Track, Engage, & Neutralize Threats – Asymmetric & Conventional – in the Littoral Environment
TSSE Team

Faculty
Prof. Fotis Papoulias
Prof. Bill Solitario
Prof. Greg Miller
Prof. J. Mike Green
Prof. Robert Ashton

2005 Student Design Team

Payload
LT B. C. Black, USN, ME/CSST
LCDR M. A. Glova, USN, ME
LT J. S. Hall USN, AE
LCDR C. J. Hickle, USN, ME

Combat Systems
LTjg S. Bouabid, Tunisian Navy, EE
LCDR G. M. Harden, USN, EE
LT P. Majewicz, USN, EE
LT A. B. Nozik, USN, EE

13 Students
3 Countries
4 Academic Curricula

H M & E
LCDR L. H. Bollock, USN, ME
LTjg S. Hosoglu, Turkish Navy, ME
LT K. Mullenix, USN, ME
LCDR S. F. Sarar, USN, EE
LTjg H. Ucar, Turkish Navy, ME
Agenda

• Overall Design Process
  – Requirements Analysis
  – Functional Analysis Allocation
• Payload and Operational Concept
• Combat Systems
• Hull, Mechanical, and Electrical (HM&E)
• Summary
The Classical Systems Engineering Process

Figure from NAVSEA Ship Design Manager (SDM) Manual
TSSE Tailored Systems Engineering Design Process

- **SEA-8 Littoral ASW Project**
- **Top Level Reqs Delivered to TSSE**
- **Refined Reqts Delivered to TSSE**
- **Define Notional Payload & Operational Concept**
- **Payload Brief**

**Requirements Analysis**

- **Requirements Clarification**
- **Notional Payload feedback To SEA-8**

**Functional Analysis Allocation**

- **AoA**
- **Ship Type & Size**
- **Ship Functional Requirements Definition**
- **IRD, Critical Design Parameters**

**Ship Design Synthesis**

- **Payload**
- **Combat Systems**
- **H M & E**

**Analysis Of Alternatives**
Top Level Requirements

- Deploy, retrieve, and regenerate large UUVs semi-clandestinely
- Sensor assets required to provide Pd 0.8 across contested OA (6,700 NM2) within 10 days
- Provide logistic support necessary to sustain SoS for 30 days
- Communicate on the following circuits:
  - High Band Width Air/Space Line of Sight (LOS) LOS Data
  - LOS Voice OTH Data
  - OTH Voice SATCOM
  - Underwater Data
- Launch, recover, and control a 7,000 lb UAV
- Deploy box-launcher weapons and torpedoes for enemy engagement
Notional Payload and Operational Concept

10 nm

100 nm

70 nm
Top Level Analysis of Alternatives (AoA)

• Conducted from Aug-Sep using notional payload architecture and SEA-8 scenario

• Competing Architectures:
  -- LCAC size craft (single and wave)    -- Mid-size ship
  -- LCS Module (single and wave)

• Selection Criteria:
  -- Capability (30)    -- Deployability (20)    -- Survivability (20)
  -- Endurance (10)     -- Flexibility (10)     -- Technical Risk (5)
  -- Cost (5)
Top Level AoA Results

- 1 LCAC
- 7 LCAC Wave
- Mid-Size Amphib
- 1 LCS
- 3 LCS
# Critical Design Parameters

<table>
<thead>
<tr>
<th>Category</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Availability</td>
<td>0.85</td>
<td>0.95</td>
</tr>
<tr>
<td>Hull Service Life</td>
<td>20 years</td>
<td>30 years</td>
</tr>
<tr>
<td>Draft @ Full Load</td>
<td>8 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Max Speed</td>
<td>30 + kts</td>
<td>40 + kts</td>
</tr>
<tr>
<td>Range @ Max Speed</td>
<td>1000 nm</td>
<td>1500 nm</td>
</tr>
<tr>
<td>Range @ Cruise Speed</td>
<td>3500 nm</td>
<td>4500 nm</td>
</tr>
<tr>
<td>Large UUV Capacity</td>
<td>40</td>
<td>50+</td>
</tr>
<tr>
<td>Hvy Wt UUV capacity</td>
<td>80</td>
<td>100+</td>
</tr>
<tr>
<td>Cargo Weight</td>
<td>400 MT</td>
<td>800 MT</td>
</tr>
<tr>
<td>Cargo Volume</td>
<td>5000 m³</td>
<td>6000 m³</td>
</tr>
<tr>
<td>Small Boat (7 m RHIB)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>USV (11 m RHIB)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>UUV/USV/UAV Launch Recover</td>
<td>Sea State 3</td>
<td>Sea State 4</td>
</tr>
<tr>
<td>Aviation Support</td>
<td>One 7000 lb VTUAV</td>
<td>VTUAV (2)/ SH-60R</td>
</tr>
<tr>
<td>Aircraft Launch / Recover</td>
<td>VTUAV</td>
<td>VTUAV/SH-60R</td>
</tr>
<tr>
<td>UNREP MODES</td>
<td>RAS, CONREP, VERTREP</td>
<td>RAS, CONREP, VERTREP</td>
</tr>
<tr>
<td>Core Crew Size</td>
<td>≤130</td>
<td>≤100</td>
</tr>
<tr>
<td>Crew Accommodations</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Provisions</td>
<td>30 days</td>
<td>45 days</td>
</tr>
</tbody>
</table>
Agenda

