Seakeeping Assessment of Large Trimaran for Naval Aircraft Operations

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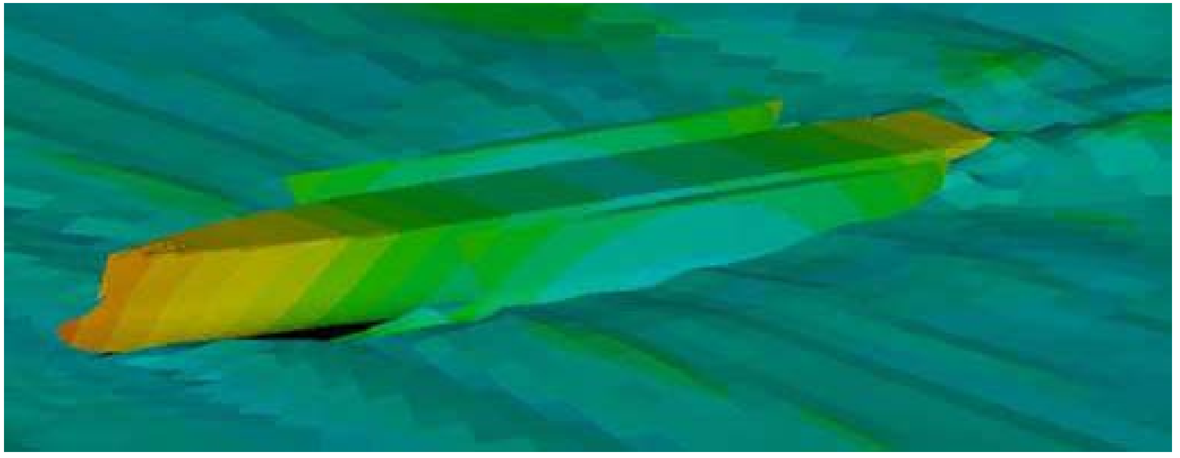
Trimaran Assessment Presentation Topics:

1. Development of Tool for Motions and Structural Loading Assessment
2. Design of Hulls by Advanced Fully 3D Hydrodynamic Assessment
3. Application to HALSS Trimaran Concept for Sealift Missions
4. Evaluation to NATO Seakeeping Criteria for Naval Aircraft Operations
5. Evaluation to NATO Seakeeping Criteria for Sealift Transit Operations
6. Presentation of Trimaran Systematic Series Seakeeping Results
7. Interesting Findings, Conclusions, and Future Studies



CCDOTT Center for the Commercial Deployment of Transportation Technologies

Sponsored by CCDOTT 1999-2006 High Speed Trimaran Technology Development Program

Background of Selected Vessel - HALSS

- **HALSS helps Early Insertion & Logistic Support:**
  - **Deploys at High Speed (35 Knots)**
  - **Operate fixed wing aircraft between advanced base and sea base**

- **HALSS helps Force Deployment:**
  - **Operate fixed wing aircraft for theater operations**
  - **Arrange and Configure military loads in preparation for early entry to the Theater operations**

HALSS Principal Characteristics

Flight Deck Length	**1,100 FT**
Flight Deck Width / Docking Hull Beam	**274 FT / 180 FT**
Draft	**37.9 FT**
Depth	**100 FT**
Payload:	
Combat forces sustainment	**8,900 ST**
Aircraft Fuel Supply	**2,650 ST**
Fixed Wing Aircraft	**Six C-130J**
Stowage Factor	
Main (Flight) Deck	**185,900 SQFT**
II Cargo Deck	**141,000 SQFT**
III (Crossover) & IV Decks	**51,100 SQFT**
HALSS Stowage Factor	**46.7 SQFT/MT**

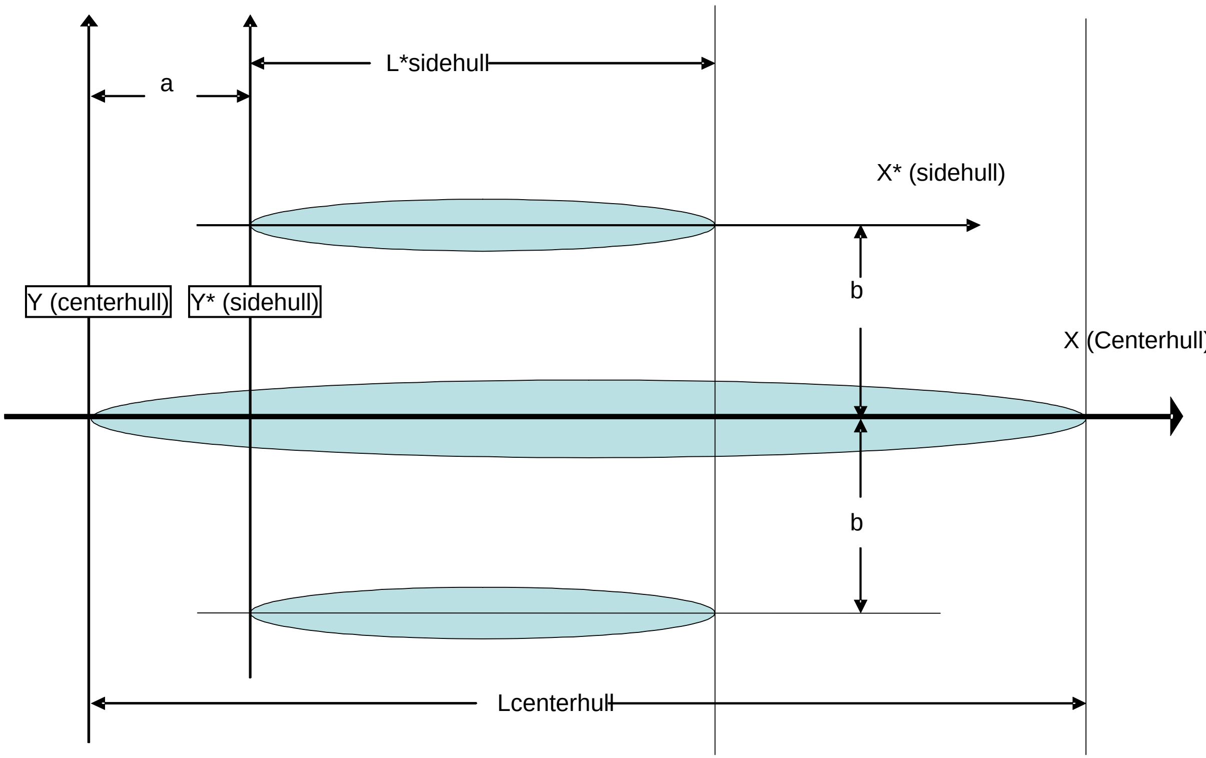
Unrefueled Range of Sea Voyage - CONUS to Advanced Base or to JOA

10,000 NM at 35 knots
>15,000 NM at 25 knots
Followed by 10 days endurance in JOA

High Speed Trimaran Seakeeping Study - Objectives

- **Establish Reliable Trimaran Analysis Procedure:**
  - **Displacement, Velocities, Accelerations;**
  - **Relative Motions for Slamming and Emergence;**
  - **Hull Girder Loads and Local Pressures;**
  - **Interaction between Main and Side Hulls.**
- **Determine Criteria for Assessment:**
  - **Naval Air Operations (NATO STANAG 4154, 1997)**
  - **Transit (NATO Generic Frigate)**
- **Assess Motion, Slamming, Emergence & Hull Girder Loads:**
  - **Sea States 4 through 7;**
  - **Vessel Speeds of 15, 25, 35 knots;**
  - **Vessel Headings of 0, 45, 90, 135, 180 degrees;**
  - **Multiple Hull Configurations**

Design Variables - Trimaran Synthesis Model



$$Stagger = \frac{\left(MS_{SH} - \frac{LOA_{SH}}{2}\right)}{\left(LOA_{MH} - LOA_{SH}\right)}$$

MS_{SH} - Distance from AP to Midship of Side Hull
LOA_{SH} – Overall Length of the Side Hull
LOA_{MH} – Overall Length of the Main Hull

$$Separation = \frac{Clearance}{Beam_{MH}}$$

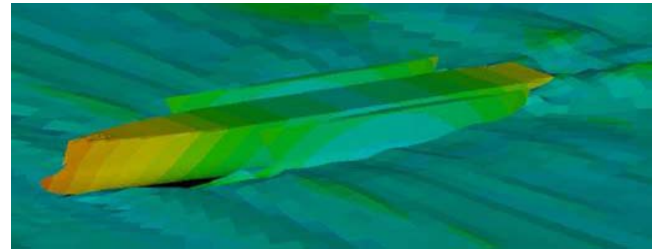
Clearance - Distance between the Outside of the Main Hull and the Inside of the Outer Hull at the waterline
$Beam_{MH}$ - Maximum Beam of the Main Hull

- **Stagger of side hulls 0.00, 0.24, 0.40 & 0.80**
- **Separation of side hulls 0.36, 0.75, 1.25**
- **Overall vessel size 150m, 200m, 250m & 300m**

Method and Software - Selection Criteria :

- Ability to Handle Trimaran Type Hull
- Time-Domain Hydrodynamic Analysis
- Transformation to Frequency Domain for RAOs / Scaling
- Non-Linear Capability for Detailed Investigation
- Ability to Assess NATO Criteria
- Extendable to FEA Structural Analysis
- Ability to Rapidly Model Geometric Variations
- Ability to Work with Existing Software

Selection of Hydrodynamic Software



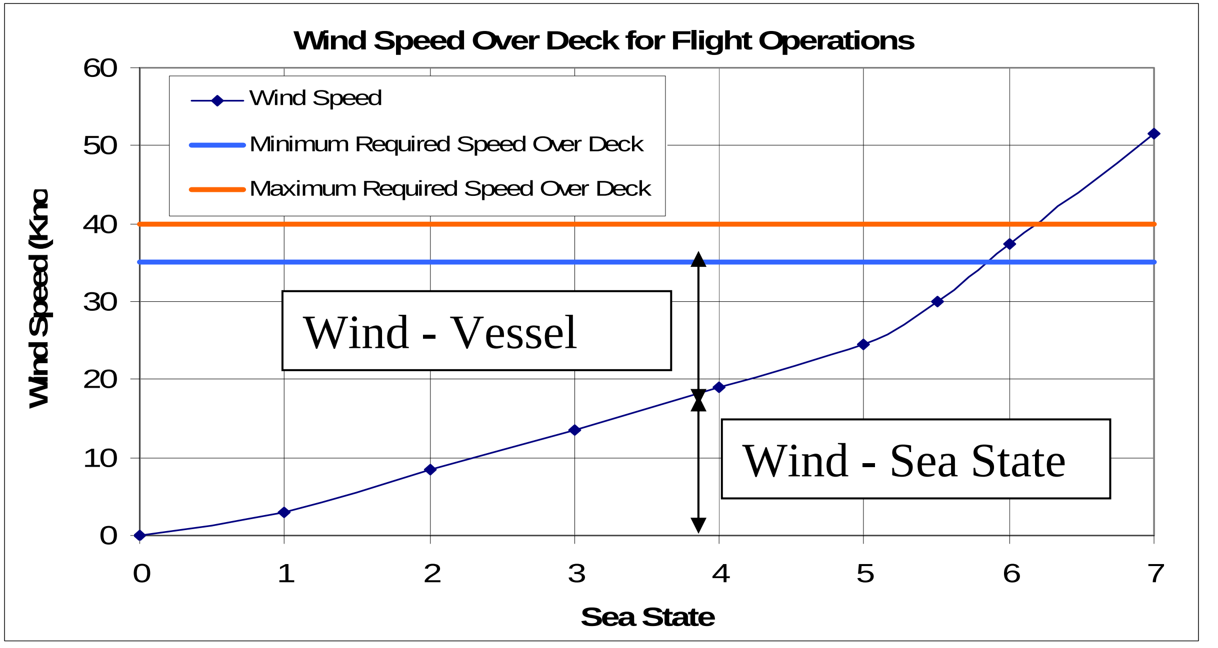
- Codes Considered
  - LAMP (SAIC)
  - SWAN (MIT)
  - WASIM (DNV implementation of SWAN)
- WASIM is Chosen as Project Software
  - WASIM is advanced fully 3-D ship motion assessment tool
  - Assessment in Time Domain
  - Capable of Non-Linear Hydrostatics
  - WASIM previously used for trimaran type hull (M/V Triton)
  - Viking Systems has extensive experience with DNV Software
  - WASIM is integrated with SAGA Software

