14801

Combat Vehicle Engine Selection Methodology Based on Vehicle Integration Considerations

US Army RDECOM / TARDEC

Charles Raffa

Ernest Schwarz

John Tasdemir

SAE 2005-01-1545

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **13 APR 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Combat Vehicle Engine Selection Methodology Based on Vehicle Integration Considerations**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Raffa, Charles; Schwarz, Ernest; Tasdemir, John**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **USA TACOM 6501 E 11 MILE ROAD WARREN, MI 48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM TARDEC** 11. SPONSOR/MONITOR'S REPORT NUMBER(S) **14801**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at SAE World Congress 2005, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**18**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Engine Selection Methodology Outline

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

- 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

TARDEC
U.S. ARMY TANK-AUTOMOTIVE RESEARCH DEVELOPMENT AND ENGINEERING CENTER

Combat Vehicle Problem
Power Dense Engine Not Sufficient

Need high power density of complete propulsion system *

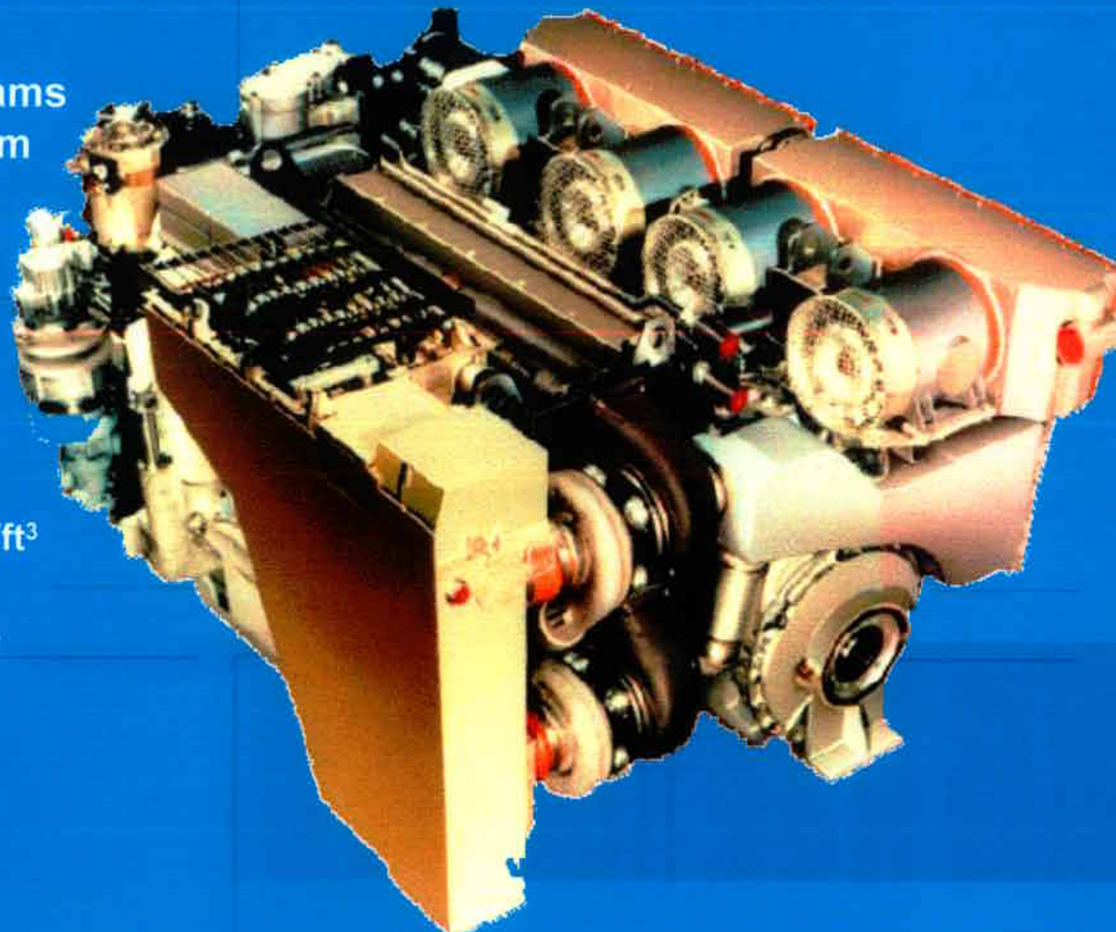
- ❖ Engine
- ❖ Transmission including steering and brakes for tracked vehicle
- ❖ Cooling system
- ❖ Air filtration system
- ❖ Inlet and exhaust ducting
- ❖ Propulsion control system
- ❖ Accessory drive interfaces
- ❖ Batteries (for propulsion), wiring harnesses
- ❖ Fuel tanks and plumbing (sized for 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

