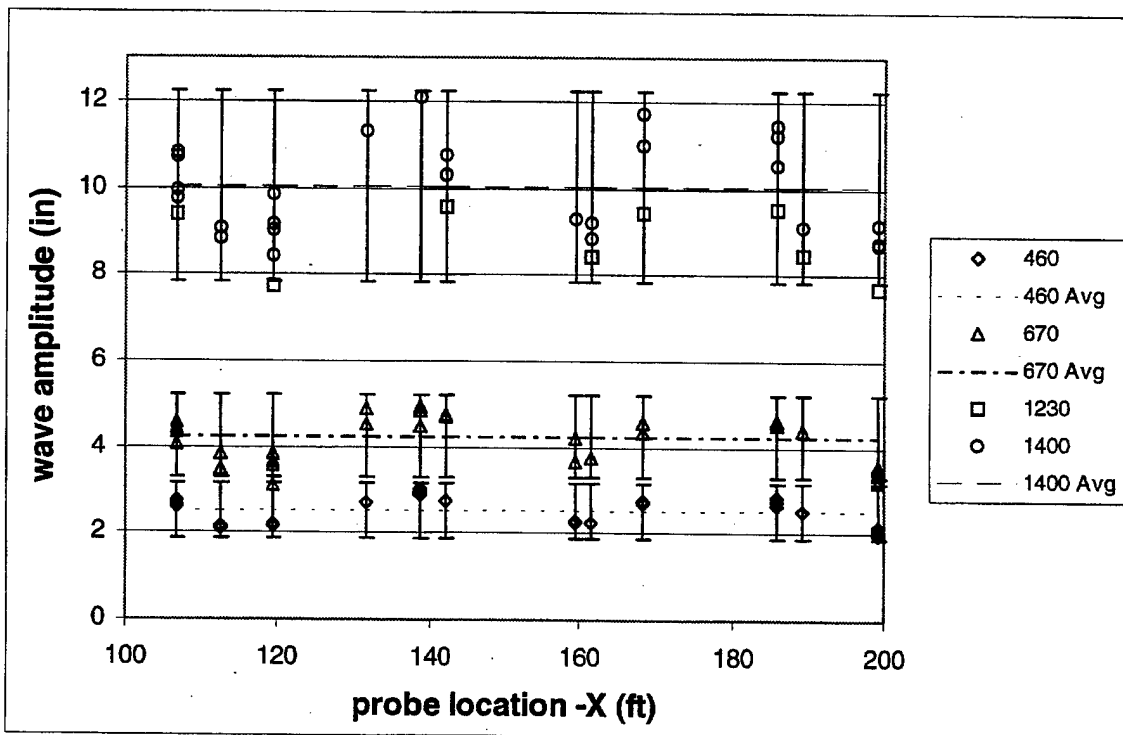


Figure 9. Wave amplitude by probe location and blower speed (rpm) for 2.58 second period.

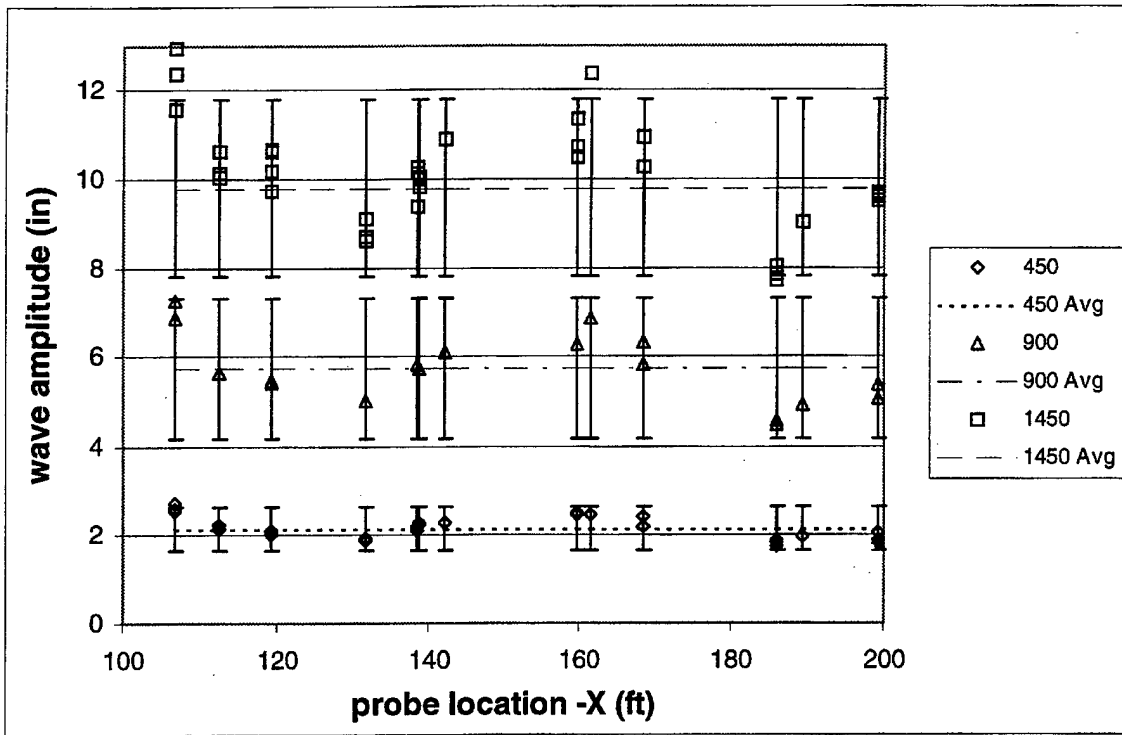


Figure 10. Wave amplitude by probe location and blower speed (rpm) for 3.10 second period.

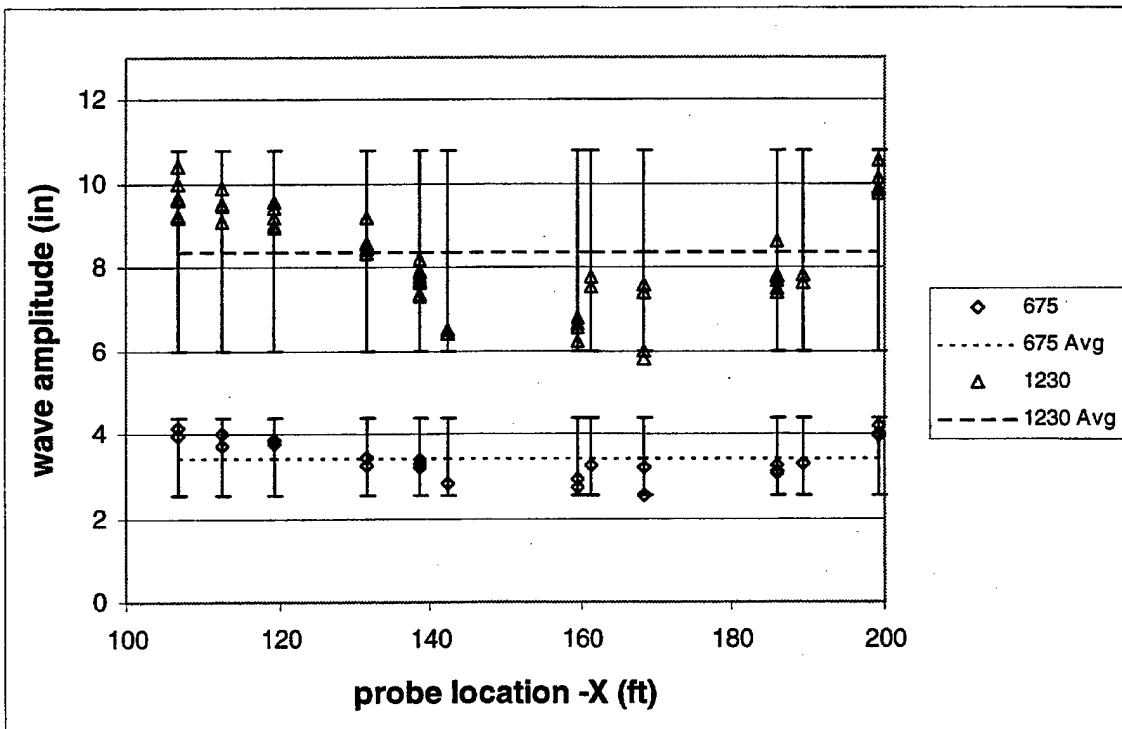


Figure 11. Wave amplitude by probe location and blower speed (rpm) for 3.61 second period.

