Potential Benefits of Selected Applications of Cryo-Technology

Prepared by
R.J. Thome

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Topics

Superconducting Homopolar Motors & Projections for Ship Propulsion

Power Conversion System Benefits Of Reduced Temperature Operation

NOTE:
Search for the interplay of technical disciplines!!!!!
Homopolar Motor Outline

- Homopolar Motor Basics
- Homopolar Motor Technology Validation
- Advanced Motor Concept Development
  - Features of a 25 MW motor
- Integration of motor & power distribution
  - Comparison to IPS Philadelphia
  - Ship Integration Studies
Homopolar Motor Ship Propulsion Systems have been Demonstrated

Eg-Walters\textsuperscript{1}:

“In 1980 a 300 KW superconductive homopolar generator driven by a high speed gas turbine supplied power to a 400 HP superconductive homopolar motor during at-sea demonstrations aboard the Jupiter II test craft. This motor/generator set powered the Jupiter II through 13 sea trials.”

**Drawbacks:** liquid helium for coils & NaK brushes

**Overcome by New Technology:** Cryocoolers & Cu Fiber brushes\textsuperscript{2}

\textsuperscript{1}J.D. Walters, et al, “Reexamination of Superconductive Homopolar Motors for Propulsion”, Naval Engineers Journal, January 1998, p 107

\textsuperscript{2}D. Kuhlmann-Wilsdorf, “Metal Fiber Brushes”, in Electrical Contacts, P.G. Slade, ed, Marcel Dekker, NY, 1999, p 943
Baseline with Multi-turn Armature, NbTi Coils, & Advanced Cu Fiber Brushes
Homopolar Motor Technology Validation Program for ONR

300 KW Test Stand Motor

Operated Successfully with SC magnet at full field and brushes at full current for a Full Scale motor

3.7 MW Motor

Under Final Assembly and Test

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Homopolar Motor Test Stand for 300KW and 3.7 MW motor tests
Homopolar Motor Rotor and Stator Segment

Rotor is a nested set of solid copper cylinders and discs  
Stator uses solid copper bars

Motor torque and torque reaction is on solid copper
Superconducting coils do not experience this torque
All fields and currents are DC
During motor current (torque) transients, the SC coils remain DC
SC coils are stationary; there are no rotating cold seals
Advanced Homopolar Motor Concept Evolution

2 SC coil baseline
• 1 armature on 1 shaft

(Same concept as 3.7 MW Technology Validation Motor)

3 SC coil advanced concept
• 2 armatures on 1 shaft
• Power increases by x2
• Length increases by <2
• Diameter is ~same
• Weight increases by <2
Conceptual Design for a 25 MW, 120 rpm Advanced Configuration Motor

3 SC coil advanced configuration with 2 armatures on 1 shaft

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Advanced Design: 3 SC Coils are in a Stationary Cryostat within the Rotating Torque Tube having 2 Armatures
Exploded View of 25 MW Advanced Homopolar Motor

- STATOR MODULES (16 REQD)
- IRON
- BRUSHES
- END CAP
- SUPPORT FRAME STRUCTURE
- END CAP
- DRIVE END
- 1 of 3 SUPERCONDUCTING COI LS
- TORQUE TUBE
- 1 of 2 ACTIVE ROTOR SECTIONS

GENERAL ATOMICS
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Estimated Weight Distribution Among Components for 25 MW, 120 rpm Motor

