Carderock Division
Naval Surface Warfare Center
West Bethesda, Maryland 20817-5700

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Bow Wave Measurements of the R/V Athena I: 2004

by

Thomas Fu
Anna Karion
Don Walker
James Rice
Toby Ratcliffe

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Thomas Fu, Anna Karion,, Don Walker, James Rice, Toby Ratcliffe

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The bow wave of the R/V Athena I was quantified in calm water and in a Sea State 3 using a Quantitative Flow Visualization (QViz) system developed at the Naval Surface Warfare Center, Carderock Division. This effort represents the second time that the QViz system has been taken aboard the research vessel Athena. These experiments were performed in both the protected waters of St Andrews Bay (Panama City, FL) and in the Gulf of Mexico. The data was collected over a five day period from May 17-21, 2004. The Athena was operated at six speeds; 2 knots (1.0m/s), 6 knots (3.1 m/s), 9 knots (4.6m/s), 10.5 knots (5.4m/s), 12 knots (6.2m/s) and 13.9 knots (7.2 m/s), corresponding to Froude numbers based on waterline length (47m) of 0.05, 0.14, 0.21, 0.24, and 0.28, and, 0.32 respectively. Data were collected at seven axial locations, in 1-foot (0.3m) intervals, along the bow. Predictions from the non-linear potential flow code, DAS BOOT are compared to the experimental data. In addition to the QViz data, video cameras captured the flow around the hull at six camera locations. Additional data was obtained by other cooperating research groups and included laser altimeter measurements of the stern wake, conductivity probes to measure the void fraction in the wake of the ship, a particle/bubble imaging system to determine bubble size distributions, a defocusing bubble imaging system, and a high speed video system.

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ABSTRACT

The bow wave of the R/V Athena I was quantified in calm water and in a Sea State 3 using a Quantitative Flow Visualization (QViz) system developed at the Naval Surface Warfare Center, Carderock Division. This effort represents the second time that the QViz system has been taken aboard the research vessel Athena. These experiments were performed in both the protected waters of St Andrews Bay (Panama City, FL) and in the Gulf of Mexico. The data were collected over a five day period from May 17-21, 2004. The Athena was operated at six speeds; 2 knots (1.0m/s), 6 knots (3.1m/s), 9 knots (4.6m/s), 10.5 knots (5.4m/s), 12 knots (6.2m/s) and 13.9 knots (7.2 m/s), corresponding to Froude numbers based on waterline length (47m) of 0.05, 0.14, 0.21, 0.24, and 0.28, and, 0.32 respectively. Data were collected at seven axial locations, in 1-foot (0.3m) intervals, along the bow. Predictions from the non-linear potential flow code, DAS BOOT are compared to the experimental data. In addition to the QViz data, video cameras captured the flow around the hull at six camera locations. Additional data was obtained by other cooperating research groups and included laser altimeter measurements of the stern wake, conductivity probes to measure the void fraction in the wake of the ship, a particle/bubble imaging system to determine bubble size distributions, a defocusing bubble imaging system, and a high speed video system.

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 FY04 Surface Ship Technology Program (PE602121N), Program Manager Dr. L. Patrick Purtell. The work was performed under work unit numbers 04-1-5600-240, 04-1-5600-242, 04-1-5600-243, 04-1-5600-244, and 04-1-5600-245, and the Project Manager was Dr. Thomas C. Fu, Code 5600.

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INTRODUCTION

This is the second in a series of experiments aimed at quantifying the flow around the ***R/V Athena I*** in an attempt to characterize and understand bow wave breaking, bubble droplet formation and evolution, and stern wave flow. The first set of experiments has been documented in Fu et al (1) and Fu et al (2). The set of experiments described herein was performed both in St. Andrews Bay and in the Gulf of Mexico in order to document the effects of sea state and/or ship motion on the wave system around the ship. The ***R/V Athena I*** was chosen as the ship platform of interest for two reasons. First, the ***R/V Athena I*** can be scheduled as a 24-hour dedicated vessel for the purpose of testing new equipment and collecting data with this new equipment. 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.