✓ Introduction and Overall Design Process
  • Payload and Operational Concept
    – Components
    – Launch, Deployment, and Recovery
    – Handling Systems
    – Payload Modeling
  • Combat Systems
  • Hull, Mechanical, and Electrical (HM&E)
  • Summary
# Notional Architecture

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contested air space</td>
<td>Covert insertion and recovery, 200nm standoff range</td>
</tr>
<tr>
<td>30 day sustained operations</td>
<td>Centralized hub replenishment and recovery</td>
</tr>
<tr>
<td>Time and Space:</td>
<td>Single launch cycle followed by ongoing service cycles</td>
</tr>
<tr>
<td>100 nm² in 72 hrs</td>
<td></td>
</tr>
<tr>
<td>6700 nm² in 10 days</td>
<td></td>
</tr>
</tbody>
</table>
10 nm X 10 nm Network Hub
Architecture Refinement with TSSE/SEA-8 Collaboration

- 1 Large UUV (*Sea Predator)
- 1 Sled equipped with deployable RF buoy, acoustic modem, docking transducers, coupling two 21” diameter shapes
- 6 Light Weight UUVs – four for power, two for sensor processing and communications control
- 16 man-portable sensor and wire deployment vehicles

* Sea Predator, David DeMartino, NAVSEA Panama City
Payload Deck

Port and Starboard Side Doors

Amidships and Stern Ramps
Handling Systems

• X-Y-Z Overhead Hoist Array and Deck-rail Storage System
  – Longitudinal overhead monorail along centerline
  – Transverse overhead rail pairs
  – Reconfigurable two tier shelves anchored into deck rails provide secure stowage
  – Port and Starboard amidships rail extensions provide over the side lift capabilities
  – Amidships ramp cradle handles up to Large UUV’s
  – Stern ramp variable geometry cradle for larger capacity launch and recovery
Notional Architecture
2025 Notional Sensor Coverage

ASSUMPTIONS:
- 1 nm Detection Radii
- Sensor Spacing:
  - 4 nodes at 5nm
  - 8 nodes at 4nm
  - 4 nodes at 2nm
  - 1 center node
Maximum Capacity:
48 fixed hubs + 48 mobile Sea Predators

Top Level Requirement: Full AO Coverage
Loitering at 1,000nm from the Harbor Gate AO, Sea Tentacle receives urgent tasking:

- **Sea Tentacle Transit**: 800nm sprint at 35 knots (23 hrs)
- **Sea Predator Launch**: Single launch event: Predator with external docking sled (1 hr)
- **Sea Predator Transit**: 200nm transit at 5 knots (40 hrs)
- **Sensor Deployment**: Sensor deployment vehicle max range of 5nm at 5 knots (2 hrs)
- **LWV Docking**: LWV’s launch and dock with sled (2 hrs)
- **Initialize System**: Power up, system optimization and self test, communications check-in (4 hrs)
In port at < 24 underway readiness, Sea Tentacle receives urgent tasking to AO at 3,400nm range:
UUV Network Applications

• Perimeter defense of Sea Base and high value transit lanes
• Core ASW and MIW capabilities providing offensive and defensive early warning envisioned by Sea Shield
• Wide area battle-space preparation and intelligence gathering capabilities for time critical Sea Strike
# Mission Payload

## Baseline Operational Unit Count

<table>
<thead>
<tr>
<th></th>
<th>Sea Predator (Large UUV)</th>
<th>AN/WLD-1 (Large UUV)</th>
<th>11m RHIB (USV equipped)</th>
<th>7m RHIB</th>
<th>SH-60R</th>
<th>VTUAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>48</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

