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# Structural Trials of the RV *Triton* – a Status Update and Quick-Look Report



## ABSTRACT

The purpose of this paper is to provide the audience with information about the status of the Trimaran Demonstrator Program. This status update/quick-look report includes overviews of the Trimaran Demonstrator Program, trials conducted, completed analysis, and future analysis. The result of the Trimaran Demonstrator Program is the ship Research Vessel (RV) Triton. The goal of the technology demonstrator is to minimize the risk of trimaran hull forms for warship applications.

The RV *Triton* has successfully completed several months of rough water sea trials. The ship experienced a wide variety of speeds, headings, and sea states up to sea state 7 and is still currently operating with no significant damage or stability problems.

## **INTRODUCTION**

The purpose of this paper is to provide the audience with information about the status of the Trimaran Demonstrator Program. This status update/quick-look report includes overviews of the Trimaran Demonstrator Program, trials conducted, completed analysis, and future analysis.

The RV *Triton* was constructed for the Trimaran Demonstrator Project, a joint program between the United Kingdom and the United States, to assess the trimaran hull form for implementation

in future warship designs and to reduce the risks associated with the introduction of trimaran ships into either the UK or US fleets (Marshall 2000). In order to fully define the work to be completed during the RV *Triton* project, the U.S. and British governments signed a Memorandum of Understanding (MOU) in September 1997. The United States Navy provided a full suite of sensors and acquisition hardware located throughout the ship under the MOU. The Trimaran Trials Project office tasked NSWC, Code 65 to perform the data reduction and analysis of the data collected during the rough water sea trials. This task is on going.

RV *Triton* was designed as a trimaran technology demonstrator. The RV *Triton* is a 1200ton steel constructed vessel, 318 ft in overall length, 295 ft between perpendiculars, and 73.8 ft in beam length, which is about two-thirds the length of the Royal Navy's Future Surface Combatant (FSC) frigate requirement. The contract for the build was awarded in the fall of 1998. The first steel was cut in January of 1999. RV *Triton* was launched in May 2000, with delivery to Defense Evaluation and Research Agency (DERA) in September. The first trials began in October 2000 in Rosyth, Scotland.

The RV *Triton* was built using Det Norske Veritas (DNV) high-speed light craft rules and was designed and built by Vosper-Thornycroft in the Woolston Southampton yard.

RV *Triton* is made from steel that has yield strain of 1335 uStrain.

A number of tests of the RV *Triton* have been undertaken during the past two years. Some of these tests include structural trials, towing, seakeeping trials, helicopter landings, underwater visualization studies, speed and powering, and a transatlantic crossing. This battery of tests was conducted from October 2000 to December 2002.

The RV *Triton* underwent eight weeks of structural calibration trials in dry dock at the Rosyth dockyard. The calibration trials were followed by dedicated structural sea trials conducted over four



Figure 1. Cross Deck Shear Strain Raw Time History

time periods. During the sea trials the ship was operated up to high sea state 7 conditions. Over 200 strain gages and accelerometers measured the condition on the ship.

# DESCRIPTION OF THE INSTRUMENTATION SYSTEM AND INSTALLED SENSORS

All of the Triton Trials Data (TTD) were recorded by a data acquisition system developed by the United States at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The Trials Instrumentation System (TIS) recorded data at three different sample rates: 20 Hz, 200 Hz, and 2000 Hz. The 20 Hz data were recorded continuously during trials and contained data channels that were quasi-static or low frequency. The 200 Hz data were also recorded continuously during trials and contained structural strain channels, which have a higher frequency requirement. The 2000 Hz or 2 kHz data, also known as slam shot data, were recorded only when triggered during trials. The 2 kHz data consists mostly of pressure panel data during high speed or heavy sea state. Figure 1 shows an example 200 Hz time history plot of cross deck shear strain.