<table>
<thead>
<tr>
<th>PART</th>
<th>MASS (kg)</th>
<th>QUANTITY</th>
<th>TOTAL MASS (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Drive Bearing</td>
<td>$1.42 \times 10^2$</td>
<td>1</td>
<td>$1.42 \times 10^2$</td>
</tr>
<tr>
<td>Outer Drive Bearing</td>
<td>$5.72 \times 10^2$</td>
<td>1</td>
<td>$5.72 \times 10^2$</td>
</tr>
<tr>
<td>Rear Bearing</td>
<td>$2.95 \times 10^2$</td>
<td>1</td>
<td>$2.95 \times 10^2$</td>
</tr>
<tr>
<td>Drive End Cap</td>
<td>$2.60 \times 10^3$</td>
<td>1</td>
<td>$2.60 \times 10^3$</td>
</tr>
<tr>
<td>Rear End Cap</td>
<td>$2.77 \times 10^3$</td>
<td>1</td>
<td>$2.77 \times 10^3$</td>
</tr>
<tr>
<td>Stator Segment</td>
<td>$9.63 \times 10^3$</td>
<td>2</td>
<td>$1.92 \times 10^4$</td>
</tr>
<tr>
<td>Outer Plate</td>
<td>$3.24 \times 10^3$</td>
<td>1</td>
<td>$3.24 \times 10^3$</td>
</tr>
<tr>
<td>Brush</td>
<td>10.7</td>
<td>60</td>
<td>$6.44 \times 10^2$</td>
</tr>
<tr>
<td>Iron Core</td>
<td>$2.64 \times 10^3$</td>
<td>2</td>
<td>$5.28 \times 10^3$</td>
</tr>
<tr>
<td>Rotor Segment</td>
<td>$1.14 \times 10^4$</td>
<td>2</td>
<td>$2.28 \times 10^4$</td>
</tr>
<tr>
<td>Inner Coil</td>
<td>$1.59 \times 10^3$</td>
<td>1</td>
<td>$1.59 \times 10^3$</td>
</tr>
<tr>
<td>Outer Coil</td>
<td>$1.24 \times 10^3$</td>
<td>2</td>
<td>$2.48 \times 10^3$</td>
</tr>
<tr>
<td>Bearing Mount Assembly</td>
<td>$7.31 \times 10^2$</td>
<td>1</td>
<td>$7.31 \times 10^2$</td>
</tr>
<tr>
<td>Coil Support Assembly</td>
<td>$1.83 \times 10^3$</td>
<td>1</td>
<td>$1.83 \times 10^3$</td>
</tr>
<tr>
<td>Rotor Housing</td>
<td>$6.31 \times 10^2$</td>
<td>1</td>
<td>$6.31 \times 10^2$</td>
</tr>
<tr>
<td><strong>Total Mass</strong></td>
<td></td>
<td></td>
<td>$6.48 \times 10^4$</td>
</tr>
</tbody>
</table>
The Bmax in the superconducting coils must be compatible with conductor and structure properties.

The high, large volume, Bmax on the armature is the major advantage of the Hpolar machine.
External Field from the 25 MW Motor is a Dipole plus a Quadrupole

COMPONENT: Magnetic Flux (Wb/m)
Minimum: 0.6
Maximum: 4
Increment: 0.1

Quadrupole near motor
Dipole far field

\[ B \sim C_1 r^{-4} + C_2 r^{-3} \]

Decrease far field by:
- "balancing" SC coils
- use thick motor housing
- use thin motor housing plus shielding (pod)
A Shaped Pod Shields Magnetic Field from 25 MW Homopolar Motor, therefore, use a thin motor housing

The magnetic field is DC and drops to the level of the Earth’s field in ~1 m from the pod surface.
Outline of an Integrated DC Power Distribution System

- **TURBINE** → **RECTIFIED ALTERNATOR**
  - 2600 vdc

  **DC-DC Buck Converter**
  - 2000-800 vdc

  **DC-AC Inverter**
  - 800 vdc – 450 vac

  **Ship Service**

- **Propulsion** → **Buck Converter DC - DC**
  - 0-600 vdc

  **Superconducting DC Homopolar Motor**
PCS Studies Showed:

- **Least Compact = Transformer & Rectifier**

- **More Compact = AC with Hi f Converter**

- **Most Compact = Rectified AC with Buck Converter**

**General Atomics**

**EMS Division**
### 19 MW, 150 rpm, Advanced Homopolar Motor System Weight & Volume Comparison with AC Induction Motor System at Philadelphia

