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Bow Wave Measurements of the *R/V Athena I*: 2003

by

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The bow wave of the ***Research Vessel Athena I*** was quantified using a Quantitative Flow Visualization (QViz) system developed at the Naval Surface Warfare Center, Carderock Division. Although this technique has been used extensively in the towing tank, this experiment represents the first time that such measurements have been obtained in the full scale environment. Measurements were obtained in the protected waters of St. Andrews Bay in proximity to Panama City Beach, Florida over a three day time period, from 29-31 October 2003. The Athena was operated at four speeds; 6 knots (3.1 m/s), 9 knots (4.6 m/s), 10.5 knots (5.4 m/s), and 12 knots (6.2m/s), corresponding to Froude numbers based on waterline length (47 m) of 0.14, 0.21, 0.25, and 0.29, respectively. Data was collected at seven axial locations, in 1-foot intervals, along the bow. The data were of very good quality with the increase in noise being offset by an increase in signal strength. Predictions from the non-linear potential flow code, DAS BOOT, are compared to the experimental data at 9 knots and demonstrate excellent agreement..

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ABSTRACT

The bow wave of the ***Research Vessel Athena I*** was quantified using a Quantitative Flow Visualization (QViz) system developed at the Naval Surface Warfare Center, Carderock Division. Although this technique has been used extensively in the towing tank, this experiment represents the first time that such measurements have been obtained in the full scale environment. Measurements were obtained in the protected waters of St. Andrews Bay in proximity to Panama City Beach, Florida over a three day time period, from 29-31 October 2003. The Athena was operated at four speeds; 6 knots (3.1 m/s), 9 knots (4.6 m/s), 10.5 knots (5.4 m/s), and 12 knots (6.2m/s), corresponding to Froude numbers based on waterline length (47 m) of 0.14, 0.21, 0.25, and 0.29, respectively. Data were collected at seven axial locations, in 1-foot intervals, along the bow. The data were of very good quality with the increase in noise being offset by an increase in signal strength. Predictions from the non-linear potential flow code, DAS BOOT, are compared to the experimental data at 9 knots and demonstrate excellent agreement.

ADMINISTRATIVE INFORMATION

The work described in this report was performed by Code 5600, the Maneuvering and Control Division of the Hydromechanics Department, Naval Surface Warfare Center, Carderock Division. The work was sponsored by the Office of Naval Research, Mechanics and Energy Conversion S&T Division (Code 333) under the Hydrodynamics Task of FY03 Surface Ship Technology Program (PE602121N), Program Manager Dr. L. Patrcik Purtell. The work was performed under contract number N0001403WX20633, work unit 03-1-5200-053 and the Project Manager was Dr. Thomas C. Fu, Code 5600.

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INTRODUCTION

To begin to understand the effect of scale on bow wave breaking, the ability to quantify the bow wave profile was extended from the towing tank to the full scale environment. The ***R/V Athena I*** was chosen as the ship platform of interest for two reasons. First, the ***R/V Athena I*** allows a 24-hour dedicated vessel to be used, in this case, for testing new equipment and collecting data with this new equipment over a range of speeds. Secondly, the ***R/V Athena I*** has a flared bow geometry with an entrance angle which is similar to that of a naval combatant and therefore better simulates the plunging breaking wave associated with the bow wave of a flared hull ship. Qualitative bow observations have been made on the ***R/V Revelle*** (Ratcliffe, 1) but this effort represents the first time that quantitative measurements have been made in the near field of a ship.

SHIP INFORMATION

The ***R/V Athena I*** is a PG-84 class Navy decommissioned patrol gunboat. She was converted to a research vessel in 1976. She has an aluminum hull and an aluminum and fiberglass superstructure. The ship includes two dedicated lab spaces. Ship particulars are shown in Table 1 and also at www50.dt.navy.mil/facilities/Athena/ on the internet. At the time of these measurements, the Athena was based at the Naval Surface Warfare Center (NSWC), Panama City and operated by NSWC, Carderock.