The measurements being recorded fall into three categories; ship systems and navigation, ship motions, and structural response. There are 116 digital channels recorded directly from the ship

machinery control and navigation systems. The ship machinery systems include information on the power being produced from the generators, power being used by the electric drive system, control settings for the propulsion system, and fuel state. The navigation systems provide speed and course information. The ships motion data includes seven tri-axial accelerometers, and a Watson meter for measuring pitch and roll rate. The structural response instrumentation makes up the bulk of the data being recorded. There are thirty-seven longitudinal strain measurements, twenty transverse strain measurements, thirty-nine bulkhead strain measurements including axial and shear, four main hull torsion measurements, and twenty-three stress concentration measurements. There are an additional thirty-two locations instrumented to measure the structural response to wave impacts.

# STRUCTURAL TRIALS OVERVIEW

The RV *Triton* has completed an exhaustive trials program that has been underway since October 2000. There were two types of trials that comprised the structural trials; calibration trials and sea trials.

Upon delivery of the ship, she went to the Rosyth Royal Dockyard for 2 months of calibration trials. The main purpose of the structural calibration trials was to calculate scale factors that allow conversion from measured strain to known applied loads or bending moments. Additionally, it was an opportunity to debug the strain gage instrumentation installed on the ship to ensure that they were wired correctly and responding to applied loads. Another purpose of the calibration trials was to perform set of modal analysis tests, which helped us determine the natural frequency of the ship.

After completion of the calibration trials, RV *Triton* went to sea to begin filling in the trials matrix with different speed, heading, and sea state combinations. The sea trials also involved towing and sea-keeping tests, helicopter landings, underwater visualization studies, speed and powering, and a transatlantic crossing.

# **CALIBRATION TRIALS**

The calibration trials were split into two categories; primary and secondary structure. The primary structure calibration consisted of applying known horizontal and vertical loads to the outriggers. The secondary structure trials consisted of applying loads to individual stiffeners on the wet deck. Agency (DERA)<sup>1</sup> engineers and technicians did a great job given the poor weather conditions and 50-knot winds. Figure 3 shows RV Triton in dry dock.



#### Figure 3. RV Triton in Dry Dock at Rosyth Royal Dockyard

Once *Triton* was sitting on all of the dock blocks, scaffold towers and loading jacks were erected at frames 22, 29, 34, and 40 on the port and starboard sides. These locations correspond to the main transverse bulkheads in the outrigger portions of the ship as shown in Figure 2, Figure 4, and



Figure 2. RV Triton Loading Jack Locations

## **Primary Structure Calibration Trials**

The primary structure calibration trials were by far the most time consuming to setup. The weather in Scotland during the months of October and November are far from ideal for this type of trial. The former Defense Evaluation and Research Figure 5. The first trials to be conducted were the horizontal loading. The ship managers did not want the load spreaders to be welded to their new ship. This made alignment of the spreaders difficult and time consuming. One difficult part of the trial was simultaneously controlling all eight jacks. An

<sup>&</sup>lt;sup>1</sup> DERA has since been privatized and is now called QinetiQ.

added degree of complexity was that there were two types of hydraulic actuators. The control unit was able to control the jacks properly but was unable to rebroadcast the load and displacement information to the TIS system for two of the jacks. Load was recorded using one Data Acquisition System (DAS) and the strain was recorded on another, while keeping written records of applied load.



Figure 4. RV *Triton* Horizontal Loading Jack Cad Work

Upon completion of the horizontal trials the jacks were repositioned to apply vertical load to the outrigger at the same locations; as described in Figure 6 and Figure 7. The vertical loads were applied to the port and starboard simultaneously. Vertical load was also applied to torque the outriggers. Vertical load was applied at frame 22 port and frame 40 starboard and vice versa. All of the load cases are summarized in Table 1.



Figure 5. RV *Triton* Horizontal Loading Jack Assembly



Figure 6. RV *Triton* Vertical Loading Jack Cad Work



Figure 7. RV Triton Vertical Loading Jack Assembly

A third primary structure trial was attempted. This consisted of applying a vertical load to the center hull of the ship. This was not successful due to limitation in the load spreading system and time constraints did not permit modification to the fixture.

During the calibration trials, load versus strain was plotted primarily to monitor the condition of the ship and to verify strain gage response to the applied load. After consolidating the actual applied loads with the measured strains into a complete data set a rigorous data reduction was performed.