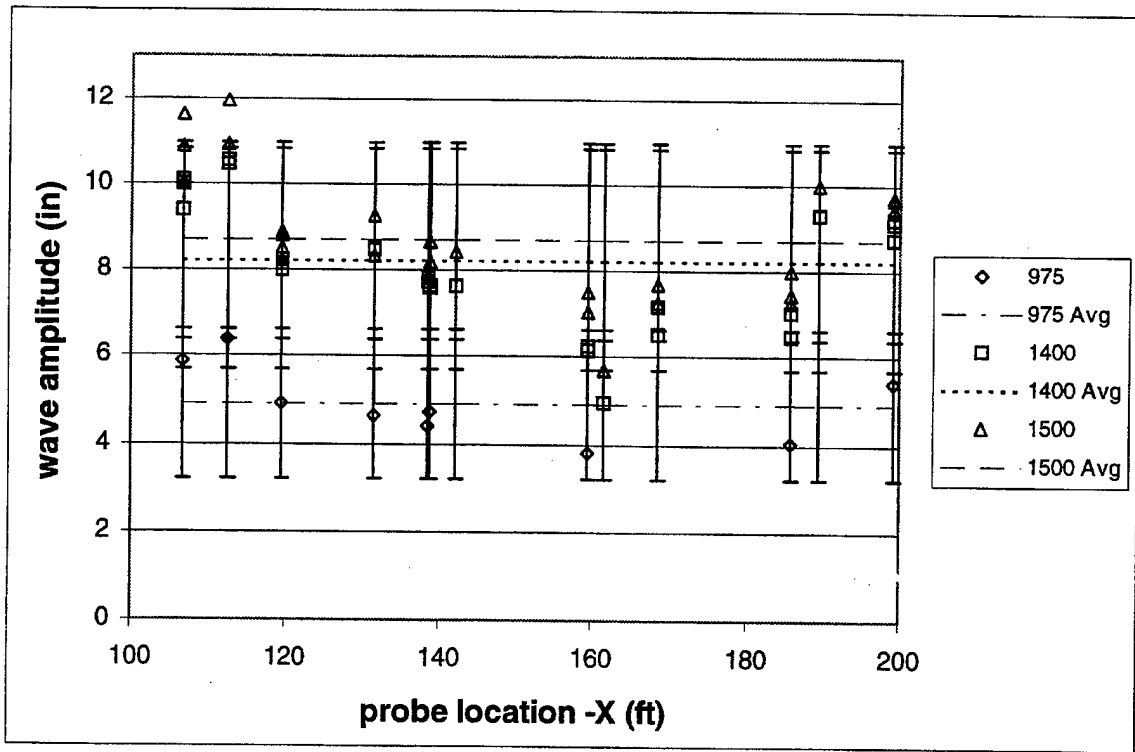


Figure 12. Wave amplitude by probe location and blower speed (rpm) for 4.13 second period.

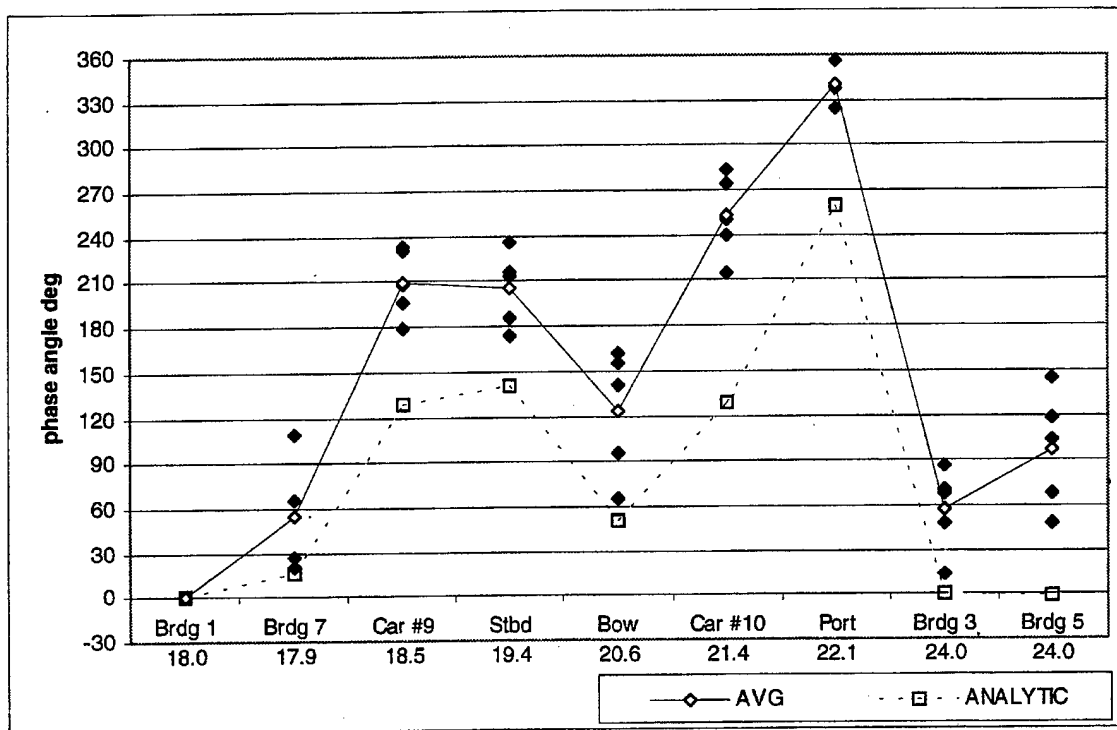


Figure 13. Wave phase angle by probe with wavelengths from wavemaker for 1.03 seconds.

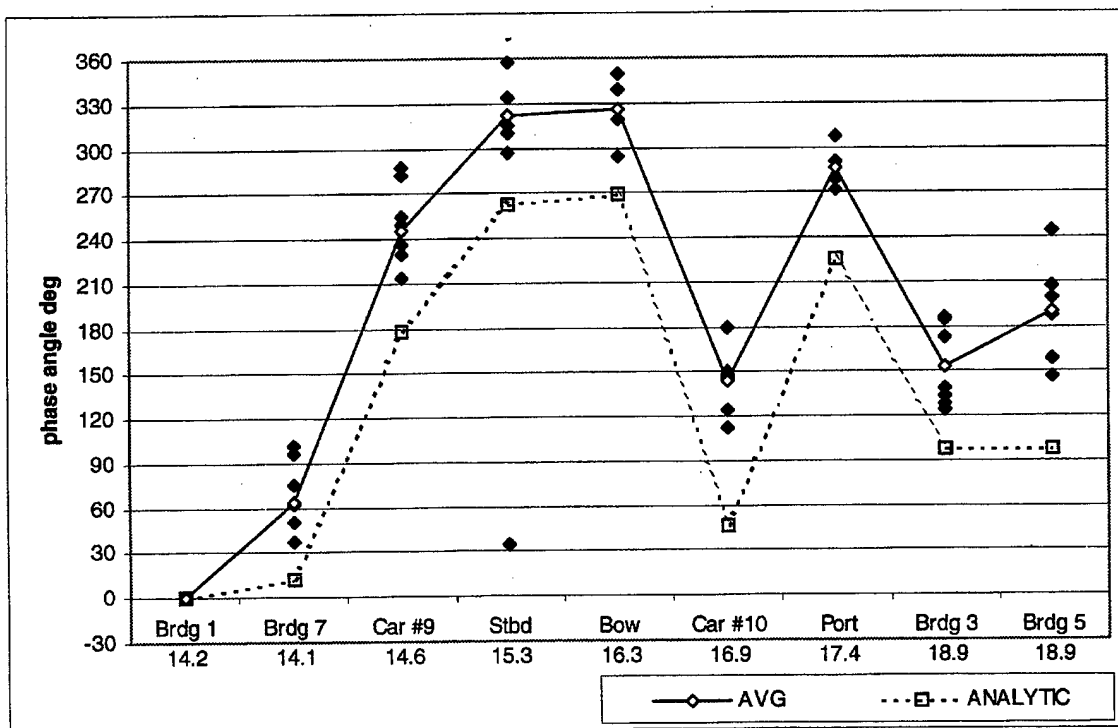


Figure 14. Wave phase angle by probe with wavelengths from wavemaker for 1.16 seconds.