![Image of various military vehicles and equipment]
Detailed Payload Deck-Plan
Payload Top Level Requirements

- Deploy, retrieve, and regenerate large UUVs semi-clandestinely
- Sensor assets required to provide Pd 0.8 across contested OA (6,700 NM2) within 10 days
- Provide logistic support necessary to sustain SoS for 30 days
  - Communicate on the following circuits:
    - High Band Width Air/Space Line of Sight (LOS) LOS Data
    - LOS Voice OTH Data
    - OTH Voice SATCOM
    - Underwater Data
  - Launch, recover, and control a 7,000 lb UAV
  - Deploy box-launcher weapons and torpedoes for enemy engagement
Agenda

- Introduction and Overall Design Process
- Payload and Operational Concept
  - **Combat Systems**
    - Derived Requirements
      - Weapons Deployment
      - Communications
    - Design Philosophy
    - ICMS Architecture
    - Component Selection
      - Layered Defense
      - Radio Frequency Systems
    - Radar Cross Section Analysis
    - Summary
  - Hull, Mechanical, and Electrical (HM&E)
  - Summary
# Threat Matrix

<table>
<thead>
<tr>
<th>Threat</th>
<th>AMRFS</th>
<th>TISS</th>
<th>EW Suite</th>
<th>ISMD/A</th>
<th>ASROC</th>
<th>ESSM</th>
<th>SSM</th>
<th>Millenium Gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCM</td>
<td>D</td>
<td>D</td>
<td>D - SK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submarine</td>
<td>D</td>
<td></td>
<td>D</td>
<td>D</td>
<td>HK</td>
<td></td>
<td></td>
<td>HK</td>
</tr>
<tr>
<td>Small boats</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>HK</td>
</tr>
<tr>
<td>Mines</td>
<td></td>
<td>D</td>
<td></td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>HK</td>
</tr>
<tr>
<td>Shore Fire</td>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HK</td>
</tr>
</tbody>
</table>

D – Detection    SK – Soft Kill    HK – Hard Kill

HK* - Anti-ship ESSM requires software upgrade
Defense in Depth

Inner Defense Layer

- ESSM
- SSM
- Millennium Gun
- VLA

Mid Defense Layer

- AIRCRAFT
- ASCM
- SEA SKIMMING MISSILE
- SURFACE VESSEL / LITTORAL TARGET

Range:
- 1.5 nm
- 2.0 nm
- 3 nm
- 5 nm
- 7 nm
- 50+ nm
- 80+ nm
External Communications

RF External Communications
• The ship will be fully interoperable with the following systems:
  – CEC
  – Joint Planning Network
  – Joint Data Network
  – GCCS-M
  – SIPRNET
  – NIPRNET
• The following frequency ranges / data rates will be supported:
  - UHF SATCOM  512 – 4.5 Mbps
  - SHF SATCOM  1.544 Mbps (T-1) – 45 Mbps (T-3)
  - UHF LOS  200 kbps
Integrated Combat Management System

**OBSERVE**

- DETECT
  - Sensors and Comms
  - Multi-Function Radar
  - DE-1160 ISMD/A
  - SLQ-32
  - IRST
  - IFF

- Tactical LAN

**EXTERNAL SOURCES**
- Remote Vehicles (UAV, USV, UUV)
- Advanced Deployable Systems
- LINK
- CEC
- GiG

**CONTROL**
- Mission Control Elements
- Local C&C
- Sensor Coordination & Control
- Tactical LAN

**ENGAGE**
- Weapons and CM
- ESSM
- Millenium Gun
- ASROC
- ASM

**ACT**

- System Track Management
- Weapons Direction & Control

**ORIENT & DECIDE**
Operating Characteristics:

- Net-Centric
- Collaborative
- Distributed Functionality
- Strong HSI Focus

Mission Areas:

- Littoral ASW/MIW
- SUW (Maritime Surveillance)
- AAW
Inner Defense Layer AoA

Design Requirements | Weight | Sea Ram | CIWS 1B | Millennium Gun | Goal Keeper
--- | --- | --- | --- | --- | ---
Modularity | 0.15 | 1.00 | 5.00 | 5.00 | 2.00
Personnel | 0.10 | 4.00 | 2.00 | 3.00 | 2.00
Operational Availability | 0.15 | 4.50 | 2.00 | 3.00 | 2.00
Range | 0.10 | 5.00 | 5.00 | 3.00 | 3.50
Surface Threat Capability | 0.15 | 1.00 | 2.50 | 5.00 | 0.00
Air Threat Capability | 0.10 | 5.00 | 4.50 | 3.50 | 4.00
Responsiveness | 0.10 | 5.00 | 4.00 | 3.50 | 4.00
Footprint (Physical, RCS) | 0.15 | 2.00 | 2.00 | 4.00 | 2.00
Totals | 1.00 | 0.64 | 0.73 | **0.80** | 0.51