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 ***R/V Athena I*** was based at the Naval Surface Warfare Center (NSWC), Panama City and operated by NSWC, Carderock.

Table 1. R/V Athena 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 five-day period from 17-21 May 2004. The ship left the dock at the Naval Coastal System Center at midnight local time each morning and returned at noon the same day. Data were collected in both St. Andrews Bay, where the sea conditions are calmer, and the Gulf of Mexico, where more waves were present. While in St. Andrews Bay, the boat transited back and forth between two stations located approximately 2 nautical miles apart and oriented in a North-Northeast direction. The ship's headings were 60° – 80° and 240° – 280°. For the runs in the Gulf of Mexico, the ship ran various courses based upon the dominant wave direction, in that head seas and following seas were the conditions of interest. The location of the ship tracks in relation to St. Andrew's Bay and Panama City is shown in Figure 1.

Figure 1. Ship Tracks for the Experimental Runs in St. Andrew's Bay and in the Gulf Of Mexico

COORDINATED DATA GATHERING

This experiment brought together researchers from five laboratories: the Naval Surface Warfare Center, Carderock Division, Scripps Institution of Oceanography/University of California at San Diego, California Institute of Technology, Science Applications, Inc. (SAIC), and the University of California at Davis. Each group concentrated on specific measurements around the hull of the R/V Athena. In total, seventeen different data sensors were deployed. A list of these sensors is shown in Table 2.

Table 2. Coordinated Data

Laboratory/Affiliation	Sensor	Description of data obtained
NSWC, Carderock	Quantitative Visualization	Bow wave contour plots
	EM log	Speed through the water
	Ship board video cameras	Bow-Stern views of the ship wake
	Ship board anemometer	Wind speed
Scripps Institution of Oceanography/ University of California at San Diego	Scanning Laser Altimeter	Wave heights in the stern
	Conductivity	Bubble Void fraction
	6 Degree of Freedom Motion Package	Ship Motion
	1.7 MHz range-gated sonar	Bubble distribution under the ship
	Pan-Tilt Underwater Camera	Bubble source identification
	Bottom Mounted Acoustic Doppler Current Profiler	Ambient wave height and direction
California Institute of Technology	DDPIV (Defocusing Bubble Imagery)	Bubble velocity, size, and population distributions in the stern wake
SAIC	High Speed Video Camera	Droplet formation and size distribution
University of California at Davis	Microscopic analysis of bubble dissolution	Bubble dissolution times

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. Figure 2 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 Nd-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 two black and white, progressive scan cameras as seen in Figure 2.