Table 1: *R/V Athena I* Details

Length Overall	165 ft
Extreme Beam	24 ft
Draft	5.5 ft
Propulsion	Twin screw, twin diesel (low speed)
	Gas Turbine, (high speed)
Speed	12 knots (diesel)
	35 knots (turbine)
Range	2300 n.m. at 13 knots

TEST DESCRIPTION

This test spanned a three-day period from 29-31 October 2003. The ship left the dock at the Naval Coastal System Center at 2:00 AM local time, each morning and returned at 11:00 AM the same day. Data were collected while the boat transited back and forth between two stations located approximately two nautical miles apart and oriented in a North-Northeast direction. The ship's headings were 60° – 80° and 240° – 280°. The ship track location in relation to St. Andrew's Bay and Panama City is shown in Figure 1. Testing in the protected waters of the bay minimized ship motion from ambient seas and provided measurements in relatively calm conditions. Testing was performed at night, providing a stronger signal-to-noise ratio in the quantitative flow visualization, described in the next section. Specifically, data were collected from 3:00 AM to 6:00 AM local time. This time period, coupled with the time of year (October 29-31), also made for calm test conditions. The winds, which typically build as the day progresses were minimal (typical speeds from 3.5 to 5.5 m/s), and it was a new moon, so tidal excursions were minimized. Data was collected at 3.1, 4.6, 5.4, and 6.2 m/s, corresponding to Froude numbers based on water line length (47 m) of 0.14, 0.21, 0.25, and 0.29, respectively.

Figure 1: Map Showing Ship Track for the Experimental Run in St. Andrew's Bay

Ship Motion Data / GPS Compass

Ship motions were recorded from the ship's onboard GPS compass; a wave buoy recorded the ambient seas; and the wind speed and direction were measured using the ship's onboard anemometer. Maintaining constant GPS speed (speed over land) proved to be easier for the Captain than constant speed through water, due to the type of readout (crude dial for speed through the water, digital display for the GPS speed). To maintain as constant a speed as possible during a run, GPS speed was used, introducing some variability due to currents. Some attempt will be made to characterize these currents by looking at the differences between successive runs made at opposite headings.

The ship motion data from the GPS compass were reduced to provide time-averaged heading, speed, pitch and roll for each run. RMS values of each of these quantities were also calculated to evaluate the "steadiness" of the run. Figure 2 shows the pitch, roll, speed and heading time series for a typical run and the RMS values calculated for that run. It can be seen that within the accuracy limits (1.5 deg RMS Max. Error) of the GPS compass (FURUNO SC-120) there is minimal ship motion. This is important when interpreting results and in assessing the accuracy of the free-surface elevation measurements.