Seakeeping Criteria – Naval Air Operations

- **NATO STANAG 4154 (Edition 3, 1997)**
- **Single Amplitude RMS Values:**

Governing Factors	Performance Limitations		
	Motion	**Limit**	**Location**
Aircraft Handling	Roll	Period > 20s, 1 Deg.; Period > 20s, 1.5 Deg	
Sink off bow and OLS limits	Pitch	Period > 10s, 0.5 Deg.; Period > 15s, 1 Deg	
Ramp Clearance	Vertical Displacement	0.8 m	Stern Ramp at Flight Deck
Landing Line-up	Lateral Displacement	2.3 m	Stern Ramp at Flight Deck
Landing Gear	Vertical Velocity	0.7 m/sec	Touchdown Point
Crosswinds and Landing loads	Relative Wind	35 to 40 knots envelope, +/- 15 degrees from the bow	

Naval Air Operations - Environment Conditions



Sea State	Wind Speed	Minimum Vessel Speed	Maximum Vessel Speed
	(Knots)	(Knots)	(Knots)
0	0.0	35.0	40.0
1	3.0	32.0	37.0
2	8.5	26.5	31.5
3	13.5	21.5	26.5
4	19.0	16.0	21.0
5	24.5	10.5	15.5
5.5	30.0	5.0	10.0
6	37.5	-2.5	2.5
7	51.5	-16.5	-11.5

Head Sea Cases used for Analysis

Insufficient Forward Speed to Maintain Maneuverability

Using Wind Speed Criteria:

The wind associated with a Sea State defines the required vessel speed to maintain 35 - 40 knot apparent wind speed over flight deck

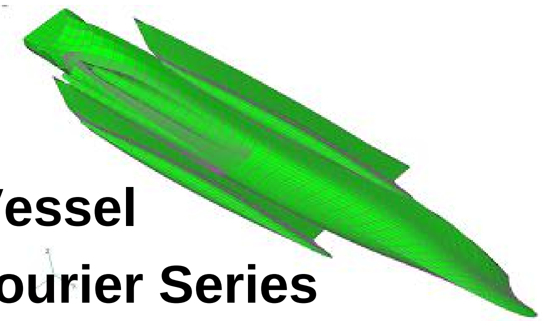
Seakeeping Criteria - Transit

- **NATO Generic Frigate Criteria (Pattison & Sheridan, 2004)**
- **Single Amplitude RMS Values:**

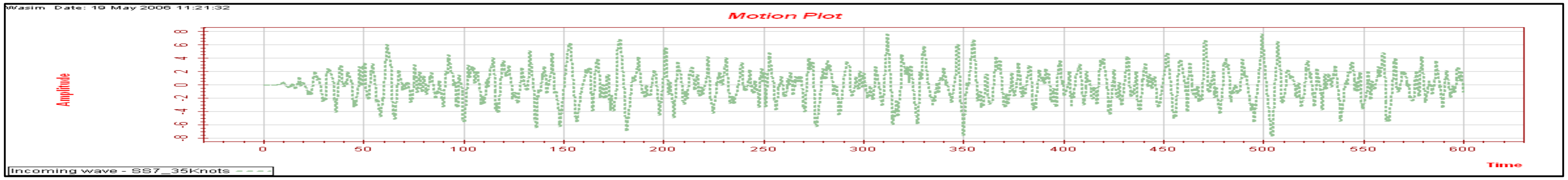
Parameter	**Limit Value**
Roll Angle	4.0 deg
Pitch Angle	1.5 deg
Vertical Acceleration	0.2 g
Lateral Acceleration	0.1 g
Bottom Slamming Index	20 per hour
Propeller Emergence Index	90 per hour

- **Comparison to Rule Hull Girder Loads**

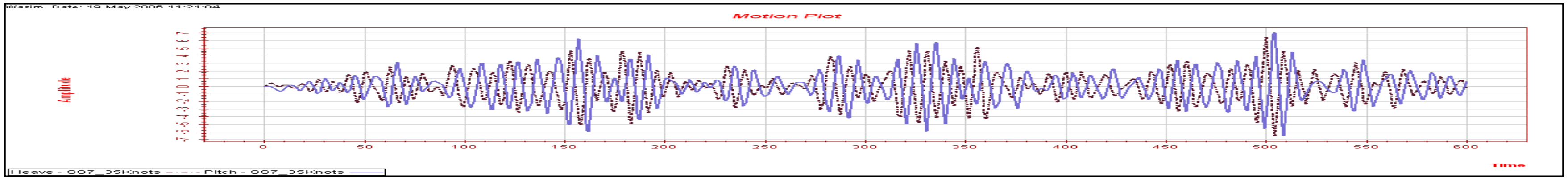
Hydrodynamic Analysis



- **Define Vessel and Incoming Waves**
  - **Panel and Mass Models defined to Represent Vessel**
  - **Wave Elevation for Time Domain Analysis as Fourier Series of Cosine Waves with Amplitude According to PM Spectrum**



- **Recording Output & Results**
  - **Time Series Recorded for 6 DOF Motions, Velocities & Accelerations**
  - **Relative Wave Elevations Recorded for Series of 30 Locations Along the Length of Main and Side Hulls**
  - **Hull Girder Shear Force & Bending Moments Recorded at Stations**



Result Processing - Time vs. Frequency

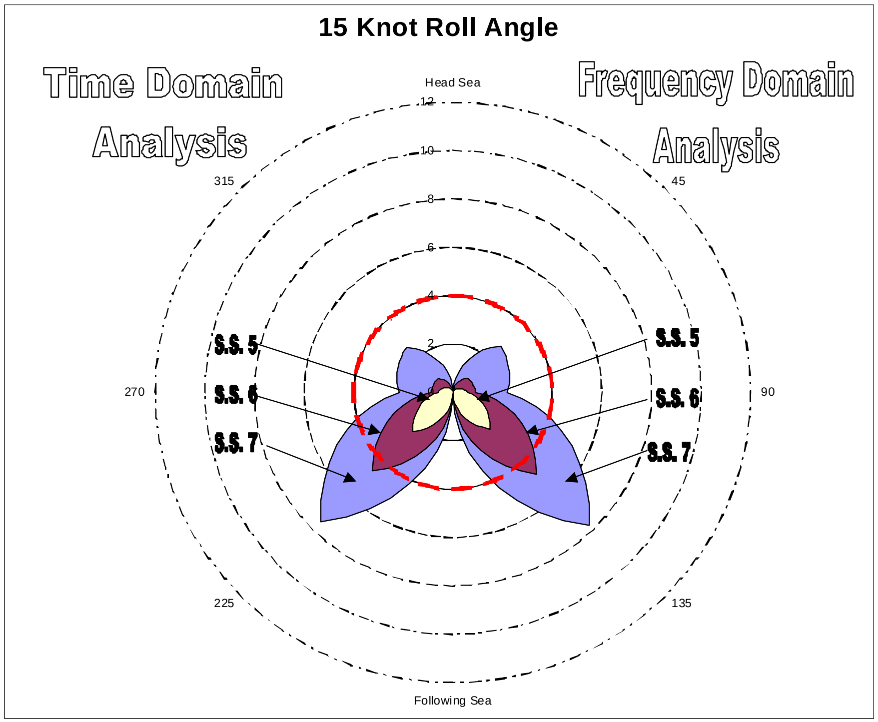
Hydrodynamic Analysis is Performed in the Time Domain, Results can be Transformed into Frequency Domain.

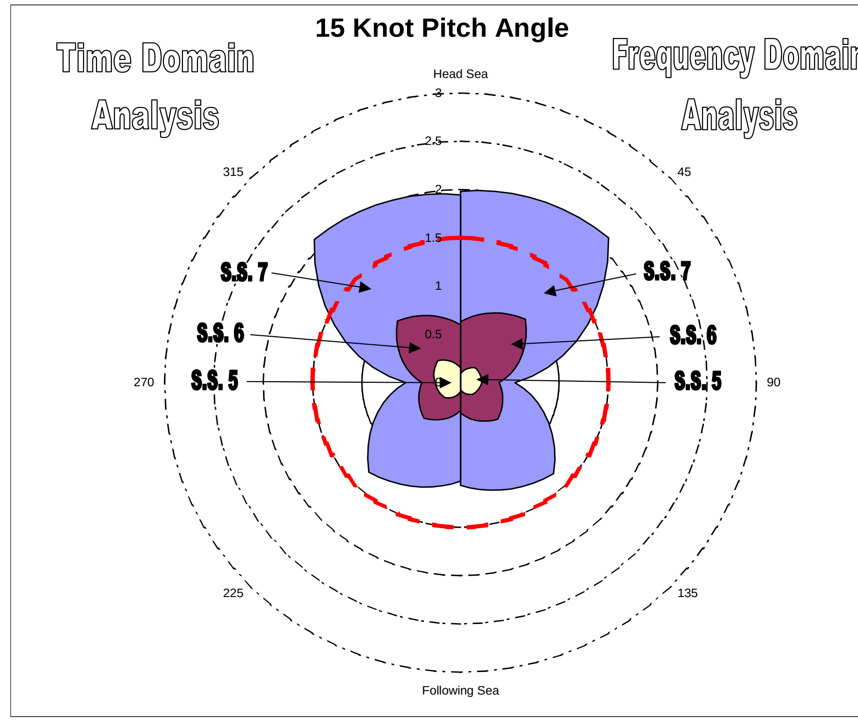
- **Result Processing in the Time Domain - Benefits**
  - **Statistical Analysis of Time Series for Result Variables**
  - **Ability to Track Occurrence of Individual Phenomenon**
  - **Unique Analysis Run for Each Sea State, Heading & Speed**
- **Result Processing in the Frequency Domain - Benefits**
  - **Results Transformed into Response Amplitude Operators (RAO)**
  - **Response to Unit Wave (RAO) Combined with Sea Spectrum**
  - **Requires Fewer Analysis Runs – Saves Computational Time**
  - **Results can be Scaled for Vessels of Varying Length**