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Load Cases	Max Load KN (kip)		
Horizontal - 22 Port	500 (112.4)		
Horizontal - 29 Port	700 (157.4)		
Horizontal - 34 Port	700 (157.4)		
Horizontal - 40 Port	500 (112.4)		
Horizontal - 22 Starboard	500 (112.4)		
Horizontal - 29 Starboard	900 (202.3)		
Horizontal - 34 Starboard	800 (179.8)		
Horizontal - 40 Starboard	500 (112.4)		
Horizontal - All Port	813.2 (182.8)		
Horizontal - All Starboard	999.3 (224.6)		
Horizontal - All 8 Jacks	518.3 (116.5)		
Vertical - 22 Port and Starboard	800 (179.8)		
Vertical - 29 Port and Starboard	1400 (314.7)		
Vertical - 34 Port and Starboard	1400 (314.7)		
Vertical - 40 Port and Starboard	1200 (269.8)		
Vertical - Torsion 22P+40S	1000 (224.8)		
Vertical - Torsion 22S+40P	1000 (224.8)		
Vertical - 29+34	1400 (314.7)		
Vertical - All 8 Jacks	1352 (303.9)		

 
 Table 1. Loading Sequences and Maximum Loads for the Global Response Trials

Secondary Structure Calibration Trials



#### Figure 8. Secondary Loading Finite Element Model

The purpose of the secondary structure calibration was to validate the finite element models, shown in Figure 8, which were being used to determine equivalent static pressure response to a wave impact. The load fixture, shown in Figure 9, consisted of a "foot" that went over the stiffener, a housing for the hydraulic jack and extension pipe to support the fixture from the overhead. Static loads were applied in increments and the corresponding strain values recorded using the TIS. From these results, load per unit strain terms were calculated. These terms were compared with the results from the finite element analysis. Based on the comparison of the results, the finite element model mesh was refined until the results differed by less than 10%. Results from these calibrated models were used to convert measured structural responses into equivalent uniform static pressure, suitable for design evaluation.



Calibration Jack Assembly

## Data Analysis of Primary Structure Calibration Trials

The data reduction consisted of a linear regression of load versus strain for every channel; an example is shown in Figure 11. Ideally, only selected channels would respond to a given load condition to assure independence of the calibration matrix. This was in fact the case. The longitudinal strain measurements did not respond to transverse bending and vice versa. The responses from a set of gages were used to develop a load response matrix. This matrix will be used later when processing the sea trials data; when converting measured strains to seaway loads.



Figure 10. Bulkhead 22 Cad Drawing and Gage Locations

The completed response matrix was subdivided, by channel and ship location; an example of this is shown in Table 2, where the red numbers represent strain gage locations and the corresponding gage number. The example channels 600 and 601 are located in the cross deck structure that connects the center hull to the outriggers and are visible in Figure 10.



Figure 11. Typical Plot of Applied Load vs Measured Strain

Table 2.	Calibration 7	Frials	Example	Response
	Μ	atrix		

101ati	14		
BHD 22	uStrain per Newton		
Load Case	Gage ORC 600	Gage ORC 601	
Horizontal – 22 Port	-14.03	0	
Horizontal – 29 Port	24.20	0	
Horizontal – 34 Port	44.92	0	
Horizontal – 40 Port	0	0	
Horizontal – 22 Starboard	0	-12.84	
Horizontal – 29 Starboard	0	22.68	
Horizontal – 34 Starboard	0	42.66	
Horizontal – 40 Starboard	0	0	
Horizontal – All Port	0	0	
Horizontal – All Starboard	0	0	
Horizontal – All 8 Jacks	0	0	
Vertical – 22 Both	8.03	7.80	
Vertical – 29 Both	25.98	25.22	
Vertical – 34 Both	63.06	59.92	
Vertical – 40 Both	0	0	
Vertical – Torsion 22P+40S	7.60	0	
Vertical – Torsion 22S+40P	0	7.26	
Vertical – 29+34	36.36	34.40	
Vertical – All 8 Jacks	22.85	21.76	

# ADDITIONAL GLOBAL LOADS CALIBRATION

The results of the calibration trial were successful in providing information on how the ship responded to transverse bending loads on the outriggers. It did not however provide information for longitudinal vertical bending or lateral bending. In order to determine strain to bending moment factors for these loads a full ship finite element model has been built. This model, shown in Figure 12, was constructed to represent the "as-built" condition of the ship.