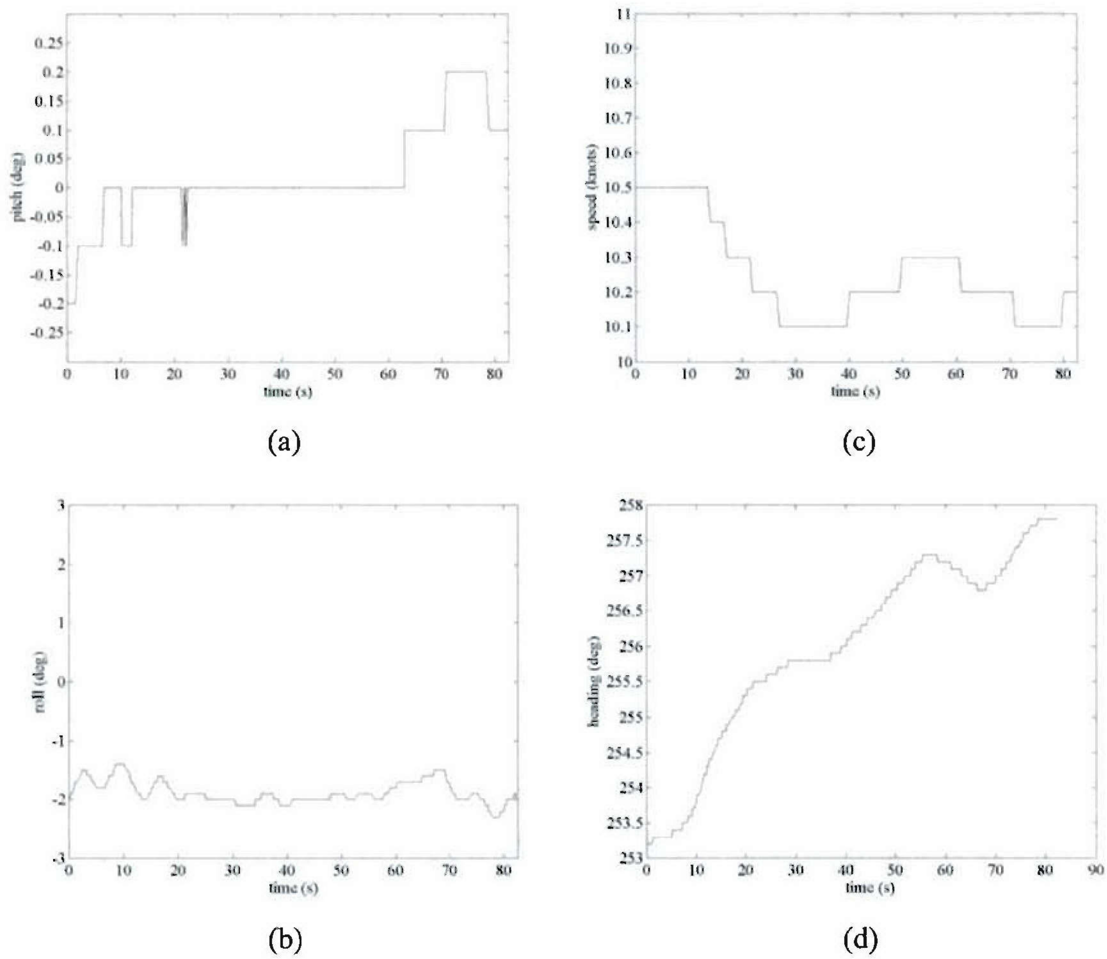


Figure 2: Typical time series of a) pitch angle: mean=0.02 degrees, RMS=0.08; b) roll angle: mean=-1.88 degrees, RMS=0.19; c) speed: mean=10.25 knots, RMS=0.14; and d) compass heading: mean=256.0 degrees, RMS=1.3; for the R/V Athena I in St. Andrews Bay.

As mentioned above, an attempt was made to characterize the currents in the test region. By looking at the average GPS speed and the average speed through the water for each pair of successive runs, the magnitude of the current in the direction of boat travel can be estimated. This analysis proved to be less straightforward than anticipated. There proved to be no consistent result from the analysis, i.e. each pair of runs did not show a consistent bias in speed or direction. This result most likely stems from inaccuracies in the recording of the speed through the water and from the lack of stationary statistics. Taking into account all the data, one can characterize the speed of the current as being approximately 0.6 knots (0.3 m/s) and is viewed as an uncertainty in the reported speed.

QViz Instrumentation and Data Processing

A laser sheet quantitative flow visualization method (QViz) was utilized to measure free-surface wave profiles at several axial locations in the bow region of the ship. The technique was developed to measure free-surface elevations in regions where bubbles and spray are effective scatterers of the laser light, and has been used to measure elevations of breaking waves in previous experiments (Furey and Fu, 2; Rice, 3). Figure 3 shows the components of the ship-board system. The free-surface was illuminated by a laser light sheet generated by a scanning mirror. The laser used was a diode-pumped, solid state YAG laser, with an output of 2.5-3.0 watts at 532 nm (Melles-Griot Model MLM-0532). The laser sheet was imaged by three black and white, progressive scan cameras. The cameras were placed inside waterproof housings on remotely operated pan and tilt units, allowing full control from the control room on the ship. As seen in Figures 3 and 4, two of the cameras faced aft, while the third camera pointed forward. This camera arrangement insured that if the wave blocked the aft facing camera's view of the laser sheet, the forward facing camera would still be able to obtain unobstructed images.