Reliable and Repeatable Post-Processing of Data is Essential

Result Processing – Method Validation

- **HALSS is evaluated in both Time and Frequency Domains**
  - **Roll Motion Results Compared for Sea State 5, 6 & 7**
  - **Pitch Motion Results Compared for Sea State 5, 6 & 7**





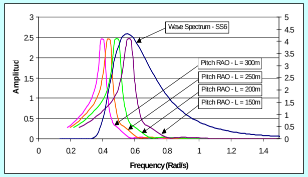
Time & Frequency Domain Calculations Provide Nearly Identical Results

Result Processing - Time vs. Frequency

- **<u>Frequency</u> Domain Analysis using RAO's possible for Motion, Velocity, Acceleration, Shear and Bending Loads – saves calculation time**

- **<u>Time</u> Domain Analysis needed for Slamming and Emergence Assessment – Head Sea Governs – saves calculation time**

<u>Frequency Domain:</u>



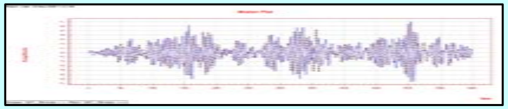
Pitch & Roll Motion

Heave & Sway Acceleration

Vertical Bending Moment

Vertical Shear Force

<u>Time Domain:</u>



Slamming Occurrence Center Hull

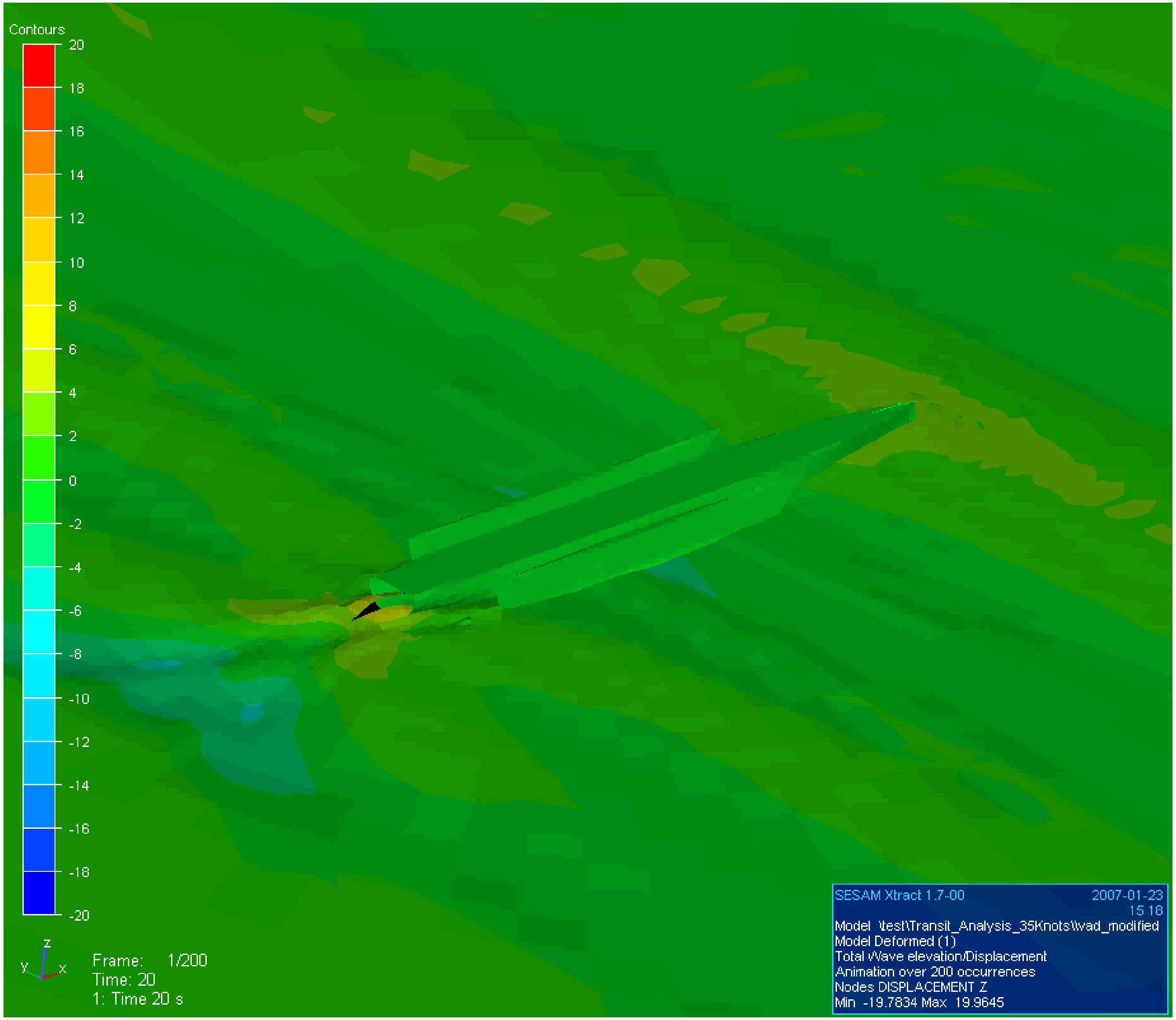
Slamming Occurrence Side Hull

Bridge Deck Slamming Occurrence

Propeller Emergence Occurrence

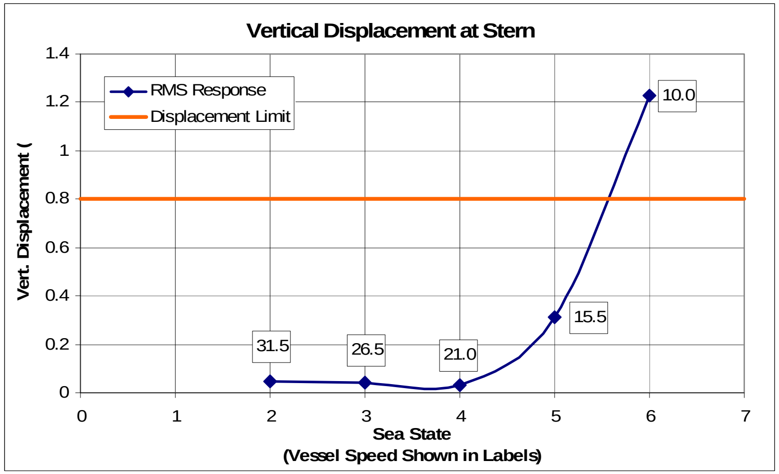
Results Summary for HALSS

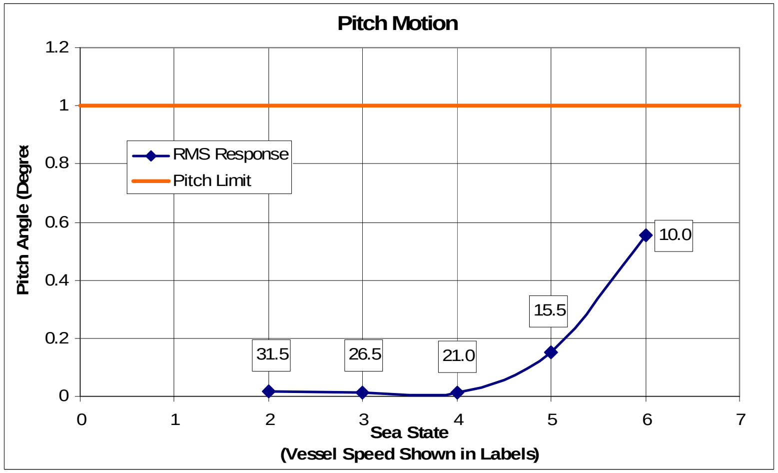
HALSS Trimaran Hull Configuration – 35 knots in SS7 – Head Seas

