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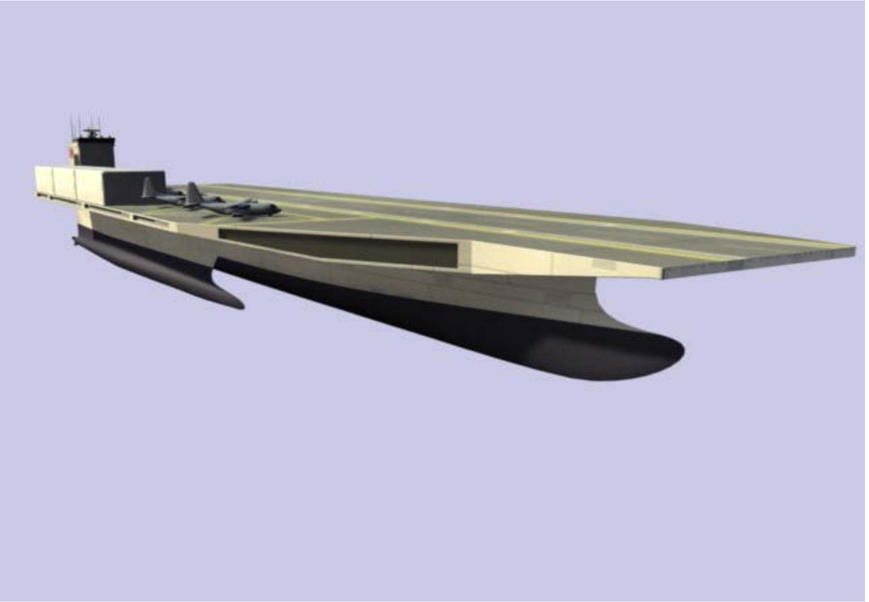
Large Trimaran Concepts and Technology Elements



By Dr. Igor Mizine, CSC Advanced Marine Center

Presentation at Joint SD-5 Panel and International Hydrofoil Society Meeting
April 1, 2008

Presentation Content

- **Background: HALSS Mission and Capabilities**
- **HALSS Concept Design Characteristics**
  - **General & Machinery Arrangement**
  - **Productivity Studies**
- **Performance Validation & Selected Technology Elements**
  - **Hull Forms and Resistance Model Tests**
  - **Seakeeping**
- **Summary**

HALSS Technology and Concept Evaluation Team:

CCDoTT – Center for the Commercial Deployment of Transportation Technologies

CSC – EXPERIENCE. RESULTS.

HEC – HERBERT ENGINEERING CORP. – Naval Architects • Marine Engineers • Software Specialists

LOCKHEED MARTIN

NSWCCD | **Viking Systems**

SPAR Associates | **Global Management Partners**

Design Approach and Trimaran Rational

- Multihull (Trimaran) ships allow high slenderness of the hulls to reduce resistance at hump Froude numbers. Design goal is to find the best compromise between increase of wetted surface, maximum possible slenderness and resistance interference between the hulls. There is a flexibility in Trimaran configuration, which helps finding best solution.

- Trimaran has substantially higher stowage capacity than equivalent monohull. Trimaran is conducive to transport high area/volume consuming payloads: Light Army and USMC equipment, hellos, sustainment, troops. In commercial application – Trimaran is the best concept for carrying cargo on wheels, allowing enough spaces for internal maneuvers at loading and offloading. Excessive deck area is useful for aerial support.

- For high speed and large sizes, Trimaran allows the propulsion power to be split between hulls, thus reducing the limitation of maximum power installed in one narrow hull. With distributed propulsion the flexibility for transit and loitering operations is added and maneuvering efficiency increases.

CCDOTT High Speed Trimaran Technology and Concept Development Program

Very High Speed Sealift Trimaran (VHSST) Concept Design.

Concept Evaluation; Trimaran Hull Forms Development & *Model Testing*

CCDOTT Program FY 99 – 01 (CY 00-02)

DASH 70-knot Slender & Small Waterplane Trimaran (SWAT).

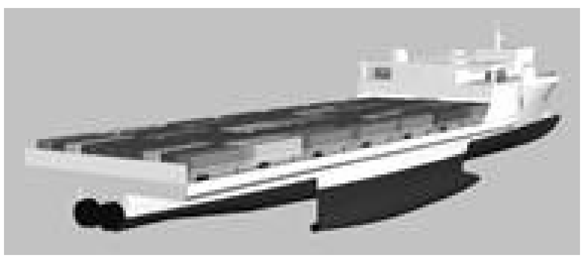
Design Parametric Studies; Propulsion & Interaction Analysis; Hull Forms & *Model Testing*

ONR R&D Project FY 00-01 (CY 01-02)

Dual Cruise & Sealift Large Trimaran Ship.

Concept Evaluation

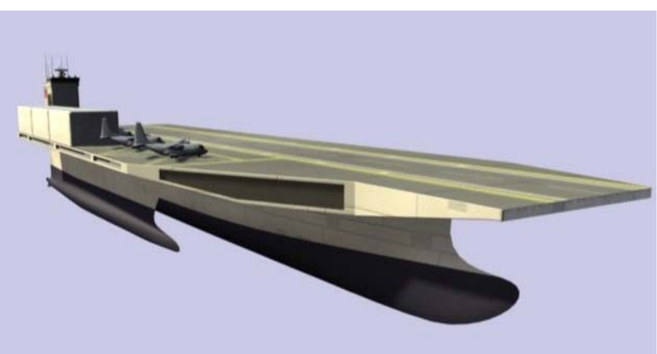
CCDOTT Program FY 02 (CY 03-04)



Dual Short Sea Shipping Trailership Concept Design for USA SuperRoutes Commercial Alliance.

Short Sea Shipping & Theater Support Vessel Requirements; Concept Design; Cost Estimate

CCDOTT Program FY 02 (CY 03-04)



Heavy Air Lift Support Ship (HALSS).

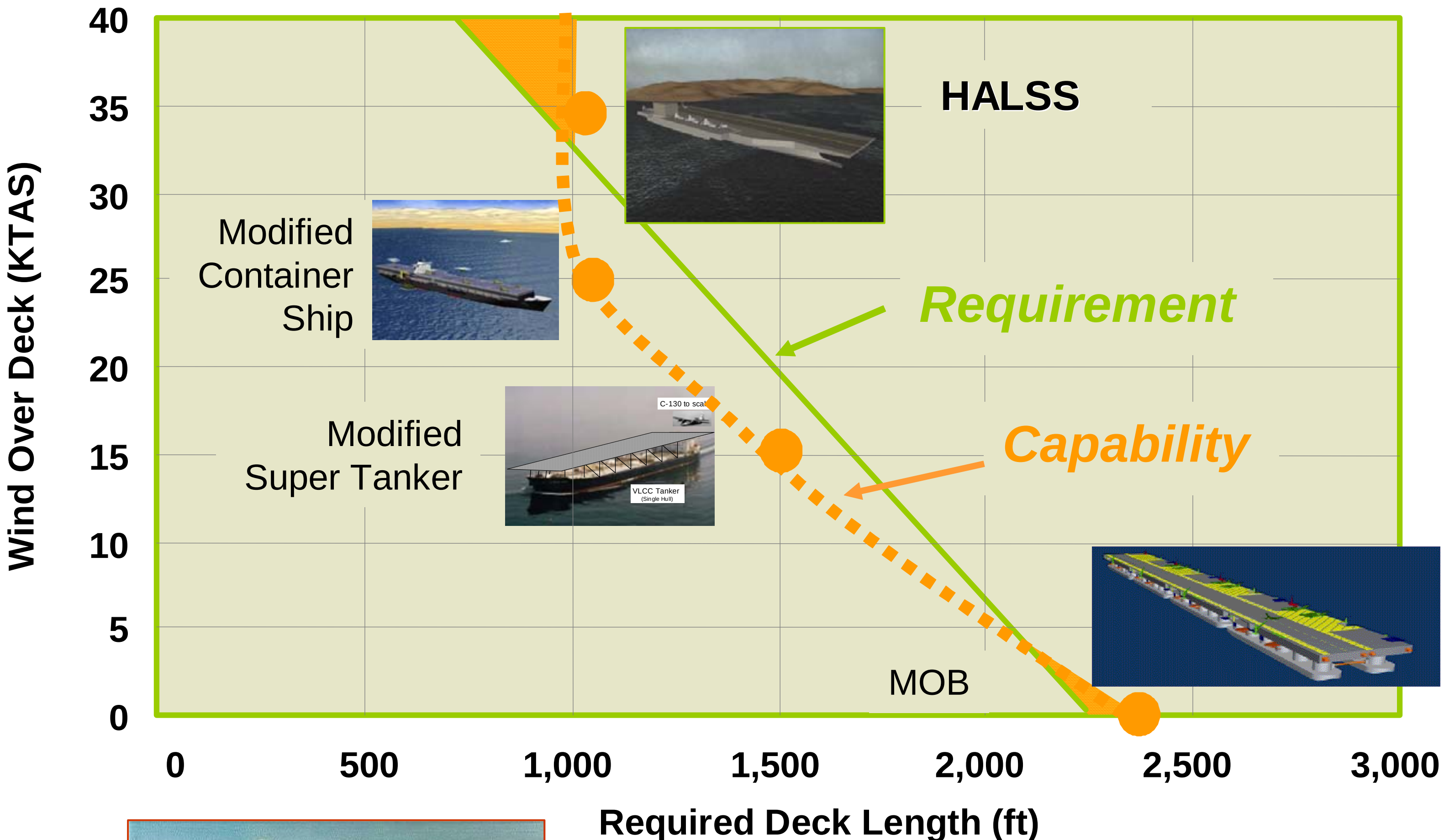
Sealift/Seabasing Mission Analysis; Hull Forms Development; Interference & Propulsion Study; *Model Tests;* Seakeeping Analysis; Buildability & Cost estimate

CCDOTT Program FY 04-06 (CY 05-07)

HALSS Design Approach

- **Ensure wind speed over the deck: Transit and maneuver at speed 35 knots**
- **Use Trimaran Configuration for large Flight Deck Operations Area and for split of Propulsion Systems between hulls**
- **Maximize Seakeeping & Minimize Sea Motions**
- **Utilize proven current commercial Machinery Propulsion Technologies**
- **Maximize range: Use fuel most efficient Diesel Engines**
- **Affordable: Build to commercial standards using commercial business practices**
- **Build and maintain in existing US facilities**

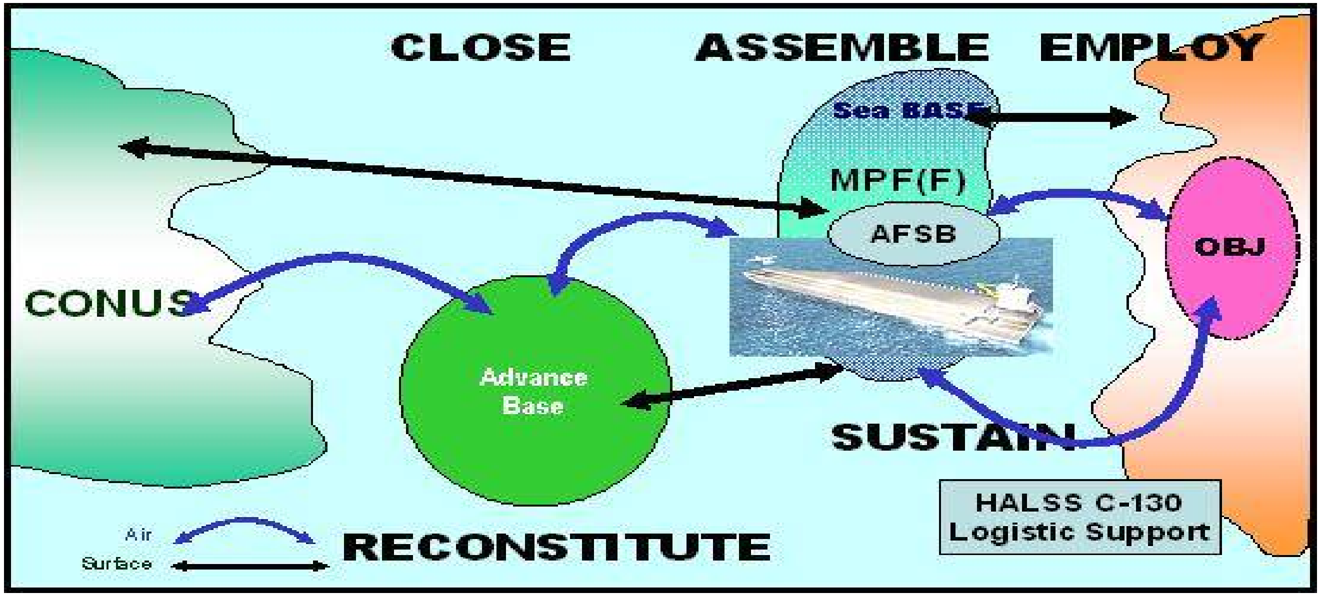
More wind speed over deck – less required length of runway.



In 1963 launching and landing of C-130 was successfully tested onboard the USS FORRESTAL.

HALSS Support of the Sea Basing

- **HALSS helps Early Insertion & Logistic Support:**
  - **Deploys at High Speed (35 Knots) to move MEB Rotary Wing, military loads for Force Employment, PAX/Troops & airplanes fuel from CONUS directly to sea base**
  - **Operate fixed wing aircraft between advanced base and the 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**



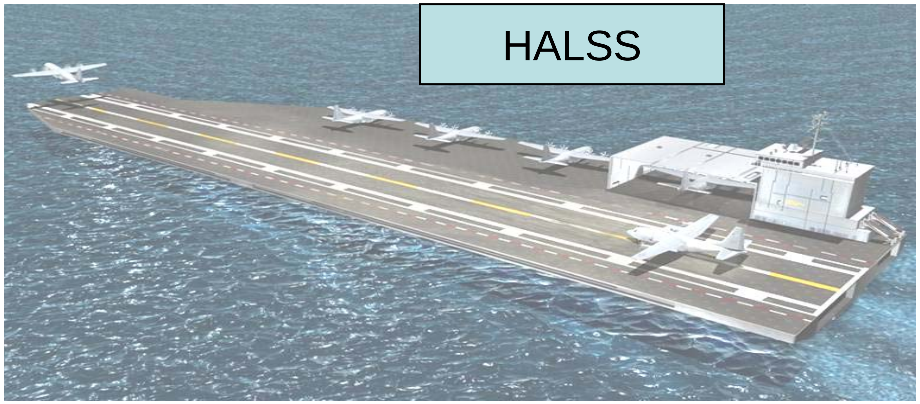
HALLS Mission Flexibility and Potential As Afloat Forward Staging Base

■ **HALSS is a flexible platform and can support vertical maneuver from a sea based platform**

■ **Phased approach: HALSS can be considered as "bridge" platform with near- and far-term objectives.**

➢ **In Near-term - support C-130J operations, which together with existing helos provide vertical maneuver with light forces to a depth of 300 nautical miles, utilizing a air drop capability, as required.**

➢ **In Far-term the same ship platform (with flight deck under hot exhaust shield requirements) would support HLVTOL capability to provide complimentary effects to Ship To Objective Maneuver (STOM) capabilities.**



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**
Full Displacement	**65,000 MT**
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**

