Combat Vehicle Engine Selection Methodology Based on Vehicle Integration Considerations

US Army RDECOM / TARDEC

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### Combat Vehicle Engine Selection Methodology Based on Vehicle Integration Considerations

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Engine Selection Methodology

- Definition of the Propulsion System for Military Applications
- Advanced Integrated Propulsion System (AIPS) Power Pack
- Assessment of the Overall System Power Density Potential
  - Cooling System and Parasitic Fan Power Sizing
  - Inlet and Exhaust System Impact
  - Mission Fuel Determination
  - Propulsion System Volume Estimates
- Conclusions
Combat Vehicle Problem
Power Dense Engine Not Sufficient

Need high power density of complete propulsion system *
- Engine
- Transmission including steering and brakes for tracked vehicle
- Cooling system
- Air filtration system
- Inlet and exhaust ducting
- Propulsion control system
- Accessory drive interfaces
- Batteries (for propulsion), wiring harnesses
- Fuel tanks and plumbing (sized for mission requirement)
- Final drives
- Maintenance access and clearances
- Unusable volume

* Power pack is that subset of the propulsion system that lifts or rolls out for replacement or periodic checks. Typically includes engine, transmission, air filtration, cooling and control systems.
Advanced Integrated Propulsion System (AIPS) Power Pack

- Began in 1982 to replace Abrams Main Battle Tank propulsion system
  - Increased Power Density
  - Improved Fuel Economy
  - Improved Maintainability

- Power Density Comparison
  - AIPS – 6 sprocket hp/ft³
  - Abrams – 3.26 sprocket hp/ft³

- AIPS Evaluated Power Systems
  - AIPS Turbine
  - AIPS Diesel
AIPS Turbine and Diesel Concentration

**Superior Technology for a Superior Army**

- High Efficiency Components
- Dense Component Packaging
- Reduction of Parasitic Losses Throughout the System
- Engine Technologies Specific to the Diesel or Turbine types

<table>
<thead>
<tr>
<th>Turbine AIPS Efforts</th>
<th>Diesel AIPS Efforts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Turbine Inlet Temp</td>
<td>Improved Engine Power Density</td>
</tr>
<tr>
<td>High Recuperator Effectiveness</td>
<td>Improved Fuel Consumption</td>
</tr>
<tr>
<td>Reduced Pressure Losses</td>
<td>Low Heat Rejection</td>
</tr>
<tr>
<td>Reduced Air Consumption</td>
<td>Higher Coolant Temp Technologies</td>
</tr>
<tr>
<td>Improved Fuel Efficiency</td>
<td></td>
</tr>
</tbody>
</table>
Volumetric Comparison: AIPS and Abrams Engine

AIPS Volume: 170 ft³

Abbots Volume: 291 ft³

Transmission = 20%

Fuel tanks = 23%

Exhaust = 1%

Unused space = 24%

Transmission = 14%

Fuel tanks = 26%

20% = Engine

11% = Batt/misc

10% = Cooling

5% = Air filter

11% = Engine

6% = Batt/misc

5% = Cooling

11% = Air filter

3% = Exhaust

10% = Unused space
Primary Differences Between AlPS and Abrams Propulsion Systems

- Density of Packaging
- Air Consumption Differences
- Fuel Consumption Differences
- Heat Rejection Differences
- Parasitic Loss Differences

1 & 5 are primarily controlled by propulsion integrator and component supporters

2, 3 & 4 are primarily controlled by engine developer
## AIPS vs. Marine Propulsion

**Superior Technology for a Superior Army**

During AIPS development a new power dense diesel appears

<table>
<thead>
<tr>
<th><strong>AIPS Diesel</strong></th>
<th><strong>Marine Diesel</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1500 rated HP @ 2600 rpm</td>
<td>1500 rated HP @ 1800 rpm</td>
</tr>
<tr>
<td>12 Cylinders</td>
<td>3 Cylinders</td>
</tr>
<tr>
<td>28 Liter Displacement</td>
<td>7 Liter Displacement</td>
</tr>
<tr>
<td>4 Stroke / Cycle</td>
<td>2 Stroke / Cycle</td>
</tr>
<tr>
<td>Single Stage VG Turbocharger</td>
<td>3 Stage Turbocharger</td>
</tr>
<tr>
<td>Synthetic Oil Cooling Fluid</td>
<td>Water / Glycol Cooling Fluid</td>
</tr>
<tr>
<td>340° F Max Coolant Temp Out</td>
<td>230° F Max Coolant Temp Out</td>
</tr>
<tr>
<td>Air to Oil After Cooling</td>
<td>Air to H₂O Jacket After Cooling</td>
</tr>
<tr>
<td>34 ft³ Engine Dunk Volume</td>
<td>20 ft³ Engine Dunk Volume</td>
</tr>
</tbody>
</table>