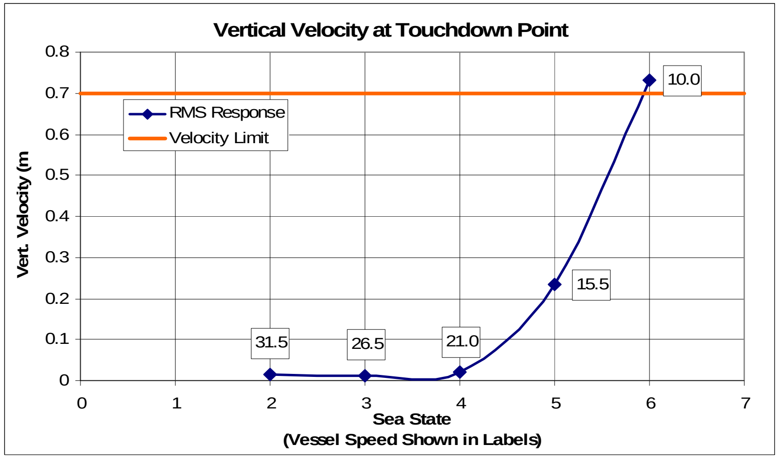


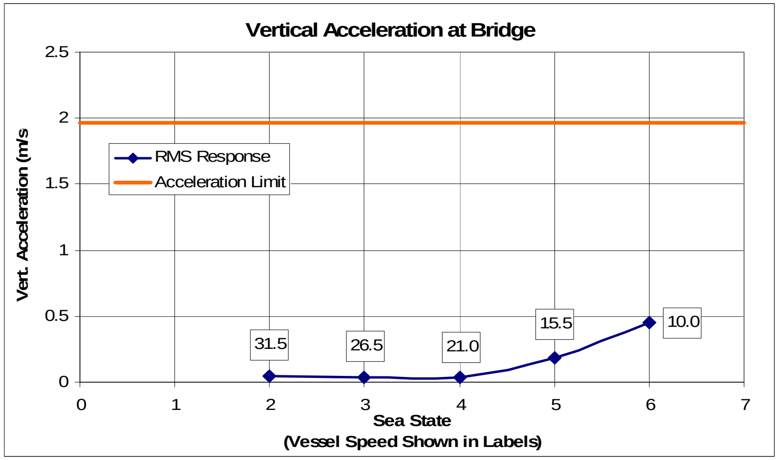
Results Summary for HALSS

Comparison of Hydrodynamic Results to NATO Criteria for Naval Air Operations



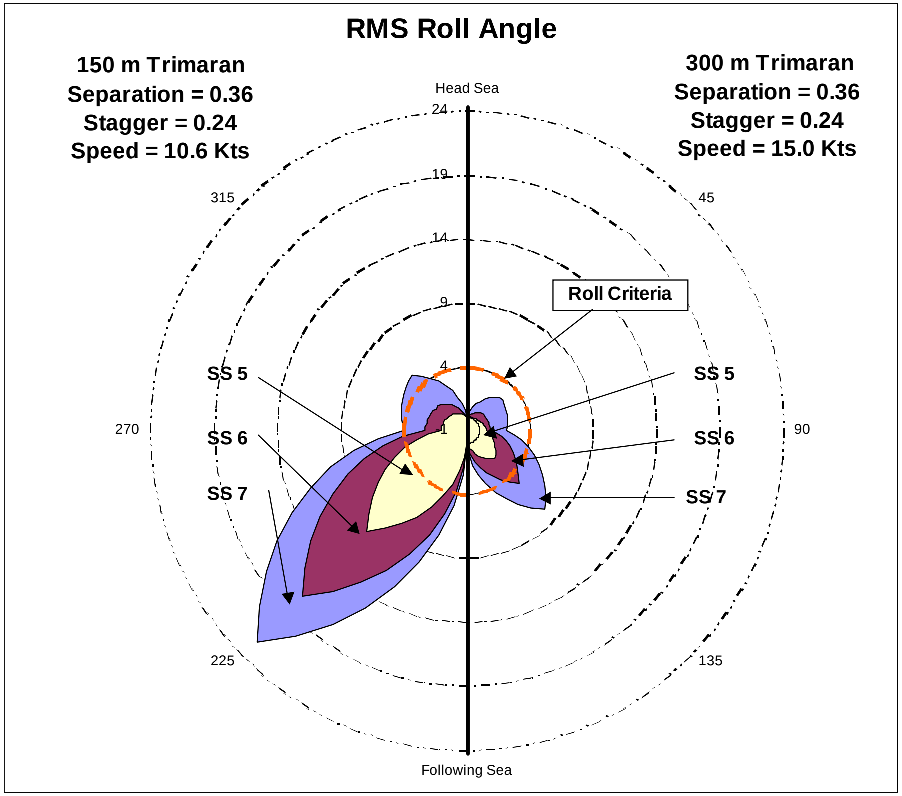


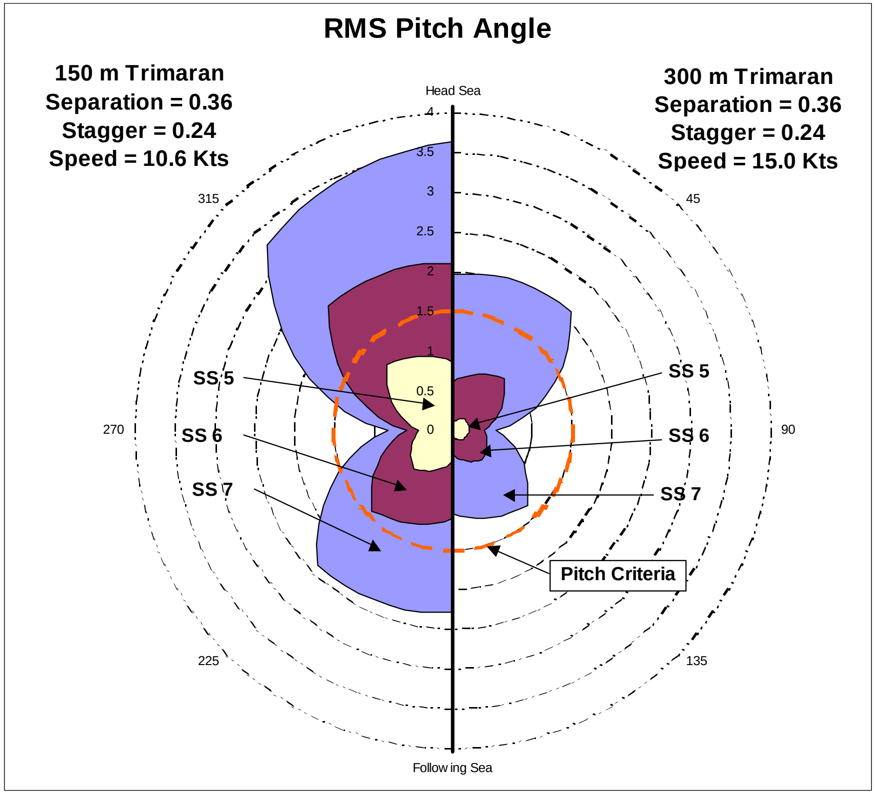




Results Summary for HALSS

- Comparison of Results to NATO Criteria for Transit
  - Polar Plots to Facilitate Comparisons, 150 m vs. 300 m:



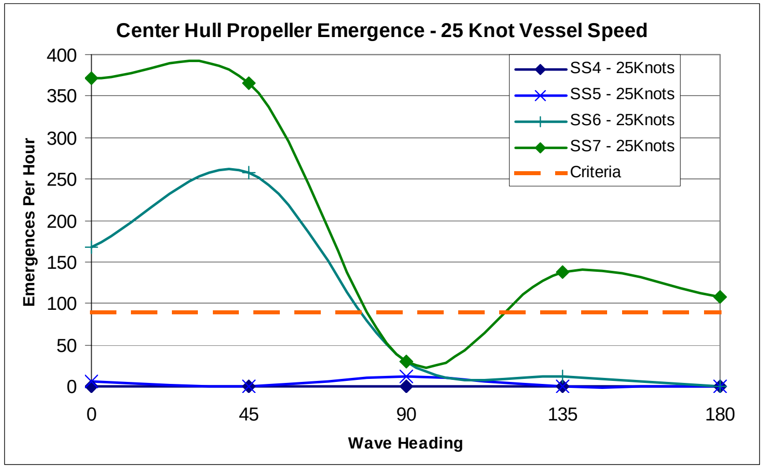


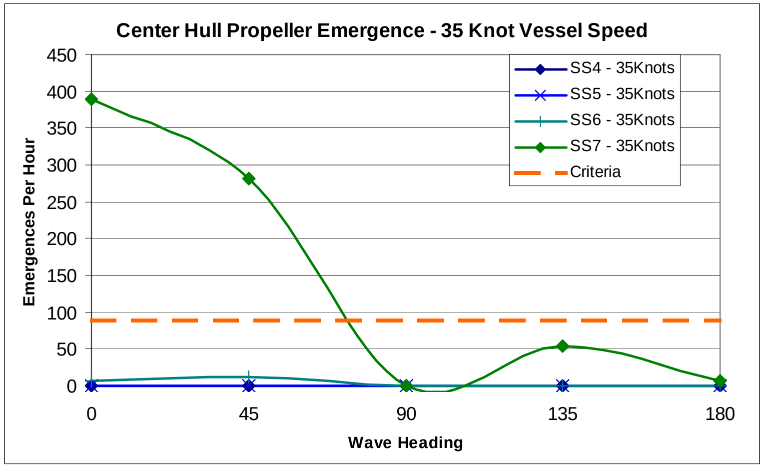
- Results for 150 m Vessel Created by Length Scaling RAOs

Results Summary for HALSS

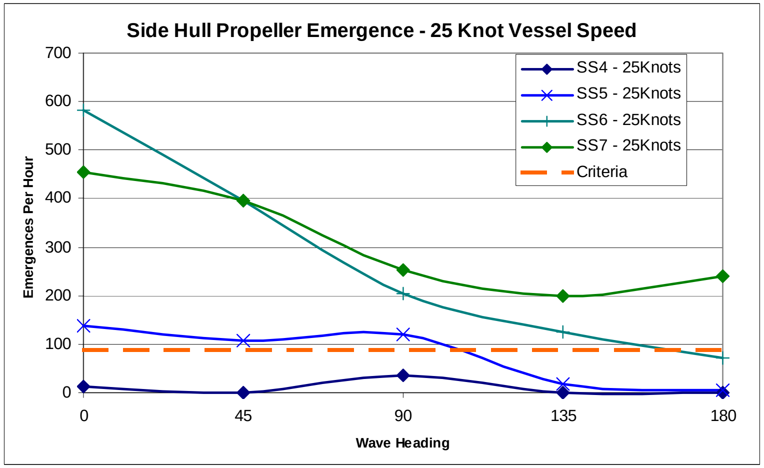
Comparison of Results to NATO Criteria for Transit