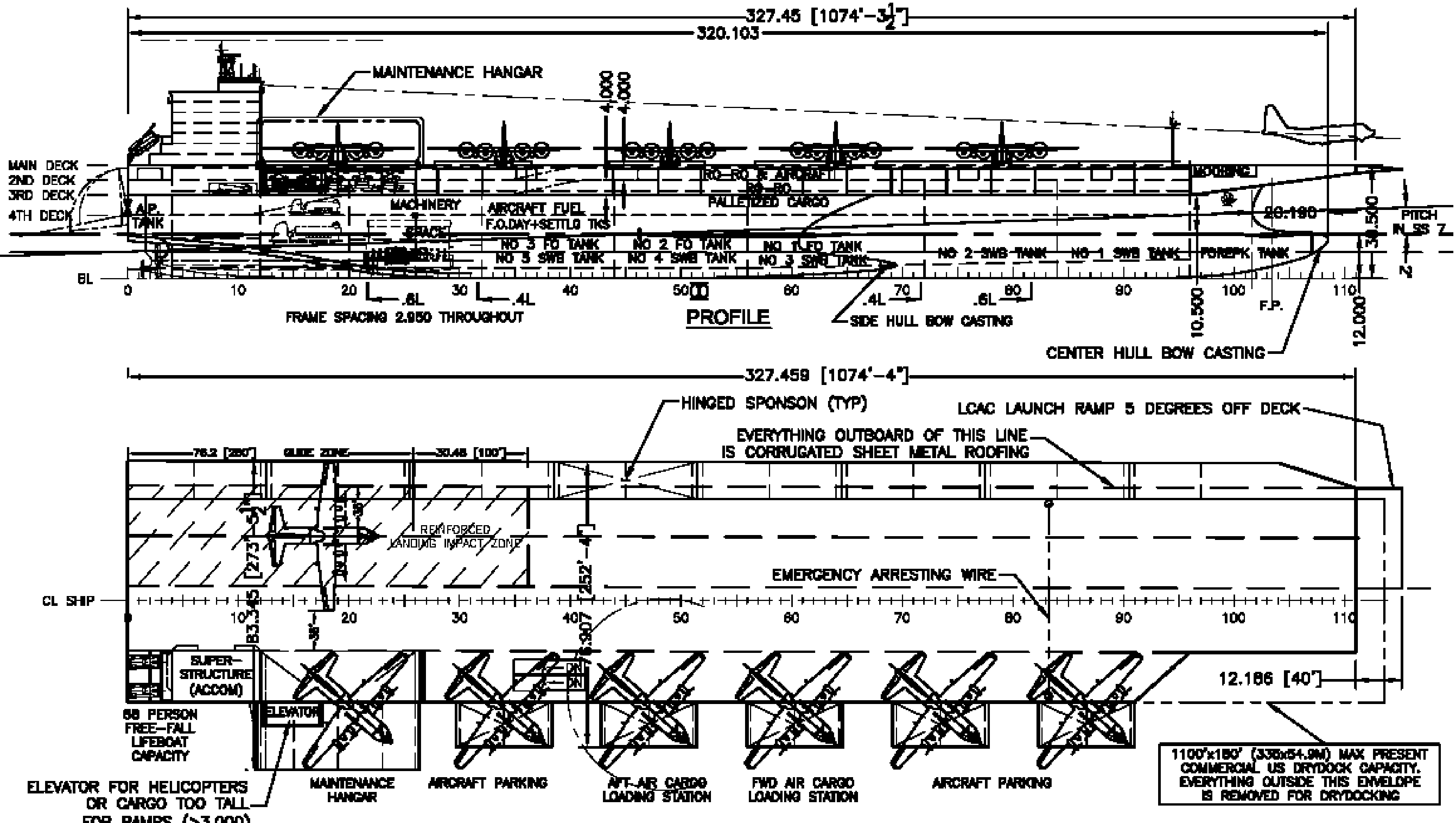
Unrefueled Range of Sea Voyage - CONUS to Advanced Base or to JOA

10,000 NM at 35 knots

>15,000 NM at 25 knots

Followed by 10 days endurance in JOA

HALSS Early Insertion – C-130 J OPS

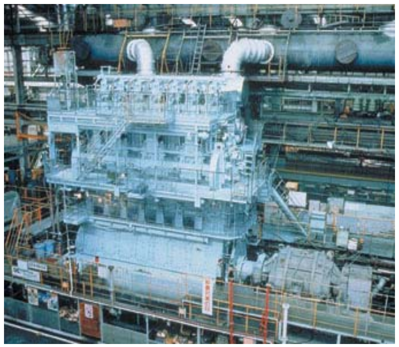


- ❖ **Flight deck configuration assures aircraft launch and recovery into the wind enabling maximum takeoff and landing weight under most conditions.**
- ❖ **Sponson deck is removable to reduce beam to facilitate construction and dry-docking.**

Baseline Machinery & Propulsion Technology

Diesel – Diesel / Electric @ Propeller Option

HALSS Center Hull: 2 x MAN or Sulzer RTA 96 (102 RPM) @ 2 x Lips FP Propellers

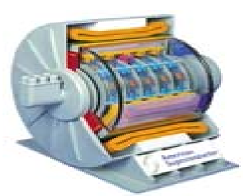


MAN or Sulzer low-speed RTA and RT-flex engine 69 MW.

Large and most powerful propellers – Propeller diameter 9.10 m; 6 blades, total weight 102 mt

Side Hulls: 2 Electric Motors powered by 4 x Wartsila 16V46 @ 2 x Lips CP Propeller

Wärtsilä Medium-Speed Diesel



36 MW HTS Superconducting AC Motor OR 500 RPM conventional motor w/ reduction gear

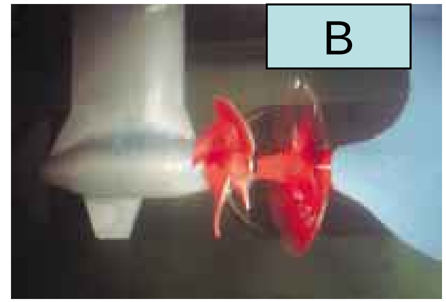
World's Largest Controllable Pitch Propeller 44 MW

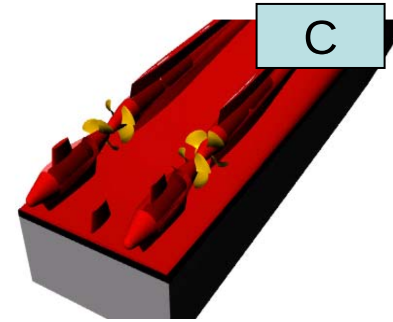
HALSS Propellers:
Center hull FPP ~ 68.6 MW - 8 m
Side hull CPP ~ 31 MW - 4.8 m

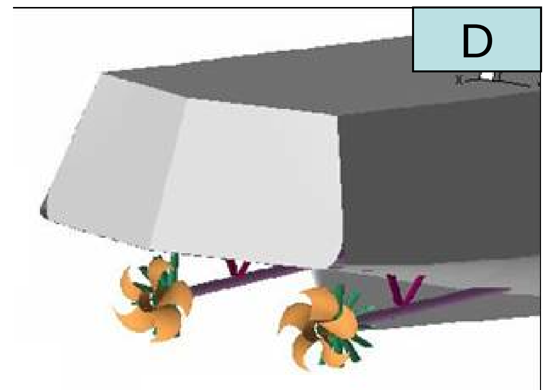
Technology Propulsion Options for HALSS Concept

Predicted Power Requirements

Speed	Propulsive Coefficient: 0.685				
Knots	Effective Horse Power	Shaft HP (US)	Shaft Power (MW)	With 10% Sea Margin	RPM
10	3,239	4,728	3.5	3.9	30
15	11,240	16,408	12.2	13.5	45
20	25,667	37,470	28	31	59
25	48,859	71,327	53	59	74
30	94,867	138,491	103	114	89
35	**148,766**	**217,177**	**162**	**178**	104







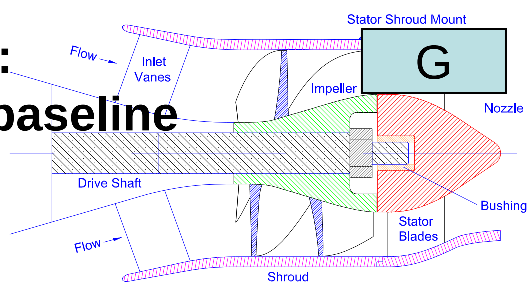
Allows to increase propulsion efficiency for 8%

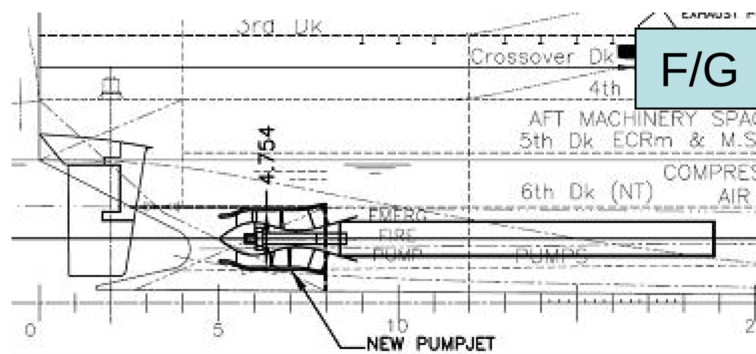
Center Hull Alternative Propulsion Options:

- ❑ **FPP – A - baseline**
- ❑ SSPA Contra Rotating Units - B
- ❑ ABB Pod for 150MW Sealift Concept under evaluation in NSWCCD - C
- ❑ Preswirl Vanes – D

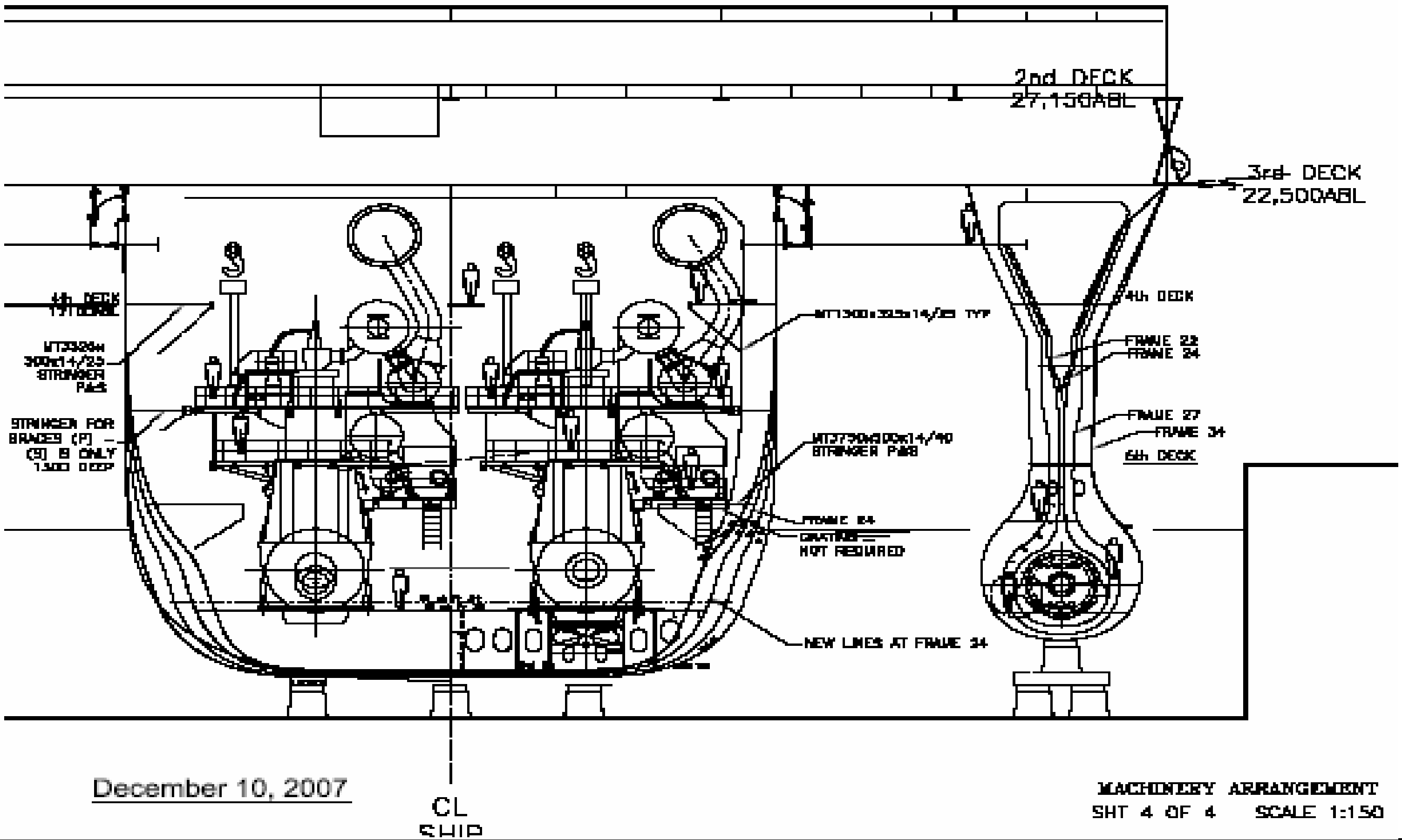
Side Hull Options:

- ❑ **FPP/CPP – E - baseline**
- ❑ AWJ - F
- ❑ PumpJet - G





Diesel-Propeller Section at MAN Diesel Engines

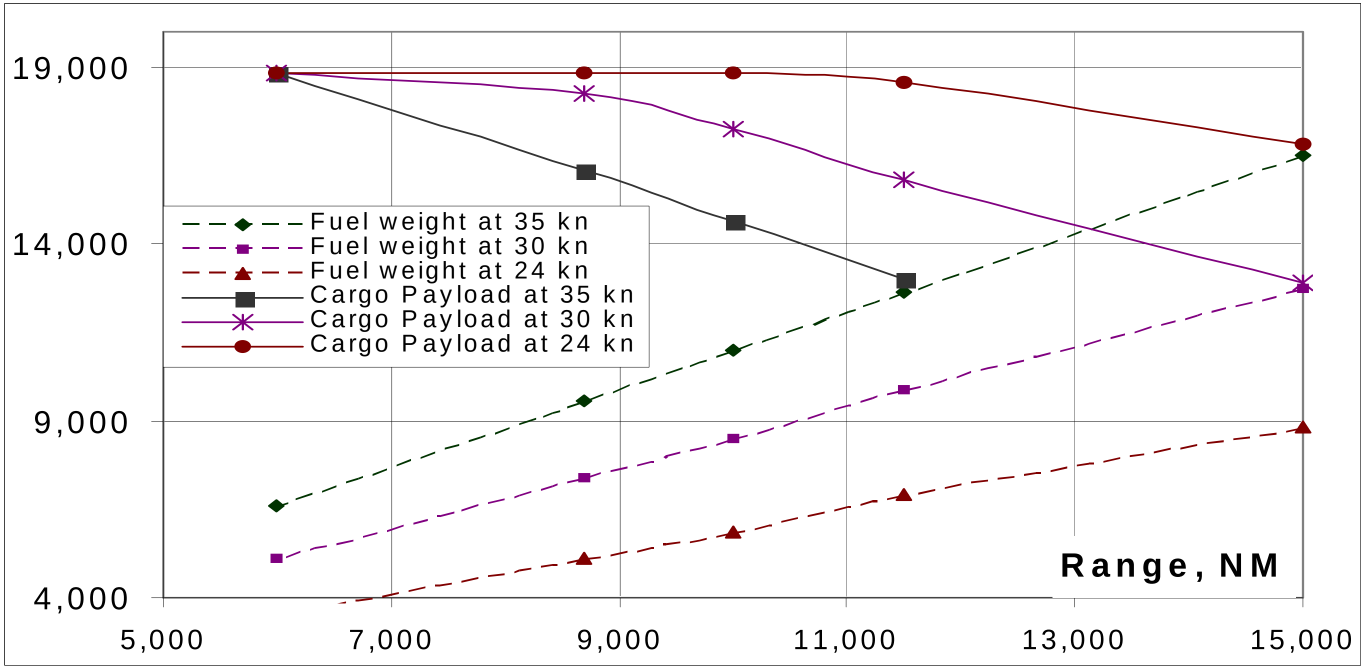


- ❖ Twin MAN engines directly connected to 102 RPM FPP have arrangement and overall size advantages in comparison with baseline Sulzer engine. Both engines are commercially available and provide the best combination for the power.
- ❖ Additional power for boost and for maneuvering is provided by medium speed diesel engines driving 514 RPM generators in the center hull, powering electric motors in the side hulls with FPP, CPP or Waterjet propulsors.