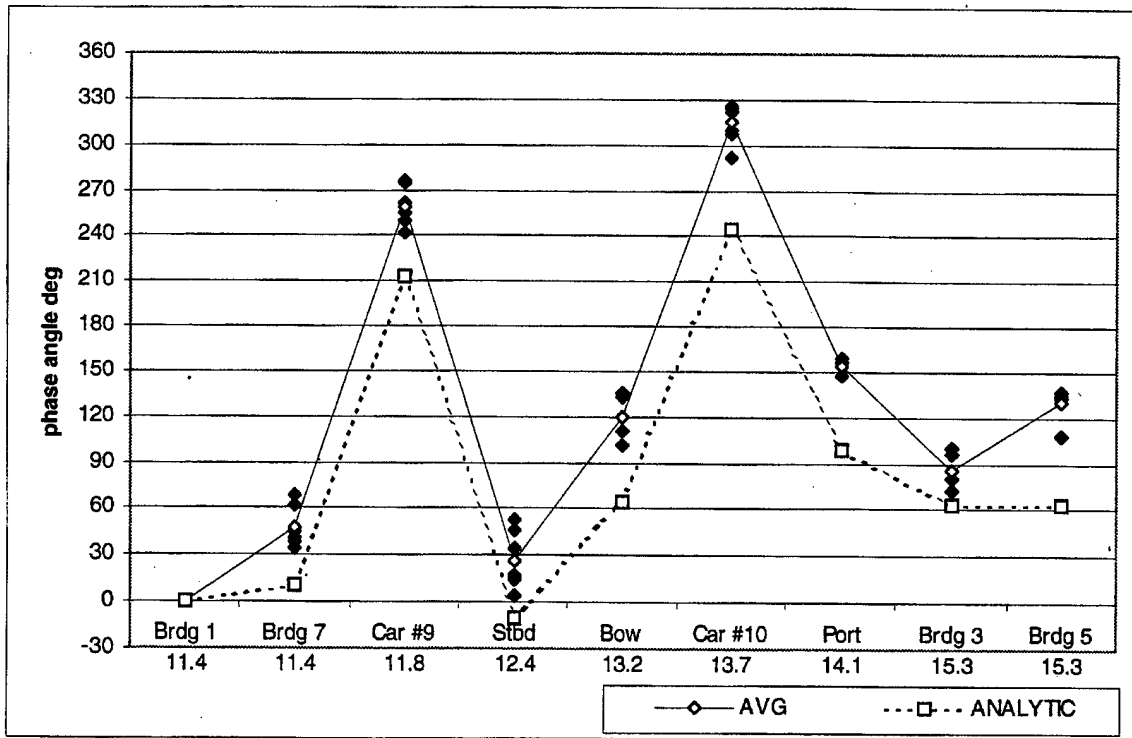


Figure 15. Wave phase angle by probe with wavelengths from wavemaker for 1.29 second period.

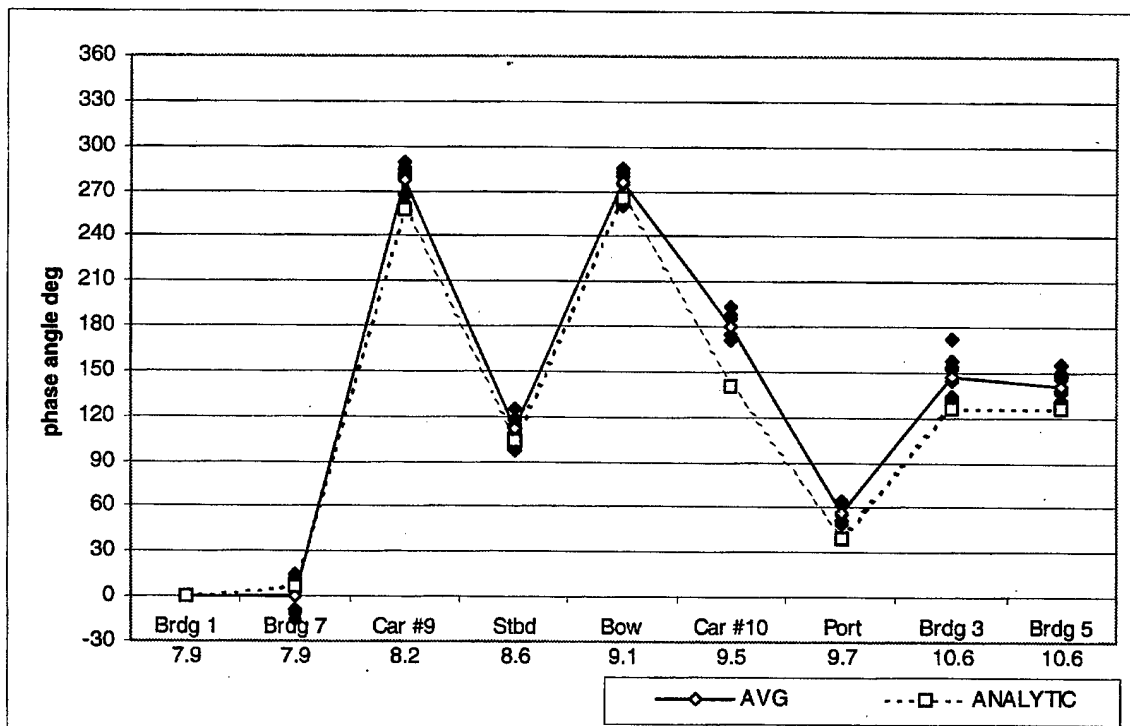


Figure 16. Wave phase angle by probe with wavelengths from wavemaker for 1.55 second period.

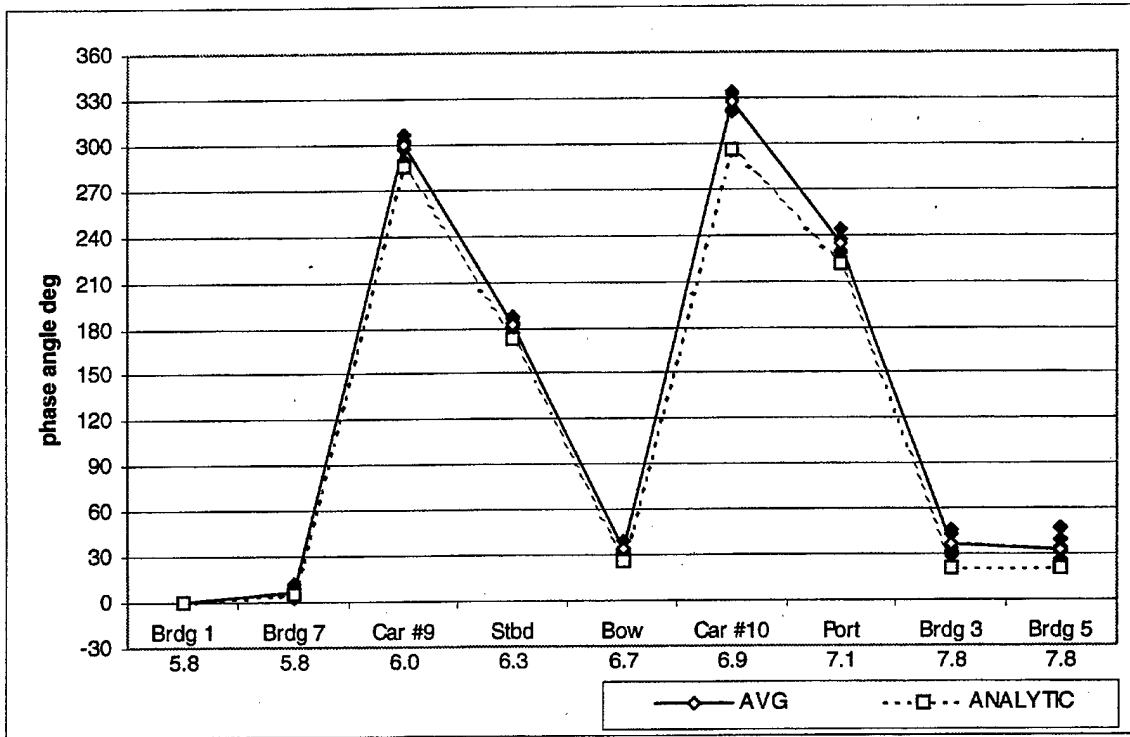


Figure 17. Wave phase angle by probe with wavelengths from wavemaker for 1.81 second period.