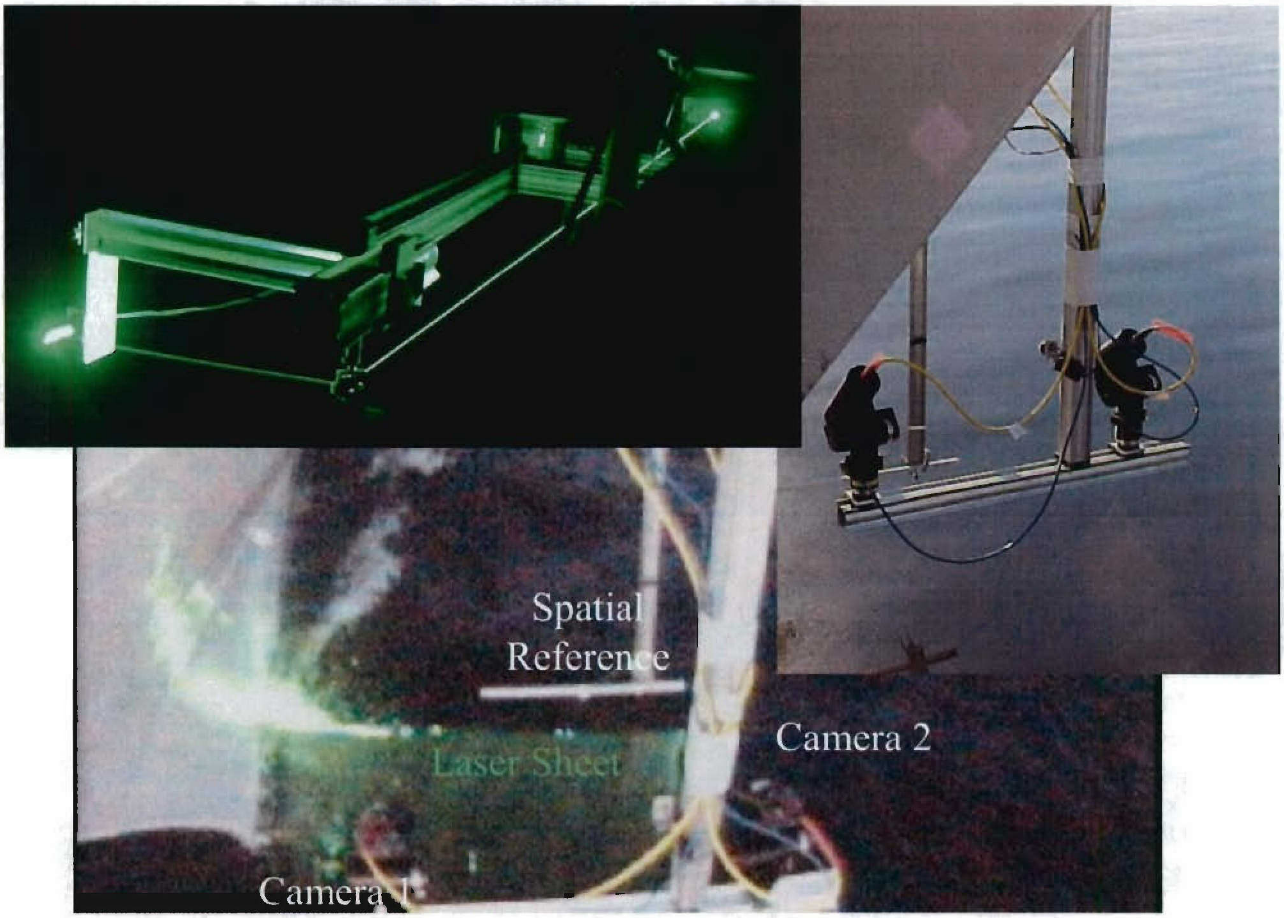


Figure 2. Ship-board Quantitative Flow Visualization Configuration

Both cameras faced aft. This was a change from the first set of experiments in 2003 where three cameras were used; the third camera pointed forward in case the steepness of the bow wave blocked the aft-facing camera's view. But this was not a problem for any of the speeds, so only two cameras (both facing aft) were used during this experiment.

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 extend the surface profile. Figure 3 shows a sample image with the processed profile superimposed.

Free-surface 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. For an example of a series of processed single images, see Fu, et. al (1).

To characterize the unsteadiness of the free-surface profiles, the mean and the standard deviation for each speed and location were computed. Comparing mean free-surface profiles for the same location, for two separate runs, it was observed that two mean profiles were very similar, as shown in Figure 4. The most obvious difference was a slight amplitude offset, due to a slight difference in speed.

