High Speed Connector

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Initial Requirement

- Part of System of Systems
  - Intra-theater Connector within the Sea Basing Concept
  - High Speed, Agile, Versatile Platform
- Focused Logistics
  - “…ensure the delivery of the right equipment, supplies, and personnel to the right place, at the right time to support operational objectives.”*
- Affordable
- Industry Standard vs. Navy Standard

Required Capabilities

- Cargo:
  - 500-1000 Itons
- Speed >40 kts
- Range ~2000nm
- Interface: Roll-on-roll-off, Cargo, Vertical Movement of Cargo.
- Manning 20~30
- Navigational Agility:
  - Low Draft
- Limited Self-defense:
  - Air: point defense
  - Surface: visual range
  - Sub-surface: passive

\[ R = \frac{\text{Weight}_{\text{fuel}}}{\text{Weight}_{\text{cargo}} * \text{Range}} \]

*Pegrum, M., Kennell, C. “Fuel Efficiency Comparison between High Speed Sealift Ships and Airlift Aircraft” Marine Technology, Vol. 39, April 2002*
Design of Experiments:
- Data points were produced with proper randomization for the execution of the experimental runs.

Range of operational requirements:
- Speed: 32 knots to 44 knots.
- Payload: 500 ltons to 1000 ltons.

Developed Variants:
- Catamarans (26)
- Monohulls (27)
- Trimarans (28)

Comparison of alternative solutions by means of:
- Quantitative attributes (Transport Factor)
  \[
  \text{TransportFactor} = \frac{\text{Payload} \cdot \text{Speed}}{\text{InstalledPower}}
  \]
- Qualitative attributes
  - Seakeeping
  - Loading interface
  - Survivability
  - Feasibility
  - Ability to manufacture
Hull Selection
Transport Factor (TF) -vs- Cost

- Catamarans demonstrate the best combination of TF/LCC
- Trimarans give smaller TF for slightly lower LCC
- Monohulls represent the least attractive combination

- Trimarans demonstrate higher acquisition cost than catamarans due to high R&D
- Monohulls become more competitive in terms of acquisition cost
Hull Selection
TF and Cost in Speed-Payload Space

- Monohulls: worst performance in all combinations of speed-payload
- Trimarans: excel only in High speed - High payload case
- Catamarans: best TF in the rest of Speed-Payload space

- Monohulls: worst solution in terms of LCC
- Trimarans: marginally lower LCC in High speed - High payload region
- Catamarans: lowest LCC in the rest of Speed-Payload space
Qualitative Analysis - Catamarans

- **Seakeeping Capability**
  - Recent designs have demonstrated the ability to travel with 30 knots in sea state 6
- **Loading interface**
  - Lowest draft
  - Highest maneuverability
  - Best arrangeability due to rectangular configuration of cargo area
  - Lowest rolling angle
  - Capability for Vertical Access, Cargo Ramps for RO-RO
- **Survivability**
  - Large reserve cross-structure volume
  - Duplicated systems in fair separation
- **Tested technology**
  - 37 catamarans on 49 HSC were delivered on 2003
- **Ability to manufacture**
  - Demonstrated over a number of shipyards across US
TF and Cost for Catamarans

- Excellent performance in low speed regions
- Serious degradation with high speeds
- Low degradation with payload

- Very attractive choice for low speed regions
- High increase in LCC with speed
Vessel Performance – vs- Seabasing System Performance

Non Dominated Variants:
- Aluminum hull
- Waterjet propulsion
- Diesel Propulsion plant

Optimization of overall system:
- Speed: 32knots
- Payload: 1000tons
- Number of required vessels: 4
Geometry

- Round bilge hull FW
- Flat bottom AFT
- High L/B ratio
- Low draft
- Bulbous bow
- Raised wet deck
- Small bottom rake angle AF