**Selected System:** Millennium Gun
- Range (air): 3.5 nm
- Range (cruise missiles): 1.08 nm
- Range (sea-skimming missiles): 0.8 nm
- Firing Rate: 1,000 rounds/min
- 152 sub-projectiles per round
Advanced Multifunction RF System (AMRFS) Capabilities

Multi-functional:

- Communications
  - Satellite Communications
  - Line-of-Sight Communications
- Electronic Attack (EA)
  - Noise Jamming
  - Deceptive Jamming
- Electronic Surveillance (ES)
- Radar
  - Surface Navigation Radar
  - Volume Search
- Reduced Maintenance
  - Array & Subsystem Calibration, Characterization, and Diagnostics

Source: Raytheon DBR
Benefits:
- Reduces Total Number of Required Topside Arrays
- Increases Potential for Future Growth without Major Ship Alterations
- Tighter Control over EMI/EMC Issues
- Functionality Primarily Defined by Software
- Potential for Substantial Reduction in Life Cycle Costs
- Enables Reallocation of RF Functions

Summary:
- RF functions can be customized to tactical environment, enhancing war-fighting capabilities !!!

W. Gottwald, "An Overview of the Advance Multifunction RF Concept (AMRFC) Test-Bed", 04APR14
For our design RCS estimation, we used two techniques:

- Empirical Method (Skolnik)
- Physical Optics Method (POFACETS Software)
Skolnik (1980) suggested a formula to estimate the median RCS of a ship based on its displacement and the frequency of operation of a given seeker:

\[
\sigma_m^2 = 1644 \cdot \sqrt{D_{KT}^3 \cdot f_{GHz}}
\]

For our design, with a displacement of around 7000 LT and a frequency of operation of 0.3 GHz:

\[
\sigma_{\text{Sea-Tentacle}} = 16677 \, m^2 = 42 \, \text{dBsm}
\]

This approximation varies with the angle. 13 dB (for broadside) are added and 8 dB (for minima) are subtracted.

\[
34 \, \text{dBsm} \leq \sigma_{\text{Sea-Tentacle}} \leq 55 \, \text{dBsm}
\]
POFACETS is a RCS tool developed by Dr. Jenn of the ECE Dept. of NPS.

It is based on the Physical Optics Method.

Ship Parameters used by POFACETS were generated with RHINO software.
Composite material ship yields a median RCS of approximately 5dBsm

Steel ship yields a median RCS of approximately 25dBsm
RCS as a Function of Seeker Frequency

RCS: Beam target angle for steel ship.

Steel material selection renders lowest RCS at frequencies:
- 2.3 GHz
- 4.1 GHz
- 7.2 GHz

RCS Results using a Steel Ship model vs. Seeker frequency at a 090/270 TA
RCS Conclusions

- Empirical and simulation results for RCS are similar.
- POFACETS results facilitated material considerations.
- RCS Comparisons are comparable between 2004 and 2005 TSSE designs.
- RCS Analysis (unclassified) and does not take into account AMRFS RF emissions.
Deploy, retrieve, and regenerate large UUVs semi-clandestinely
Sensor assets required to provide Pd 0.8 across contested OA (6,700 NM2) within 10 days
Provide logistic support necessary to sustain SoS for 30 days

Communicate on the following circuits:
- High Band Width Air/Space Line of Sight (LOS) - LOS Data
- LOS Voice - OTH Data
- OTH Voice - SATCOM
- Underwater Data

Launch, recover, and control a 7,000 lb UAV
Deploy box-launcher weapons and torpedoes for enemy engagement
ICMS Summary

• Integrated Design philosophy can summed up as “no stovepipes.”

• Open Architecture Focus Embraces Technology Growth.