<table>
<thead>
<tr>
<th></th>
<th>IPS AC Induction Weight, t</th>
<th>GA Homopolar Weight, t</th>
<th>IPS Induction Volume, m³</th>
<th>GA Homopolar Volume, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>50.5</td>
<td>51.5</td>
<td>34.7</td>
<td>38</td>
</tr>
<tr>
<td>Converter</td>
<td>9.0</td>
<td>NA</td>
<td>21.0</td>
<td>NA</td>
</tr>
<tr>
<td>Filter</td>
<td>4.3</td>
<td>NA</td>
<td>10.6</td>
<td>NA</td>
</tr>
<tr>
<td>Rectifier</td>
<td>NA</td>
<td>1.6</td>
<td>NA</td>
<td>3.4</td>
</tr>
<tr>
<td>Buck Converter</td>
<td>NA</td>
<td>3.4</td>
<td>NA</td>
<td>9.3</td>
</tr>
<tr>
<td>Motor</td>
<td>117.4</td>
<td>44.6</td>
<td>44.7</td>
<td>7.5</td>
</tr>
<tr>
<td>Total</td>
<td>181.2</td>
<td>103+5</td>
<td>111.0</td>
<td>59.2</td>
</tr>
</tbody>
</table>

Note: Hpolar uses the same generator, includes 5t for heavier bus, & 2 t and 1 m³ for cryocooler.
Preliminary Study on Ship Integration with Gibbs and Cox

• Surface Combatant
• G&C International Frigate
• 6585 t
• 28 kts
• 2 x 19 MW @ 150 rpm
## G&C International Frigate with IPS AC System

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Weight/Unit (kg)</th>
<th>Total Weight (kg)</th>
<th>L x W x H (m)</th>
<th>Unit Volume (m³)</th>
<th>Total Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGM-1 Power Generation Submodule, 21 MW</td>
<td>2</td>
<td>121,146</td>
<td>242,291</td>
<td>13.1 x 3.6 x 5.7</td>
<td>268.1</td>
<td>536.2</td>
</tr>
<tr>
<td>PFM-15th Harmonic Filter</td>
<td>2</td>
<td>6,218</td>
<td>12,436</td>
<td>4.5 x 1.8 x 1.8</td>
<td>14.6</td>
<td>29.2</td>
</tr>
<tr>
<td>PMM-1 Converter</td>
<td>2</td>
<td>12,973</td>
<td>25,945</td>
<td>5.0 x 1.8 x 1.8</td>
<td>16.2</td>
<td>32.4</td>
</tr>
<tr>
<td>PFM-1 Harmonic Filter Switchgear</td>
<td>2</td>
<td>1,388</td>
<td>2,776</td>
<td>2.0 x 1.1 x 1.8</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td>PMM-1 Dynamic Braking Resistor</td>
<td>6</td>
<td>373</td>
<td>2,238</td>
<td>0.8 x 0.9 x 0.8</td>
<td>0.6</td>
<td>3.5</td>
</tr>
<tr>
<td>PMM-1 Motor, 19 MW</td>
<td>2</td>
<td>111,715</td>
<td>223,430</td>
<td>4.5 x 4.8 x 4.0</td>
<td>86.4</td>
<td>172.8</td>
</tr>
<tr>
<td>PMM-1 Thrust/Journal Bearing</td>
<td>2</td>
<td>10,028</td>
<td>20,056</td>
<td>1.9 x 1.5 x 1.5</td>
<td>4.3</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>529,172</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>790.7</strong></td>
</tr>
</tbody>
</table>

**GENERAL ATOMICS**

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G&C International Frigate with SC Homopolar Motor & DC Distribution