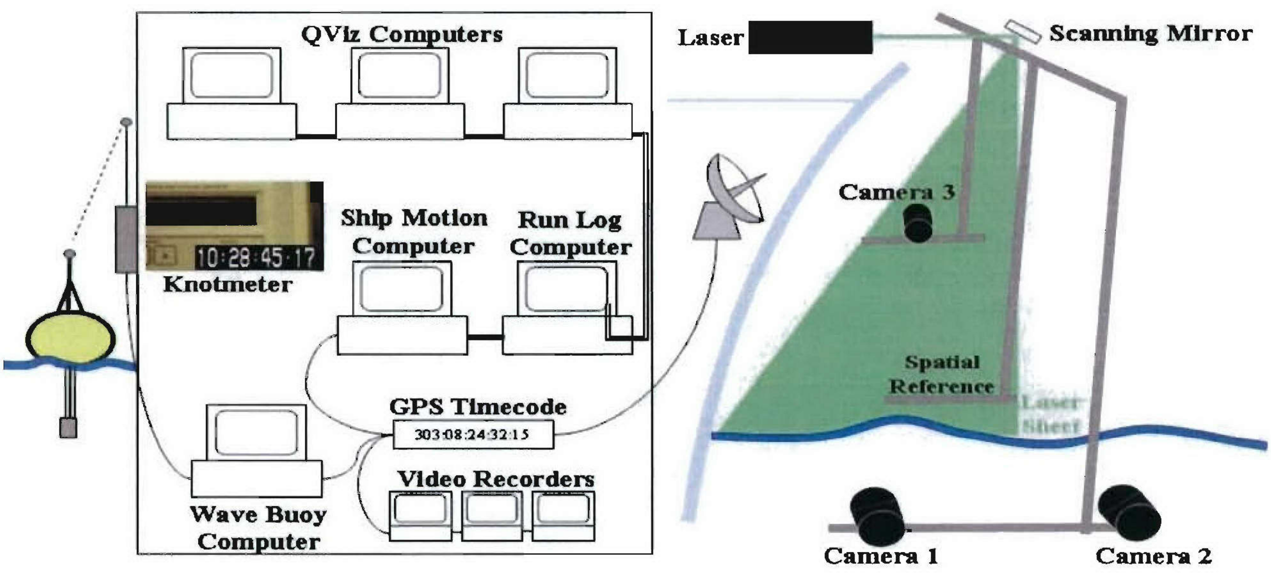


Figure 3: Ship-board quantitative flow visualization schematic

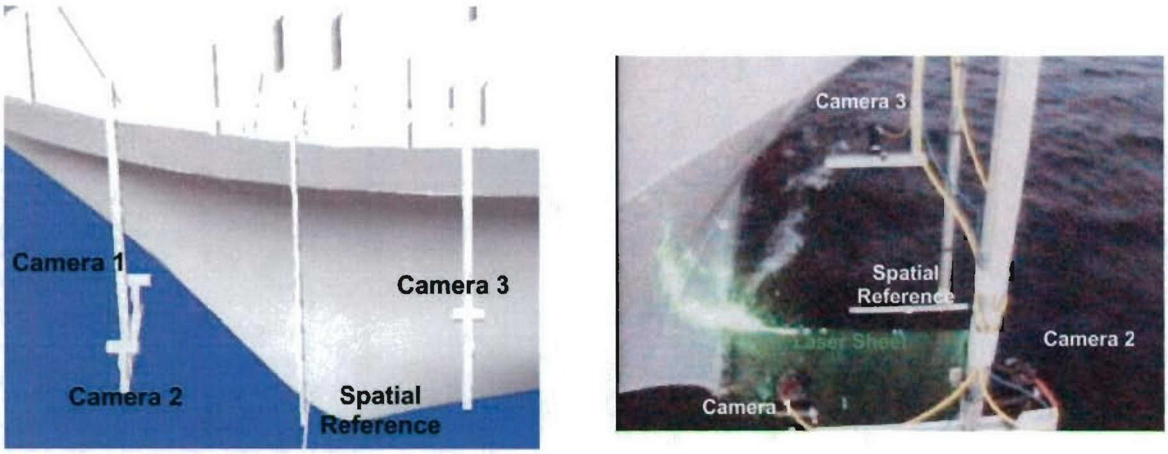


Figure 4: Diagram (top) and photograph (bottom) of the QViz setup showing the three cameras and the spatial reference

The recorded digital images were corrected for distortion and then a calibration was performed using an in-situ measured grid, photographed during the daylight hours of the trial, when the ship was docked. The distortion-corrected and calibrated images were then processed to provide free-surface profiles. An image analysis program developed at NSWCCD using National Instruments LabView software with the Image Processing (Vision) toolbox was used to determine the surface profile. Figure 5 shows a sample image with the processed profile superimposed.

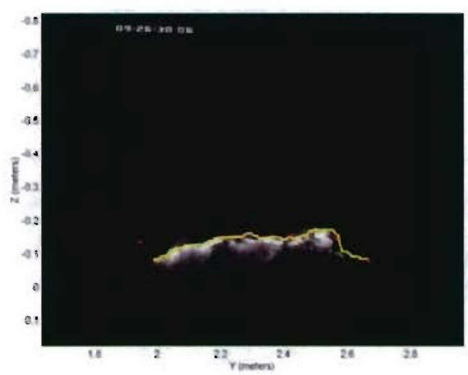


Figure 5: Example of a QViz image of the R/V Athena I bow wave at U=4.6 m/s, with the edge detected by the data processing algorithm superimposed in red (points) and yellow (smoothed line).