• Multi-mission capability supports dynamic mission requirements.
Agenda

- Introduction and Overall Design Process
- Payload and Operational Concept
- Combat Systems
  - Hull, Mechanical, and Electrical (HM&E)
    - Initial Hull Selection AoA
    - Hydrostatics, Damaged Stability, Structures
    - Resistance, Propulsion, Electrical
    - Seakeeping
  - Summary
• Systems Engineering Waterfall Model used

• Applied up to component development stage
Hull Type Comparison

Monohull

- Long endurance at low speeds
- Ruggedness, simplicity, and durability
- Tolerance to growth in weight and displacement
- Existing infrastructure of yards, docks, and support facilities is designed for monohulls
- Low cost
Hull Type Comparison

Trimaran

- Reduced powering requirements at high speeds
- Reduced draft
- Increased deck area and growth margin
- Increased seakeeping
- Increased powering requirements at low speeds because of large wetted surface area
Hull Type Comparison

Catamaran

In addition to Trimaran;

- Good stability after dropping off all the payload
- Advantage of using the space between demihulls as launching / recovering stations (semi-covert operations)
- Best speed for high weight / cargo load
Mission Bay Comparison

- Monohull: 16 ISO containers
- Catamaran: 21 ISO containers
- Trimaran: 7 ISO containers
- ISO: 6 x 2.5 x 2.5m
Hull Type AoA

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Weight</th>
<th>Weighted</th>
<th>Weighted</th>
<th>Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance at low speed</td>
<td>0.06</td>
<td>5.00</td>
<td>0.30</td>
<td>4.00</td>
</tr>
<tr>
<td>Endurance at high speed</td>
<td>0.07</td>
<td>3.00</td>
<td>0.21</td>
<td>4.50</td>
</tr>
<tr>
<td>Risk</td>
<td>0.08</td>
<td>5.00</td>
<td>0.40</td>
<td>4.00</td>
</tr>
<tr>
<td>Cost</td>
<td>0.10</td>
<td>5.00</td>
<td>0.50</td>
<td>4.00</td>
</tr>
<tr>
<td>Draft</td>
<td>0.10</td>
<td>3.50</td>
<td>0.35</td>
<td>4.50</td>
</tr>
<tr>
<td>Deck Area</td>
<td>0.16</td>
<td>3.00</td>
<td>0.48</td>
<td>5.00</td>
</tr>
<tr>
<td>Growth Margin</td>
<td>0.08</td>
<td>4.00</td>
<td>0.32</td>
<td>5.00</td>
</tr>
<tr>
<td>Sea Keeping</td>
<td>0.10</td>
<td>4.00</td>
<td>0.40</td>
<td>5.00</td>
</tr>
<tr>
<td>Stability</td>
<td>0.15</td>
<td>4.00</td>
<td>0.60</td>
<td>4.50</td>
</tr>
<tr>
<td>Footprint (RCS)</td>
<td>0.10</td>
<td>4.00</td>
<td>0.40</td>
<td>5.00</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Monohull Catamaran Trimaran
Catamaran was selected
Hull Design

New System Components

Hull Design → New Displacement → Resistance Calculations

Power Plant Selection → Power Requirements
Hydrostatics

Displacement = 7023 MT
DWL = 117.4 m
Design Draft = 5.2 m
VCG = 5.925 m (from keel)

Results obtained using standard and custom hydrostatics software and weight data for the ship
Intact Stability

Positive Righting
Arm up to $85^\circ$
Damaged Stability

Can survive in case of loss of one demi-hull

Can survive with all engine rooms flooded
 Structural Strength

Max. Bending Stress = 154.4 MPa at hogging condition at midship section

Steel was selected
Ship Characteristics

Light Ship = 4504 MT
Loaded Displacement = 7023 MT
LOA = 120 m
LWL = 117.4 m
Beam = 25 m
Design Draft = 5.2 m
Metacentric Height = 16.05 m
Design Trim = 0.1° to Bow
Design Heel = 0.51° to Port
Power Estimation from Resistance Calculations

Shaft Power (kW) vs. Speed (kts)

<table>
<thead>
<tr>
<th>Speed (kts)</th>
<th>Shaft Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>403.02</td>
</tr>
<tr>
<td>10</td>
<td>2645.84</td>
</tr>
<tr>
<td>15</td>
<td>7528.65</td>
</tr>
<tr>
<td>20</td>
<td>15419.89</td>
</tr>
<tr>
<td>25</td>
<td>26510.43</td>
</tr>
<tr>
<td>30</td>
<td>40627.94</td>
</tr>
<tr>
<td>35</td>
<td>56712.14</td>
</tr>
<tr>
<td>40</td>
<td>72155.12</td>
</tr>
<tr>
<td>45</td>
<td>91213.34</td>
</tr>
</tbody>
</table>