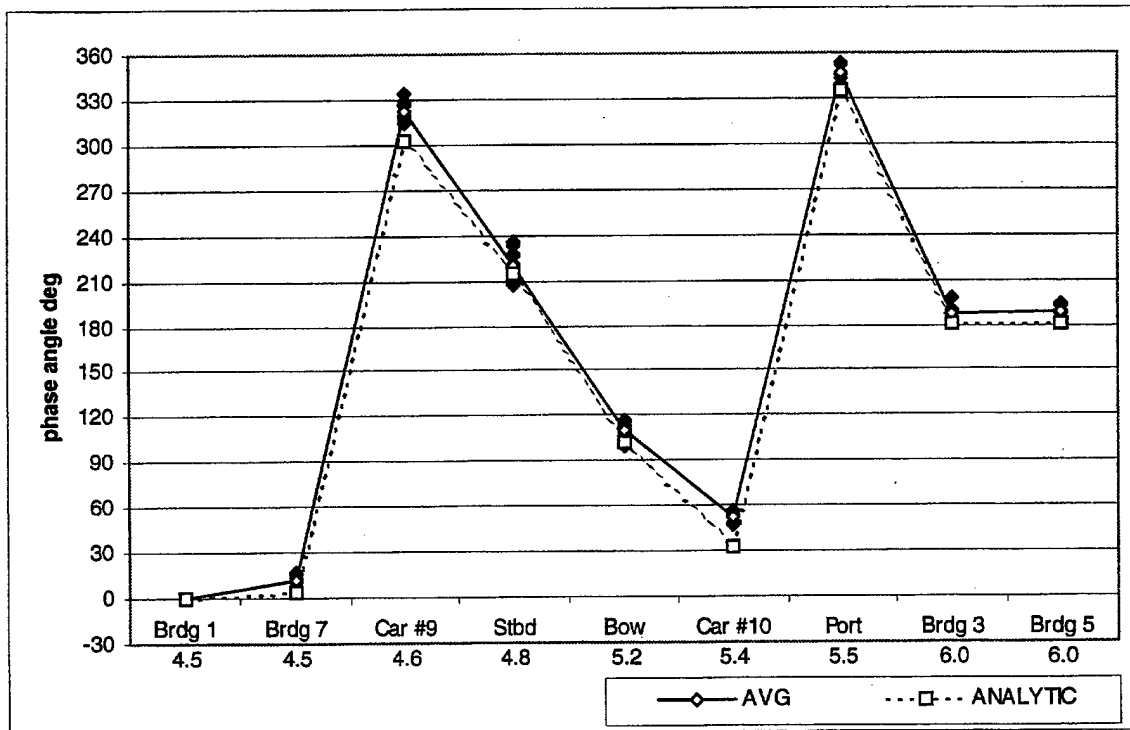


Figure 18. Wave phase angle by probe with wavelengths from wavemaker for 2.06 second period.

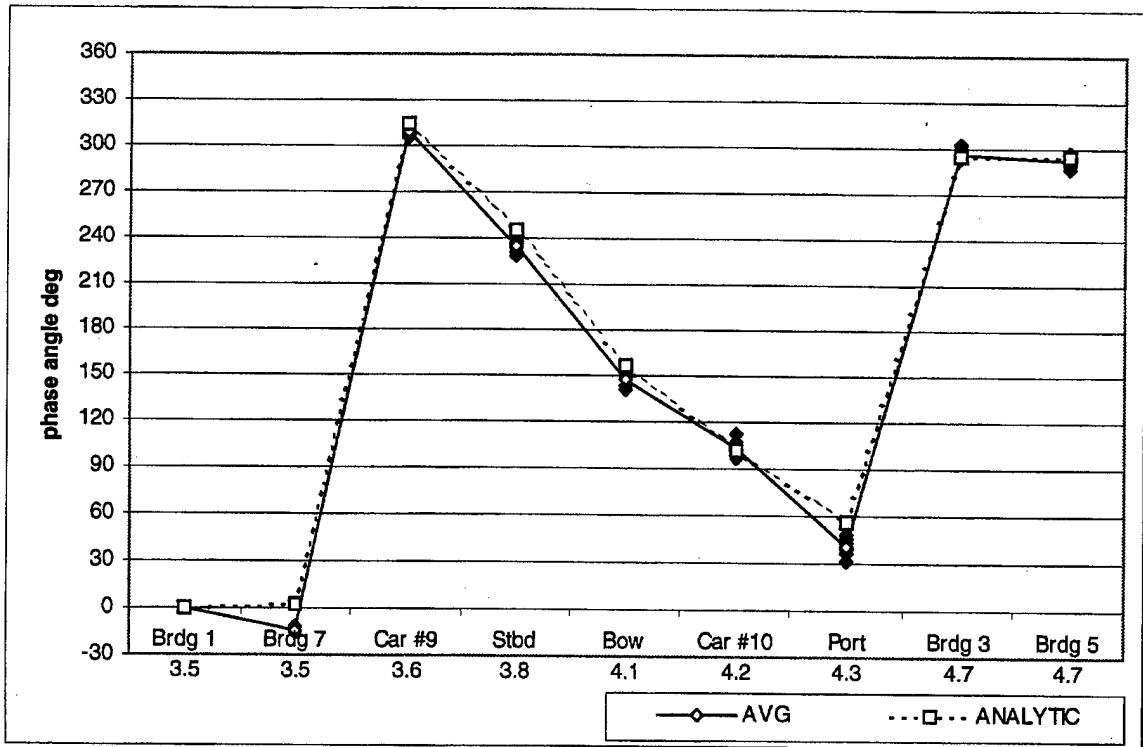


Figure 19. Wave phase angle by probe with wavelengths from wavemaker for 2.32 second period.

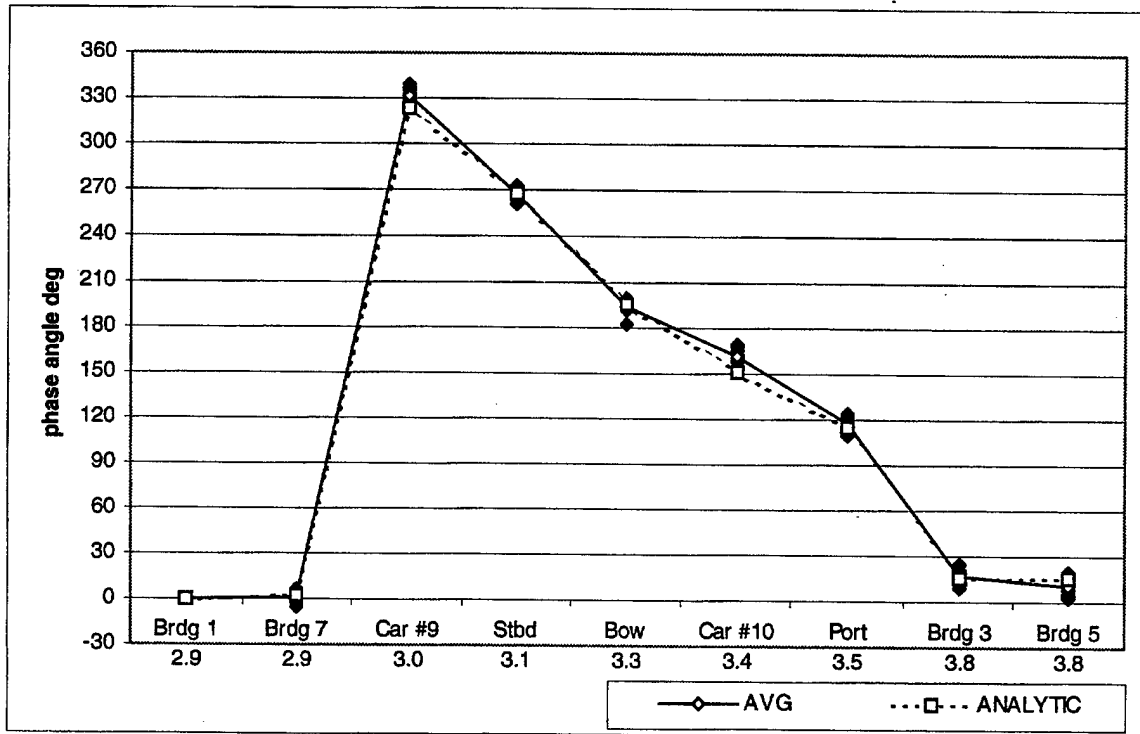


Figure 20. Wave phase angle by probe with wavelengths from wavemaker for 2.58 second period.

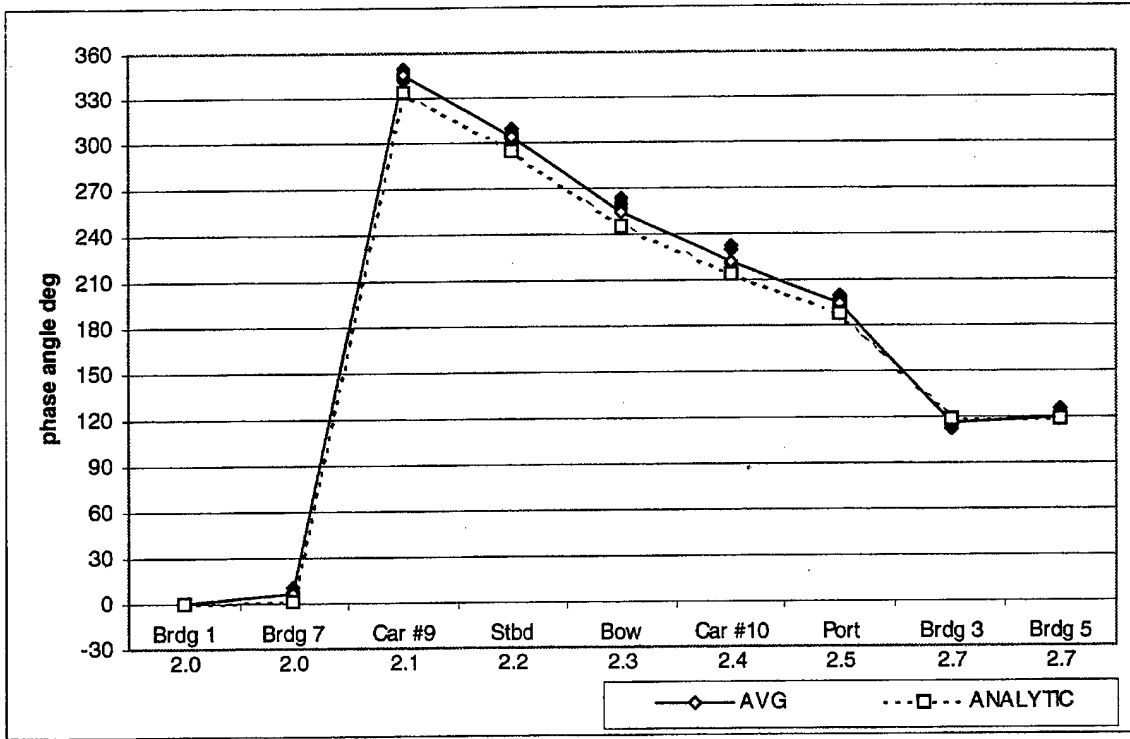


Figure 21. Wave phase angle by probe with wavelengths from wavemaker for 3.10 second period.