Video

Video cameras were mounted on the ship at various locations and recorded video during the test. These cameras were placed such that they recorded images of the bow wave and the QViz apparatus. The video was used to make qualitative observations of the bow wave and determine the breaking conditions. Images taken from these cameras and a diagram of their locations are shown in Figure 6. The photo in the lower left shows the control room on board. The other three images are taken from each of the video cameras. The laser sheet from the QViz system is visible in the lower right; the other views show the railing and cameras for the QViz system. The diagram in the center shows the three video camera locations relative to the ship.

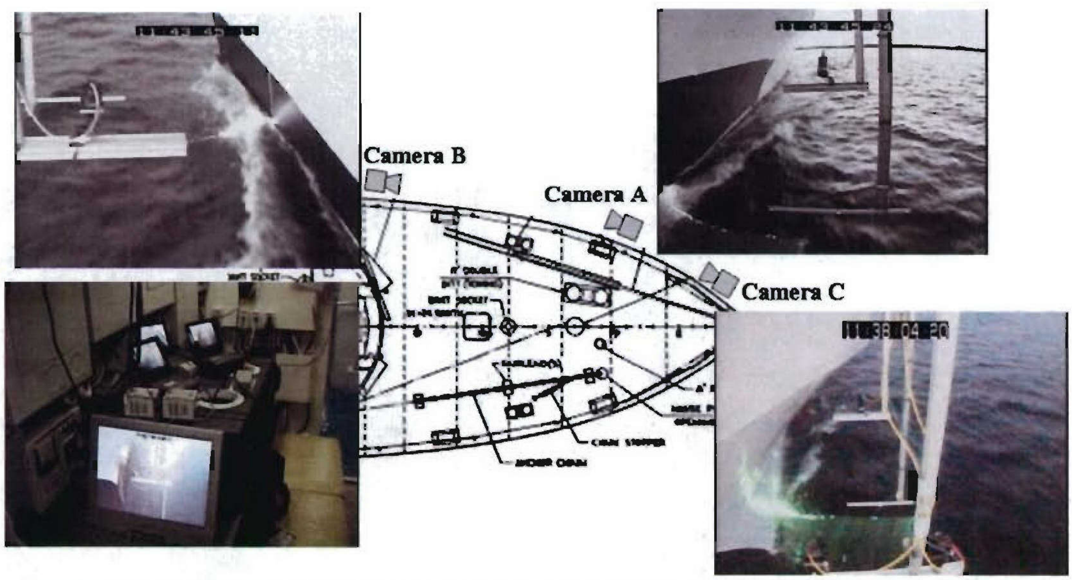


Figure 6: Views and locations of the three video cameras and the recording system.

Predictions

The DAS BOOT free surface potential flow prediction code, developed at SAIC (courtesy of Don Wyatt), was used to predict the flow at each of the speeds which would be measured full scale. The predictions for the four speeds are shown in Figure 7.