# SEA TRIALS

Upon completion of the calibration trials, RV *Triton* began a very aggressive schedule of sea trials. The battery of sea trials consisted of seakeeping (ship motions and structural response in sea state 4 and below), speed and powering,

maneuvering, naval operations, flight operations, and rough water seakeeping (sea state 4 and above).



#### Figure 12. Global Calibration Finite Element Model

The sea trials were carried out over four time periods; December 2001, February 2002, March 2002, and December 2002. Each trial period was approximately 2 weeks in duration. The two-week

664	Speed (Kts)		88 <i>5</i>	Speed (Kts)			
SS4 Heading	Low 4-9	Medium 10-13	High 14- 18	SS5 Heading	Low 0-9	Medium 10-13	High 14-18
Head		2	2	Head	10	11	5
Port Bow		1	1	Port Bow	7	11	6
Port Beam		1	1	Port Beam	4	5	2
Port Stern		1	1	Port Stern	6	11	6
Following		1	1	Following	5	6	4
Stbd Stern		1	1	Stbd Stern	7	11	6
Stbd Beam		1	1	Stbd Beam	6	6	4
Stbd Bow		1	1	Stbd Bow	6	11	6
Speed (Kts)			Speed (Kts)				
556		Speed (Kts	)	<b>S</b> \$7		Speed (H	<ts)< td=""></ts)<>
<b>SS6</b> Heading	Low 4-9	Speed (Kts Medium 10-13	) High 14- 18	<b>SS7</b> Heading	Low 0-9	Speed (H Medium 10-13	<ts) High 14-18</ts) 
SS6 Heading Head	Low 4-9 7	Speed (Kts Medium 10-13 21	) High 14- 18 3	<b>SS7</b> Heading Head	Low 0-9	Speed (H Medium 10-13 4	Kts) High 14-18
SS6 Heading Head Port Bow	Low 4-9 7 4	Speed (Kts Medium 10-13 21 20	) High 14- 18 3 3	SS7 Heading Head Port Bow	Low 0-9	Speed (H Medium 10-13 4 3	Kts) High 14-18
SS6 Heading Head Port Bow Port Beam	Low 4-9 7 4 3	Speed (Kts Medium 10-13 21 20 11	) High 14- 18 3 3 2	SS7 Heading Head Port Bow Port Beam	Low 0-9	Speed (H Medium 10-13 4 3 2	Kts) High 14-18
SS6 Heading Head Port Bow Port Beam Port Stern	Low 4-9 7 4 3 4	Speed (Kts Medium 10-13 21 20 11 19	) High 14- 18 3 3 2 3	SS7 Heading Head Port Bow Port Beam Port Stern	Low 0-9	Speed (H Medium 10-13 4 3 2 3	Kts) High 14-18
SS6 Heading Head Port Bow Port Beam Port Stern Following	Low 4-9 7 4 3 4 4	Speed (Kts Medium 10-13 21 20 11 19 12	) High 14- 18 3 3 2 3 2 3 2	SS7 Heading Head Port Bow Port Beam Port Stern Following	Low 0-9	Speed (H Medium 10-13 4 3 2 3 2 2 3 2	Kts) High 14-18
SS6 Heading Head Port Bow Port Beam Port Stern Following Stbd Stern	Low 4-9 7 4 3 4 4 4 4	Speed (Kts Medium 10-13 21 20 11 19 12 18	) High 14- 18 3 3 2 3 2 3 2 3 3	SS7 Heading Head Port Bow Port Beam Port Stern Following Stbd Stern	Low 0-9	Speed (H Medium 10-13 4 3 2 3 2 3 2 3 3	<ts) High 14-18</ts) 
SS6 Heading Head Port Bow Port Beam Port Stern Following Stbd Stern Stbd Beam	Low 4-9 7 4 3 4 4 4 4 4	Speed (Kts Medium 10-13 21 20 11 19 12 18 12	) High 14- 18 3 3 2 3 2 3 2 3 2 3 2 2 3	SS7 Heading Head Port Bow Port Beam Port Stern Following Stbd Stern Stbd Beam	Low 0-9	Speed (H Medium 10-13 4 3 2 3 2 3 2 3 2 3 2 2	<ts) High 14-18</ts) 