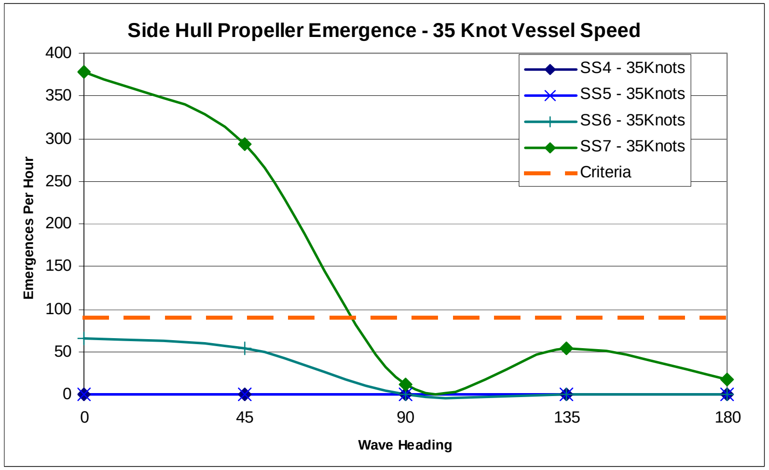
Center Hull Propellers





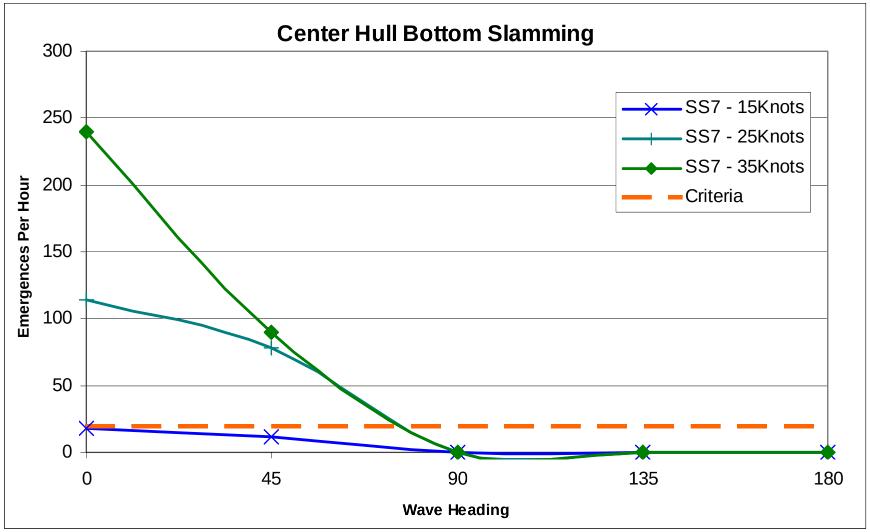
Side Hull Propellers

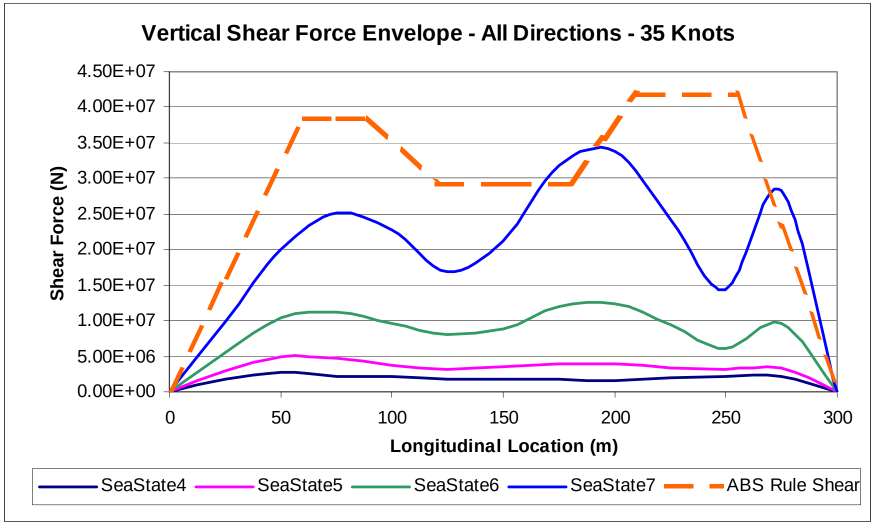




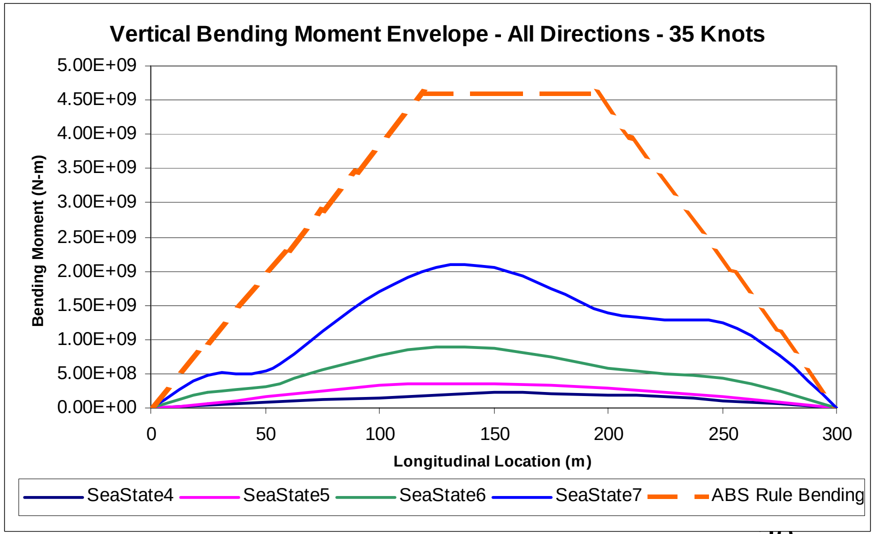
HALSS Transit Slamming and Hull Girder Loads

Comparison of Results to NATO Transit Criteria and ABS Rule Loads



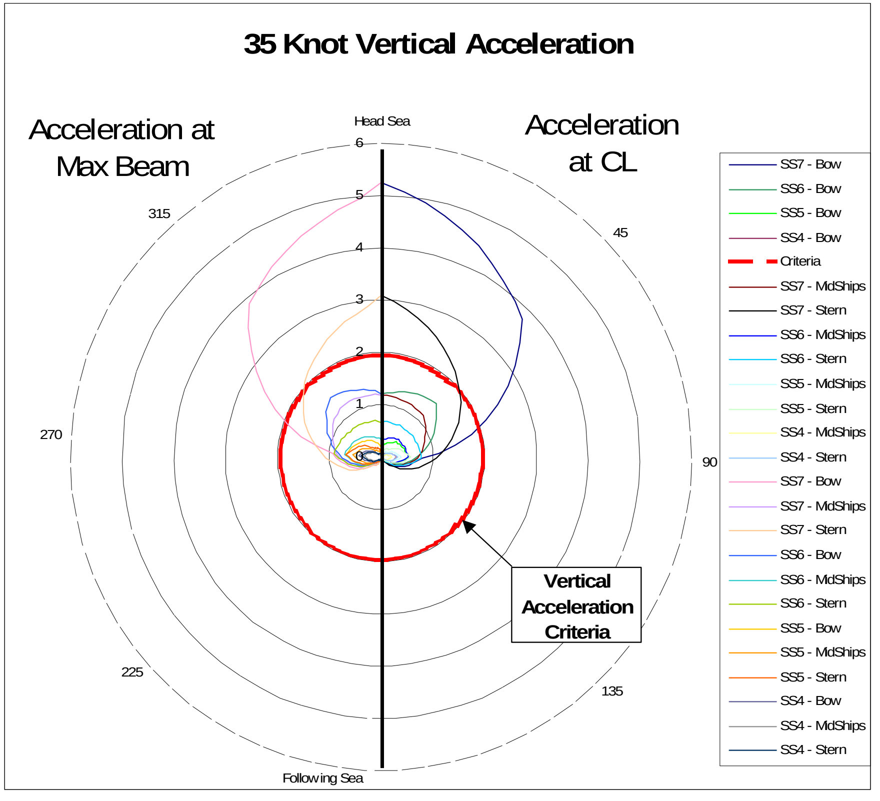


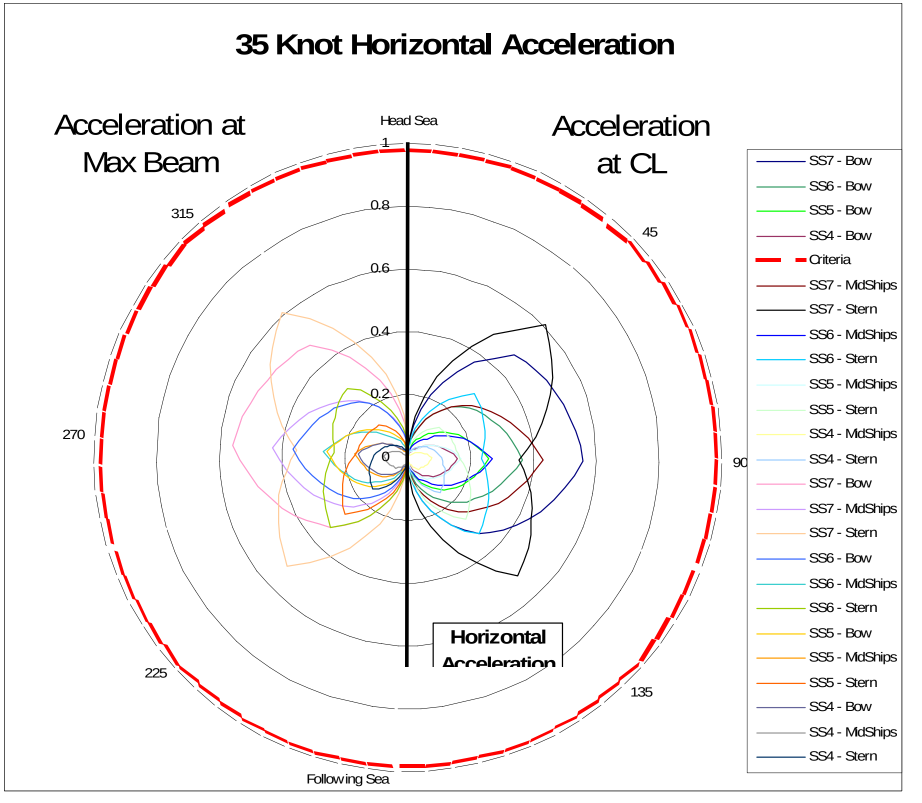
- No Slamming below Sea State 7
- Head Sea is the worst wave heading for slamming
- ABS Rule Shear for equivalent monohull = 4.18×10^7 N
- ABS Rule Bending Moment for equivalent monohull = 4.60×10^9 N-m



HALSS Transit Acceleration Results

Comparison of Results to NATO Criteria for Transit





- Trimaran meets vertical acceleration criteria up to sea state 6
- Trimaran meets horizontal acceleration criteria up to sea state 7

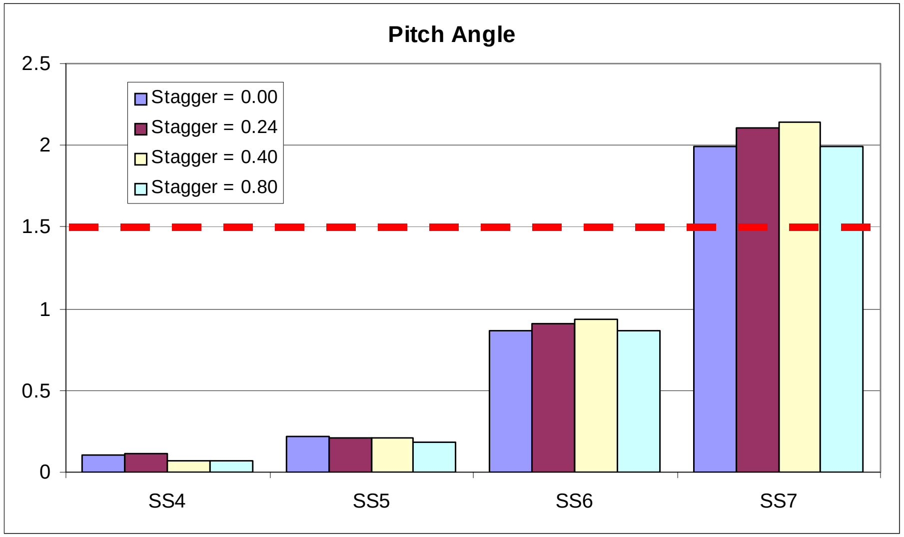
Result Highlights for Other Hull Configurations

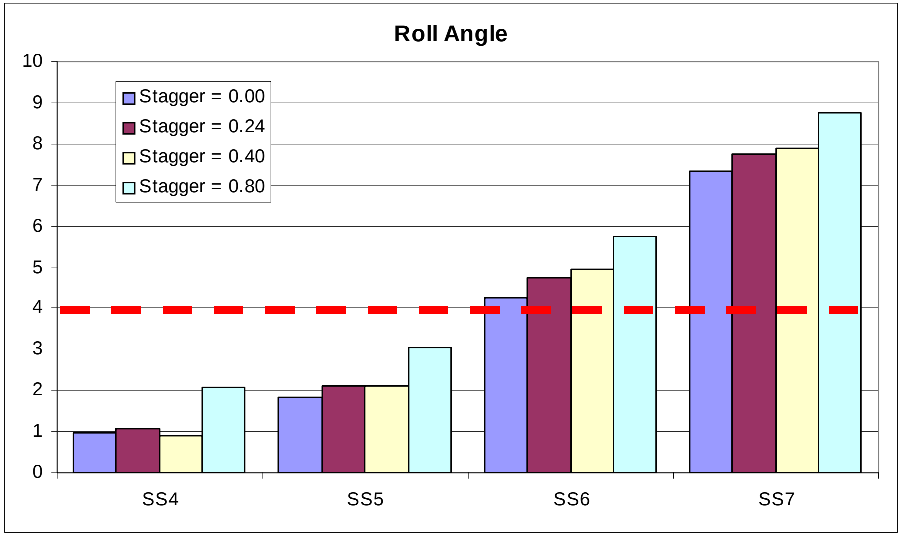
Result Data Sheet for Each Stagger, Separation, Length, Speed & Sea State