HALSS Operational Efficiency

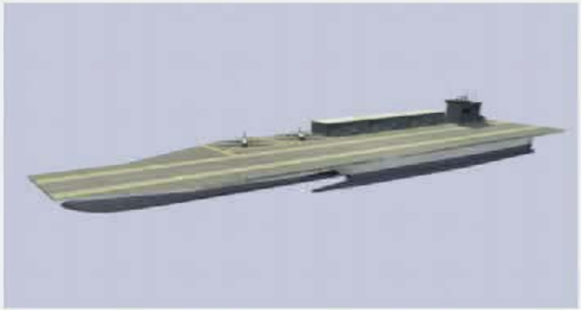
Speed kts	Power MW	Provided by	Fuel Rate g/kW-hr	Fuel, t (10,000 NM)	Days per 10,000 NM
10	5	D/G	210	1,129	41.7
20	44	14RTA96	175	3,864	20.8
25	91	14RTA96	175	6,378	16.7
30	146	14RTA96	175	8,509	13.9
35	206	All	187	10,993	11.9

HALSS Operational Fuel Consumption & Cargo Weights Available Vs. Range & Transit Speed



HALSS Operational Modeling and Parametric Studies

HALSS provides 1,100' axial deck with airplane parking off to one side and a ship capable of 35 knots



With 35 knots wind over deck and an 1100 ft flight deck, the ship is large enough for the C-130J to launch with a 40,000 lb payload and fly a 300 nm radius mission.

Preliminary analysis shows we can land the C-130J at 120,000 pounds on the HALSS deck with adequate margins. This weight is consistent with the scenario previously described.

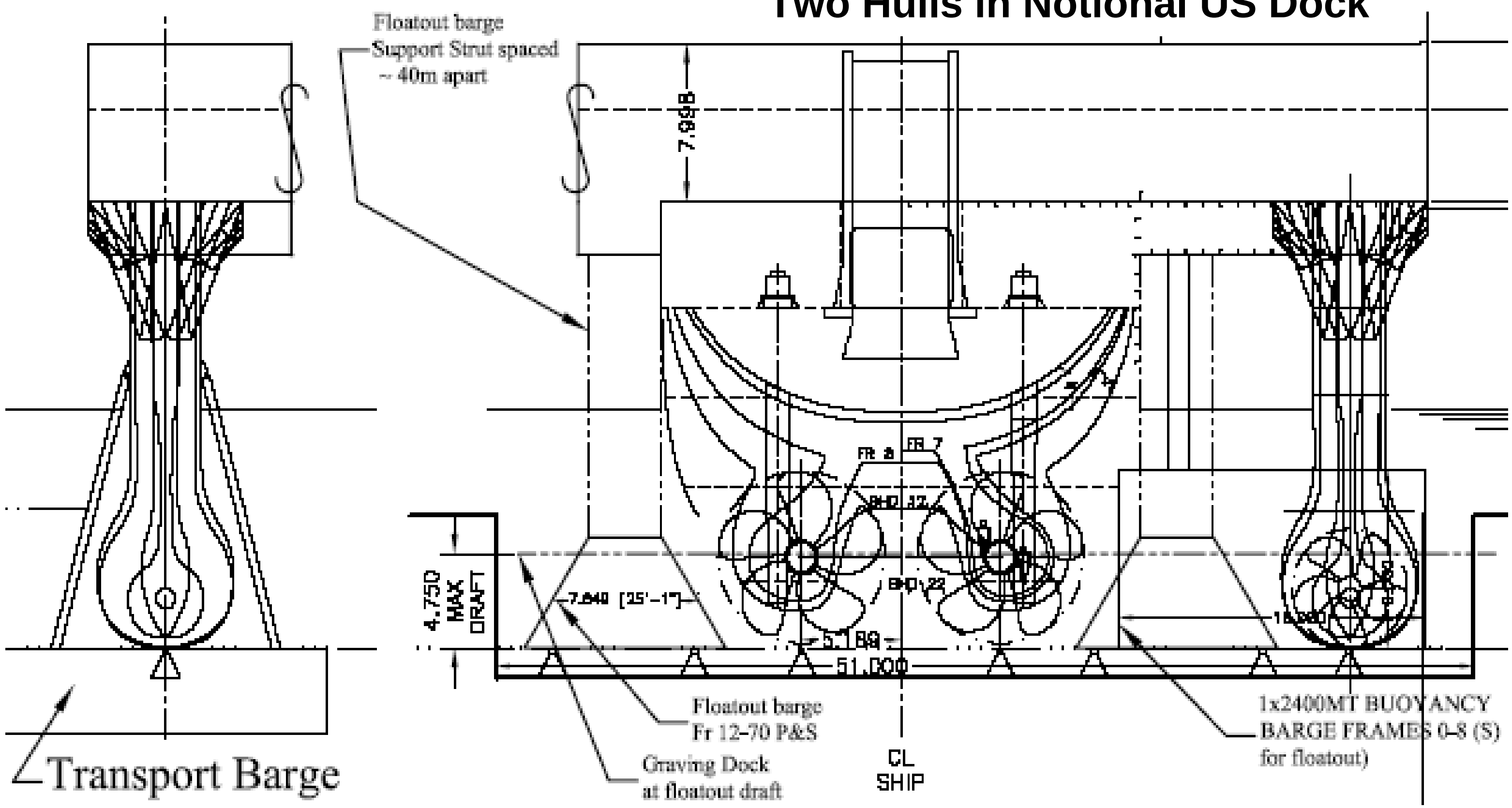
The Lockheed Martin 6 Degree of Freedom (6-DOF) model with HALSS Sea Motion Data is used for the analysis of various operational constrains:

- Payload/radius sensitivities for the C-130J aircraft operating in the HALSS concept ship.
- Parametrically vary the deck length and wind over deck
- Target length is less than 1,000 ft

HALSS Buildability Study Findings

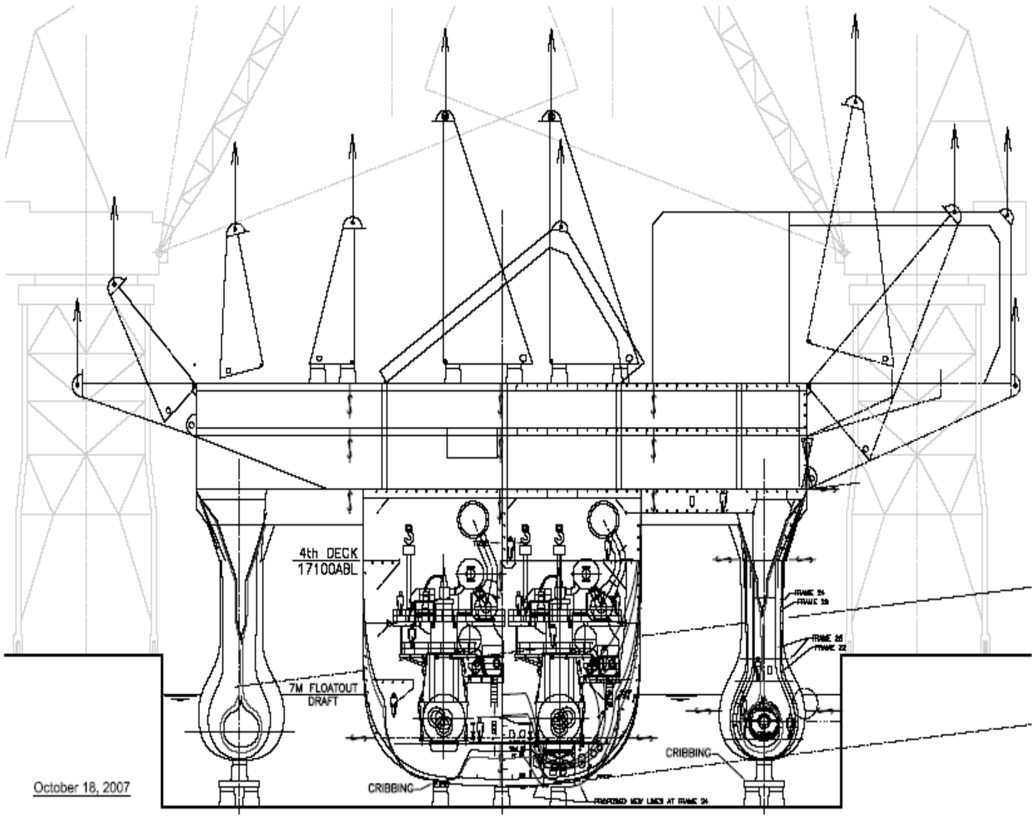
- Comprehensive ship construction analysis done for both assembly on land and in the water. Construction of center and one connected side hull in drydocks with joining of the other side hull in the water after launching using buoyancy barges
- HALSS three hull configuration is well suited to a modern Virtual Shipbuilding approach

Two Hulls in Notional US Dock



An Affordable HALSS Built in the USA to Commercial Standards

HALSS Fits in Sparrows Point Dock
(*Dock currently in operation)*

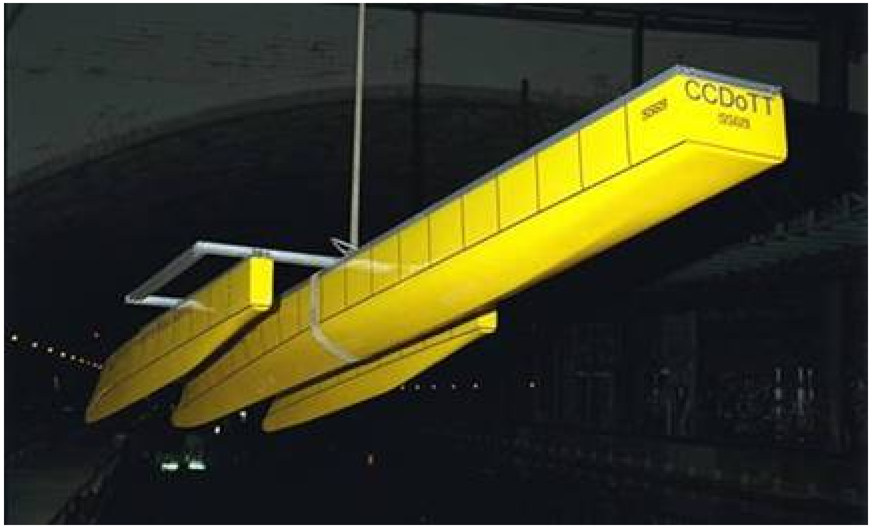


One piece construction at Sparrows Point, Baltimore in the old BethShip graving dock using extensive outsourcing of preoutfitted hull blocks and float out using buoyancy barges

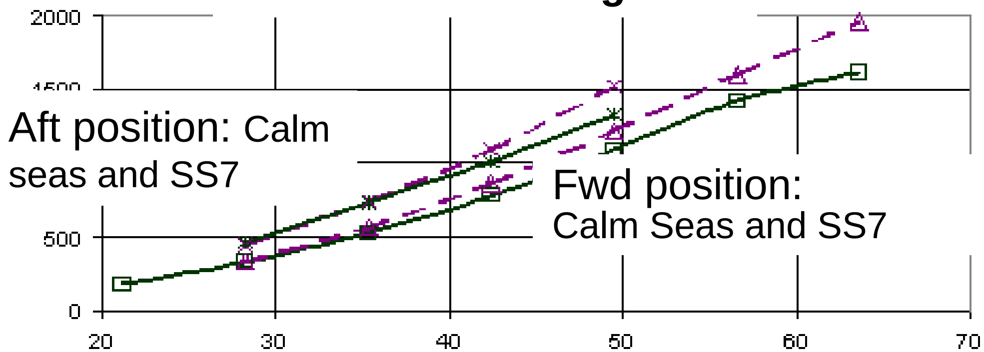
- Combatant ship construction yards are not affordable
- Large Commercial Ship and Naval Auxiliary yards are candidate companies
- Mid-tier yards using Virtual Shipbuilding approaches are candidates
- Starting with a quality contract design and properly planned and managed, a Virtual Shipbuilding approach can reduce design and construction costs by 20%

HALSS Technology Elements

VHSST-50 Hull Forms Development and Trimaran Resistance Interference Study

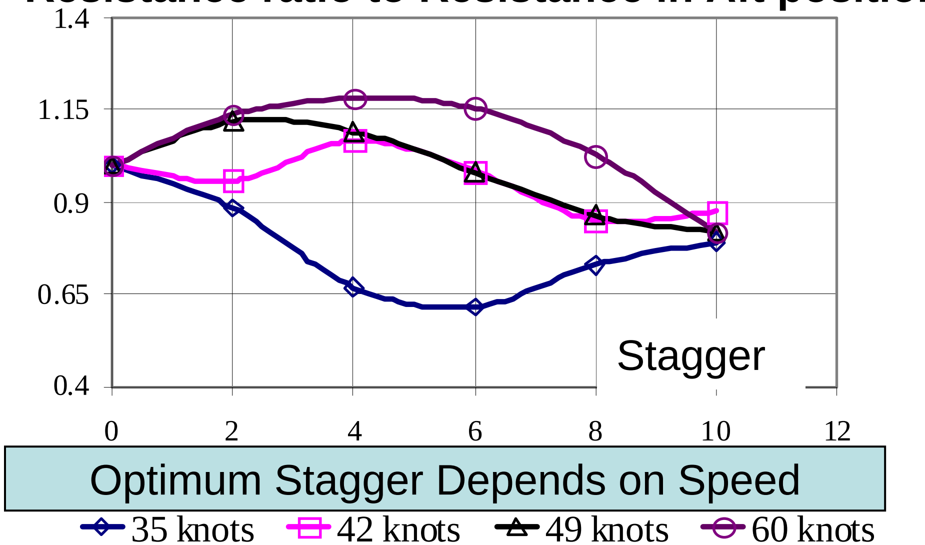


Model 5569 Testing Data



At 50kn Only 15% Increase of Resistance at SS7

Resistance ratio to Resistance in Aft position

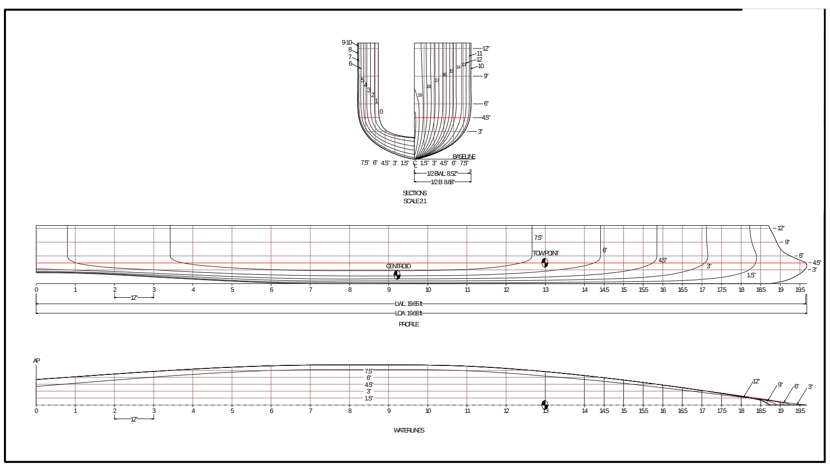


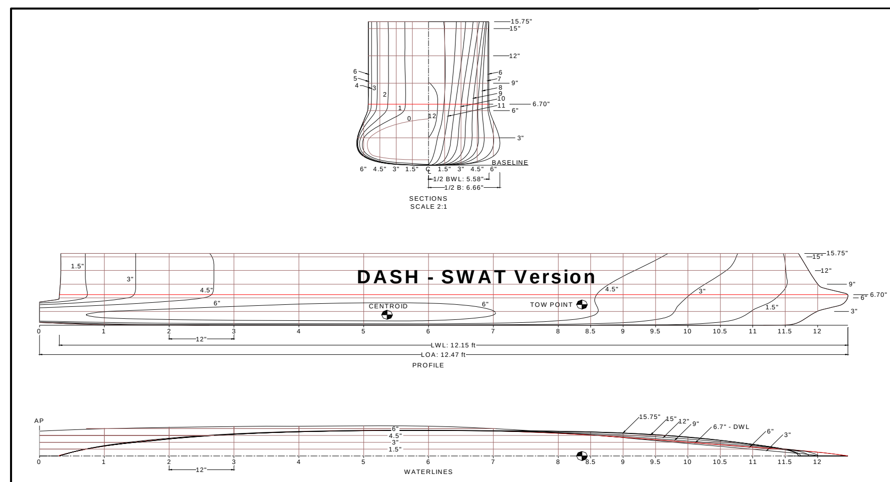
Optimum Stagger Depends on Speed

Slender & SWAT Hull Forms Development
CCDOTT & ONR – DASH Projects (2001)