<table>
<thead>
<tr>
<th>Displacement</th>
<th>2222</th>
<th>Long Ton</th>
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<tbody>
<tr>
<td>Lwl</td>
<td>91.59</td>
<td>m</td>
</tr>
<tr>
<td>Beam</td>
<td>30.15</td>
<td>m</td>
</tr>
<tr>
<td>Draft</td>
<td>3.8</td>
<td>m</td>
</tr>
<tr>
<td>Cp</td>
<td>0.82</td>
<td>-</td>
</tr>
<tr>
<td>Cb</td>
<td>0.61</td>
<td>-</td>
</tr>
<tr>
<td>Cm</td>
<td>0.77</td>
<td>-</td>
</tr>
<tr>
<td>Cwp</td>
<td>0.83</td>
<td>-</td>
</tr>
<tr>
<td>LCB from zero pt</td>
<td>-3.1</td>
<td>m</td>
</tr>
<tr>
<td>LCF from zero pt</td>
<td>-5.1</td>
<td>m</td>
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<tr>
<td>KB</td>
<td>2.25</td>
<td>m</td>
</tr>
<tr>
<td>BMt</td>
<td>57.1</td>
<td>m</td>
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<tr>
<td>BMI</td>
<td>214.6</td>
<td>m</td>
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<tr>
<td>KMt</td>
<td>59.3</td>
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<tr>
<td>KMI</td>
<td>216.8</td>
<td>m</td>
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<td>Immersion (TPc)</td>
<td>8.14</td>
<td>Long Ton/cm</td>
</tr>
<tr>
<td>MTc</td>
<td>52.6</td>
<td>Long Ton.m</td>
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</table>

Draft
Hydrostatics

When draft increases:

- Displacement and WSA increase linearly due to vertical sides of hull
- LCB, LCF move back
- Transverse and longitudinal metacentric radii decrease resulting to lower but still more than efficient stability
Equilibrium conditions

- Very large variation of characteristics with cargo
- Challenge to maintain neutral trim
  - In general, catamarans very sensitive due to small WPA
  - Usage of ballast tanks had to be avoided due to extra weight, system complexity, environmental considerations
- Tankage volume 140% of required for specified range
  - Negligible KG correction for free surface
  - Adaptability: replacing 130 tons of cargo with fuel will result to ~40% higher range

<table>
<thead>
<tr>
<th></th>
<th>Total Weight (ltons)</th>
<th>Draft (m)</th>
<th>LCG (m)</th>
</tr>
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<tbody>
<tr>
<td>Empty of cargo - Low fuels</td>
<td>963.5</td>
<td>2.2</td>
<td>-0.66</td>
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<tr>
<td>Full of cargo - Low fuels</td>
<td>1959</td>
<td>3.4</td>
<td>-3.22</td>
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<tr>
<td>Full of cargo - Hi fuels</td>
<td>2219</td>
<td>3.8</td>
<td>-2.60</td>
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Intact and Damaged Stability

- Fulfills IMO Intact and Damaged stability requirements
- High max GZ value
- Low equilibrium angles
- Max GZ appears at a small angle of inclination due to
  - high metacentric height
  - extremely high beam/freeboard
- Double hull extending from FW perpendicular to FW machinery room
- Compartment subdivision: Designed for 15%LWL floodable length
Main machinery components

Main Engines
• MTU 20V 1163 TB73L (x4)
  • Power: 6500kW (8710hp) at 1230rpm
  • SFC: 220gr/(kWhr)

Waterjets
• KaMeWa Quadruple 112SII (x4)
  • 6500kW at 582 RPM
  • Steerable, Reversible
  • seven bladed impellers with skew

Gear Boxes
• RENK ASL 53 (x4)
  • single-engine, non reversible
  • reduction ratio 2.05:1
  • Shaft offset on horizontal
Resistance and Powering Prediction

Variation of overall propulsive coefficient with speed & draft

Power requirements

Achievable speeds

<table>
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<tr>
<th>Condition</th>
<th>Speed (knots)</th>
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<tr>
<td>Full load</td>
<td>33</td>
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<tr>
<td>Empty load</td>
<td>43.1</td>
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<tr>
<td>After consumption of 10% margin</td>
<td>33</td>
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<tr>
<td>Sea Trials</td>
<td>34.1</td>
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<tr>
<td></td>
<td>44.1</td>
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Seakeeping Conditions and Criteria

Examined Conditions

Criteria
- Roll angles
- Pitch angles
- Accelerations at the bridge
- Wet deck slamming
- Waterjet aeration
- Deck wetness at the stern

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MEASURE (in significant values)</th>
<th>LIMIT VALUE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Full Load</td>
</tr>
<tr>
<td>CG</td>
<td>Roll angle (deg)</td>
<td>8</td>
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<tr>
<td>CG</td>
<td>Pitch angle (deg)</td>
<td>3</td>
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<tr>
<td>Bridge</td>
<td>Absolute vertical acceleration (m/sec^2)</td>
<td>0.5g</td>
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<tr>
<td>Bridge</td>
<td>Lateral vertical acceleration (m/sec^2)</td>
<td>0.2g</td>
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<tr>
<td>Wet deck FW</td>
<td>Relative vertical motion (m)</td>
<td>4.7</td>
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<tr>
<td>Stern ramp</td>
<td>Relative vertical motion (m)</td>
<td>2.1</td>
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<tr>
<td>WaterJet inlet</td>
<td>Relative vertical motion (m)</td>
<td>2.9</td>
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</table>
Seakeeping Results

Wave Height 4m

Wave Height 5m

Wave Height 6m

Wave Height 7m

Full Load

Empty Load

Speed (Knots)

180 deg
90 deg

Unrestricted operation

Restricted operation
• **Design Criteria**
  – Based On Det Norske Veritas (DNV) High Speed Light Ship Rules.