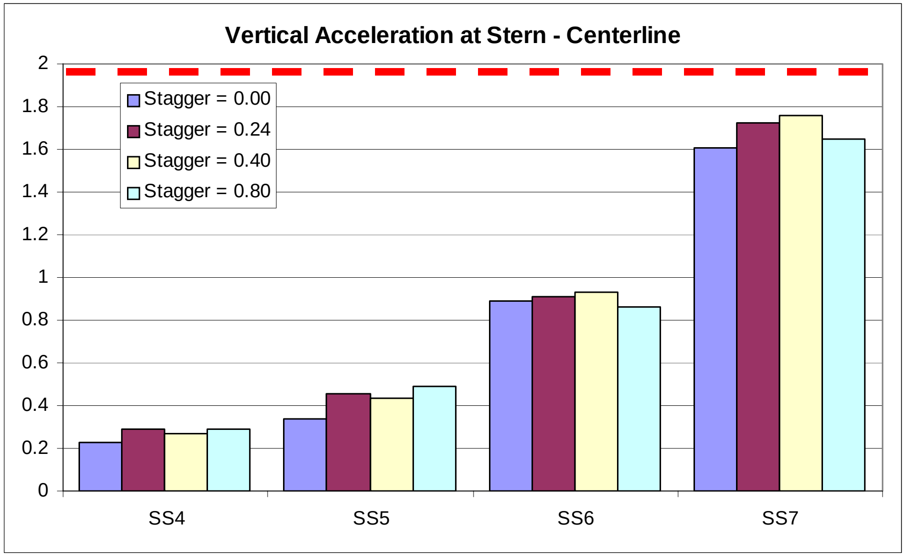
Vessel Characteristics			Vessel Length (m)		300	Vessel Breath (m)		51	Hull Depth (m)		11.5	Displacement (mT)		60,495	Stagger Ratio		0.24	Separation Ratio		0.36		
SPEED	NO.	CRITERIA	SEASTATE 4 (Hs=2.08m)					SEASTATE 5 (Hs=2.97m)					SEASTATE 6 (Hs=5.18m)					SEASTATE 7 (Hs=9.91m)				
			HEADINGS					HEADINGS					HEADINGS					HEADINGS				
			0	45	90	135	180	0	45	90	135	180	0	45	90	135	180	0	45	90	135	180
25 Knots	1	Pitch Displacement	0.005	0.018	0.109	0.060	0.013	0.054	0.135	0.208	0.128	0.025	0.671	0.924	0.409	0.419	0.197	2.345	2.431	0.631	1.112	0.976
	2	Roll Displacement	0.000	0.044	0.376	0.819	0.000	0.000	0.110	0.551	2.034	0.000	0.000	0.437	0.847	5.444	0.000	0.000	1.261	2.180	10.551	0.000
	3	Vertical Acceleration (Midship/Centerline)	0.006	0.016	0.222	0.007	0.001	0.026	0.066	0.350	0.013	0.002	0.178	0.293	0.538	0.040	0.013	0.492	0.632	0.719	0.121	0.066
	4	Vertical Acceleration (Midship/Beam)	0.006	0.034	0.319	0.070	0.001	0.026	0.082	0.483	0.156	0.002	0.178	0.320	0.694	0.365	0.013	0.492	0.704	0.845	0.617	0.066
	5	Vertical Acceleration (Bow/Centerline)	0.020	0.052	0.325	0.026	0.003	0.094	0.244	0.500	0.053	0.007	0.850	1.226	0.716	0.148	0.049	2.340	2.639	0.847	0.336	0.199
	6	Vertical Acceleration (Stern/Centerline)	0.014	0.030	0.292	0.036	0.002	0.051	0.125	0.450	0.068	0.005	0.517	0.708	0.745	0.171	0.039	1.517	1.663	1.046	0.362	0.186
	7	Transverse Acceleration (Midship/Centerline)	0.000	0.008	0.081	0.372	0.000	0.000	0.017	0.145	0.449	0.000	0.000	0.065	0.275	0.553	0.000	0.000	0.183	0.439	0.652	0.000
	8	Transverse Acceleration (Midship/Beam)	0.000	0.008	0.081	0.372	0.000	0.000	0.017	0.145	0.449	0.000	0.000	0.065	0.275	0.553	0.000	0.000	0.183	0.439	0.652	0.000
	9	Transverse Acceleration (Bow/Centerline)	0.000	0.029	0.148	0.388	0.000	0.000	0.056	0.212	0.520	0.000	0.000	0.152	0.344	0.765	0.000	0.000	0.321	0.519	1.129	0.000
	10	Transverse Acceleration (Stern/Centerline)	0.000	0.035	0.097	0.551	0.000	0.000	0.068	0.147	0.751	0.000	0.000	0.196	0.256	1.114	0.000	0.000	0.401	0.396	1.577	0.000
	11	Centerhull Bottom Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	84	n/a	n/a	n/a	n/a
	12	Sidehull Bottom Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a
	13	Bridge Deck Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a
	14	Propeller Immersion	0	n/a	n/a	n/a	n/a	18	n/a	n/a	n/a	n/a	288	n/a	n/a	n/a	n/a	420	n/a	n/a	n/a	n/a
	15	Bending Moment (Midships)	2.47E+07	5.27E+07	1.06E+08	9.02E+07	1.83E+07	8.73E+07	1.42E+08	1.78E+08	1.98E+08	5.84E+07	3.56E+08	3.79E+08	3.42E+08	4.47E+08	2.73E+08	8.01E+08	6.33E+08	5.87E+08	7.51E+08	7.73E+08
	16	Shear Force (Quarter Forward)	6.29E+05	8.51E+05	1.25E+06	1.55E+06	4.24E+05	1.64E+06	2.14E+06	2.35E+06	2.82E+06	1.05E+06	6.25E+06	6.29E+06	4.85E+06	6.01E+06	3.62E+06	1.47E+07	1.19E+07	8.14E+06	9.65E+06	9.37E+06
35 Knots	1	Pitch Displacement	0.004	0.011	0.117	0.057	0.014	0.023	0.078	0.213	0.119	0.048	0.579	0.767	0.401	0.409	0.256	2.912	2.503	0.632	1.071	0.850
	2	Roll Displacement	0.000	0.032	0.352	0.881	0.000	0.000	0.063	0.525	1.296	0.000	0.000	0.236	0.782	2.622	0.001	0.000	0.778	2.044	4.997	0.001
	3	Vertical Acceleration (Midship/Centerline)	0.004	0.010	0.211	0.005	0.001	0.016	0.047	0.333	0.011	0.003	0.164	0.291	0.515	0.036	0.015	0.621	0.698	0.693	0.113	0.054
	4	Vertical Acceleration (Midship/Beam)	0.004	0.025	0.308	0.071	0.001	0.016	0.060	0.463	0.101	0.003	0.164	0.305	0.666	0.181	0.015	0.621	0.749	0.816	0.333	0.054
	5	Vertical Acceleration (Bow/Centerline)	0.014	0.032	0.320	0.026	0.004	0.048	0.139	0.471	0.051	0.014	0.597	0.953	0.658	0.147	0.071	2.609	2.418	0.774	0.330	0.197
	6	Vertical Acceleration (Stern/Centerline)	0.012	0.022	0.321	0.031	0.002	0.030	0.076	0.492	0.061	0.010	0.316	0.460	0.788	0.161	0.055	1.510	1.373	1.081	0.344	0.162
	7	Transverse Acceleration (Midship/Centerline)	0.000	0.006	0.079	0.341	0.000	0.000	0.013	0.142	0.596	0.001	0.000	0.052	0.272	0.937	0.003	0.000	0.152	0.440	1.216	0.005
	8	Transverse Acceleration (Midship/Beam)	0.000	0.006	0.079	0.341	0.000	0.000	0.013	0.142	0.596	0.001	0.000	0.052	0.272	0.937	0.003	0.000	0.152	0.440	1.216	0.005
	9	Transverse Acceleration (Bow/Centerline)	0.000	0.017	0.157	0.335	0.000	0.000	0.041	0.218	0.565	0.001	0.000	0.131	0.346	0.858	0.003	0.000	0.280	0.531	1.126	0.005
	10	Transverse Acceleration (Stern/Centerline)	0.000	0.023	0.107	0.374	0.000	0.000	0.054	0.150	0.680	0.001	0.000	0.169	0.255	1.161	0.003	0.000	0.373	0.389	1.573	0.005
	11	Centerhull Bottom Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	234	n/a	n/a	n/a	n/a
	12	Sidehull Bottom Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	96	n/a	n/a	n/a	n/a
	13	Bridge Deck Slamming	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	240	n/a	n/a	n/a	n/a
	14	Propeller Immersion	0	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	6	n/a	n/a	n/a	n/a	396	n/a	n/a	n/a	n/a
	15	Bending Moment (Midships)	3.30E+07	5.49E+07	1.17E+08	8.33E+07	2.16E+07	9.38E+07	1.53E+08	1.87E+08	1.85E+08	7.52E+07	4.20E+08	4.80E+08	3.32E+08	4.60E+08	3.43E+08	1.11E+09	9.16E+08	5.58E+08	7.95E+08	8.02E+08
	16	Shear Force (Quarter Forward)	6.79E+05	8.41E+05	1.20E+06	1.43E+06	4.86E+05	1.62E+06	2.07E+06	2.10E+06	2.69E+06	1.31E+06	6.28E+06	6.71E+06	4.25E+06	6.00E+06	4.60E+06	1.81E+07	1.39E+07	7.42E+06	9.97E+06	9.66E+06