DASH	
LOA:	299.86 m
LWL:	299.35 m
Beam (total):	61.46 m
BWL (center):	21.63 m
Depth:	16.00 m
Draft:	5.75 m
Displ:	18,548.99 mT
Wet Surf.:	6,202.78 sq.m.
Slenderness	11.40

DASH - SWAT Gondola	
LOA:	190.00 m
LWL:	185.24 m
Beam (total):	61.46 m
BWL (center):	14.20 m
Depth:	20.00 m
Draft:	8.50 m
Displ:	17,971.93 mT
Wet Surf.:	5,245.04 sq.m.
Slenderness	7.13

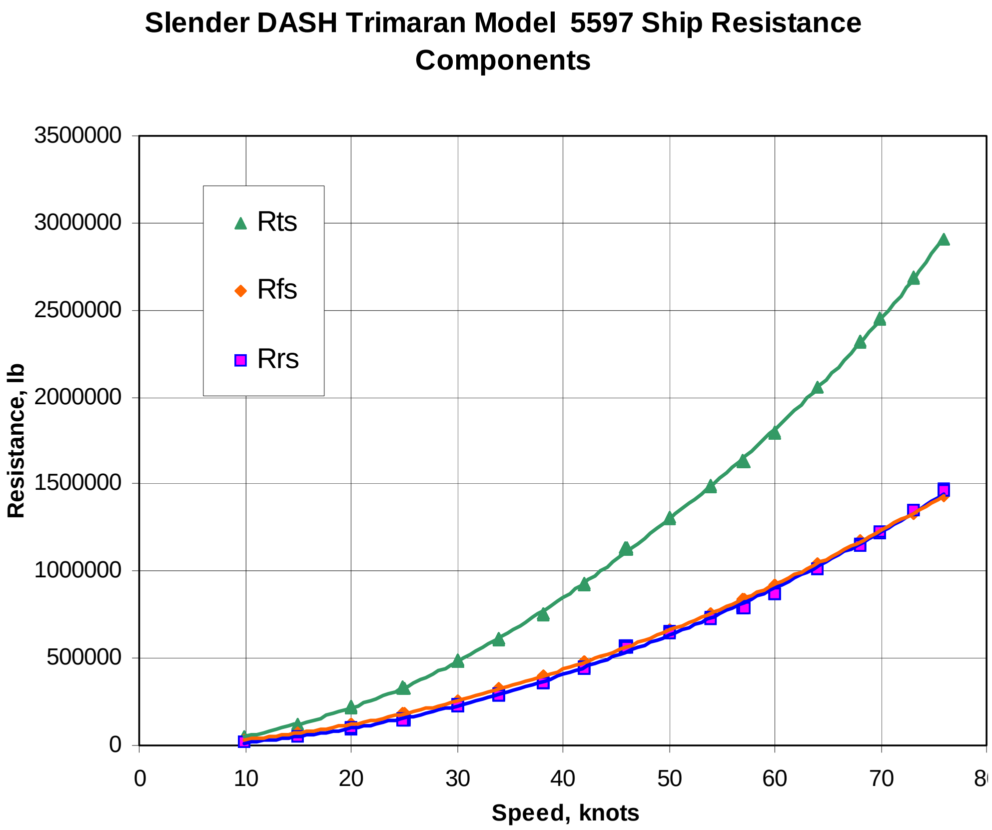


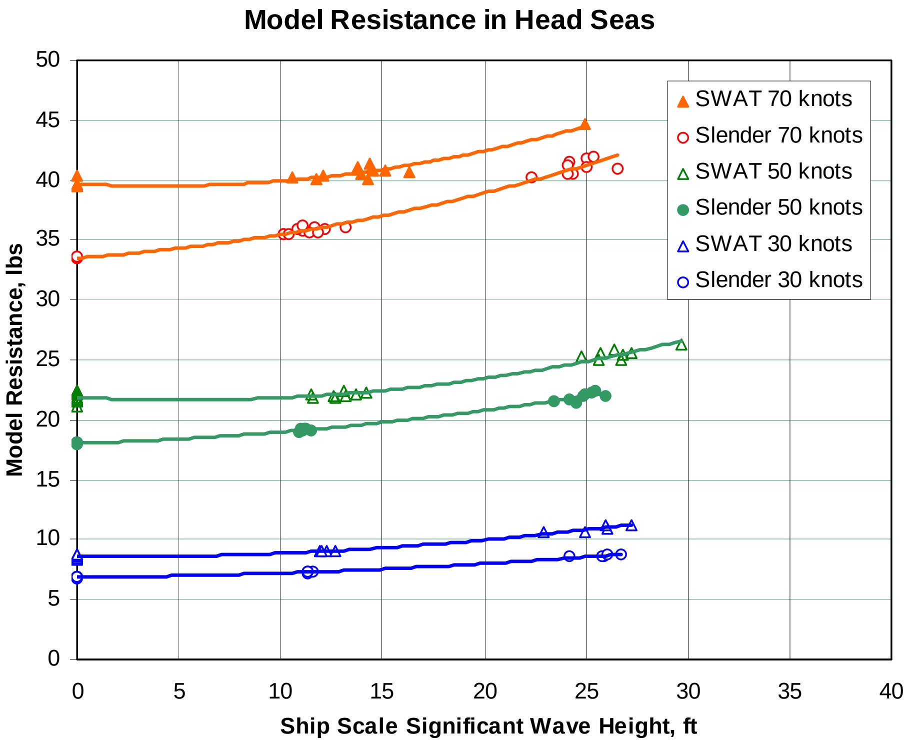


Slender Center Hull

SWAT Center Hull

Slender & SWAT Resistance & Seakeeping Model Tests in DTMB (2001)



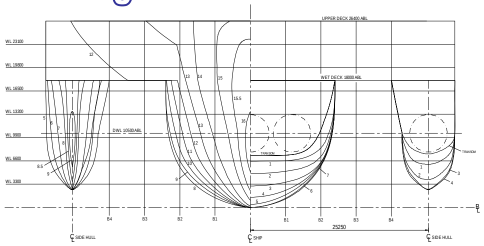


Both Slender and SWAT Trimarans at Sea States 0, 5, 7 showed remarkably small increase in resistance: low levels of pitch , reduced drag, slamming, green water on deck

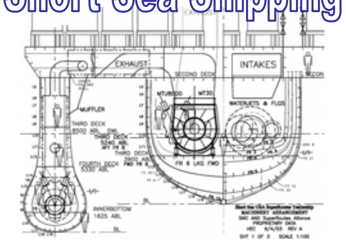
HALSS Hull Forms Development

High Speed Trimaran technology development & hull forms optimization experience based on results of CCDOTT & ONR 98-04 projects:

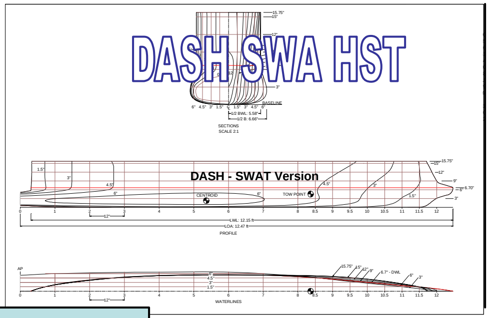
Large Dual Use HST



Short Sea Shipping HST



DASH SWA HST

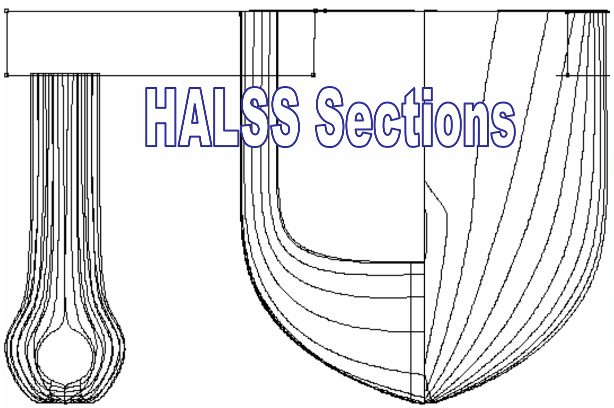


HALSS Multi Disciplinary Optimization:

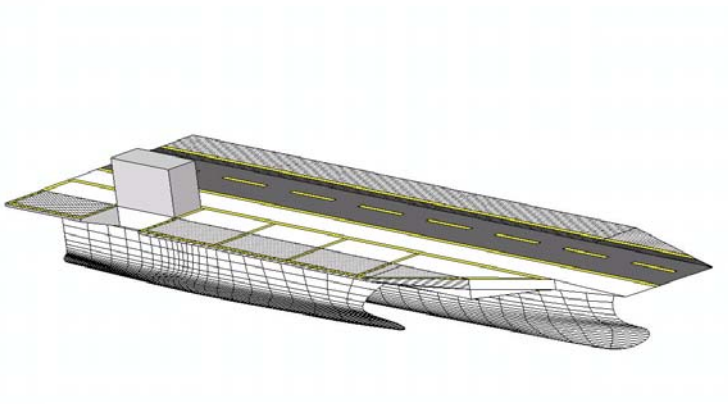
Wave & Viscous-Inviscid Interaction, Scaling factors, Sea Motions & Wave Loads, Structural Integrity

- ❑ **High Speed Performance & Structural Requirements Compromise**
- ❑ **Excellent Seakeeping & Structural Support**
- ❑ **Enough Area/Volume for all of Propulsion Machinery Options**

HALSS Sections



HALSS Hulls Forms



HALSS Hull Forms Development

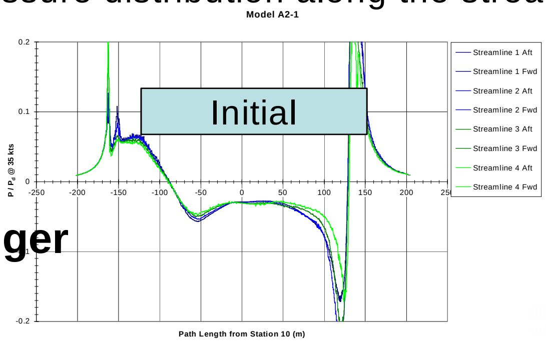
- ❖ Various tradeoffs performed with variants of the hull forms for Center and Side hulls: different angles of skeg arrangement, angles of Waterline entrances, buttocks shape, etc.
- ❖ The baseline hull forms were assessed with calculations of hydrostatics and **MQLT**. The variants of the hulls lines and Trimaran configuration were analyzed wih use of CFD **FLUENT**.

HULSS Lines Design with FLUENT

Pressure distribution along the streamlines – reducing positive pressure gradients

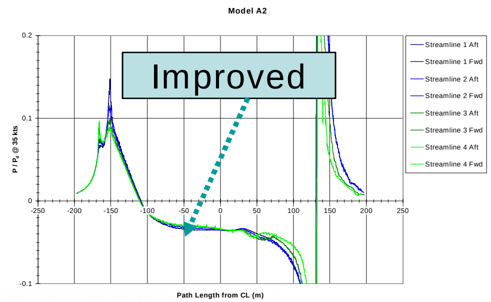
AFT

Stagger



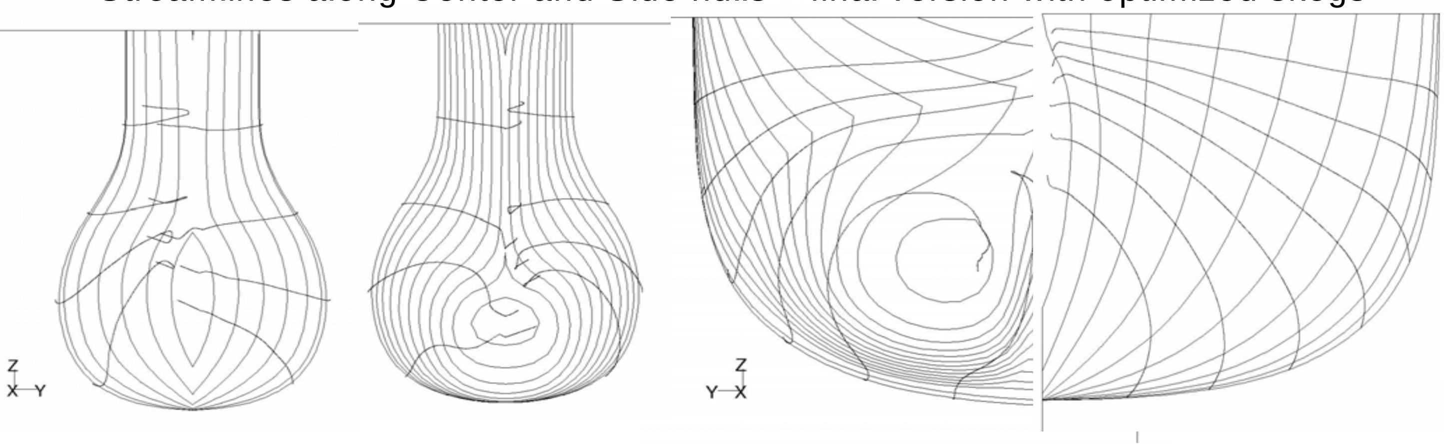
Middle

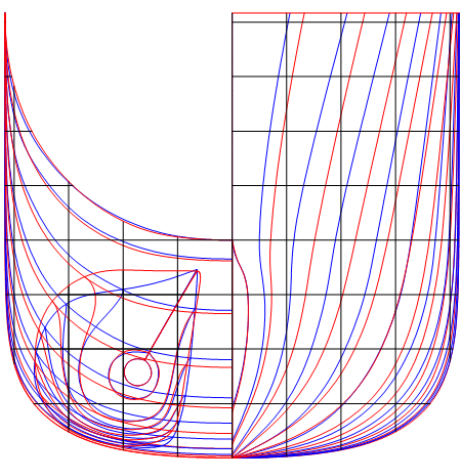
Stagger



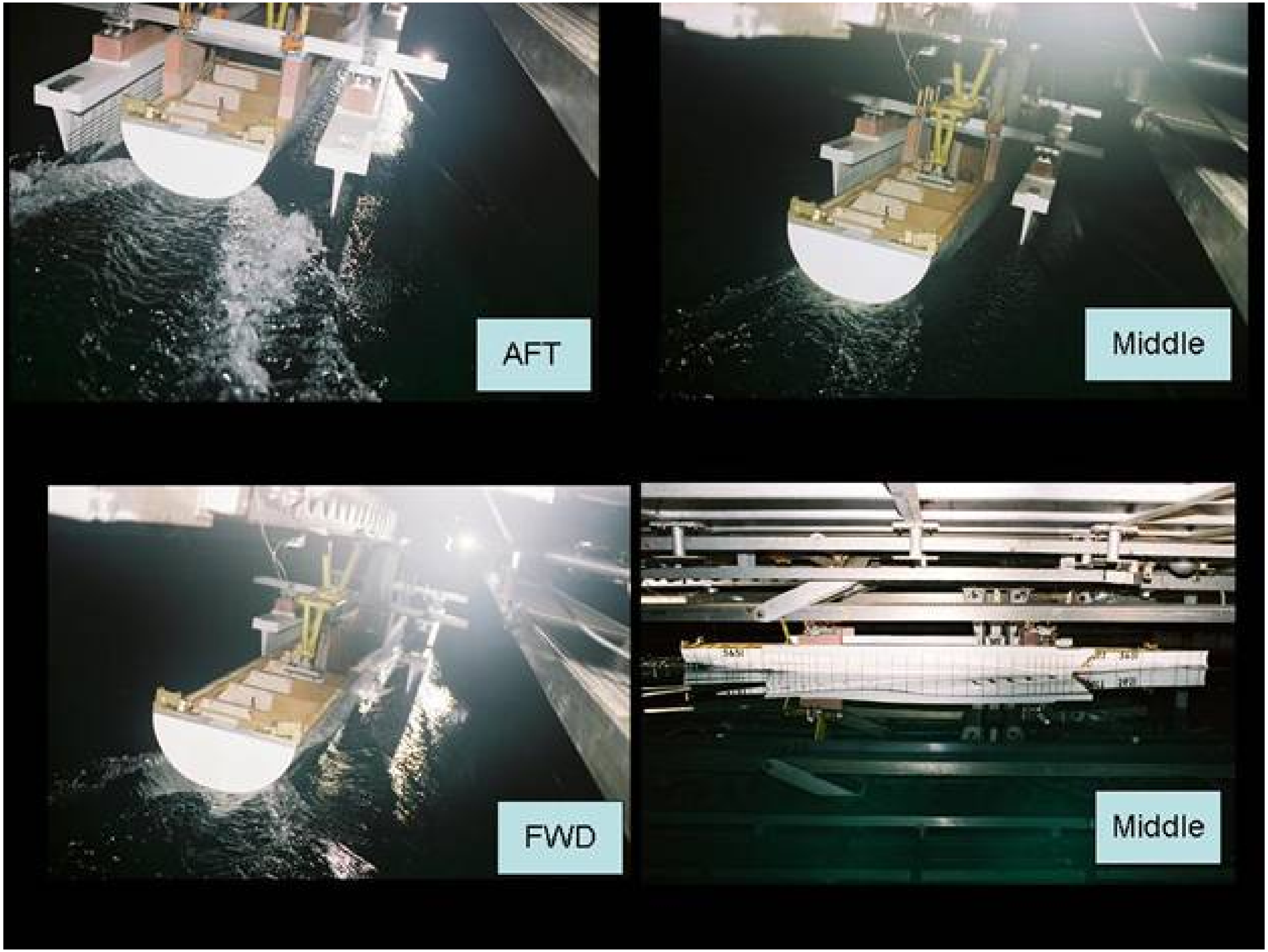
CFD/FLUENT&MQLT optimized HALSS Center hull forms *(blue lines)*