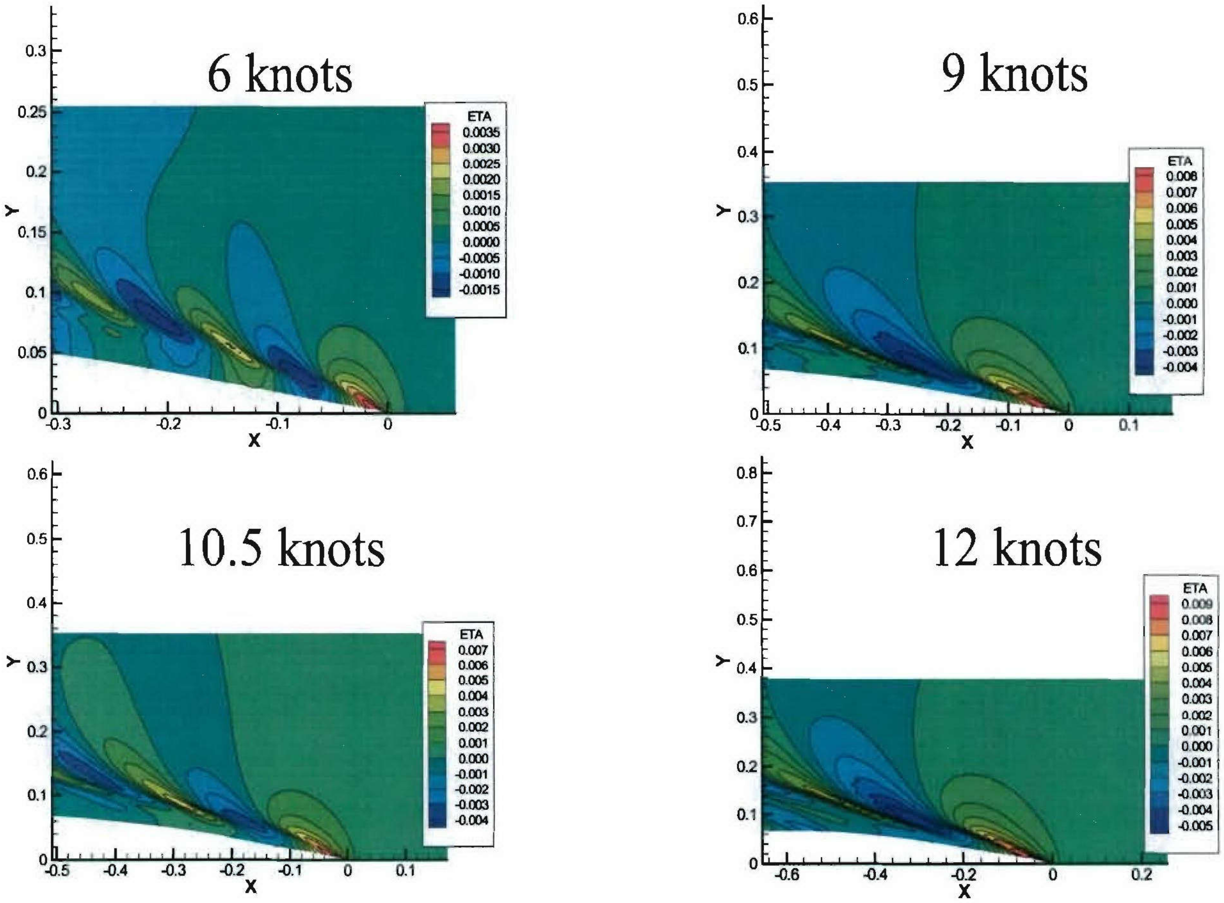


Figure 7: DAS BOOT Predictions

RESULTS

The images obtained from the QViz cameras were analyzed and combined to obtain average free-surface heights in the bow region. Images were recorded at 30 frames per second for one minute giving 1800 profiles. Each frame, for each speed and axial position, was analyzed to generate time-averaged profiles and the standard deviation for each location. A sample of successive frames with the extracted edge superimposed in red, for U=4.6 m/s at an axial location 5.9 m from the bow stem are shown in Figure 8. Note the wave crest amplitude changes by approximately 0.15 m in ~ 1/6th of a second.