Table 3. Matrix of Rough Water Trials; Number Of Recorded Sea Conditions

fatigue. Sea conditions experienced during this time an example is shown in Figure 14. frame ranged as high as upper sea state 7. The matrix of sea trials test conditions is shown in Table 3. There are 392 conditions that are part of the trials test plan and have been analyzed. There are an additional 102 test runs, from the December 2002 sea trials, that have not been analyzed as of the writing of this paper. The TIS system recorded all of the strain and ship information continuously from the time the ship left the dock until she returned.

General observations from the trials include that the ship successfully operated in high sea states. The ship rarely took green water over the bow. In all weather conditions, the ship rode better at speeds greater than 12 knots.

While the TIS was designed to run continually during the time the ship was at sea, the first data to be analyzed is for the star patterns. These are specific speed and relative course headings, as shown in Figure 13, during which heading and speed were held constant.



Figure 13. Sea Trials Star Pattern

## Data Analysis of Rough Water Seakeeping **Trials**

The sea trials and data analysis assume the convention that head seas is 0 degrees, starboard beam seas is 90 degrees, and following seas is 180 degrees.

The analysis of the rough water trials data is on going. For each sea trial condition, all of the channels recorded are being analyzed. Approximately 285 channels of raw data are being processed. An additional 45 virtual channels, which are derived from the raw data and difficult to record directly, have also been generated for the 392 conditions. The virtual channels are computed using

time limit was based on fuel consumption and crew linear combinations of recorded raw data channels;



**Figure 14. Virtual Channel Generation Example** 

All 392 conditions have been analyzed for basic time domain statistics of measured strains. The basic time domain statistics calculated are the mean. minimum, maximum, standard deviation and kurtosis values for each channel for each condition in the data set. Each trials run represents a condition. The purpose of this analysis is to ensure that each channel to be used in subsequent analyses is functional, free of noise, and representative of the measurement of interest. Other results include the number of mean crossings, absolute range, and the largest single-cycle peak-to-peak amplitude.

All 392 conditions have also been analyzed for frequency domain response. The frequency domain analysis is the process of calculating power spectral densities (PSD's) for hull girder response and wave height. This analysis can also be used to examine the vibratory nature of the hull girder with respect to each load response.

The calculation of response amplitude operators (RAO's) has begun. RAO's are linear transfer functions, which are defined as the response spectra divided by the wave height spectra with units of ship response per unit wave height at a given frequency. RAO's will be used to predict ship life for given operational profiles.

Another analysis planned will be Weibull distribution analysis and prediction. Weibull distributions are computed from wave, whipping, and combined amplitudes. Once the Weibull parameters are determined they can in turn be used to predict lifetime maximum expected values.

#### Data Analysis Software

Our primary data analysis solution for the RV *Triton* rough water trials has been our High Volume Data Analysis Suite (HVDAS), which is a suite of parallelized statistical analysis software packages for Linux clusters and is written in C++. The most recent HVDAS version is 11-18-2002, which was developed by the Naval Surface Warfare Center Carderock Division (NSWCCD) Code 653 and George Washington University. HVDAS was designed and built on a seven-node i686-based Linux cluster.

The HVDAS suite of data analysis software packages consists of HVDALibrary, HVDAMMMAnalysis, HVDAPSDAnalysis, HVDARAOAnalysis, and HVDAWeibullAnalysis. Each of these software packages is designed to run as an automated process to analyze data in bulk.