Streamlines along Center and Side hulls – final version with optimized skegs

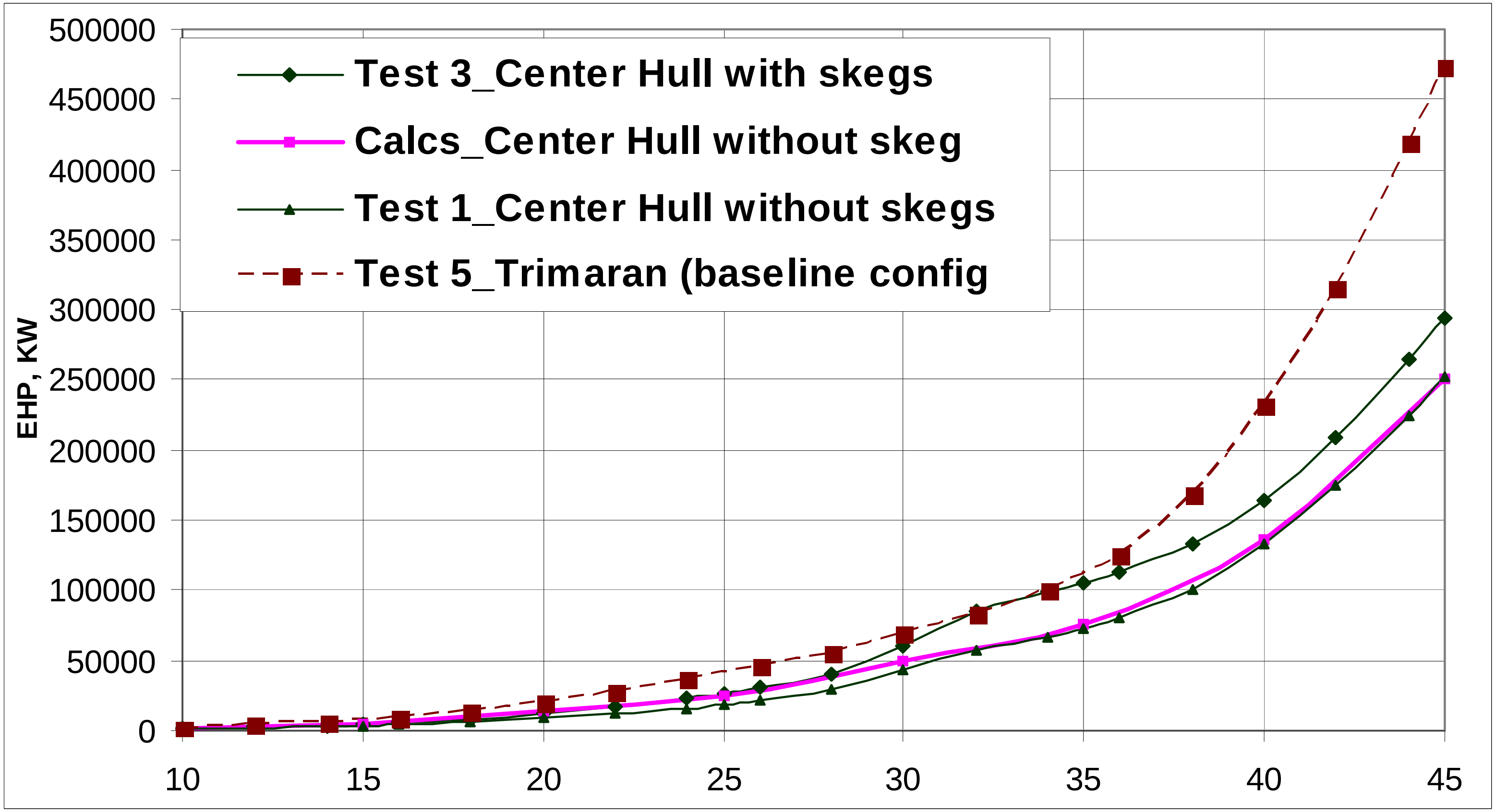




Flow Visualization at Three Staggers at 35 knots



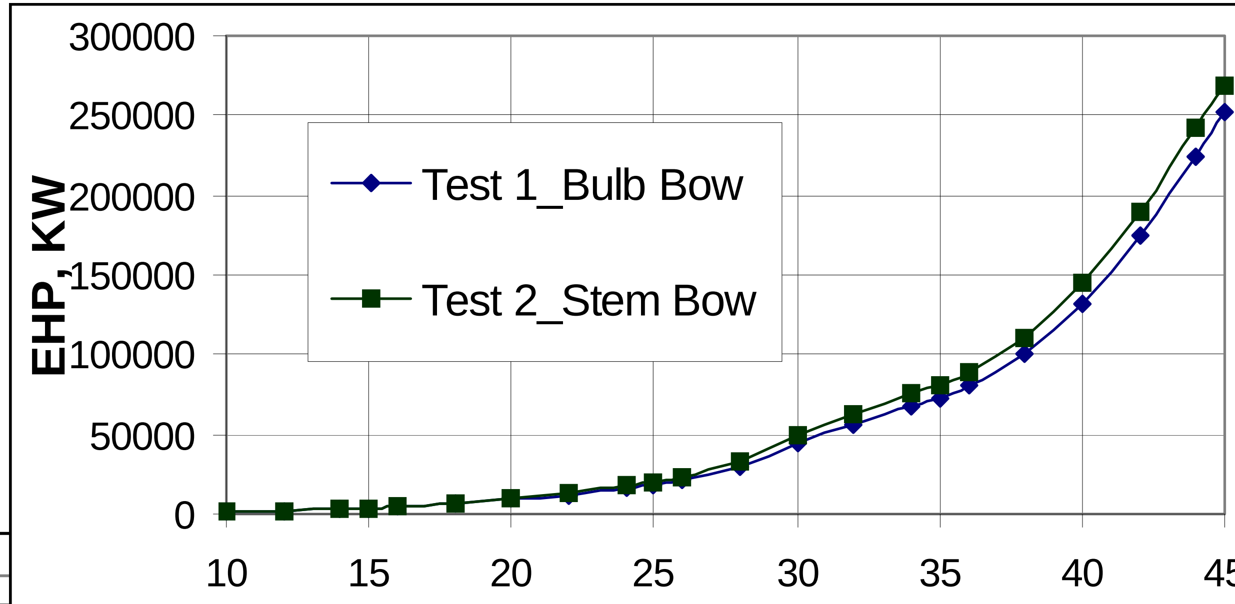
HALSS Center Hull w/o Skegs Test Results and Comparison

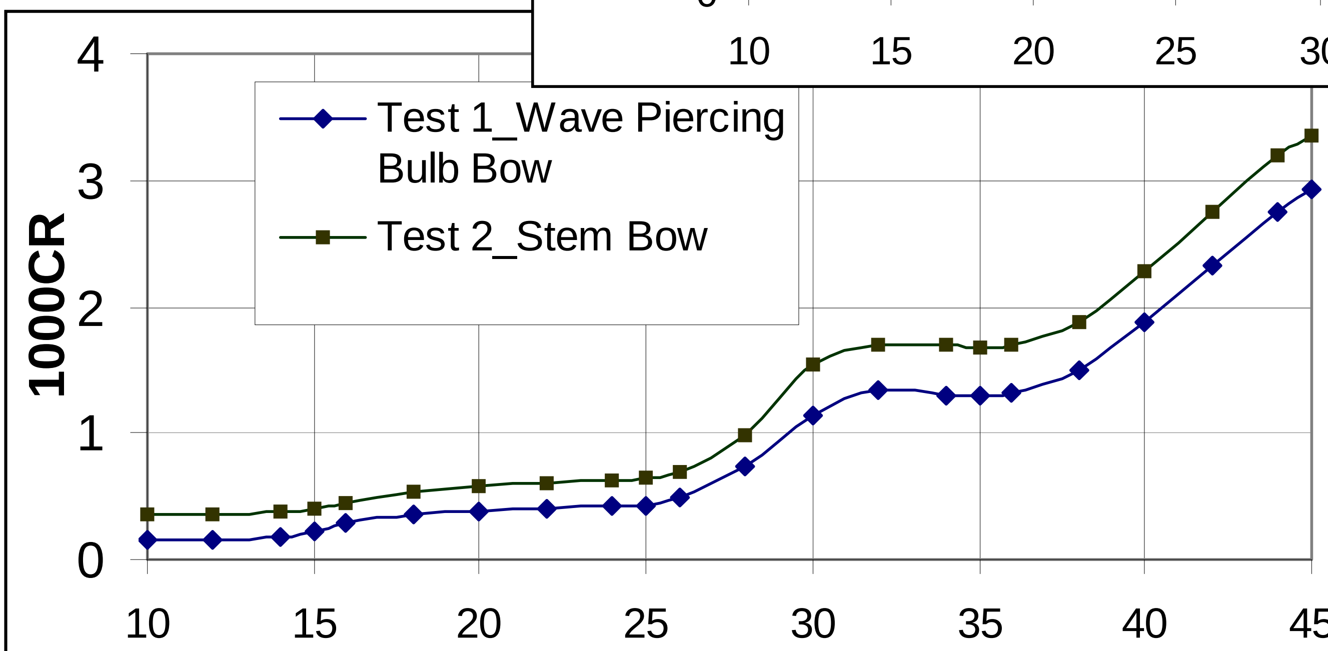


- Baseline HALSS Trimaran configuration, which was chosen by minimizing the positive pressure gradients along the Center hull has demonstrated strong favorable interference between the Center and Side hulls
- For other staggers this phenomenon is negative
- The Center hull stern hull forms need further optimization to minimize skegs-hull interaction and improve propeller wake

Wave Piercing Bow Bulb vs. Stem Bow Test Results

Original Wave Piercing Bow Bulb allowed to achieve about 10% reduction of EHP Vs. Stem Bow





HALSS Model Test Results and Conclusions

- ❑ The most efficient HALSS configuration appeared to be minimal spacing.

- ❑ Middle longitudinal position of the side hulls selected by minimization of pressure gradients along center hull streamlines proved to be validated by model tests. At middle position an extremely favorable interference has been observed. With adequate CFD tools this finding can lead to the innovative, highly efficient concepts of HALSS-type new ships.

- ❑ Wave Piercing Bow Bulb (WPPB) proved to be efficient for the HALSS-type hull forms.

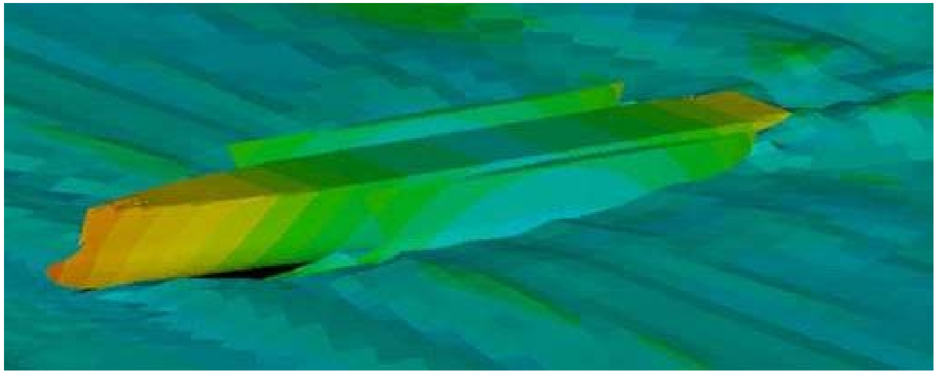
- ❑ Skeg-Stern center hull interference has been underestimated and led to development of one center plane skeg (instead of two side skegs) and shaft and strut propellers arrangement. New improvement requires testing and more computational analysis.

- ❑ Test results proved potential of utilizing favorable Viscous-Inviscid interference phenomenon in designing Trimarans. It requires better physical understanding and Tools, applicable to implement this potential for powering efficiency. This area of investigations is highly recommended for future R&D plans.

High Speed Trimaran Seakeeping Study

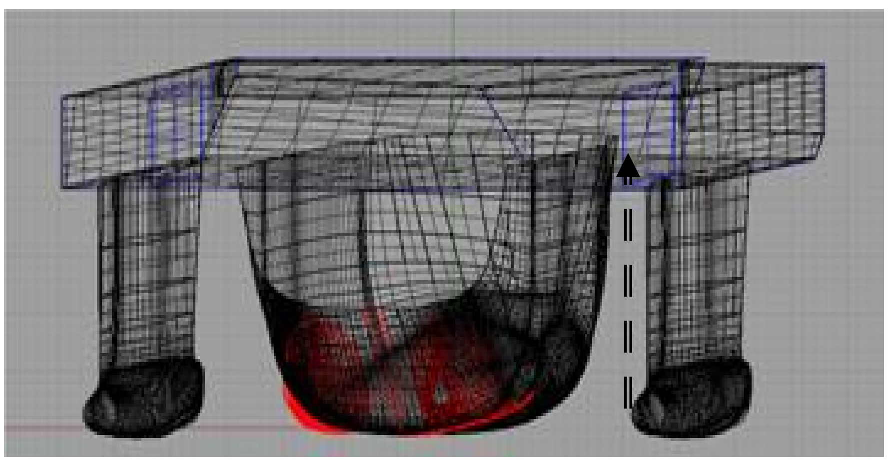
- **WASIM Trimaran Prediction and Analysis Procedure**
  - **Displacement, Velocities, Accelerations;**
  - **Relative Motions for Slamming and Emergence;**
  - **Hull Girder Loads and Local Pressures;**
  - **Interaction between Main and Side Hulls.**
- **Assessment Criteria:**
  - **Naval Air Operations (NATO STANAG 4154, 1997)**
  - **Transit (NATO Generic Frigate)**
- **Results of HALSS Seakeeping Analysis:**

HALSS Provides Favorable Seakeeping Performance: meets vertical motion criteria up to sea state 6; horizontal acceleration criteria up to sea state 7; no Slamming below Sea State 7, etc