- 1LM 2500+
- 1LM 6000
- 2LM 2500+'s
- 1LM 2500+1LM 6000
- 2LM 2500+'s+1LM 6000

Graph showing the relationship between speed (kts) and shaft power (kW) for different configurations of machinery.
Gas Turbine Analysis Snapshot

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Weighting Factor</th>
<th>Alternative – 1</th>
<th>Alternative – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specific Fuel Consumption</td>
<td>0.4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>0.2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Thermal Efficiency</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Total Score</td>
<td>1</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Summary of Chosen Propulsion Systems

- Propulsion Plant: Gas Turbines
- Specifically: 2 LM2500+
  1 LM6000
  1 Allison 501-K34
Summary of Chosen Propulsion Systems

- Electric drive
- 2 Bird-Johnson AWJ-21 water jets
- 2 bow thrusters
Range Calculations

Range vs Speed

Endurance Load vs Speed (for 4500 NM)

<table>
<thead>
<tr>
<th>Speed (kts)</th>
<th>Max. Range (NM)</th>
<th>Speed (kts)</th>
<th>Endurance Load for 4500 NM (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1831.094</td>
<td>5</td>
<td>4367</td>
</tr>
<tr>
<td>10</td>
<td>2468.7828</td>
<td>10</td>
<td>3239</td>
</tr>
<tr>
<td>15</td>
<td>5439.71939</td>
<td>15</td>
<td>1470</td>
</tr>
<tr>
<td>20</td>
<td>5462.01332</td>
<td>20</td>
<td>1464</td>
</tr>
<tr>
<td>25</td>
<td>2212.61414</td>
<td>25</td>
<td>3614</td>
</tr>
<tr>
<td>30</td>
<td>1754.36321</td>
<td>30</td>
<td>4558</td>
</tr>
<tr>
<td>35</td>
<td>1045.41607</td>
<td>35</td>
<td>7649</td>
</tr>
<tr>
<td>40</td>
<td>921.880044</td>
<td>40</td>
<td>8674</td>
</tr>
</tbody>
</table>
Endurance and Speed

- Transiting Speed of 20 kts gives Range of 5,400 nm
- Max Speed 40 kts
- Sprint Speed of 35 kts gives Range of 1,000 nm
Summary of Chosen Motor System

• Motor alternatives:
  – Conventional COTS motor
  – Superconducting DC Homopolar motor
  – High Temperature Superconducting AC motor

• High Temperature Superconducting Synchronous AC Motor Selected
Integrated Power System

- IPS is an AC/DC hybrid zonal
- Total capacity is 103 MW
- 93 MW required for 40 knots, 6MW for ship service loads, 4 MW reserve
- Gas turbines produce 3 phase 13.8 kV volt AC
- All ship service loads distributed via 1000 volts DC
Sea Tentacle Electric Plant

13.8 K volts
3 Φ

Port HTS Motor

LM2500+

1000 volts
DC

Ship Service Loads

Bidirectional AC/AC converter (w/ galvanic isolation)

Allison

LM6000

13.8 K volts
3 Φ

Stbd HTS Motor

LM2500+
Zonal Distribution

- Superstructure
- Forward
- Forward E.R.
- Handling
- Aft E.R.
- Propulsion
Seakeeping Results

• Evaluate response in regular seas; varying ship speeds and headings.
• Within linear theory, evaluate response in random seas using regular wave results.
• Assume long-crested, fully developed seas.
• Set limiting values of the response and calculate the operating envelope.
• Adjust design parameters to achieve an acceptable operating envelope.
Limiting Values

• Assume the following limiting values for the responses:
  – Significant single amplitudes:
    • Ship roll: 5 deg.
    • Ship pitch: 3 deg.
    • Absolute vertical velocity at ramp: 2 m/sec
      – Depends on ramp (x,y) location
  – Expected number of events per hour:
    • Wetness (relative vertical motion hits zero) events at ramp: 30
      – Depends on ramp (x,y,z) location
Wetness Events

All Speeds; Wetness Events per Hour; Sea State 3; Aft Ramp; Height = 2
Operating Envelope

Operations can be sustained

Operations are unsafe
Design Selection

Ramp height at 2 m above calm waterline provides adequate operability region.
2 m clearance provides adequate operating envelope even for elevated sea states
Operability Index – Aft Ramp

Low Speeds, Aft Ramp, Sea States 1 through 5

Operability Index vs Height of Ramp

Sea State: 1 2 3 4 5
Operability Index – Side Door

Low Speeds, Side Door, Sea States 1 through 5

Operability Index

Sea State:

Sea State: 1 2 3 4 5
Wave Generation

Kelvin wave pattern calculated using a 3-D panel method

V=15 Kts

V=20 Kts
Agenda

✓ Introduction and Overall Design Process
✓ Payload and Operational Concept
✓ Combat Systems
✓ Hull, Mechanical, and Electrical (HM&E)

• Summary
  – Manning
  – Cost
  – Geographical Transit Ranges
  – Requirements Summary
  – Conclusion
Manning

• Reduced manning possible concepts studied on DD(X) and TAK-E(X):
  – Human Centered Design and Reasoning Systems
  – Reliability and Condition Based Maintenance vs. Preventative Maintenance System (PMS)
  – Automated Damage Control
  – Reduced Watch Stations
  – Self Service Laundry
  – Innovative Messing
## Core Watch Stations

<table>
<thead>
<tr>
<th>WATCH STATION LOCATION</th>
<th>WATCH STATION NAME</th>
<th>NUMBER OF PERSONNEL</th>
<th>SUB - TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge</td>
<td>Officer of the Deck (OOD)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Junior OOD</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quartermaster of the Watch</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Combat Information Center (CIC)</td>
<td>Tactical Action Officer</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CIC Supervisor</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air Search Radar Operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface Radar Operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sonar Operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gun Operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Missile Operator</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Electronic Warfare Operator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aircraft Controller</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>Engineering Officer of the Watch</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>13</strong></td>
<td></td>
</tr>
</tbody>
</table>
Two methods were used to estimate cost:

- Top-down method using data from the Congressional Budget Office (CBO), Visibility and Management of Operating and Support Costs (VAMOSC), and others
- Bottom-up method using detailed weight-based Cost Estimating Relationships (CERs), labor costs, and specialized equipment costs
- The bottom-up method produced results that were less than 10% lower than the top-down method
- For brevity, only the top-down method is detailed on the following slides
## Platform Comparisons

<table>
<thead>
<tr>
<th>Ship Class</th>
<th>Type</th>
<th>Displacement (tons)</th>
<th>Crew Size</th>
<th>Armament</th>
<th>Missions</th>
<th>Follow ship procurement cost (FY05 $M)</th>
<th>O&amp;S (FY05 $M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD(X)</td>
<td>General-Purpose Destroyer</td>
<td>16,000</td>
<td>130</td>
<td>2 Helo, 2 155-mm AGS, 128 VLS</td>
<td>Land attack, ASW</td>
<td>* 3,200</td>
<td>40.8</td>
</tr>
<tr>
<td>DDG-51 (II)</td>
<td>Guided-Missile Destroyer</td>
<td>9,200</td>
<td>340</td>
<td>AEGIS, 2 Helo, 1 5-inch, 96 VLS</td>
<td>Long-range air and missile defense, land attack, open-ocean ASW</td>
<td>1,800</td>
<td>31.2</td>
</tr>
<tr>
<td>Sea TENTACLE</td>
<td>Focused-Mission Combatant</td>
<td>7,000</td>
<td>100</td>
<td>2 Helo, 2 Millenium gun, 16 VLS, AMRFS, UUV, USV, UAV launch/recove r and support</td>
<td>Littoral and open-ocean ASW, maritime interception</td>
<td>* 900</td>
<td>15.9</td>
</tr>
<tr>
<td>FFG(X)</td>
<td>Guided-Missile Frigate</td>
<td>6,000</td>
<td>120</td>
<td>2 Helo, 5-inch gun, 48 VLS</td>
<td>Convoy escort, maritime interception, open-ocean ASW</td>
<td>* 700</td>
<td>UNK</td>
</tr>
<tr>
<td>FFG-7</td>
<td>Guided-Missile Frigate</td>
<td>4,100</td>
<td>221</td>
<td>2 Helo, 1 76-mm gun, 6 Torpedo Tube</td>
<td>Convoy escort, maritime interception, open-ocean ASW</td>
<td>300</td>
<td>26.1</td>
</tr>
</tbody>
</table>

*Courtesy of Congressional Budget Office, Congressional Research Service, VAMOSC and Northrup Grumman*
### Lead Ship Cost Estimate

(in millions of 2005 dollars)