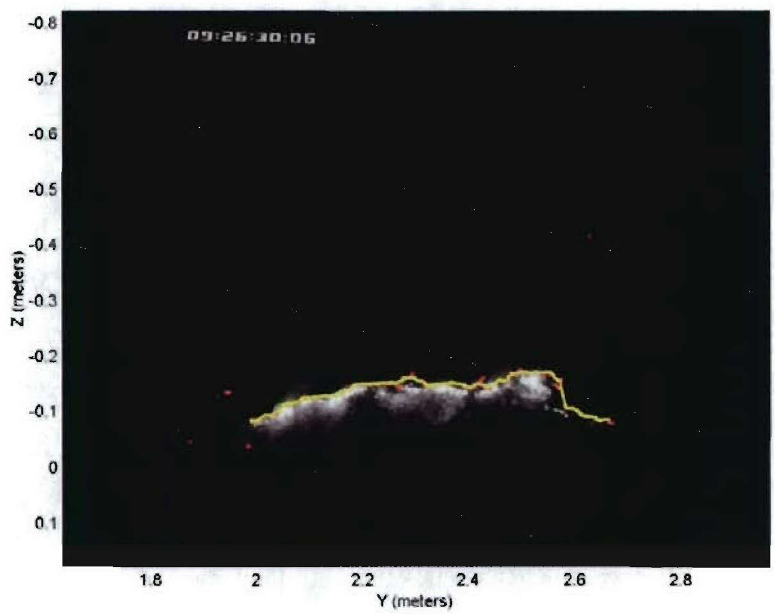
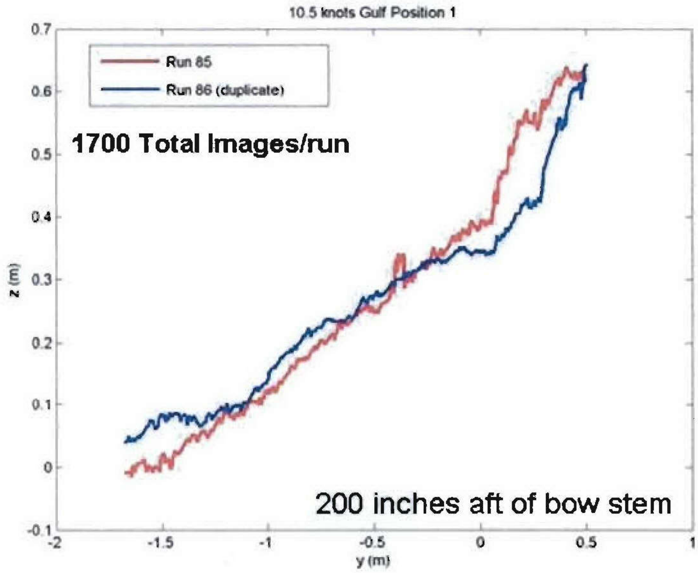


Figure 3. Example of a QViz image of the *R/V Athena I* bow wave at U=4.6 m/s, with the edge detected by the data processing algorithm superimposed in red (points) and yellow (smoothed line).



Comparison of the time averaged profile for duplicate runs

Figure 4. Mean Free-Surface Profiles for 10.5 knot run in the Gulf of Mexico

VIDEO DOCUMENTATION OF THE FLOW

Six cameras were installed around the deck of the ship to document the flow of the various waves produced by the ship. A similar qualitative set of flow observations was obtained on the R/V Revelle and is documented in Ratcliffe (3). Figure 5 shows the camera decks in the forward laboratory space on the R/V Athena I, as well as the camera boom located mid-ship. The locations of the cameras are shown in Figure 6. The camera views for a 10.5 knot speed are shown in Figure 7.

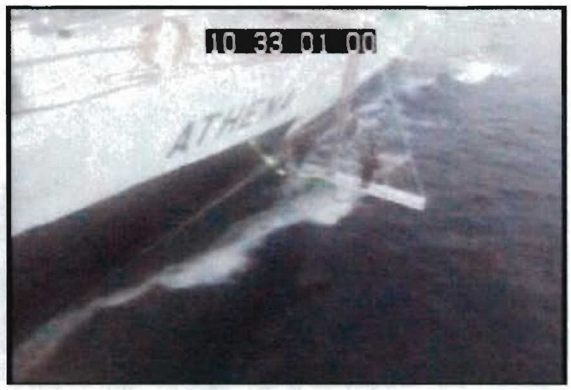
Figure 5. Camera decks in forward laboratory space (left) and camera booms located mid-ship (right).

Figure 6. Camera locations

(a) Camera 1

(b) Camera 2

(c) Camera 3



(d) Camera 4

(e) Camera 5

(f) Camera 6

Figure 7. Camera Views from Shipboard Mounted Cameras at a ship speed of 10.5 knots.