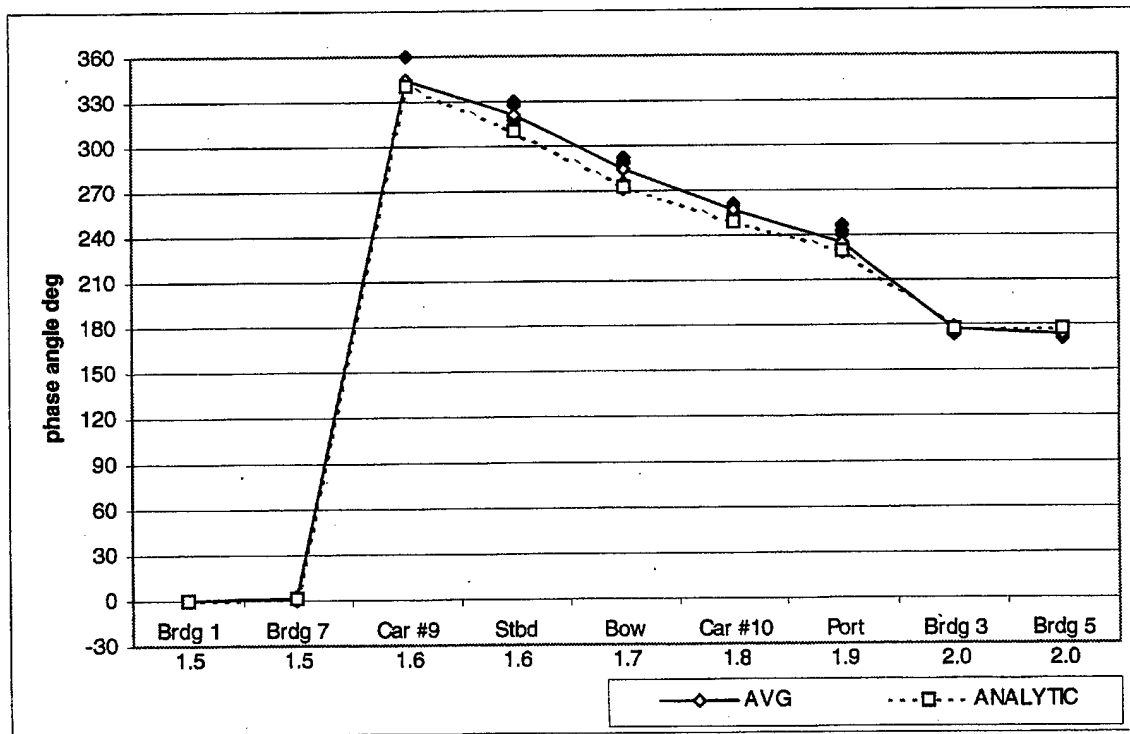


Figure 22. Wave phase angle by probe with wavelengths from wavemaker for 3.61 second period.

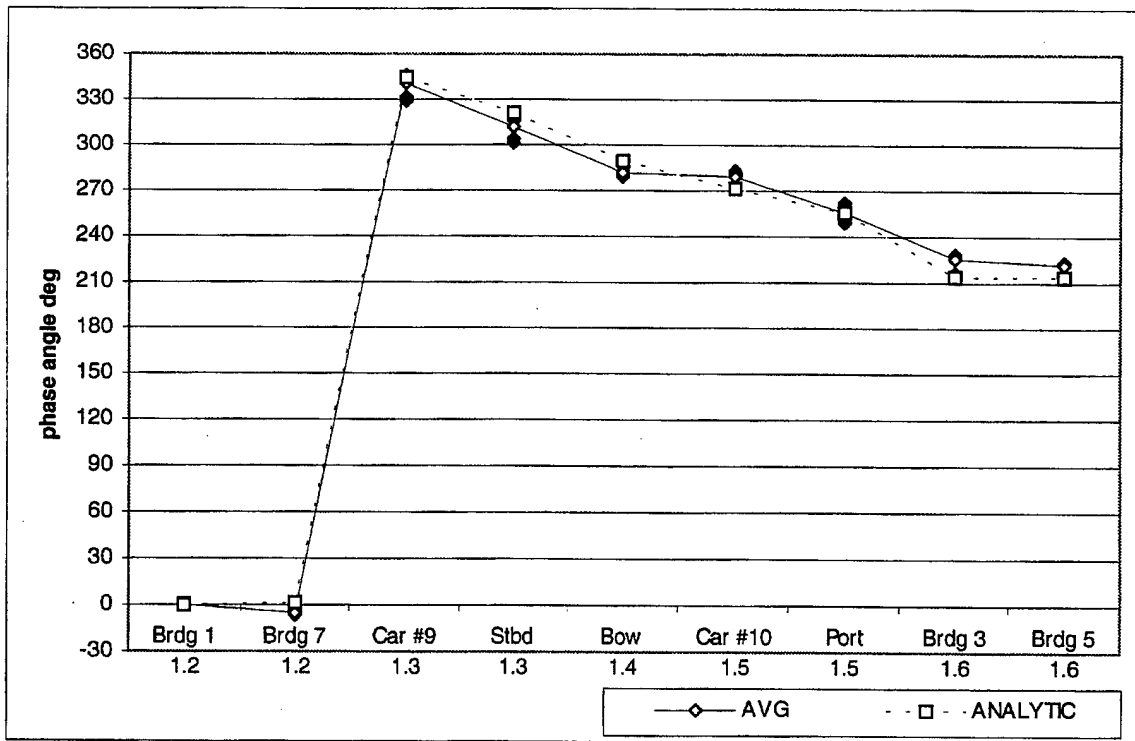


Figure 23. Wave phase angle by probe with wavelengths from wavemaker for 4.13 second period.

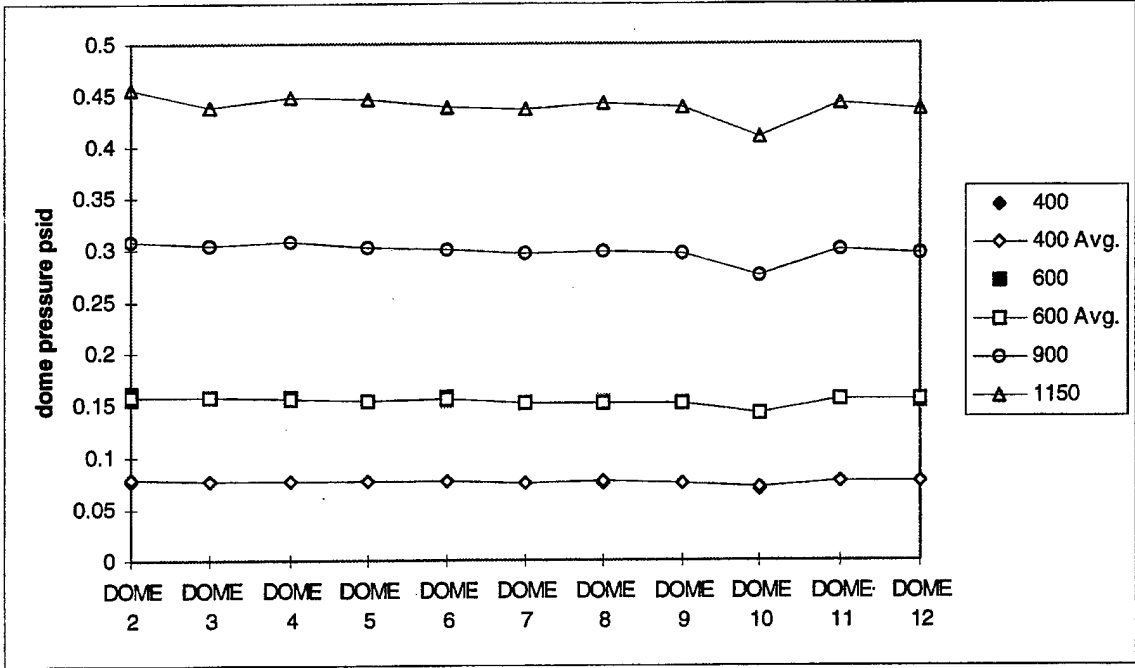


Figure 24. Dome pressure by dome and blower speed (rpm) for 1.03 second period.