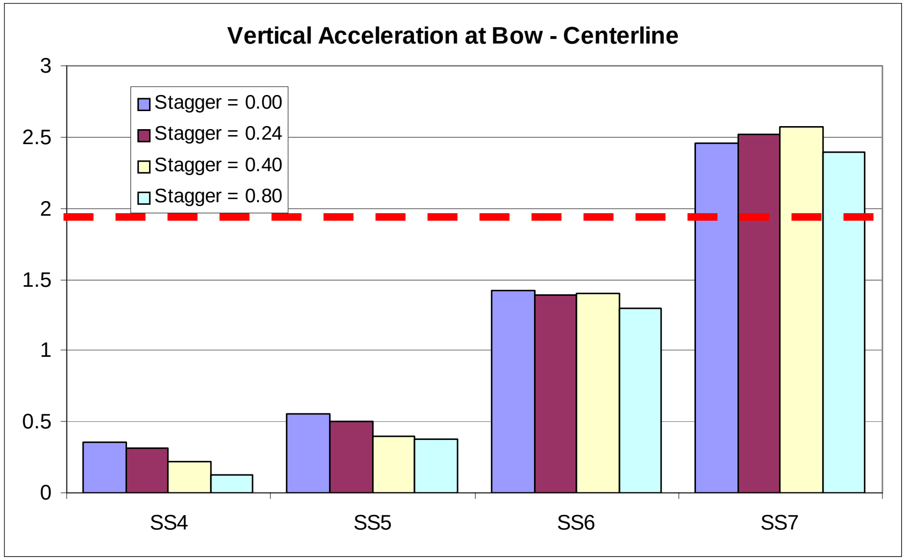
Stagger Influence

15 knots – Maximum Response from All Headings



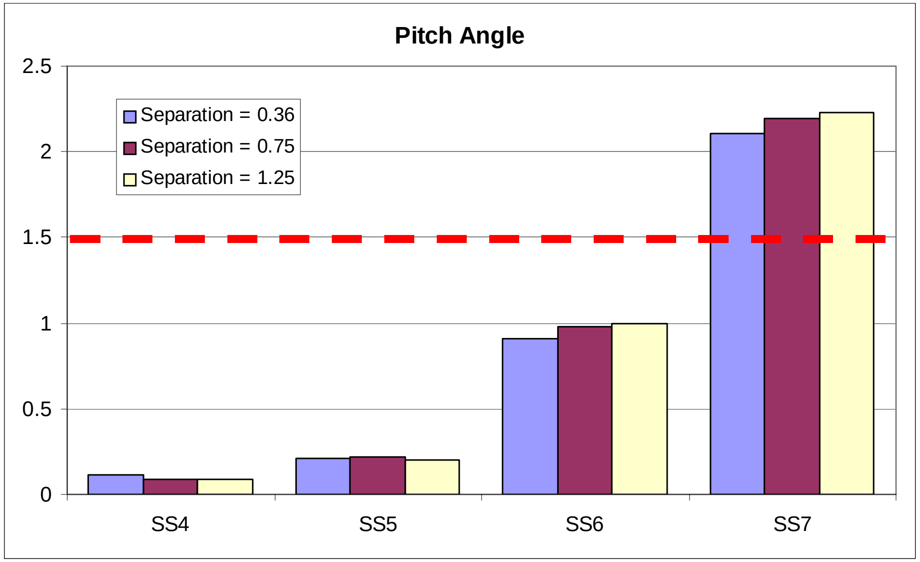


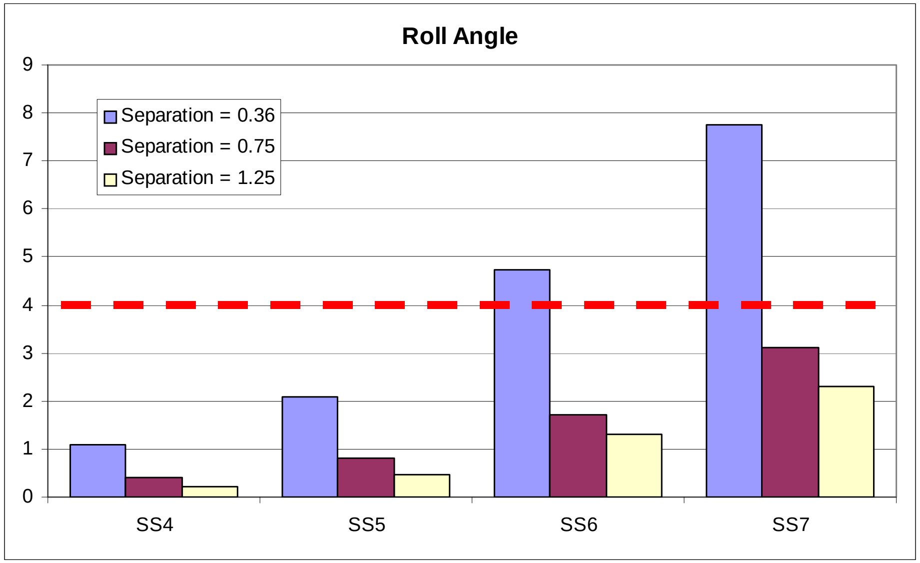


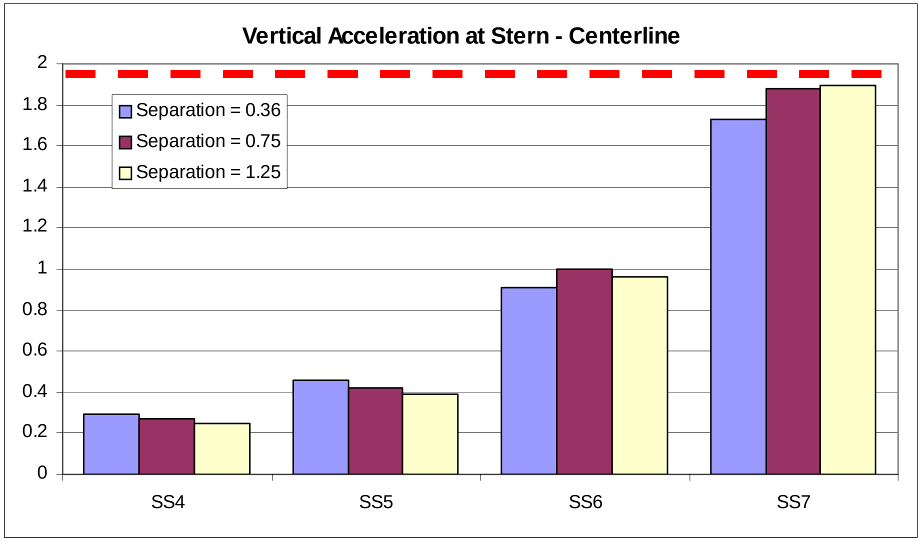


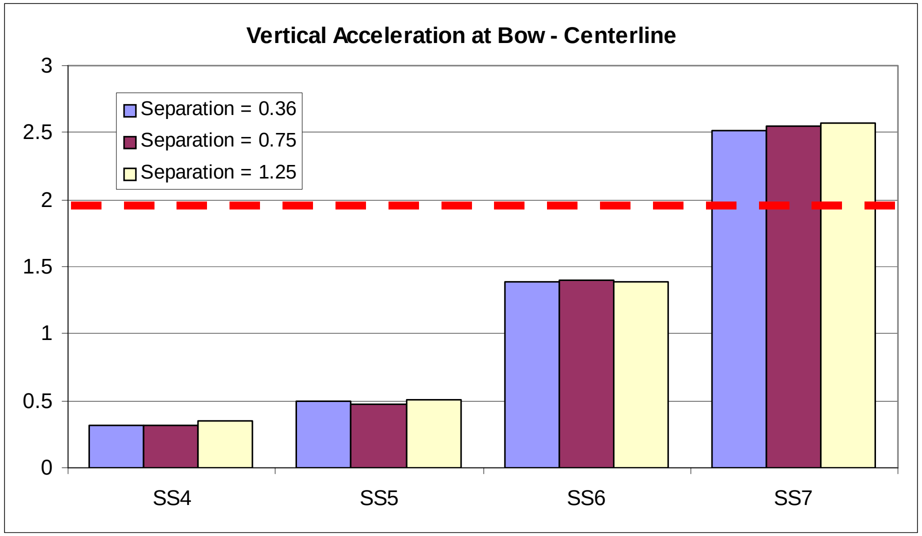
Separation Influence

15 knots – Maximum Response from All Headings



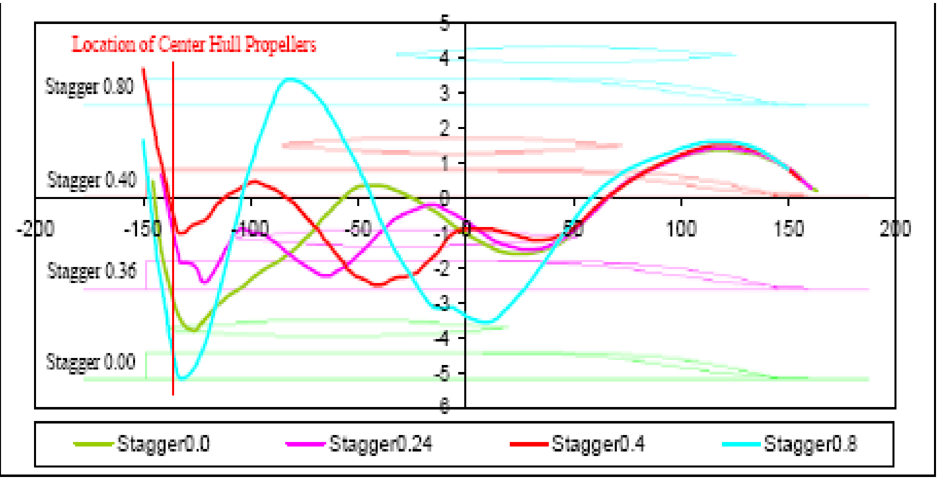




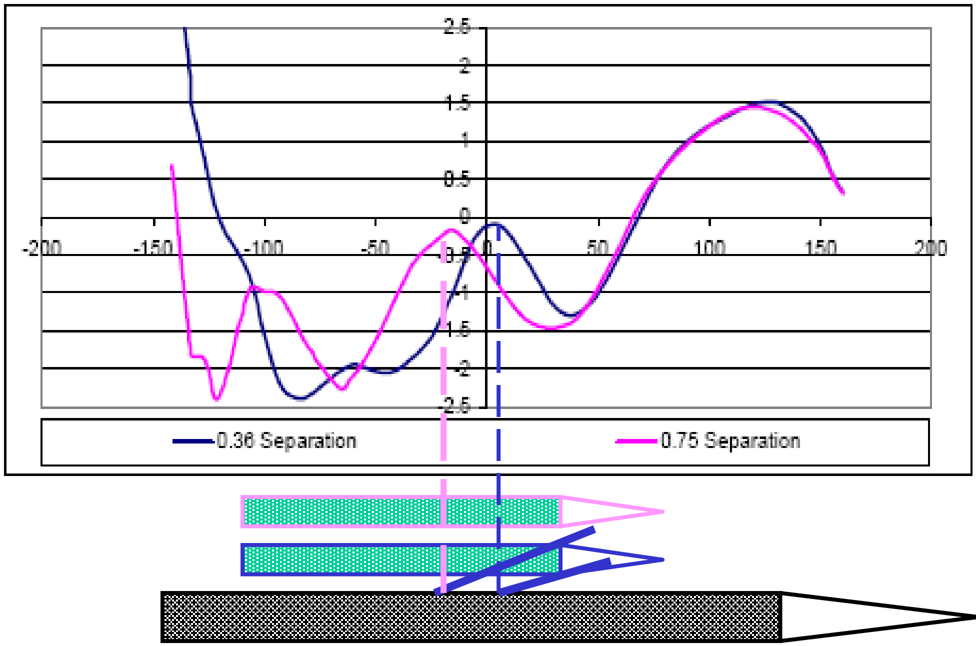


Wave Train Interaction vs. Trimaran Configuration

Effect of Stagger along the Center Hull



Effect of Separation along the Center Hull

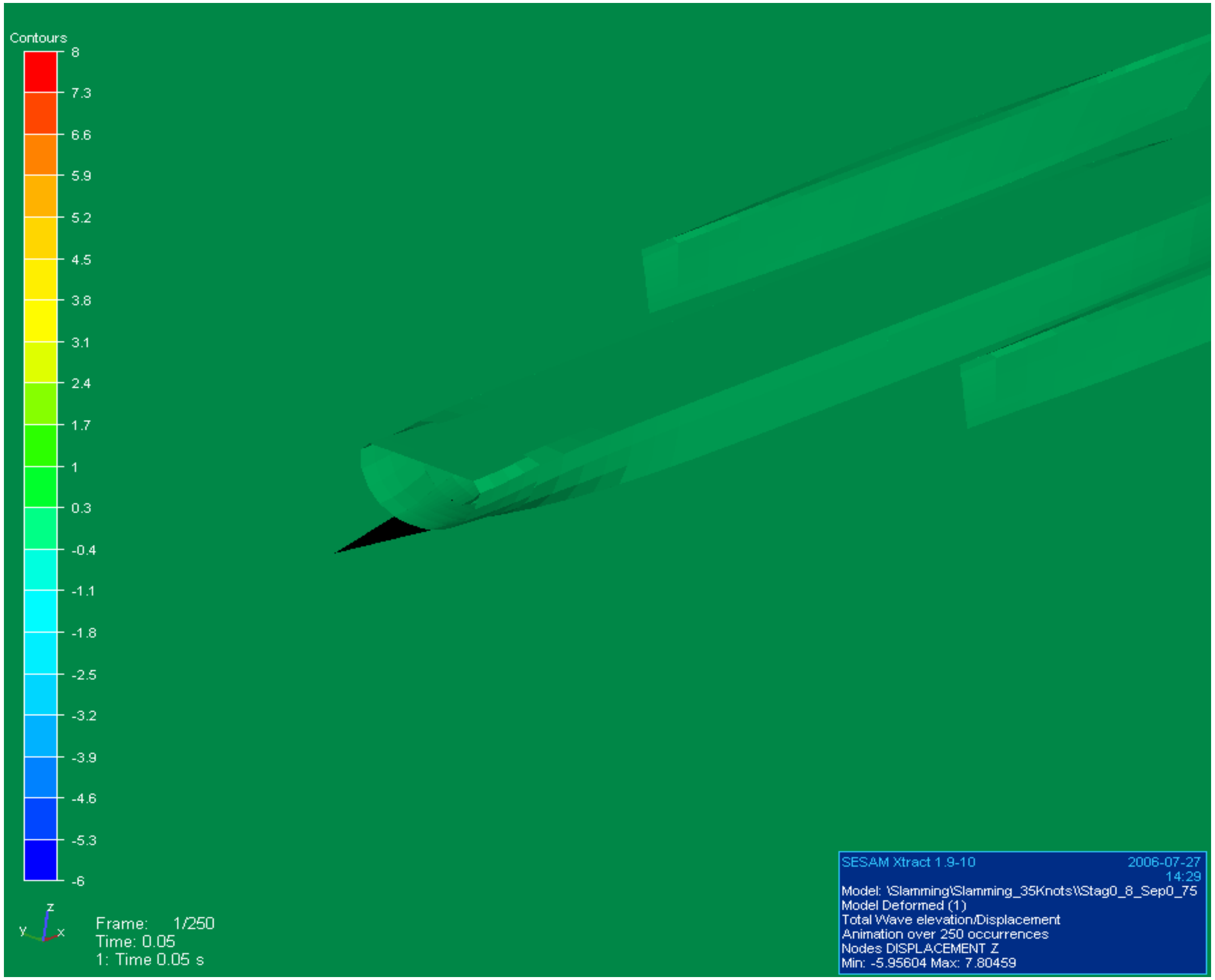


The wave train interaction between the hulls increases the amplitude of the standing wave along the length of the center hull for certain hull configurations. This amplification of center hull waves leads to additional bending moment in the hull girder loads and a wave trough in way of the props, which can induce excessive amounts of propeller emergences.

- Wave Train Interaction can have large impact on trimarans performance
- Phenomenon can guide the choice of trimaran hull configuration
- More studies are needed to fully comprehend the impact on design

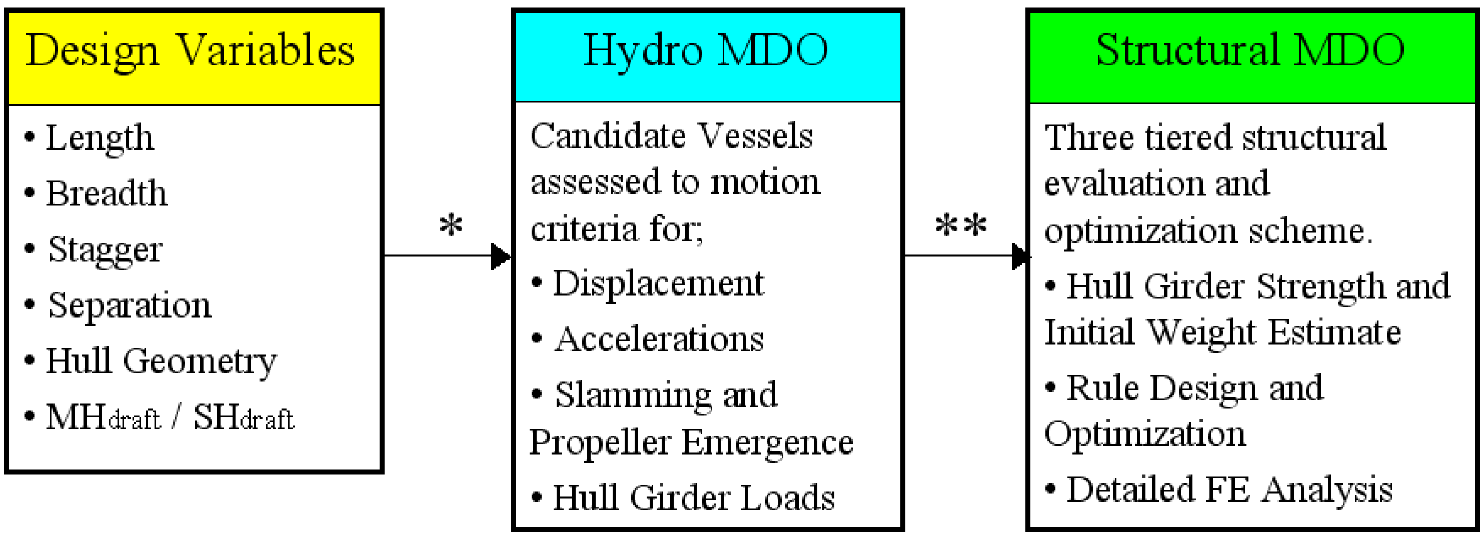
Wave Train Interaction Phenomenon

Vessel Configuration with 0.8 Stagger Ratio / 0.75 Separation Ratio – 35 knots in Sea State 5



Structural Design as a Criteria for Seakeeping Assessment