• **Iterative Process**
  – Plate Design (boundary conditions: clamped-clamped)
  – Longitudinal Girder/Stiffener Design
  – Transverse Web Frame Design
  – Torsion Stress Check
Loading Stresses

- **Major Factors**
  - Speed
  - Loading Condition
  - Sea State Condition
  - Geometry (length, width, draft)

- **Stress Due To**
  - Water Pressure
  - Longitudinal Bending
  - Slamming (bottom, cross-structure)
  - Forward Motion (bow bottom, side)
  - Vehicle Loading
Loading Stresses (cont.)

Sea Pressure Loading Stress

Slamming Pressure Loading Stress

Longitudinal Bending Stress
Scantling Design Results

- Material
  - Aluminum Alloy 3008H18
  - Density: 2730 kg per cubic meter
  - Yielding stress 225 Mpa

- Plate (5x1.849 m)
  - 27mm
  - 23mm
  - 19mm

- Stiffener
  - Type 243 CY FdaTb
  - Fundia TB 160x40 (two sizes)

- Webframe
  - Same type (two sizes).

- Safety Factor >3
  - Maxi stress 72 Mpa in Web frame with torsion
Arrangement

Profile View
Arrangement (cont.)

O-1 level

Main Deck
Arrangement (cont.)

First Deck

Second Deck
Arrangement (cont.)
Arrangement (cont.)
Cost

- Parametric ESWBS weight groups
  - Material Cost
  - Labor Cost
- Adjusted for individual items
  - Engines
  - Gensets
  - Gear boxes, cables.
- Life Cycle Cost (in 2005 US dollar)
  - 20-year span
  - 4-ship class
  - Including
    - Design: 4.42 million
    - Acquisition: 186.5 million
    - Manning: 3.95 million/year
    - Maintenance: 11.5 million/year
    - Operational Cost: 29.5 million/year
  - Total 780.12 million/195 million per ship.
  - Annual cost per ship: 9.75 million

<table>
<thead>
<tr>
<th>Production Number</th>
<th>Cost Per Ship ($Million)</th>
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<tr>
<td>ship#1</td>
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<tr>
<td>ship#2</td>
<td>42.393</td>
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<td>ship#4</td>
<td>42.0616</td>
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<tr>
<td>Total</td>
<td>186.4983</td>
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</tbody>
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Conclusion

• Success
  – Achieved payload of 1000 ltons.
  – Partially achieved speed goal of >40 knots.
  – Low-draft, agile, inexpensive and versatile.

• Future Works
  – To consider the dynamic stress load of the ramp to the stern structure
  – To design propulsion system and control for dynamic station-keeping while unloading.

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<th>Threshold</th>
<th>Goal</th>
<th>Achieved</th>
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<tbody>
<tr>
<td>Speed</td>
<td>32kts</td>
<td>&gt;40kts</td>
<td>34-44kts</td>
</tr>
<tr>
<td>Payload</td>
<td>500 ltons</td>
<td>1000 ltons</td>
<td>1000 ltons</td>
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<tr>
<td>Range</td>
<td>2000 nm</td>
<td>2000 nm</td>
<td>2100 nm</td>
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<tr>
<td>Cost</td>
<td>150 million</td>
<td>50 million</td>
<td>46 million</td>
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Principal Ship Characteristics

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</tr>
<tr>
<td>Manning</td>
<td>29</td>
<td>Personnel</td>
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<tr>
<td>Power Plant</td>
<td>4</td>
<td>MTU 20V 1163 TB7.3L Diesels</td>
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<tr>
<td>Propulsion</td>
<td>4</td>
<td>KaMeWa Quadruple 112 SII waterjets</td>
</tr>
<tr>
<td>Speed - Full Load</td>
<td>34</td>
<td>Knots</td>
</tr>
<tr>
<td>Speed - Light Ship</td>
<td>44</td>
<td>Knots</td>
</tr>
<tr>
<td>Range (Full load, max speed)</td>
<td>2100</td>
<td>nm</td>
</tr>
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Questions?