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Weight/Unit (kg)</th>
<th>Total Weight (kg)</th>
<th>L x W x H (m)</th>
<th>Unit Volume (m³)</th>
<th>Total Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGM-1 Power Generation Submodule, 21 MW</td>
<td>2</td>
<td>121,146</td>
<td>242,291</td>
<td>13.1 x 3.6 x 5.7</td>
<td>268.1</td>
<td>537.2</td>
</tr>
<tr>
<td>Water Cooled Rectifier Assembly</td>
<td>2</td>
<td>1,600</td>
<td>3,200</td>
<td>1.75 x 0.92 x 2.13</td>
<td>3.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Buck Converter</td>
<td>2</td>
<td>3,400</td>
<td>6,800</td>
<td>2 x 2 x 2.33</td>
<td>9.3</td>
<td>18.6</td>
</tr>
<tr>
<td>Braking Resister</td>
<td>2</td>
<td>850</td>
<td>1,700</td>
<td>1.83 x 1.22 x 1.22</td>
<td>2.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Water Cooled DC Cable</td>
<td>-</td>
<td>-</td>
<td>7,568</td>
<td>100 x 0.08 x 0.08</td>
<td>-</td>
<td>0.7</td>
</tr>
<tr>
<td>Circuit Breaker</td>
<td>3</td>
<td>800</td>
<td>2,400</td>
<td>1 x 1 x 2</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>SC Homopolar Motor, 19 MW</td>
<td>2</td>
<td>44,600</td>
<td>89,200</td>
<td>2.6 x 1.91 x 1.91</td>
<td>9.5</td>
<td>19.0</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>2</td>
<td>2,000</td>
<td>4,000</td>
<td>1 x 1 x 1</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>PMM-1 Thrust/Journal Bearing</td>
<td>2</td>
<td>10,028</td>
<td>20,056</td>
<td>1.9 x 1.5 x 1.5</td>
<td>43</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Total 377,215                                    Total 598.3

Same Frigate with Homopolar System saves 152 t & 193 m³!!
DC Distribution on the G&C Frigate Would Delete PCM-4’s and Save an Additional 40 t and 33 m³!

AC System: 8xPCM2 + 8xPCM1 + 3xPCM4 = 102 t & 126 m³
DC System: 8xPCM2 + 8xPCM1 + 0xPCM4 = 62 t & 93 m³

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G&C International Frigate with Pods

Max pod azimuth = 58 deg

Side thrust configuration

Homopolar motors allow a reasonable arrangement
Homopolar Propulsion Motor Conclusions

- **Technology Validation Program**
  - 300 KW Test Stand Motor has operated SC Coils & brushes at levels required for a full scale motor
  - 3.7 MW Motor is under construction-test in 2005

- **Advanced Design, Full Scale Homopolar Motor**
  - Conceptual Design Complete
  - Compact, Lightweight & Pod Compatible

- **Ship Integration Studies**
  - Show significant weight & volume reductions for a DC Homopolar System compared to AC System with an Induction Motor
  - Show pod compatibility at frigate level (& larger vessels)

Methodology to Determine Power Conversion System Benefits of Reduced Temperature Operation

3 hardware systems are being built with components that may benefit from reduced temperature operation:

- Homopolar Motor Ship Electric Drive
- Integrated Power System (IPS)
- Electromagnetic Aircraft Launch System (EMALS)

Study Approach:
Define baseline 300K system configurations for 3 systems
Perform conceptual design of elements for 80K systems
Assess system impact & potential benefits of 80K
Recommend areas for high impact R&D
Homopolar Motor Ship Electric Drive Baseline:
Transfer 25 MW DC from Terminals of Generator to Terminals of Motor

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight kg</th>
<th>Volume m³</th>
<th>Losses %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>34,100(1)</td>
<td>40.4(1)</td>
<td>5.08(1)</td>
</tr>
<tr>
<td>Cryodrive</td>
<td>16,900(0.50)</td>
<td>25.9(0.64)</td>
<td>2.47(0.49)</td>
</tr>
</tbody>
</table>

Cryo-Needs:
- Rectifier
- Converter
- 50 KA DC Cable
- Cryocooler

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Homopolar Motor Cryo-drive

Generator
- 3-Phase Generator 700 V, 10 kA
- 3 Water-cooled AC cables, 15 m ea.