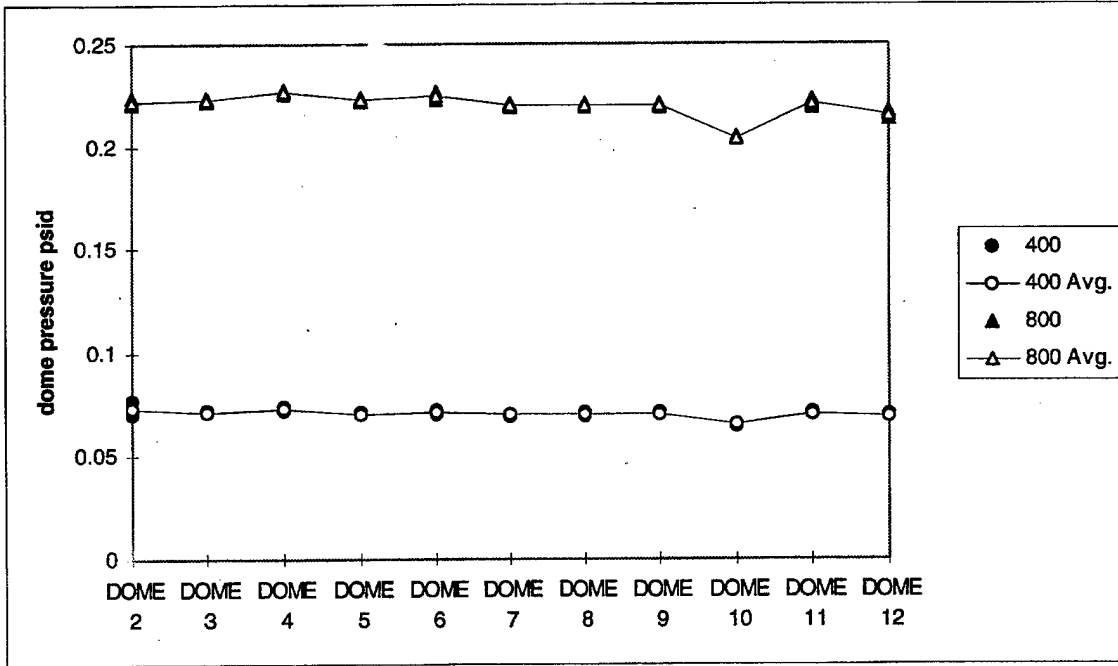


Figure 25. Dome pressure by dome and blower speed (rpm) for 1.16 second period.

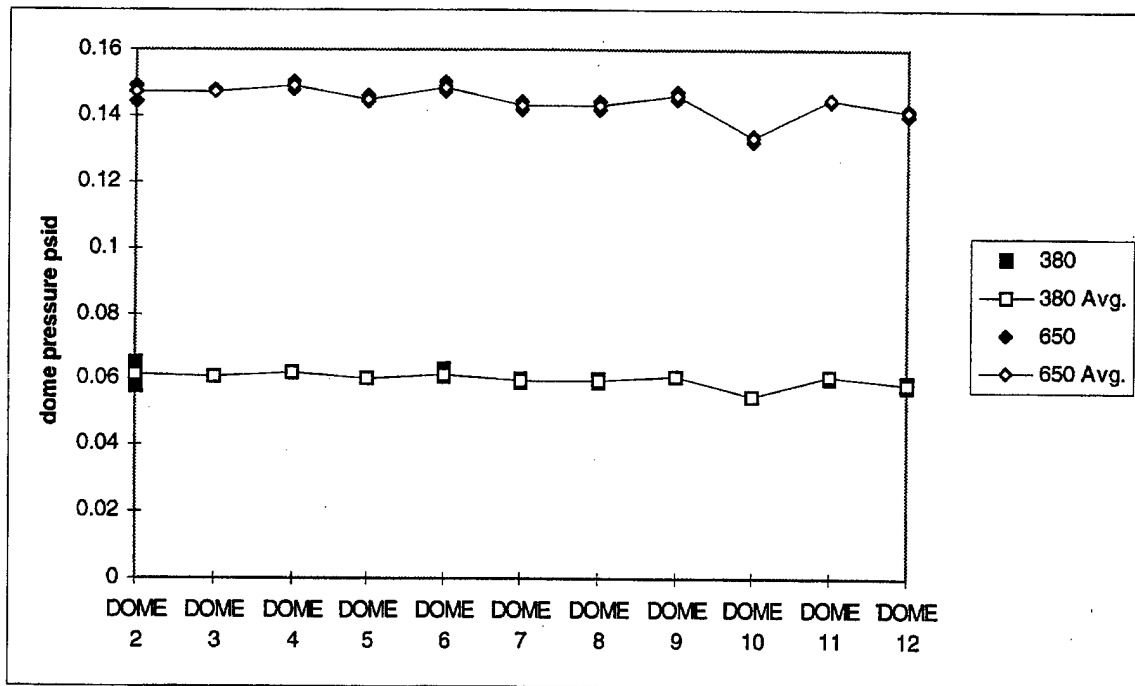


Figure 26. Dome pressure by dome and blower speed (rpm) for 1.29 second period.

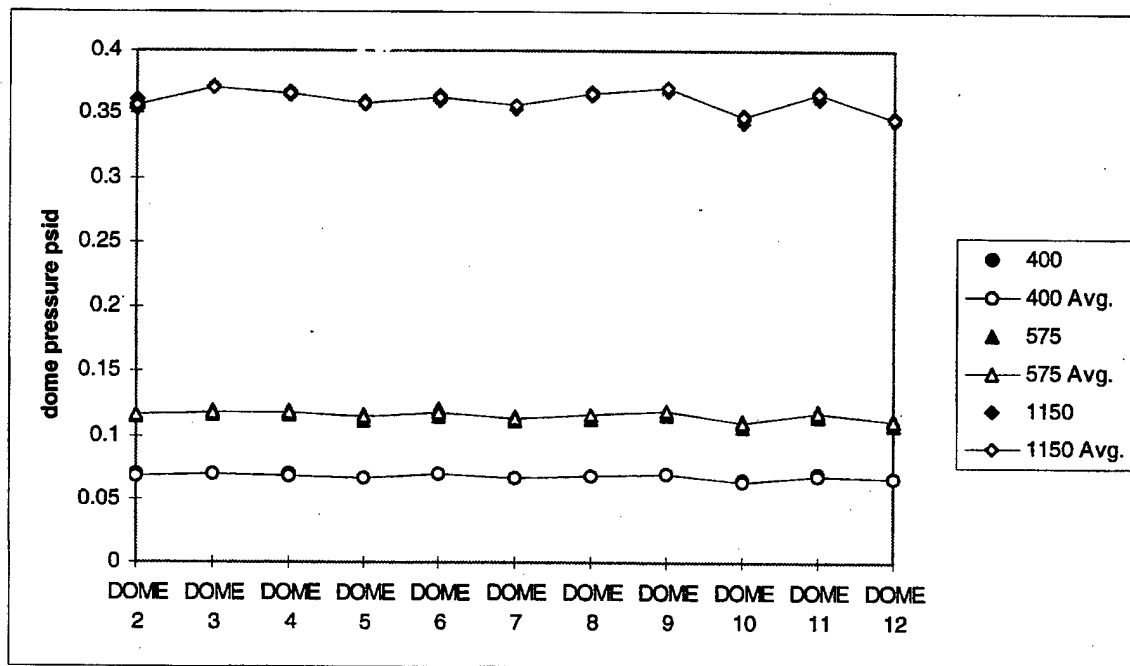


Figure 27. Dome pressure by dome and blower speed (rpm) for 1.55 second period.