New diesel smaller but system analysis shows AIPS diesel propulsion system more power dense based on cooling alone.
Manned Ground Vehicle Integration

SUPErior TECHNOLOGY FOR A SUPERIOR ARMY

Early 2000s, Engine Program Development

- Known need for high power density propulsion system
- Unknown platform characteristics
  - Weight?
  - Front or Rear Propulsion?
  - Tracked or Wheeled Vehicle?
  - Power Pack Shape or Size?
- Engine development only – remainder of power pack later

Simple methodology developed for system power density potential considering only the engine development
Methodology Descriptions

Methodology addresses:
- Certain engine characteristics
- Required cooling system impacts
- Inlet & exhaust duct impact
- Impact of required onboard fuel

Methodology doesn’t address:
- Potential tight packaging
- Opportunity for synergistic parasitic reductions

Results in:
- System volume estimate
- Power density estimate
Methodology Estimates Space Claims or Volumes

Methodology involves estimating volumes for:

1. Engine
2. Transmission
3. Cooling System
4. Air Filtration System
5. Inlet & Exhaust Ducting
6. Controls
7. Miscellaneous
8. Batteries
9. Electrical Harness
10. Fuel System for Onboard Fuel
11. Final Drive
12. Clearance & Unusable Volumes

Sum of these = Propulsion System Volume
Methodology estimates net available power

- Engine Gross Horsepower
- Subtract Estimates For:
  - Installation Loss
  - Air Filter Scavenge Fan (if any)
  - Power Loss Due to Induction & Exhaust Restrictions
  - Transmission Power Losses
  - Final Drive Power Losses
- To Arrive at Estimated Net or Sprocket Horsepower
<table>
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<tr>
<th>Engine / Application Characteristics</th>
<th>AIPS Diesel Hot Day 6 In Core</th>
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<td>Engine Specific Heat Rejection [Btu / hp·min]</td>
<td>20</td>
<td>40</td>
<td>40</td>
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<td>Engine Induction Air Flow [lbs / hr]</td>
<td>14400</td>
<td>18500</td>
<td>18500</td>
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<tr>
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<td>0.39</td>
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<td>Vehicle Weight [tons]</td>
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**Cooling System Size / Parasitic (Fan) Power Sizing**

- Heat Exchanger Type: Oil to Air or H₂O to Air
- Power Pack Net Horsepower [hp]: 1077.4, 866.51, 947.92
- Fan Power [hp]: 103.26, 366.86, 265.10
- Cooling System Volume [ft³]: 25.80, 64.15, 60.31
### Methodology Applied to 28 liter AIPS 4 Stroke vs. 7 liter Marine 2 Stroke

**SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY**

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**Inlet and Exhaust System Impact**

| Air filter System Size [ft³]      | 10                            | 12.85                         | 12.85                         |
| Inlet and Exhaust System Volume [ft³] | 2.06                          | 2.64                          | 2.64                          |
| Installation Loss (Intake and Exhaust Loss) [hp] | 50.00                        | 50.00                         | 50.00                         |
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### Mission Fuel Determination @ 60 Net hp·hr / ton

| Gallons Fuel (for 60 net hp·hrs/ton) [gallons] | 266.91 | 349.81 | 319.77 |
| Weight of Fuel [lbs]                     | 1780.29 | 2333.21 | 2132.83 |
| Volume of Fuel [ft³]                    | 35.68   | 46.76   | 42.75  |
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#### Propulsion System Volume Estimate

| Total Propulsion System Volume [ft³] | 177.32                         | 224.24                          | 212.19                          |
| Sprocket Power [hp]                | 1055.85                        | 849.18                          | 928.96                          |
| Propulsion Power Density [sprocket hp / ft³] | 5.95                           | 3.79                            | 4.38                            |
Conclusions

- The most power dense engine doesn’t always provide the most power dense system.
- Widely different prime power systems like diesel or turbine engines, fuel cells or alternative fuel engines can be fairly compared on a system to system basis.
- Similar approach can be used to evaluate other concerns like weight or affordability.
Thank You!

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