PREDICTIONS

The DAS BOOT free surface potential flow prediction code, developed at SAIC, was used to predict the flow at each of the speed which would be measured full scale. The predictions for the four speeds are shown in Figure 8.

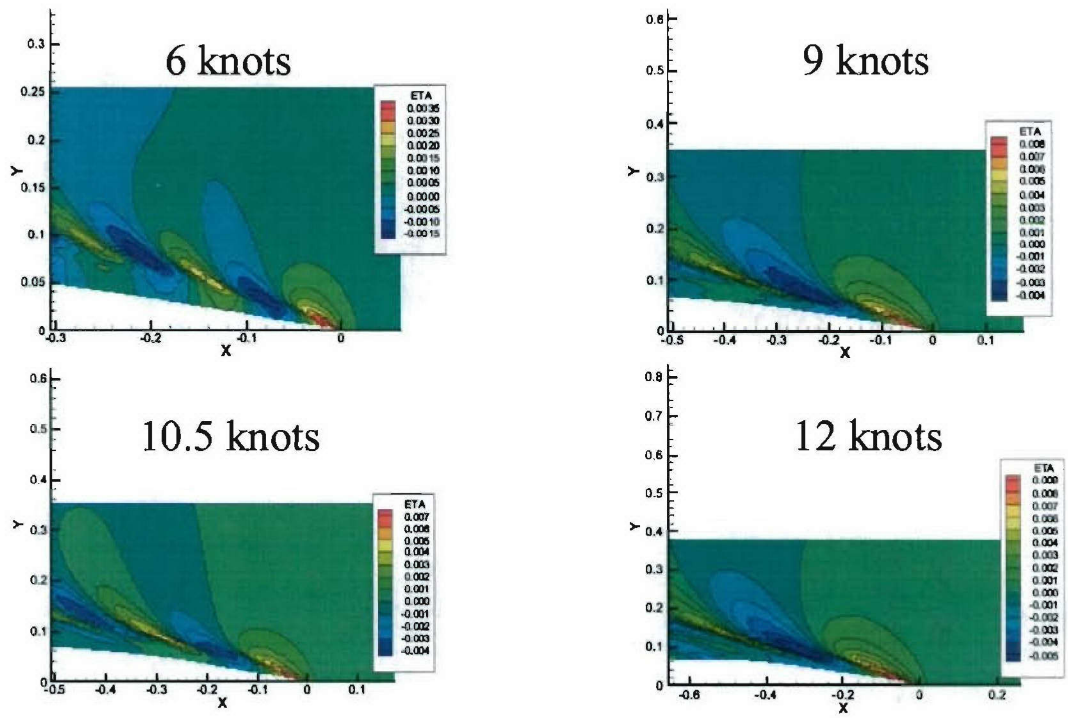


Figure 8. DAS BOOT predictions for the R/V Athena for 6 knots, 9 knots, 10.5 knots and 12 knots.

RESULTS

Figure 9 shows a comparison of a Q-Viz traverse in St. Andrew's Bay with one in the Gulf of Mexico, for the ship operating at 10.5 knots. Figure 10 shows the mean and standard deviation of these measured traverses. The red line in the center is the mean free-surface height, while the blue lines represent one standard deviation above and below the mean. The comparison shows that the variability of the bow wave is much greater when the ship is operated in a sea state, compared with the calm water of the Bay.