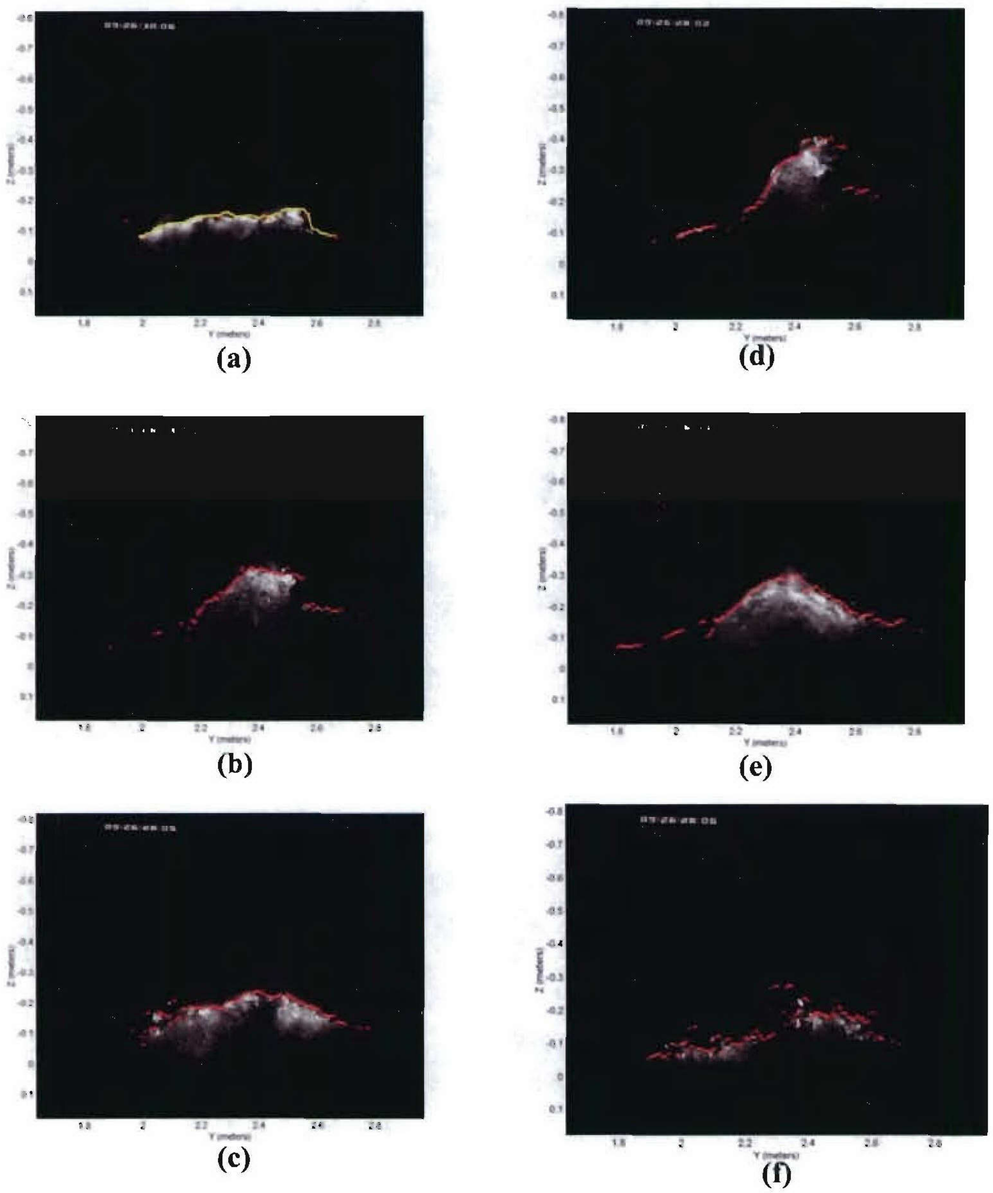
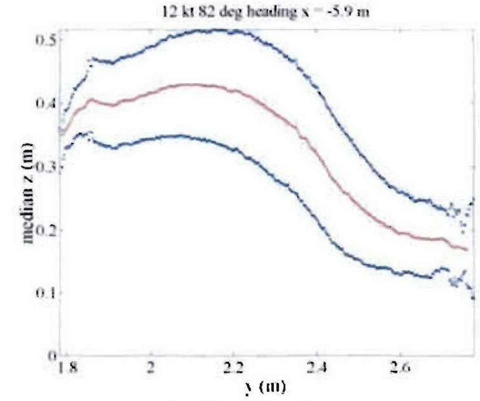
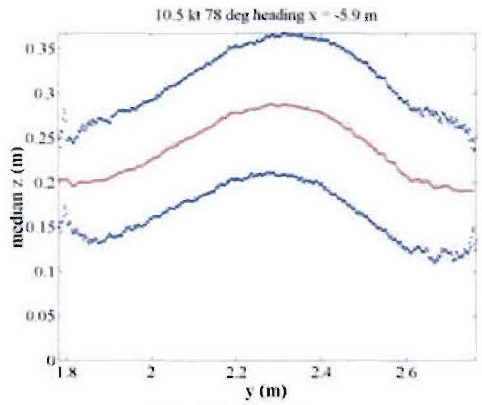


Figure 8: Successive QViz images Δt =1/30th second, U=4.6 m/s and x=5.9 m from the bow stem.