HVDALibrary contains most of the code that is common to the different analysis programs. HVDALibrary also contains most of the complex analysis functions used by each of the different analysis programs.

HVDAMMMAnalysis computes basic time domain statistics like mean, max, min, max-mean, min-mean, absolute range, maximum peak-to-peak amplitude, standard deviation, and kurtosis. HVDAMMMAnalysis can also convert data file formats and compute virtual channel data files.

HVDAPSDAnalysis computes the PSD of selected data channels, using the Finite Fourier Transform Method Segment Averaging Method (Hardin 1986) (PSDFFTMSAM).

HVDARAOAnalysis computes the Square Root Response Amplitude Operator, which is computed by sqrt(RAO)<sup>2</sup>=PSDFFTMSAM(Vertical Bending)/PSDFFTMSAM(Wave Height). When analyzing surface ship structures, the RAO is usually used to compute ship bending transfer functions based on wave height.

HVDAWeibullAnalysis computes Weibull distribution statistics on data channel amplitudes. You can choose the method of Weibull computation from 2 Parameter Linear Regression, 3 Parameter Linear Regression, 2 Parameter Moment Method, or 3 Parameter Moment Method. Weibull statistics are useful for calculating maximum lifetime loads.

All of the HVDAS programs allow you to apply scale factors, subtract initial condition zero values,

smooth, Finite Impulse Response (FIR) filter, select data files, select channels, name channels, name conditions, select output locations, and read multiple data file formats.

We developed HVDAS out of a need to automate complicated and repetitive data analysis techniques. We chose C++ and Linux because of raw speed, portability, and object oriented design. HVDAS eliminates most of the human errors associated with point and click bulk data analysis. HVDAS has also performed basic time domain statistics on model and full-scale raw (no software filters) data over twenty times faster than real time.

We developed HVDAS Data Extractor (DE) as a back end post processor to the results from the Linux cluster. DE is written in Microsoft Visual Basic for Microsoft Excel. DE allows us to filter vast amounts of results using a graphical point and click interface to generate trends quickly and accurately.

# QUICK OBSERVATIONS FROM SEA TRIALS DATA

#### Time Domain Response

The Vertical STRain (VSTR) series gages were installed so as to respond to longitudinal vertical ship bending from bow to stern. The VSTR gages experience significant wave-induced (lowfrequency) and vibratory or slamming energy (highfrequency). The mid-ship keel gage, VSTR116, experienced a maximum strain amplitude of 411 uStrain in 12-knot sea state 6 condition. The highfrequency and low-frequency components of the recorded strain channels can be separated by using High-Pass (HP) Finite Impulse Response (FIR) filtering and Low-Pass (LP) FIR filtering respectively. We chose a crossover frequency, the frequency where the LP FIR filter starts to attenuate high-frequency energy and the HP FIR filter starts to attenuate low-frequency energy, of 1.55 Hz, which lies between the wave-induced energy and the first mode vibratory response on a PSD plot. The first mode vibratory response is clearly visible in Figure 23. This maximum VSTR strain amplitude contained a 104 uStrain slamming and vibration induced component. The low-frequency wave induced component is significant and clearly evident in the 98-uStrain standard deviation calculated from raw recorded data. The general

trend for VSTR gages is increased strain resulting from increased significant wave height, which is evident in Figure 15 and Figure 16.

We determined that the higher first mode frequency maximums were mostly slamming induced by inspecting time history plots and computing very small high-frequency standard deviations of 7 uStrain or below. The high (maximum-mean)/(standard deviation) ratio is a solid indicator for this type of behavior.



Figure 15. Mid-Ship Keel Gage Max-Mean vs Significant Wave Height



Figure 16. Mid-Ship Keel Gage Standard Deviation vs Significant Wave Height

The Transverse STRain (TSTR) series gages respond to transverse ship bending from port outrigger to starboard outrigger. The largest TSTR amplitude was 95 uStrain with a 73 uStrain high frequency slamming and vibration component.