Nonlinear Effects in HALSS Seakeeping Assessment

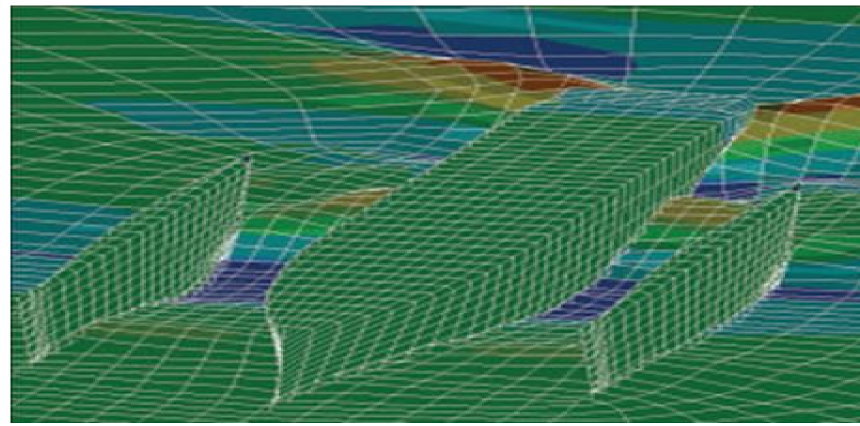
- Hull above waterline is ignored in linear theory (frequency-domain) calculations
- This precludes evaluation of cross-structure slamming (for example)
- WASIM can include structure above waterline in the time-domain analysis

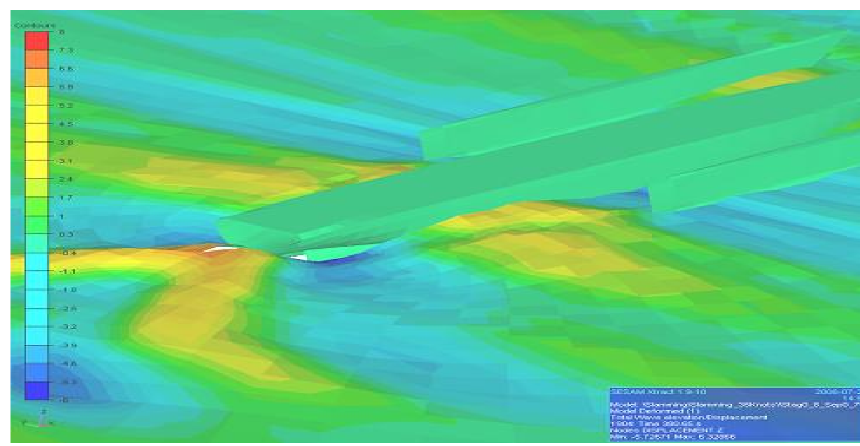


Not “seen” in linear theory

WASIM:

- Non-linear simulation effects:
  - integration of Froude-Krylov force and hydrostatics over exact wetted surfaces
  - finite rotation angles in equations of motion
  - quadratic pressure terms
  - quadratic roll damping





Output data and Criteria

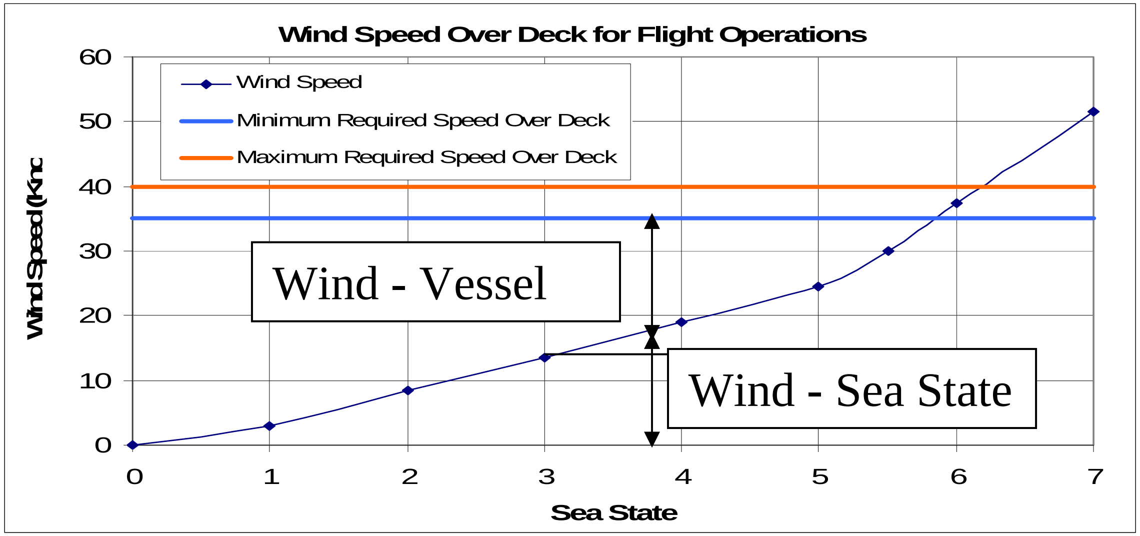
- Motions
- Accelerations at various locations
- Shear and bending moment, 25m increments
- Slamming of hulls and cross-structure
- Propeller emersion
- Available with additional/future analyses:
  - Motion sickness incidence
  - Motion induced interruptions

User-supplied criteria (example)

Pitch Displacement	1.50	deg
Roll Displacement	4.00	deg
Vertical Acceleration (Midship/Centerline)	1.962	m/s2
Vertical Acceleration (Midship/Beam)	1.962	m/s2
Vertical Acceleration (Bow/Centerline)	1.962	m/s2
Vertical Acceleration (Stern/Centerline)	1.962	m/s2
Transverse Acceleration (Midship/Centerline)	0.981	m/s2
Transverse Acceleration (Midship/Beam)	0.981	m/s2
Transverse Acceleration (Bow/Centerline)	0.981	m/s2
Transverse Acceleration (Stern/Centerline)	0.981	m/s2
Centerhull Bottom Slamming	20	per hour
Sidehull Bottom Slamming	20	per hour
Bridge Deck Slamming	20	per hour
Propeller Immersion	90	per hour
Bending Moment (Midships)	2.84E+09	N-m
Shear Force (Quarter Forward)	1.00E+06	N

Also need Operational Profile (percentage of time at each speed and heading in each sea state)

Wind Speed – Vessel Speed Correlation



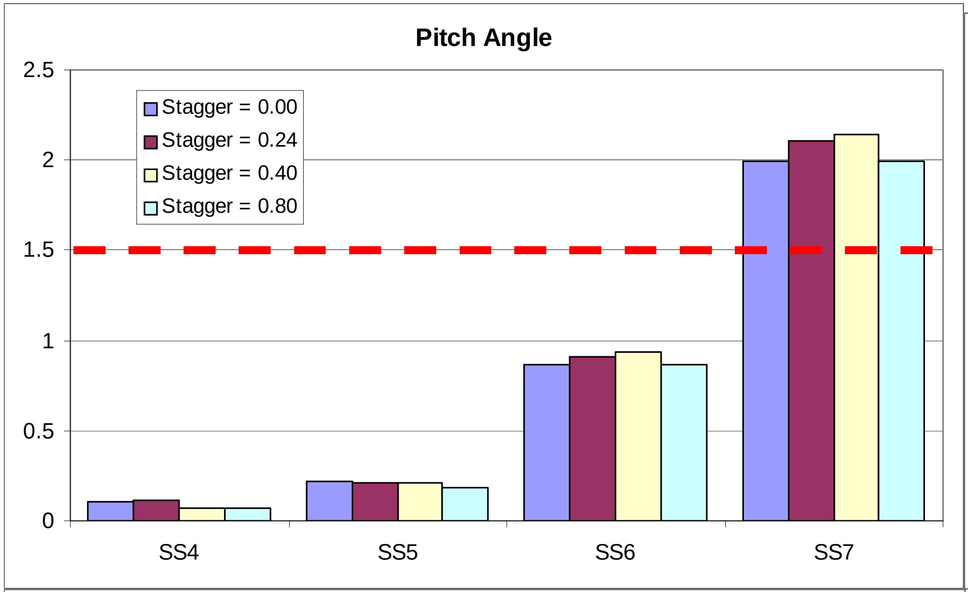
Sea State	Wind Speed (Knots)	Minimum Vessel Speed (Knots)	Maximum Vessel Speed (Knots)
0	0.0	35.0	40.0
1	3.0	32.0	37.0
2	8.5	26.5	31.5
3	13.5	21.5	26.5
4	19.0	16.0	21.0
5	24.5	10.5	15.5
5.5	30.0	5.0	10.0
6	37.5	-2.5	2.5
7	51.5	-16.5	-11.5

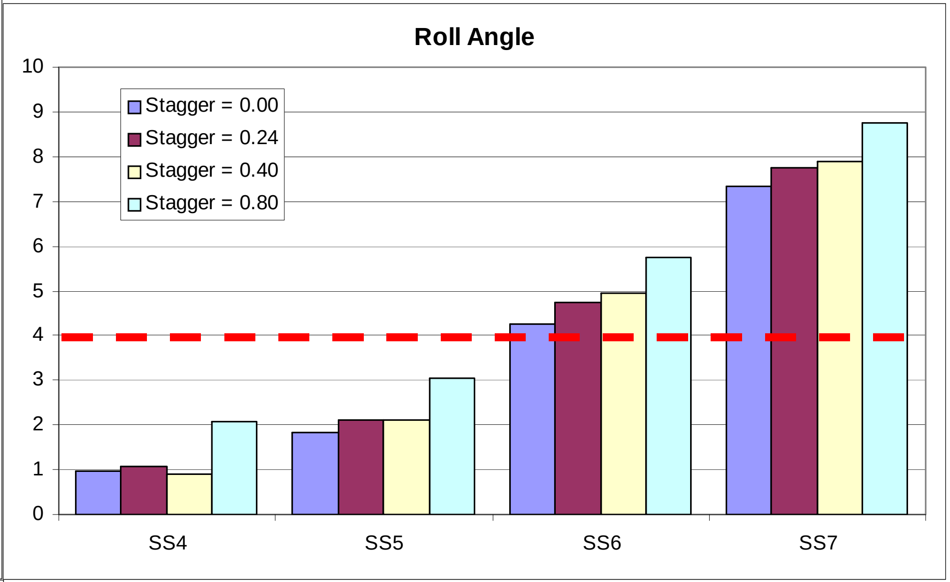
Head Sea Cases used for Analysis
Insufficient Forward Speed to Maintain Maneuverability

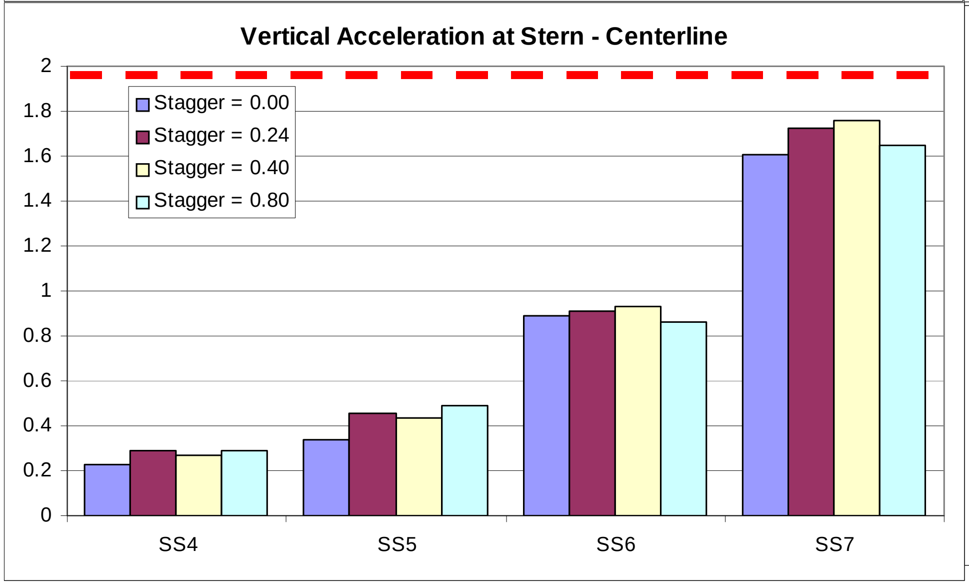
Using Wind Speed Associated with a Sea State defines the required vessel speed to maintain 35 knot apparent wind speed over deck