Rectifiers
- 300-K Control Modules
- Terminations: 85 A rms
- Terminations: 764 A rms

Buck Converter
- 50-kA de Cable
- 50-kA dc Cable
- Coaxial HTS Cables, 50 m ea.
- Cryogenic Container
- 3 Water-cooled AC cables, 15 m ea.

Homopolar Motor
- Rectifier: 77-K power electronics leg; 46 modules per leg; 1600 V, 11.3 kA
- Buck Converter: 77-K power electronics arm; 100 modules per arm; 550 V, 50 kA
- Buck Converter 77-K input, output Capacitors
- 50-kA HTS Cable

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IPS Integrated Fight-Through Cryo-Power

Baseline:
Transfer 3 MW ~60 m from input to PCM-4 to output of PCM-2’s

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight</th>
<th>Volume</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>m³</td>
<td>%</td>
</tr>
<tr>
<td>Conventional</td>
<td>27,500</td>
<td>32.2</td>
<td>10.4</td>
</tr>
<tr>
<td>Cryodrive</td>
<td>12,150</td>
<td>10.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Cryo-Needs:
- Rectifier
- Converter
- Inverter
- 1 KA DC Cable
- Cryocooler
- HTS transformer
Cryo-Integrated Power System

Step-Down Transformer: 4160 Vac to 740 Vac, 6-Phase, 1150 A/Phase

Rectifiers
PCM-4

Buck Converters
PCM-1

AC Inverters
PCM-2

Rectifier: 77-K power electronics leg; 9 modules per leg; 1 kVdc, 1.5 kA

Buck Converter: 77-K power electronics arm; 4 modules per arm; 1 kV, 750 A

Buck Converter 77-K input, output Capacitors

AC Inverter: 77-K power electronics leg; 4 modules per leg; 460 Vac, 950 A

Terminations: 31 A rms, 0.02 cm² cables

Terminations: 25 A rms, 0.06 cm² cables

Terminations: 65 A rms, 0.13 cm² cables

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Electromagnetic Aircraft Launch System
Baseline: Transfer 50 MW with 1% duty cycle from terminals of generator to terminals of LIM

Flywheel Generator    Rectifier    Inverter    Block Switch LIM

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight</th>
<th>Volume</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>20,500</td>
<td>33.0</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>Cryodrive</td>
<td>18,000</td>
<td>17.6</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>(0.88)</td>
<td>(0.53)</td>
<td>(1.07)</td>
</tr>
</tbody>
</table>

Cryo-Needs:
• Rectifier
• Inverter
• 4.2 KA DC Cable
• Cryocooler
Cryo-EMALS System

Generator

Rectifiers

Inverter

Linear Induction Motor

3 Air-cooled AC cables, 15 m ea.

Flywheel Generator 1550 Vac

3 Air-cooled AC cables, 15 m ea.

Flywheel Generator 1550 Vac

Coaxial HTS dc cable, 50 m long

Coaxial HTS dc cable, 50 m long

Air-cooled ac cable, 100 m long

Air-cooled ac cable, 100 m long

Terminations: 772 A rms

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Rectifier: 77-K power electronics leg; 10 modules per leg; 2200 V, 3.9 kA

Inverter: 77-K power electronics arm; 30 modules per arm (69 mods per 300-K control module; 2200 V, 11.3 kA

77-K Inverter input Capacitor, 25 mF, 2200 V

1 of 3 Power Trains
Top Level Summary

If cryocooled components are used in place of conventional designs,

• The Homopolar Motor Power Conversion System and the Integrated Power System Modules are “steady state systems” that project to large savings in weight, volume and energy losses.