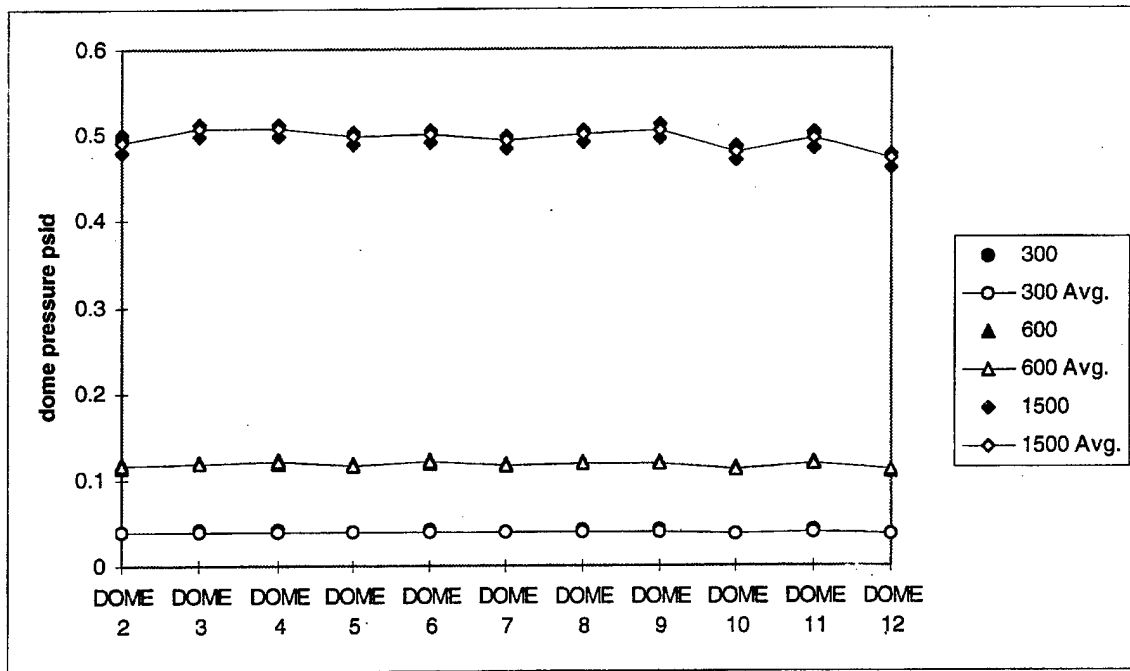


Figure 28. Dome pressure by dome and blower speed (rpm) for 1.81 second period.

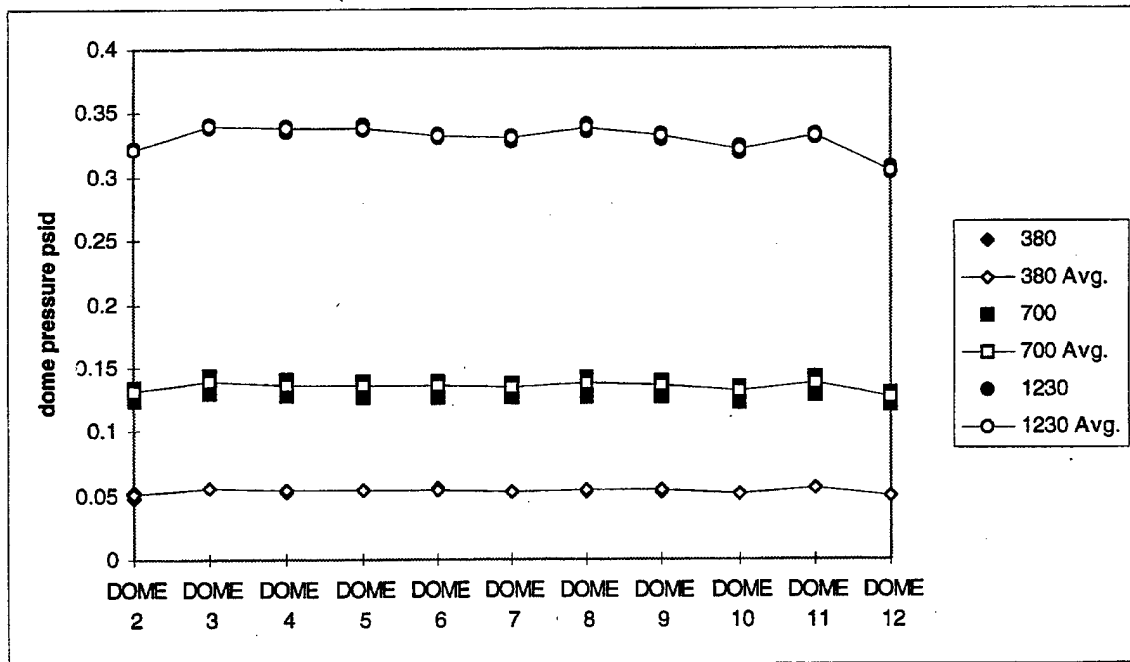


Figure 29. Dome pressure by dome and blower speed (rpm) for 2.06 second period.

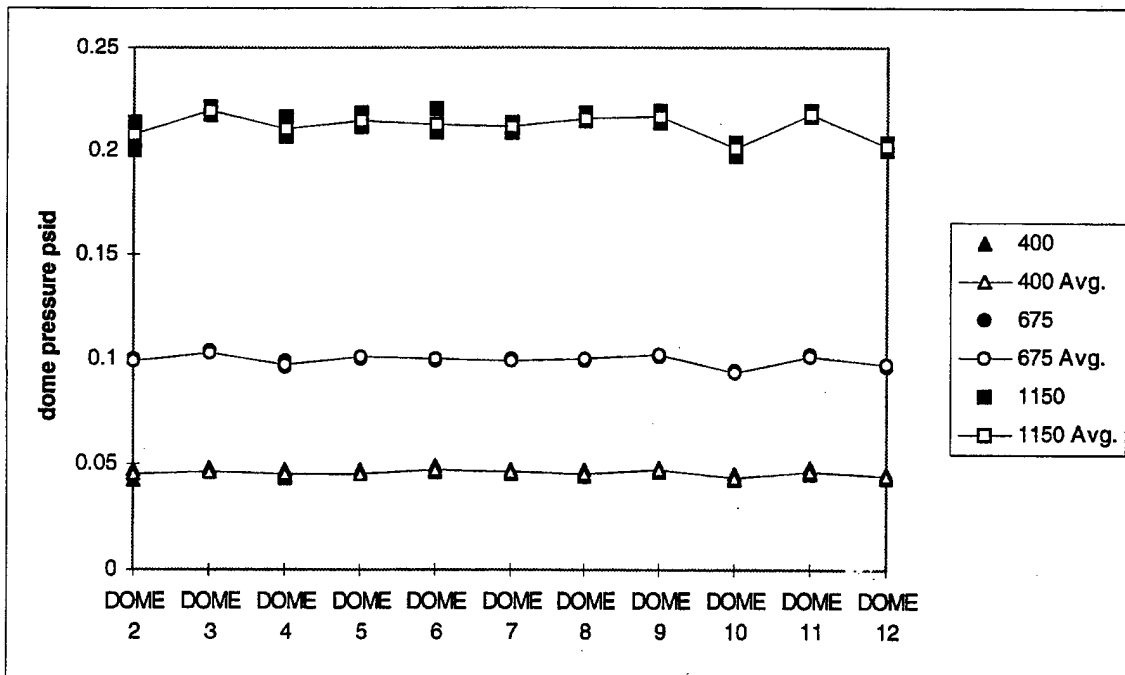


Figure 30. Dome pressure by dome and blower speed (rpm) for 2.32 second period.

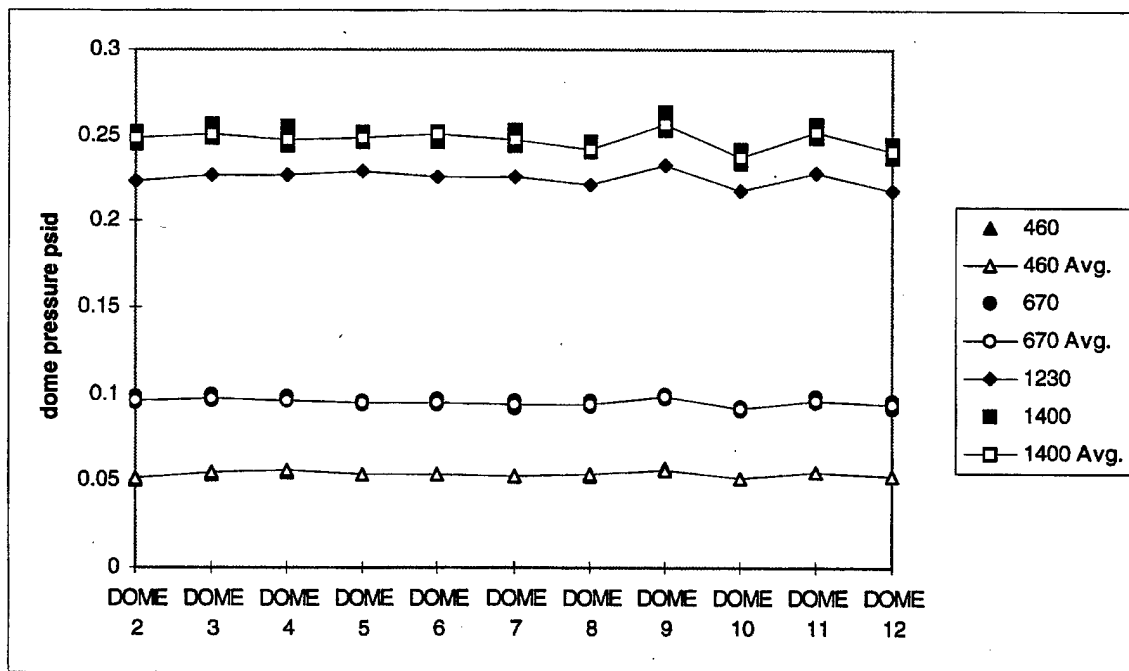


Figure 31. Dome pressure by dome and blower speed (rpm) for 2.58 second period.