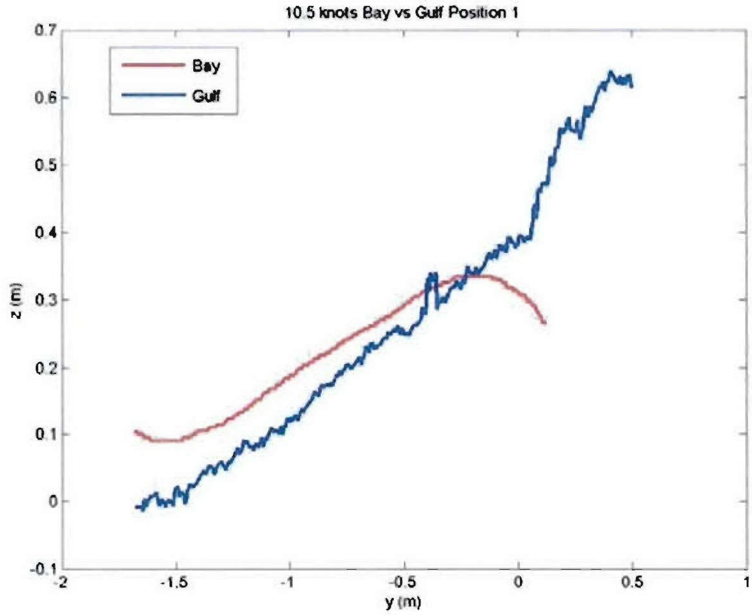


Figure 9. A comparison of Q-Viz traverses at the first longitudinal position for a run in St. Andrew's Bay and in the Gulf of Mexico.

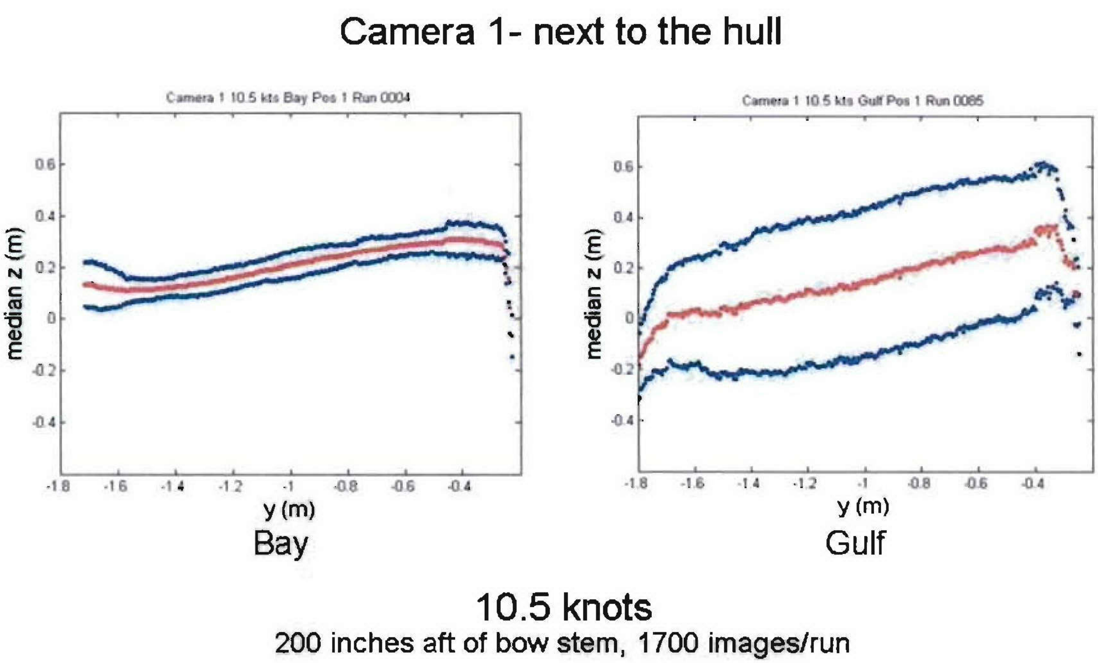


Figure 10. Mean and standard deviation for Q-Viz traverses at the first longitudinal position for a run in St. Andrew's Bay and in the Gulf of Mexico.

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 11 shows a comparison of contour plots, of Q-Viz data taken in the Bay at 10.5 knots with DAS Boot Predictions at 10.5 knots. The prediction shows the maximum bow wave crest occurring closer to the ship centerline than the data, but the range of wave heights, and the angles of the bow wave crest and trough is well matched by the predictions.