• The EMALS Power Conversion System has a very low duty cycle (~1%), but a steady state ambient cooling requirement, and does not exhibit a significant advantage if cryocooled.
# Ship Level Assessment of Cryo-Technologies by Syntek

<table>
<thead>
<tr>
<th>Ship Missions</th>
<th>Ship Platforms (in-hull &amp; pod)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibious Assault</td>
<td>LPD 17</td>
</tr>
<tr>
<td>Destroyer</td>
<td>DDG-51</td>
</tr>
<tr>
<td>Frigate</td>
<td>NFR 90</td>
</tr>
</tbody>
</table>

What is impact of Cryo-technology relative to baseline platforms?
Baseline Architecture

• All ships have an Integrated Power System (IPS) consisting of:
  – AC Power Generation Plant
  – Common Bus
  – DC Zonal Ship Distribution System
  – Advanced Induction Motor

• Baseline Shipboard Power System similar to US Navy IPS LBES configuration
Eg-Destroyer Operational Profile

- **Propulsion (In_Hull @ POD)**
  - 2 x 36,500 kW @ 170 RPM
  - Advanced Induction Motor + PWM Drive

- **Ship Power Generation**
  - 4160 VAC, 60Hz, 3Φ
  - 2 x 21,000 kW (LM2500)
  - 1 x 3,000 kW (501k)

- **Ship Service Distribution System**
  - 6,000 kW DC Zonal
  - 8 x 2,000 kW PCM-4
  - 16 x 750 kW PCM-1
  - 16 x 500 kW PCM-2

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Cryo-technologies Assessed

1 Superconducting DC Homopolar Motor
2 Cryo-cooled Motor Drive
3 Cryo-cooled Distribution System (IPS)
4 Cryo-cooled DC Main Bus
Ship-Level Metrics

Payload Fraction =
(Armament + Electronic Equipment + Fuel + Cargo) divided by (Ship Total Weight)

Ship Mobility Efficiency =
[integrated (drag x speed x time)] divided by (energy content of fuel used)

Sustained Speed =
Speed at 80% max continuous power

Affordability =
Procurement Cost & Annual Operating Cost
### Impact of Cryo-technology Relative to Baseline Platforms

<table>
<thead>
<tr>
<th>Platform</th>
<th>%change in Payload Fraction</th>
<th>%change in Ship Mobility Efficiency</th>
<th>%change in Sustained Speed</th>
<th>%improvement in Procurement Cost</th>
<th>%improvement in Annual Operating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroyer (in hull)</td>
<td>13.0</td>
<td>12.3</td>
<td>3.2</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Destroyer (pod)</td>
<td>10.0</td>
<td>14.3</td>
<td>2.8</td>
<td>2.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Frigate (in hull)</td>
<td>13.5</td>
<td>11.3</td>
<td>4.2</td>
<td>3.3</td>
<td>4.8</td>
</tr>
<tr>
<td>Frigate (pod)</td>
<td>10.9</td>
<td>11.8</td>
<td>3.5</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Amphib (in hull)</td>
<td>10.1</td>
<td>20.7</td>
<td>9.9</td>
<td>5.7</td>
<td>6.3</td>
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<tr>
<td>Amphib (pod)</td>
<td>9.9</td>
<td>15.2</td>
<td>9.1</td>
<td>5.2</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Cryo-technologies are Beneficial for all cases !!
High Impact Power Electronics R&D

- use discrete MOSFET technology to demonstrate improved efficiency & functionality
- develop MOSFET chip technology to demonstrate improved efficiency, weight and size
- integrate MOSFET technology into power modules, subsystems, and demonstrate a ~1 MW power train
Outline of Module Development to ~100 KW Level and Integrated PCM Power Train Demonstration at ~1 MW Level
High Impact Cryo-component R&D

- pursue compact 77K pulse tube cryocooler technology
- demonstrate high current DC HTS cable

**Challenge**: develop HTS termination that allows cable replacement without complete system warm-up

**Challenge**: develop ~100 KW power module that can be “hot swapped” (ie- system cold and operating)
Line Replaceable Unit Needs Cryo-development

100 kw in PCM-1

Could be several hundred kw in a cryosystem
Conclusions

Operation of Power Conversion Systems at 80K
-can offer significant reductions in size, weight, and losses depending on mission & configuration

High Impact R&D Areas:
- 80K power electronics: board, module, power train
- high current DC HTS cable
- advanced 77K cryocoolers
- HTS termination (detach without system warm-up)
- cryopower module that can be “hot swapped”