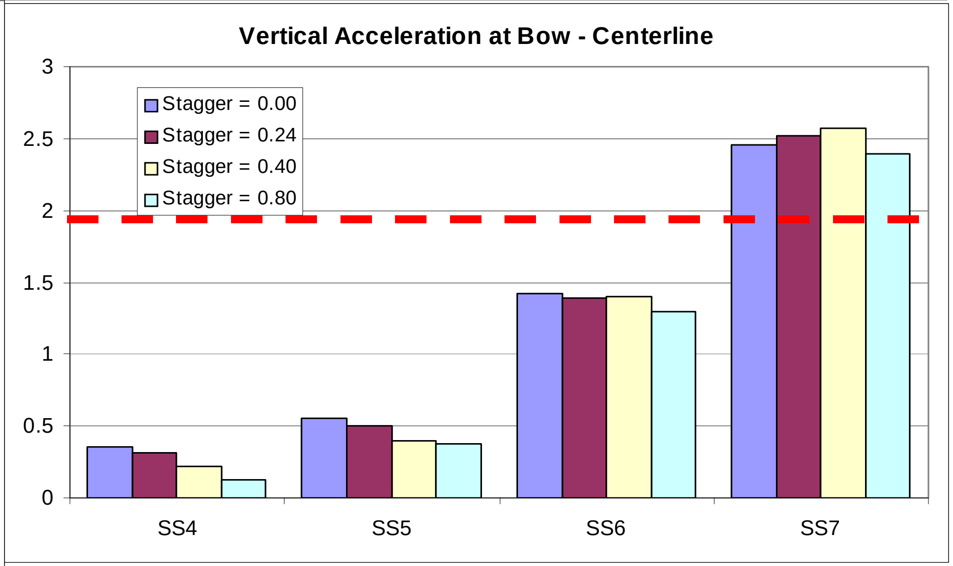
Stagger Influence

15 knots – Maximum Response from All Headings



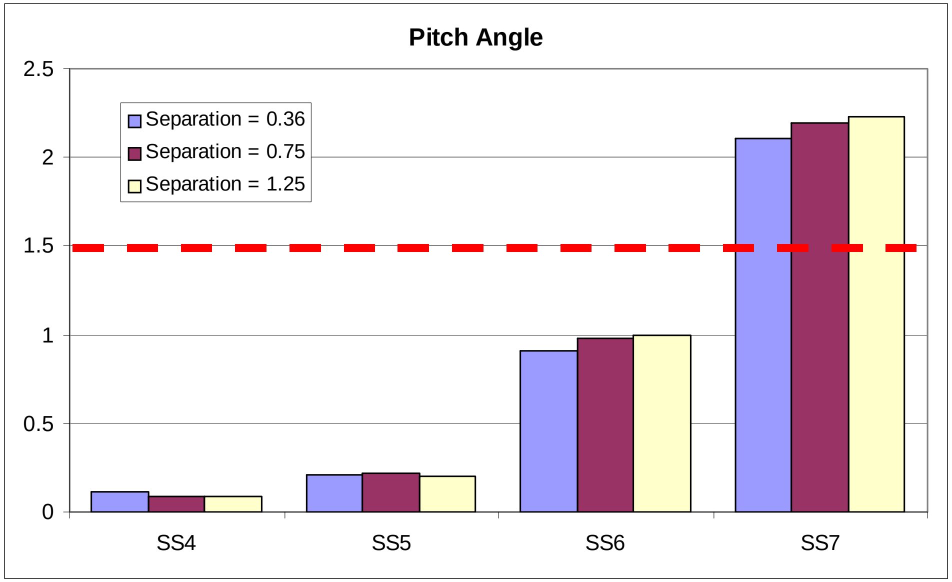


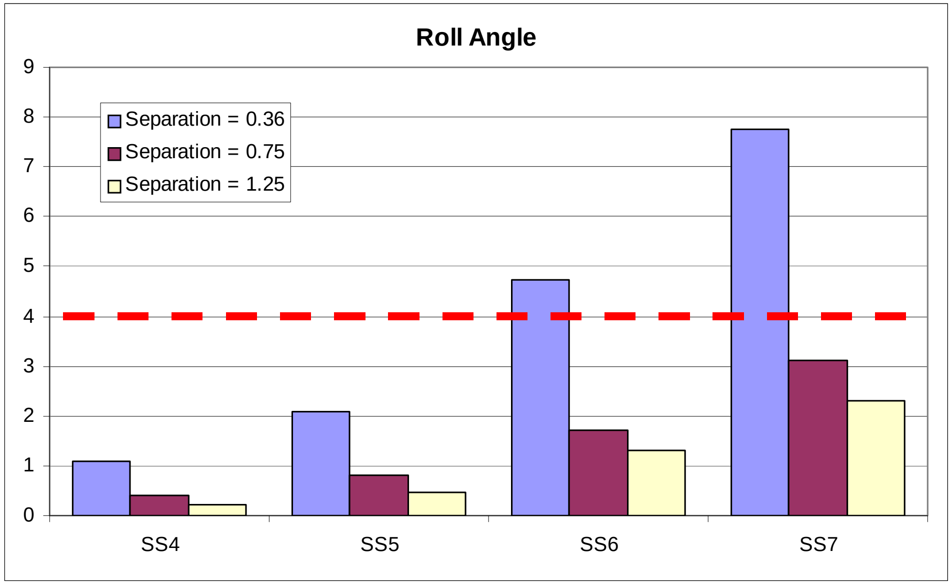


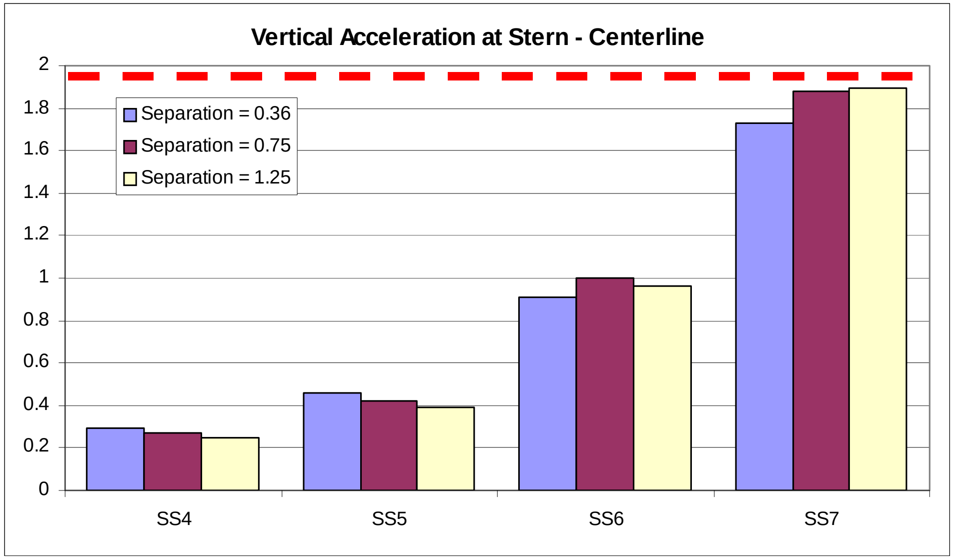


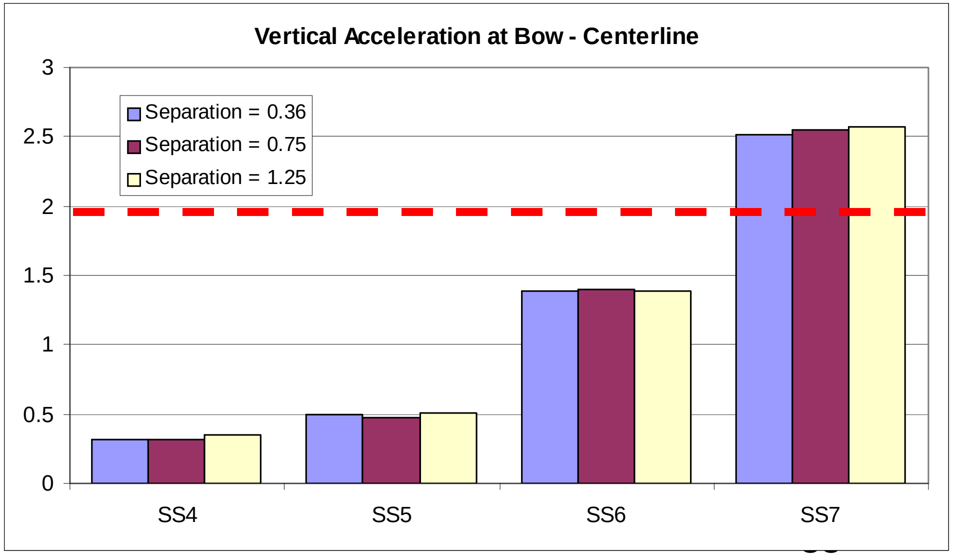
Separation Influence

15 knots – Maximum Response from All Headings

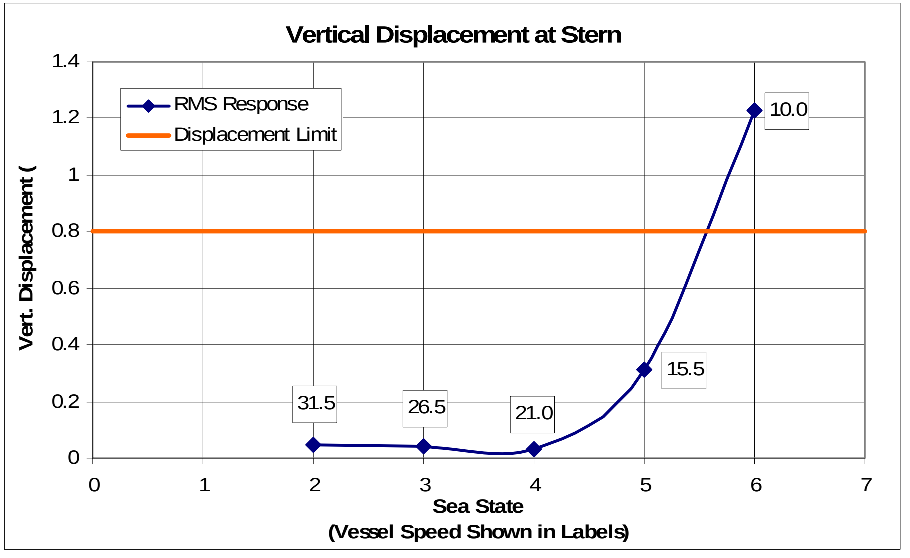


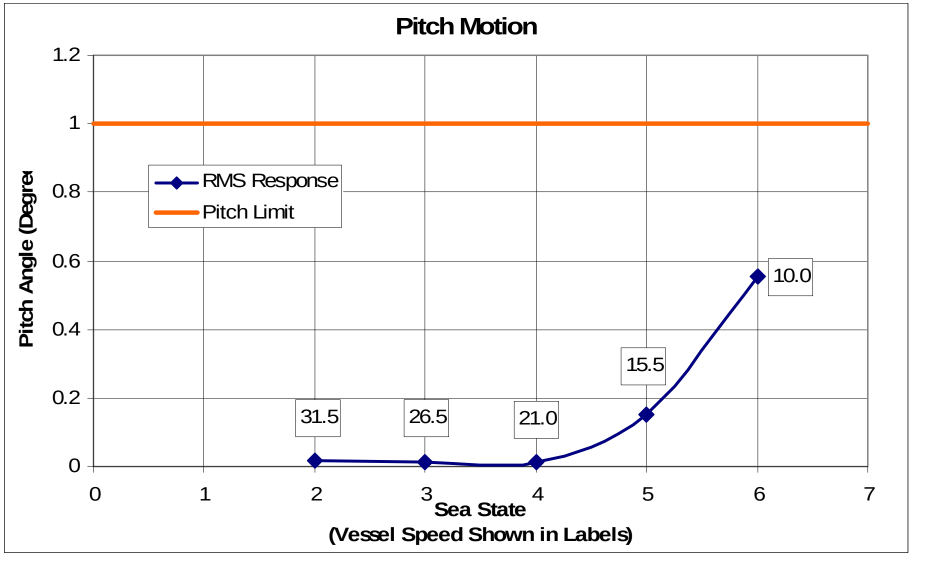


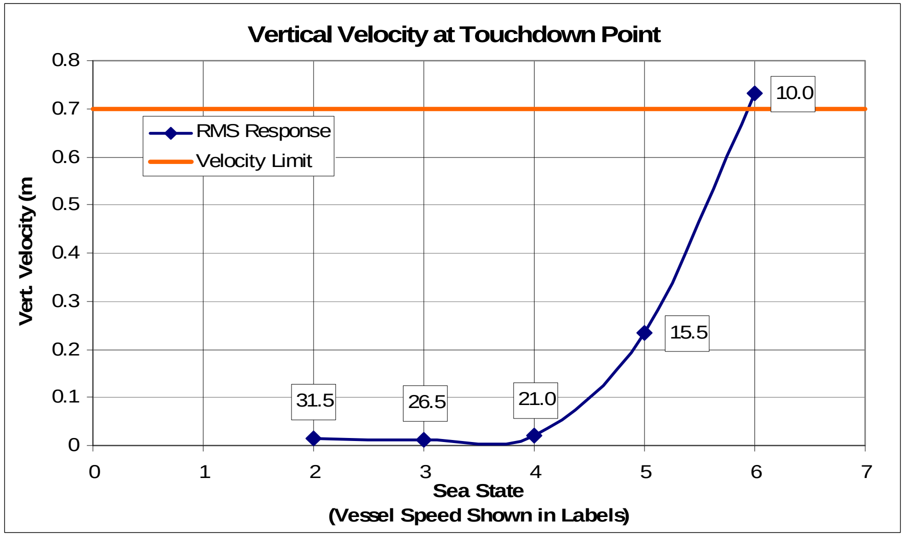


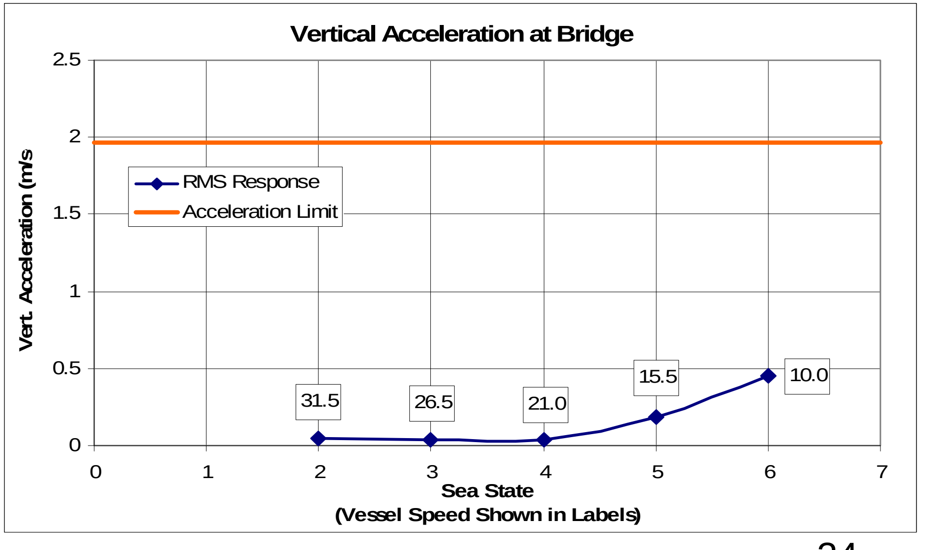


Air Craft Operation Criteria Assessment

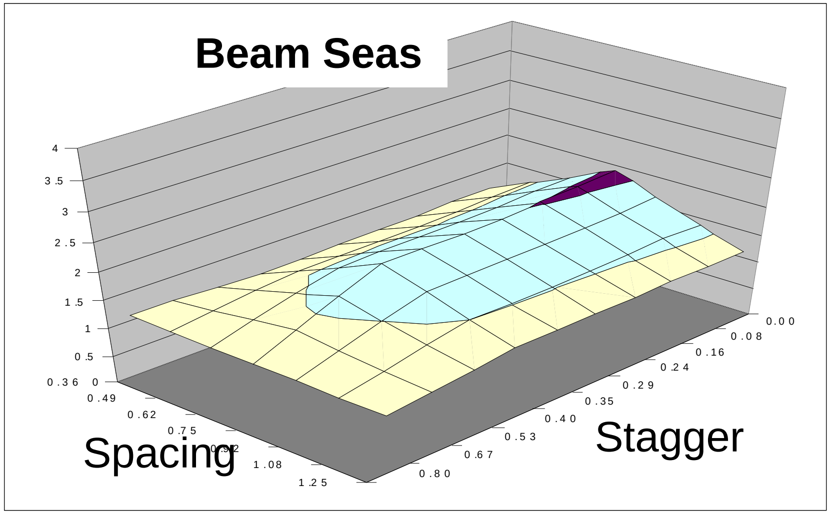


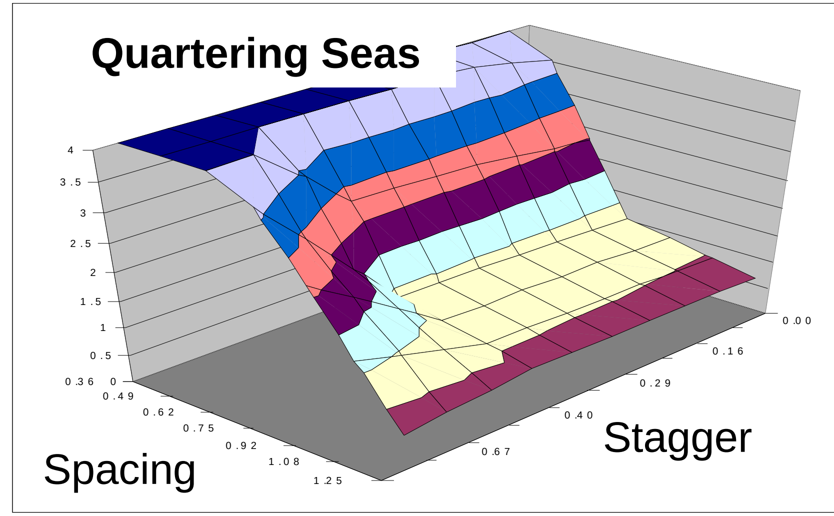






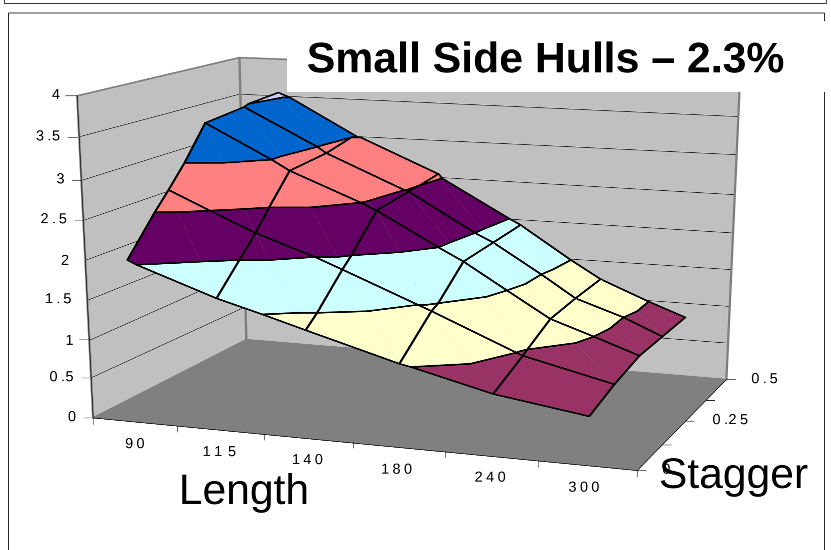
Sample HALSS (Extrapolated) Roll Motion Calculations