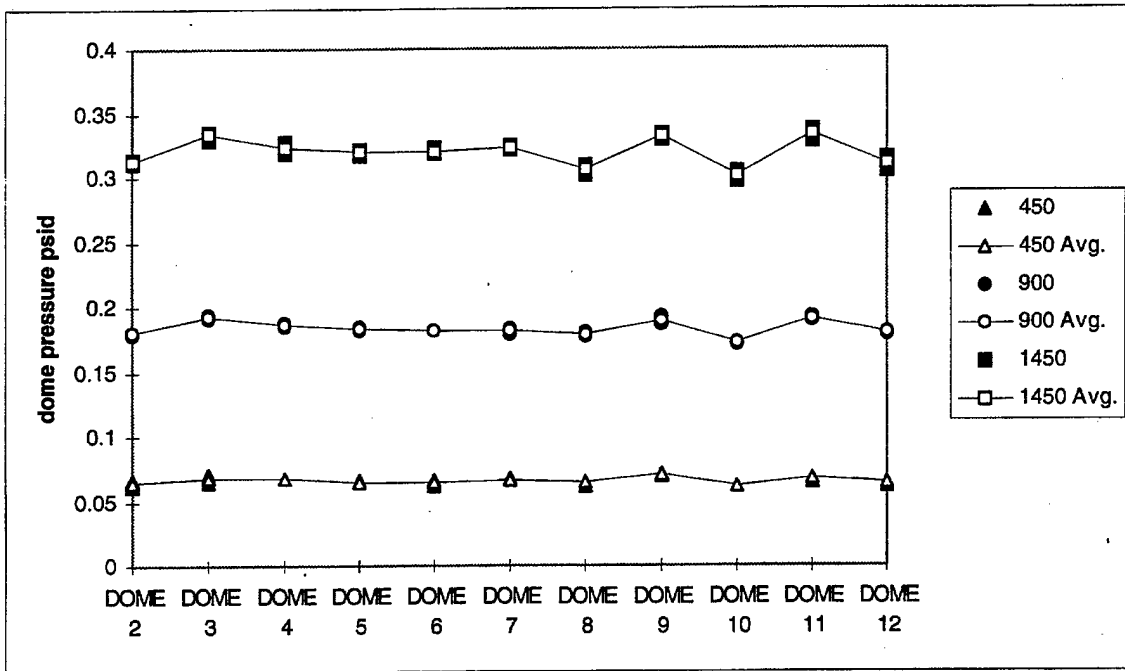


Figure 32. Dome pressure by dome and blower speed (rpm) for 3.10 second period.

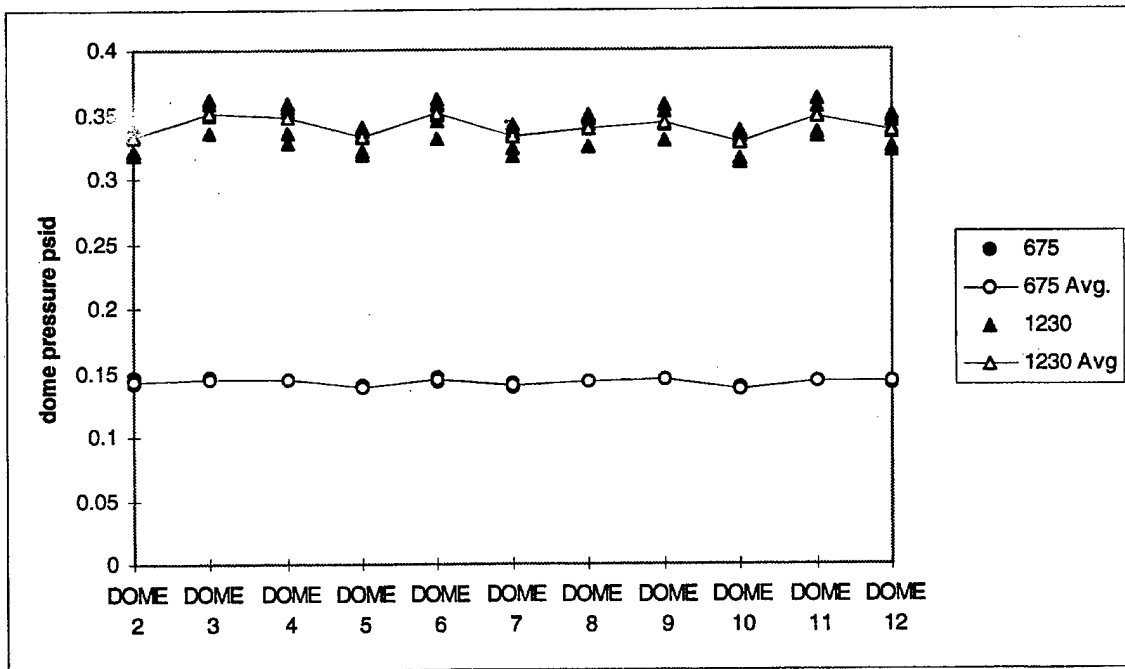


Figure 33. Dome pressure by dome and blower speed (rpm) for 3.61 second period.

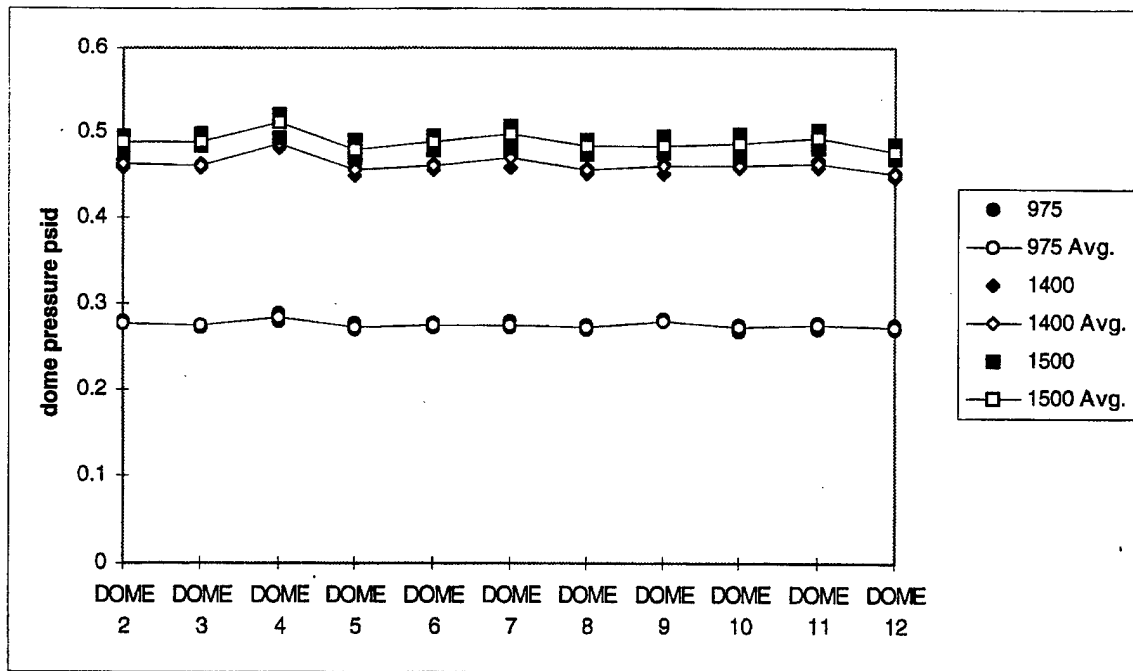


Figure 34. Dome pressure by dome and blower speed (rpm) for 4.13 second period.

REFERENCES

1. Stahl, R., "NSWCCD Wavemakers and Notes on Wavemaking", CRDKNSWC/HD-0369-12 (Jun 1998).
2. Coleman, H. and Steele, W. G., "Experimentation and Uncertainty Analysis for Engineers", John Wiley & Sons, Inc., 1989.

This page intentionally left blank.

INITIAL DISTRIBUTION

CENTER DISTRIBUTION

Copies		Copies	Code	Name
1	DTIC	2	506	K. Adams
		1	5500	L. Motter
		2	3442	Unclass. Library - C
1	G. Remmers (ONR 334)	1	653	R. Lewis
1	P. Palo (NFESC ESC51)			