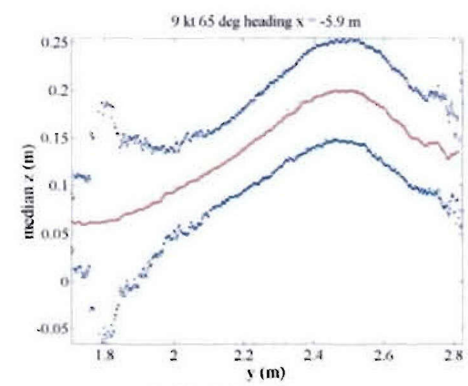
To characterize this unsteadiness of the free-surface profiles, the mean and the standard deviation for each speed and location were computed. Figure 9 shows these mean profiles in red and the standard deviation in blue for speeds of 4.6, 5.4, and 6.2 m/s at the same axial location and the same general heading.



a) U=6.2 m/s



b) U=5.4 m/s



c) U=4.6 m/s

Figure 9: Mean surface profiles (red) and standard deviation (blue) for a) 6.2 m/s, b) 5.4 m/s, and c) 4.6 m/s, at an axial position 5.9 m aft of the bow stem.

As noted above, 1800 individual profiles were collected per run. At least two runs were performed for each speed and axial position. Comparing mean free-surface profiles for the same location, for two separate runs, it was observed that two mean profiles were very similar. The most obvious difference was a slight amplitude offset, due to a small difference in speed. This difference was much smaller than the unsteady fluctuations of the instantaneous profile, where the difference between runs was approximately 2 cm and the range of the unsteady fluctuations was around 15 cm. Thus the large fluctuations are not due to the way the ship is operated, i.e. variations in speed or ship motions while recording a data set, because the mean profiles are fairly well duplicated.

Contour plots were obtained from the transverse cuts made along the hull, and compared to the predictions from the potential flow code, DAS BOOT. Figure 10 shows a comparison of the data obtained in St. Andrews's Bay with the ship operating at 9 knots. The comparison shows excellent agreement between the data and the predictions, especially given that the potential flow computation was for a steady, sea state zero case, so exact agreement is not expected.

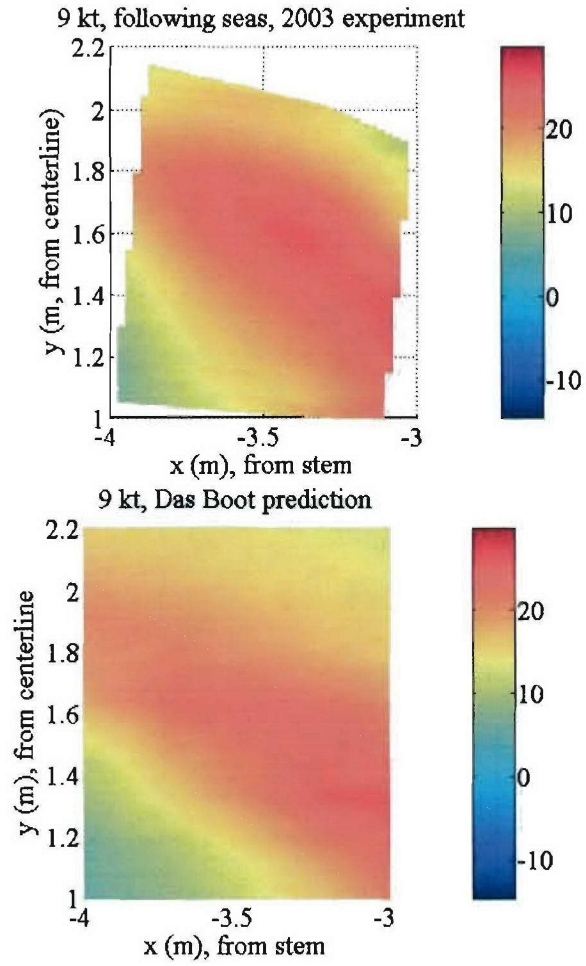


Figure 10: A comparison of contour plots of QViz data obtained at 9 knots in St. Andrews Bay with DAS BOOT predictions at 9 knots.

CONCLUSIONS

The results presented in this report represent the first time that comprehensive quantitative wave height measurements were obtained on a full scale vessel. This experiment demonstrated the potential of a laser-sheet visualization technique that had previously been used only to obtain data in a laboratory setting. Data resolution was high enough to adequately resolve the first crest and trough associated with the bow wave at each of the operating speeds where data were obtained. However, these measurements demonstrated how even relatively calm field conditions still introduce unsteadiness and variability to the free-surface wave field. The results also showed that there is some merit and fidelity to steady CFD codes like DAS BOOT, in that the time-averaged measurements give good agreement with the predictions, at least in this case where the experiment was designed to provide data for the calm water, minimal ship motion case.

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