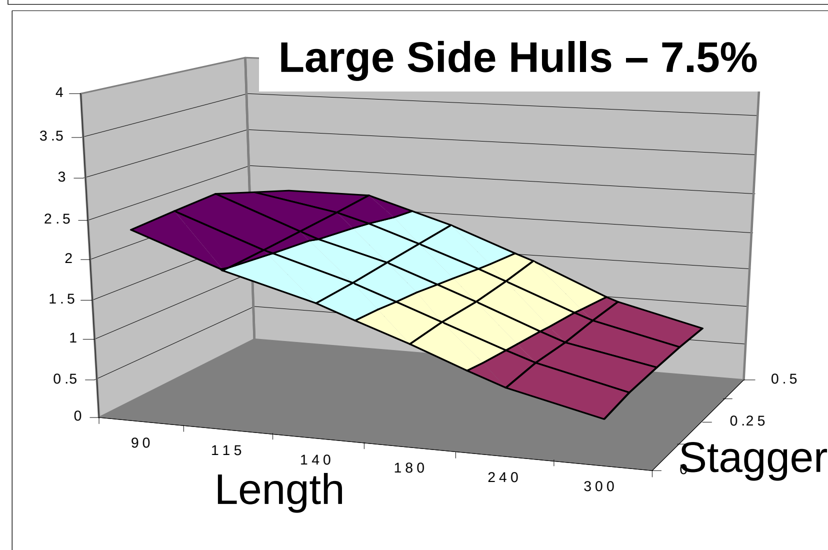




SS5

15 knots

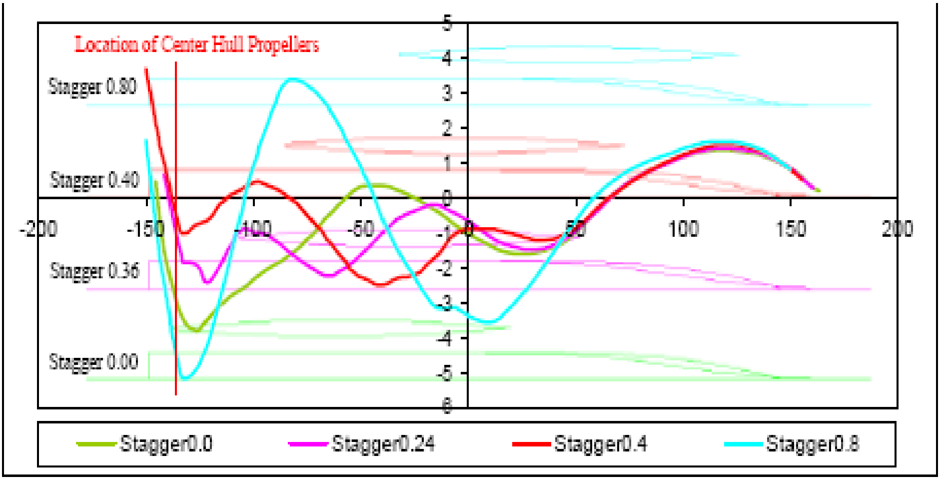


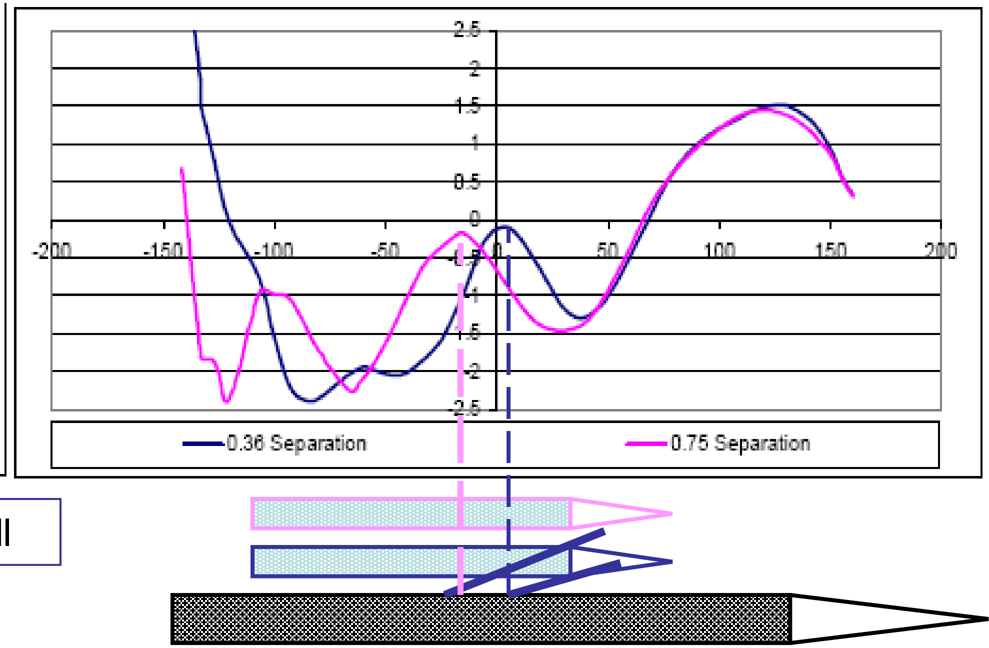


SS4

48.5 knots

Wave Elevation Interference vs. Trimaran Configuration





Effect of Stagger along the Length of the Center hull

Effect of Separation along the Center hull

The wave elevation, while in phase, at staggers maximum Aft (Stagger 0) and Maximum Fwd (Stagger 0.8), which is created by speed of the Center and Side Hulls (Speed 35 knots) and incoming waves (head seas, SS5), increase amplitude along the whole length of the Center hull. 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 also leads to the excessive amounts of prop emergences.

- ❖This is new and not well defined phenomenon.
- ❖Potentially, can guide the choice of Trimaran configuration
- ❖More studies are needed

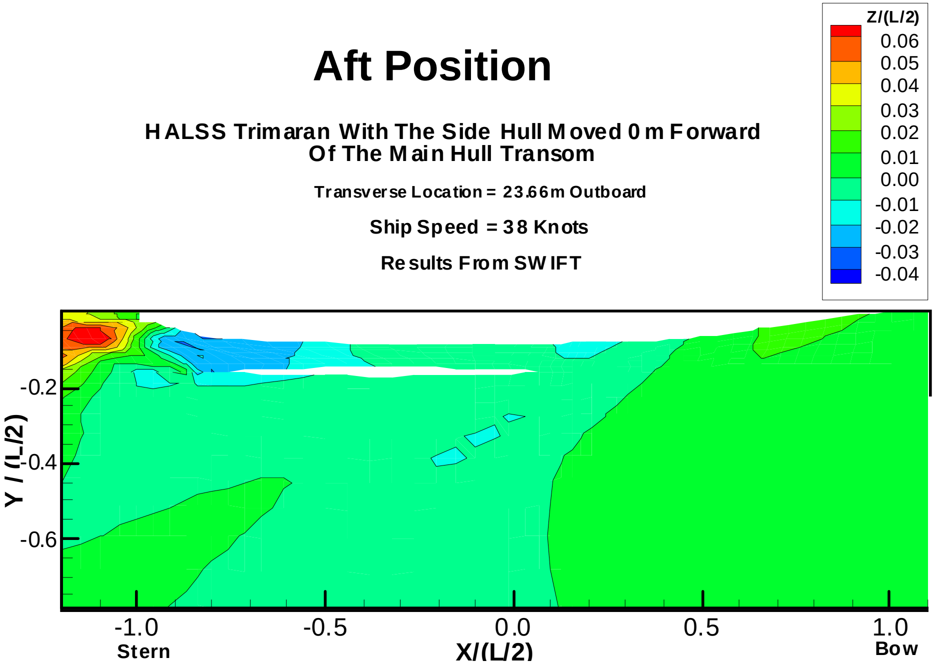
Summary

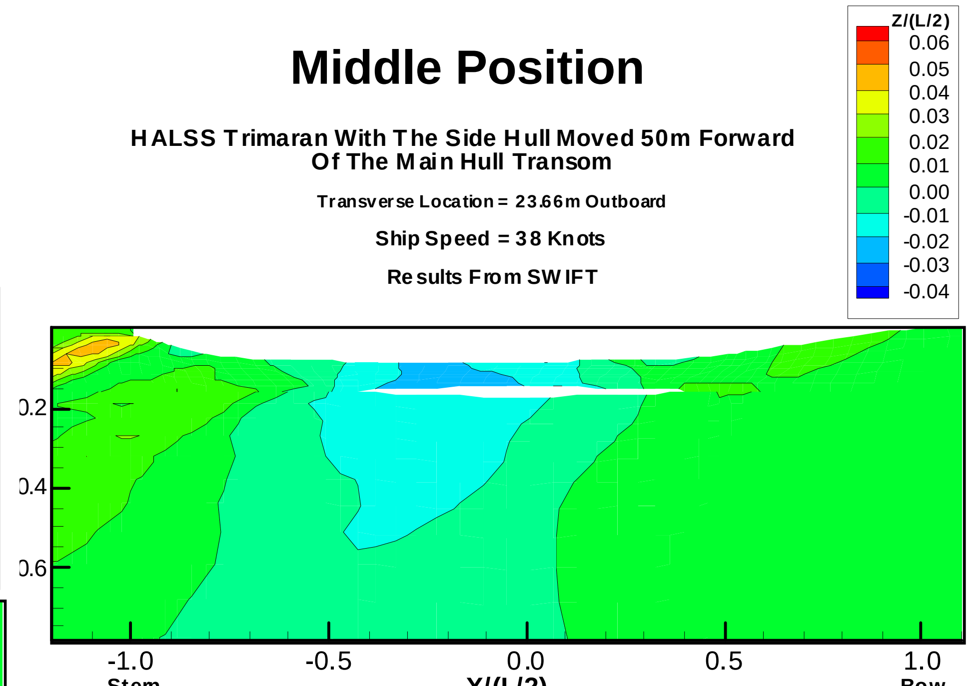
- HALSS potentially offers unique military capabilities for CONUS to Sea base logistics and early entry operations
- C-130J operations from HALSS are feasible
- R&D studies and engineering development conducted in CCDOTT multi year Program substantiate the feasibility of the design with current technology and reasonable risk. The CCDOTT HALSS program is correlated with Sealift R&D studies
- The current project demonstrated important technical findings, like potential of favorable wave interaction for trimaran ship and feasibility of commercial slow speed machinery for high speed sealift ships
- A new approach to acquisition, design and construction is proposed to end the cycle of ever increasing naval ship acquisition cost. This approach needs further detailing to ensure that Future HALSS-type ship is buildable in multiple, existing U.S. facilities

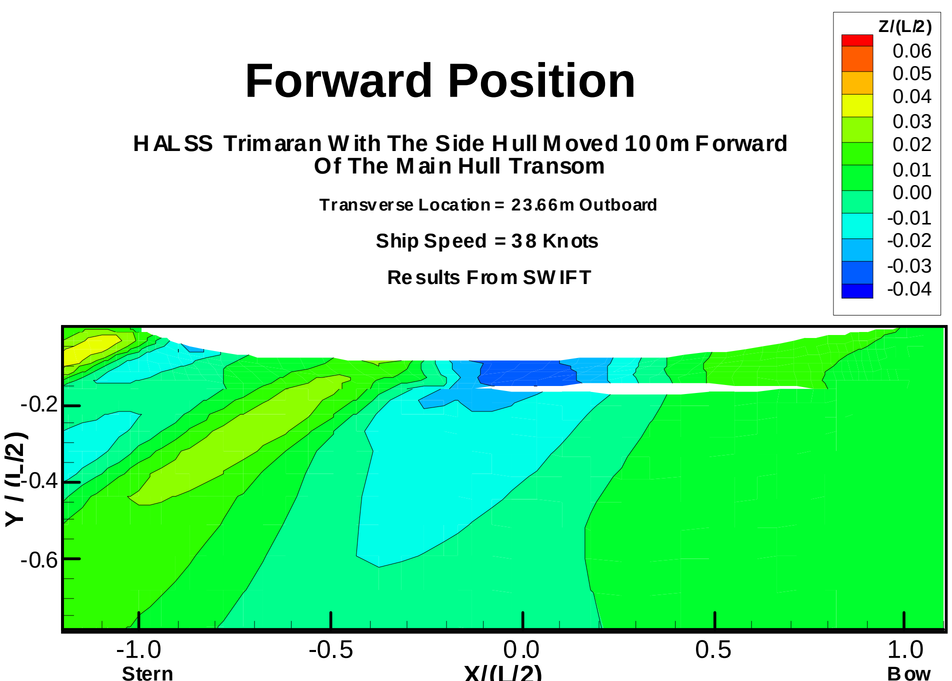
Back-Ups

Questions?

HALSS Trimaran Free Surface Elevations From SWIFT at 38 knots

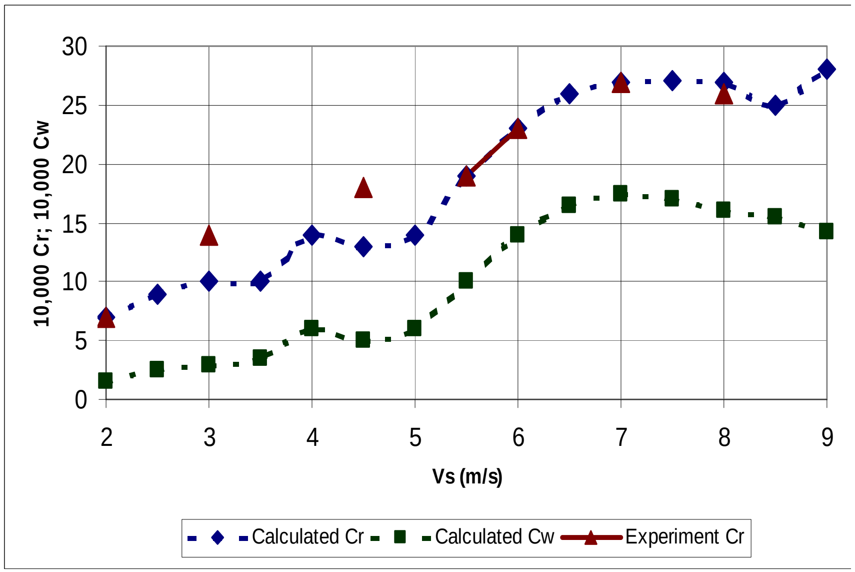




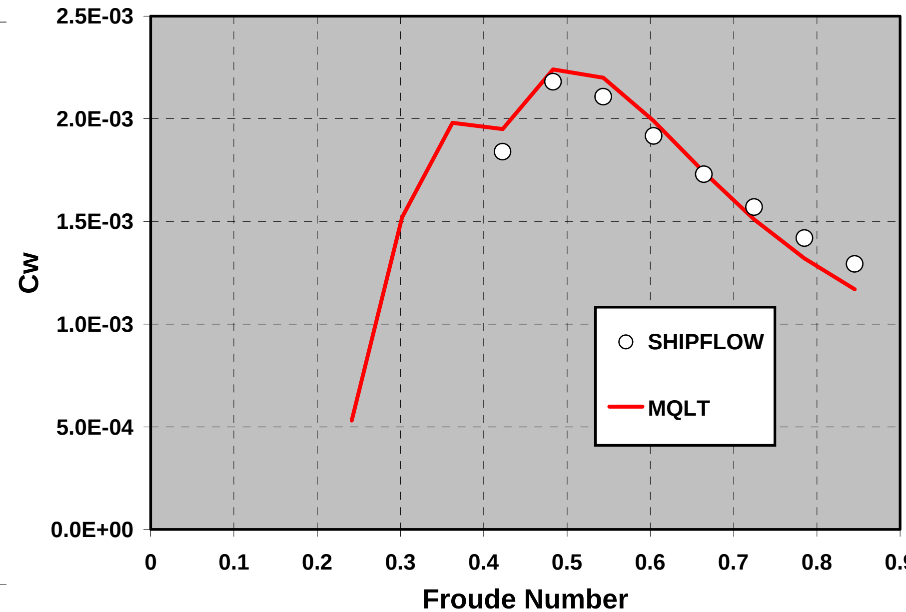


High Speed Trimaran Resistance Estimate

MQLT Validated by Model Tests



Resistance - SHIPFLOW and MQLT



- ❖ **Quasi Linear Theory method was modified to consider viscous-inviscid calculation of form resistance and transom drag – MQLT.**
- ❖ **MQLT was validated with DTMB testing results and compared with SHIPFLOW CFD calculations.**
- ❖ **MQLT is used for HST hydrodynamic design and optimization.**