The impact of the vessel configurations and hydrodynamic loads on the structural requirements of the vessel are considered in the selection of the optimal design

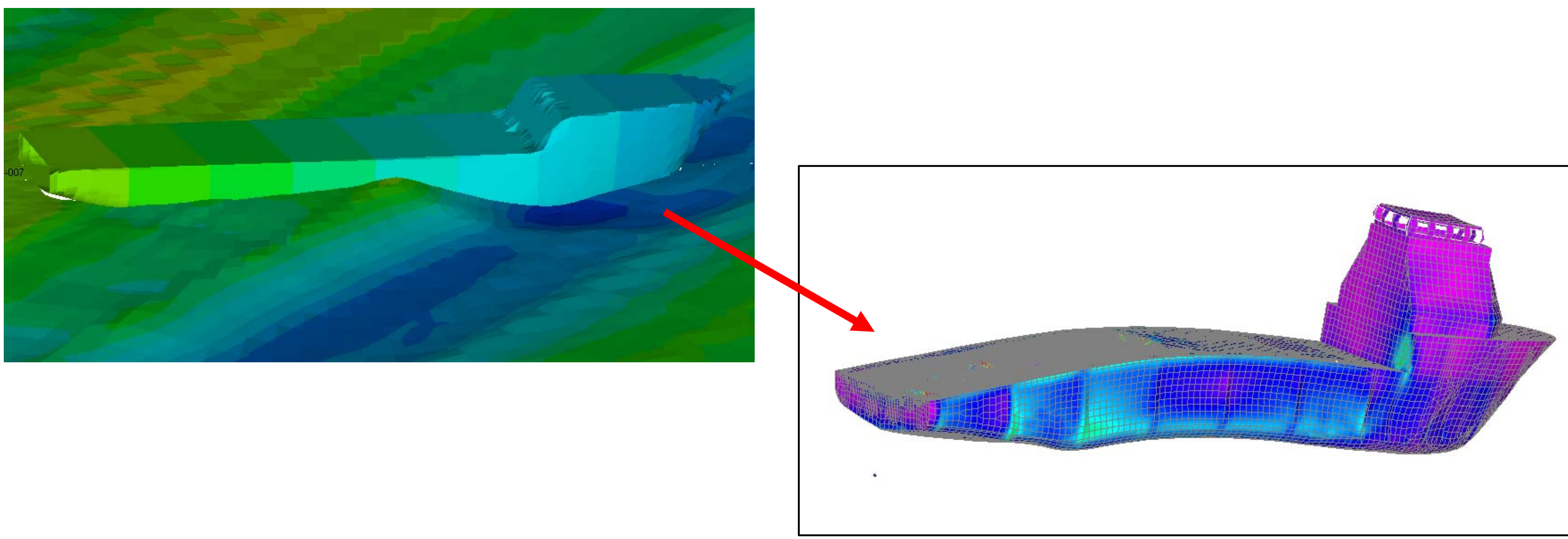


* Candidates Narrowed by; Mission Requirements, Build Feasibility, Resistance/Power, Sea keeping, etc…

** Candidates evaluated to determine which parameter variations provide desirable changes to the motion characteristics

Structural Optimization – Ongoing Work

- The design pressures and accelerations developed with the hydrodynamic analysis can be translated directly to Finite Element Analysis (FEA) models.
- FEA provides a direct assessment of the variations in motions and loads on the structural requirements of the vessel.



- Based on present results, a structural optimization routine is being developed

Conclusions

- **Systematic Seakeeping Database Established for Trimarans**
  - **Valuable for synthesis level of design**
  - **Useful as concept evaluation tools**
  - **Will be expanded with future work to include structural optimization**
  - **WASIM / SAGA is a reliable and expandable design tool**
- **Strong Wave Train Interaction Phenomenon Identified**
  - **Early detection allows problem to be addressed at the hull form development stage**
- **HALSS Provides Favorable Seakeeping Performance**
  - **Side hull propeller emergence – limiting factor**