<table>
<thead>
<tr>
<th></th>
<th>Estimated Cost</th>
<th>Primary Basis of Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detail Design</strong></td>
<td>200</td>
<td>FFG(X)/LCS Analogies</td>
</tr>
<tr>
<td><strong>Infrastructure Upgrade</strong></td>
<td>250</td>
<td>Catamaran Hull Construction</td>
</tr>
<tr>
<td><strong>Production Costs:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic Construction</td>
<td>990</td>
<td>FFG(X) Analogy</td>
</tr>
<tr>
<td>VLS</td>
<td>16</td>
<td>FFG(X) Analogy</td>
</tr>
<tr>
<td>Advanced Combat Systems</td>
<td>200</td>
<td>AMFRS</td>
</tr>
<tr>
<td>Suite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catamaran Construction</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Total Lead Ship Cost** | ~1,750

*Figures courtesy of Congressional Budget Office assuming 3% inflation rate*
Guam 10-day Striking Range

3400 nm
Diego Garcia 10-day Striking Range

3400 nm
Sasebo 3-day Striking Range

1000 nm
Arabian Gulf 3-day Striking Range

1000 nm
## Critical Design Parameter Results

<table>
<thead>
<tr>
<th>Category</th>
<th>Threshold</th>
<th>Objective</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Availability</td>
<td>0.85</td>
<td>0.95</td>
<td>N/A</td>
</tr>
<tr>
<td>Hull Service Life</td>
<td>20 years</td>
<td>30 years</td>
<td>N/A</td>
</tr>
<tr>
<td>Draft @ Full Load</td>
<td>8 m</td>
<td>5 m</td>
<td>5.1 m</td>
</tr>
<tr>
<td>Max Speed</td>
<td>30 + kts</td>
<td>40 + kts</td>
<td>40 kts</td>
</tr>
<tr>
<td>Range @ Max Speed</td>
<td>1000 nm</td>
<td>1500 nm</td>
<td>920 nm (1045 nm @ 35 kts)</td>
</tr>
<tr>
<td>Range @ Cruise Speed</td>
<td>3500 nm</td>
<td>4500 nm</td>
<td>5400 nm (20 kts)</td>
</tr>
<tr>
<td>Large UUV Capacity</td>
<td>40</td>
<td>50+</td>
<td>50 (48 SP, 2 WLD-1)</td>
</tr>
<tr>
<td>Hvy Wt UUV capacity</td>
<td>80</td>
<td>100+</td>
<td>110</td>
</tr>
<tr>
<td>Cargo Weight</td>
<td>400 MT</td>
<td>800 MT</td>
<td>570 MT</td>
</tr>
<tr>
<td>Cargo Volume</td>
<td>5000 m³</td>
<td>6000 m³</td>
<td>5500 m³</td>
</tr>
<tr>
<td>Small Boat (7 m RHIB)</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>USV (11 m RHIB)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UUV/USV/UAV Launch Recover</td>
<td>Sea State 3</td>
<td>Sea State 4</td>
<td>Sea State 4</td>
</tr>
<tr>
<td>Aviation Support</td>
<td>One 7000 lb VTUAV</td>
<td>VTUAV (2)/ SH-60R</td>
<td>VTUAV (2)/ SH-60R(2)</td>
</tr>
<tr>
<td>Aircraft Launch / Recover</td>
<td>VTUAV</td>
<td>VTUAV/SH-60R</td>
<td>VTUAV/SH-60R</td>
</tr>
<tr>
<td>UNREP MODES</td>
<td>RAS, CONREP, VERTREP</td>
<td>RAS, CONREP, VERTREP</td>
<td>RAS, CONREP, VERTREP</td>
</tr>
<tr>
<td>Core Crew Size</td>
<td>≤130</td>
<td>≤100</td>
<td>Approx 110</td>
</tr>
<tr>
<td>Crew Accommodations</td>
<td>125</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Provisions</td>
<td>30 days</td>
<td>45 days</td>
<td>30 days</td>
</tr>
</tbody>
</table>
Top Level Requirements Revisited

- Deploy, retrieve, and regenerate large UUVs semi-clandestinely
- Sensor assets required to provide Pd 0.8 across contested OA (6,700 NM2) within 10 days
- Provide logistic support necessary to sustain SoS for 30 days
- Communicate on the following circuits:
  - High Band Width Air/Space Line of Sight (LOS)
  - LOS Voice
  - OTH Voice
  - Underwater Data
- Launch, recover, and control a 7,000 lb UAV
- Deploy box-launcher weapons and torpedoes for enemy engagement
Conclusions

• Employs a large, well designed, and flexible Payload configuration

• Combat Systems offer a robust mix of Offensive and Defensive capabilities that can conduct simultaneous ASW, SUW, & AAW operations

• HM&E design delivers high speed & high power in a unique and efficient manner

Sea TENTACLE is the platform of choice for Littoral ASW in 2025