The leading transverse bulkhead (frame 22), shown in Figure 10, experiences the highest strains in the ship. Inspection of the time histories shows a significant number of impacts taking place. The best example of these impacts is the cross deck shear gage OutRigger Connecting (ORC) ORC601, which is visible in Figure 1. These slams occurred during a 12-knot sea state 7 head seas run. ORC600 and ORC601 are located in the cross deck structures, which connect the outriggers to the center hull. The maximum ORC strain amplitude was 635 uStrain with a 484 uStrain slamming and vibration component. The general trend for ORC gages is increased strain resulting from increased significant wave height, which is evident in Figure 17, Figure 18, and Figure 19. The ORC gages are interesting because they experience their maximum strains in head seas conditions, not in quartering or beam seas as one might expect, which is evident in Figure 20 and Figure 21.



Figure 17. ORC Raw Max-Mean vs Significant Wave Height



Figure 18. ORC Raw Standard Deviation vs Significant Wave Height



Figure 19. ORC High-Pass Filtered Max-Mean vs Significant Wave Height

#### Frequency Domain Response

The results of the modal analysis calibration trial found the first mode vertical bending response to be 2.9 Hz and the second mode to be 5.4 Hz. These correlated well to the finite element model predictions of 3.67(dry) and 2.96(wet) Hz for first mode and 6.9 (dry) and 5.58 (wet) Hz for second mode. The results of the PSD analysis, from trials data for mid-ship keel location, found the first mode to be 2.9 Hz, as shown in Figure 22, and second mode to be 5.4 Hz. Figure 23 shows an amplified and distorted finite element model result of first mode vertical longitudinal bending response.



Figure 20. ORC Raw Max-Mean vs Heading



Figure 21. ORC High-Pass Filtered Max-Mean vs Heading

### CONCLUSIONS

The Trimaran Demonstrator Program was developed to minimize the risk of the trimaran hull form for warship application. This program has met this objective by the successful operation of the ship in design conditions. The current analysis of measured strains shows moderate structural response relative to yield. However, not all of the analysis is complete, so we cannot fully categorize the performance of the RV *Triton* to current U.S. warship design.



Figure 22. Power Spectral Density Mid-Ship Keel Gage First Mode Response



#### Figure 23. First Mode Amplified Deflection Finite Element Model

The outrigger connecting gages, in the cross deck structure between the outriggers and the center hull, show the maximum strains experienced by the RV *Triton* to be 635 uStrain amplitude with a 484 uStrain slamming and vibration component in head seas. This maximum strain is theorized to be a result of wave impact due to either wake effect from the center hull, direct sea wave impact, or a combination of both, during a head seas run, in combination with buoyant forces acting on the individual outriggers.

The trimaran demonstrator program was a successful MOU. In a short period of time, two governments and industry came together designed, built, and tested a novel hull form. The RV *Triton* has demonstrated that a large trimaran is a viable ship configuration with application toward a true warship. All of the analysis is not yet complete, but the results will be used to further develop design guides and rules for future trimaran ships.

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J. Matthew Grassman has been with the Naval Surface Warfare Center Carderock Division (NSWCCD) since he received his B.S. degree in ocean engineering in 1987. He is currently the U.S. structures lead for the Trimaran Demonstrator Project. He was awarded the Meritorious Civilian Service Award for his work on this project and is also the only American to transit the Atlantic Ocean aboard the RV Triton. His other involvements include finite element methods for the design and analysis of naval ships, SWATHs and advanced double hull ships and ultimate strength analysis for design and analysis of naval ships.

**Gregory Alan Hildstrom** studied computer engineering at Virginia Tech (VT) for three years. The Naval Surface Warfare Center Carderock Division (NSWCCD) hired him as an engineering technician. He developed automated data analysis software, for Microsoft Windows, Linux, and Linux Clusters. In May 2002 he designed 5.2 GHz directional antennas and achieved 500m at 50mph, with a 50mW signal. After attending VT, he was hired by George Washington University to work on a Navy contract for NSWCCD. He is continuing development of performance enhancements and adding new analysis programs to the High Volume Data Analysis Suite (HVDAS) Linux Cluster software.