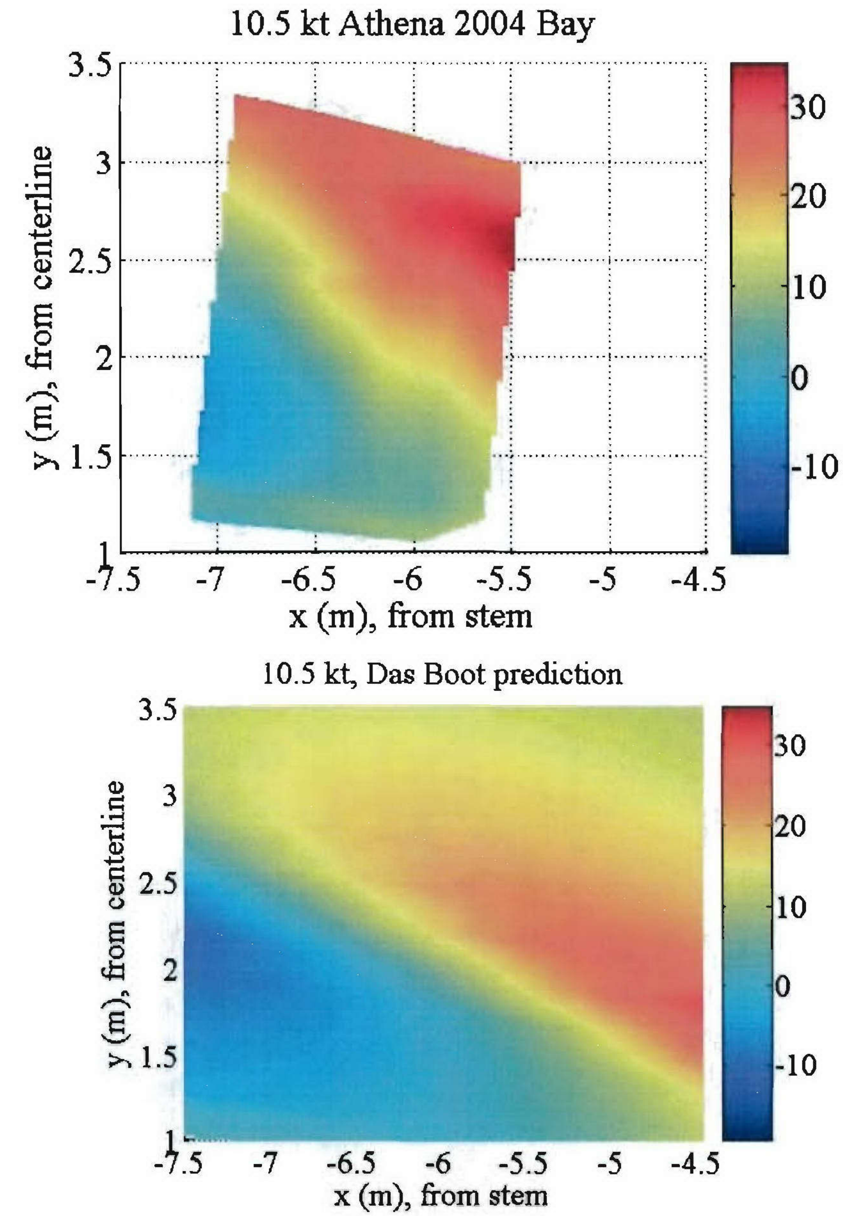


Figure 11. A Comparison of Contour Plots of Q-Viz Data Obtained at 10.5 knots in St. Andrews Bay with DAS Boot Predictions at 10.5 knots

CONCLUSIONS

The results presented in this report continue to demonstrate the potential of the laser-sheet visualization technique, which has proven to be a robust and powerful data gathering system. As in the first Q-Viz Athena Experiment, 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. The time-averaged measurements seem to 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.

The large number of sensors deployed resulted in one of the most comprehensive data sets ever taken on a research vessel. They will provide a much needed data set for understanding the flow around a surface ship.

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