SUPERIOR **TECHNOLOGY** FOR A SUPERIOR **ARMY**

- 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/ft^3
  - Abrams – 3.26 sprocket hp/ft^3
- 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

Turbine AIPS Efforts

- Higher Turbine Inlet Temp
- High Recuperator Effectiveness
- Reduced Pressure Losses
  - Reduced Air Consumption
  - Improved Fuel Efficiency

Diesel AIPS Efforts

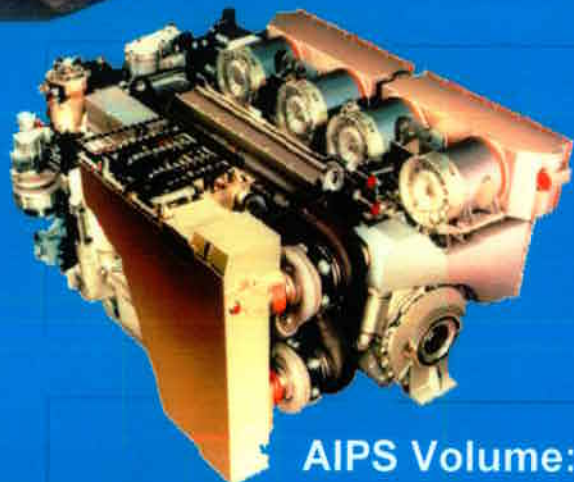
- Improved Engine Power Density
- Improved Fuel Consumption
- Low Heat Rejection
- Higher Coolant Temp Technologies

TARDEC

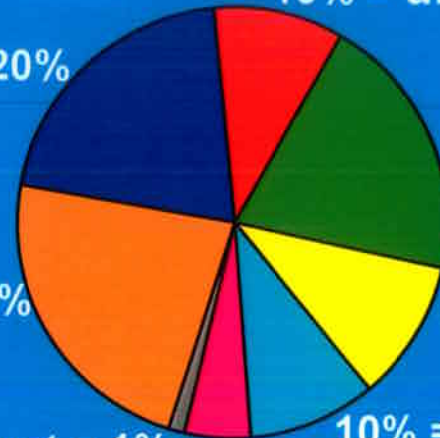
U.S. ARMY TANK-AUTOMOTIVE RESEARCH DEVELOPMENT AND ENGINEERING CENTER

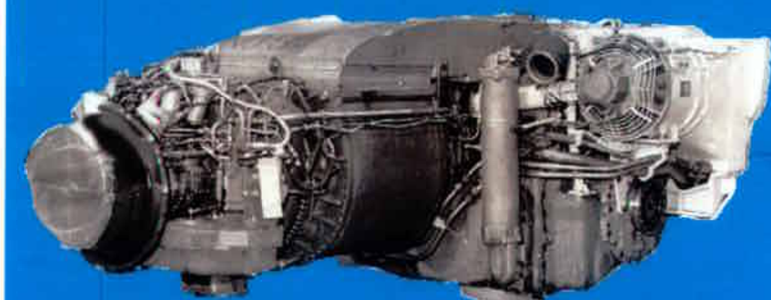
Volumetric Comparison: AIPS and Abrams Engine

SUPERIOR **TECHNOLOGY** FOR A SUPERIOR **ARMY**

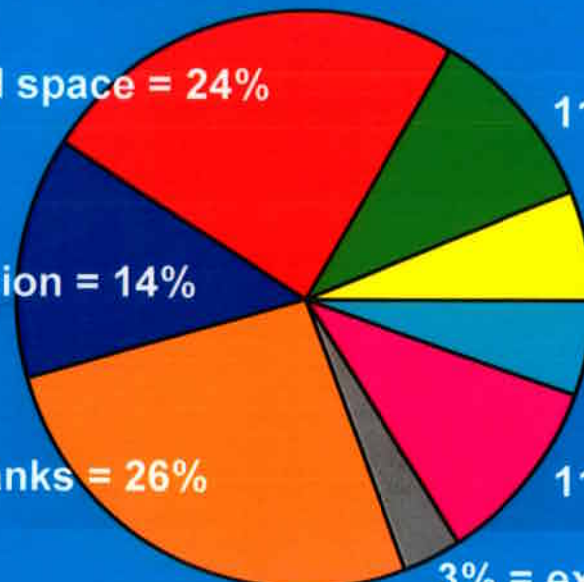


AIPS Volume: 170 ft^3





Abrams Volume: 291 ft^3



Power Density Differences

Primary Differences Between AIPS 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

AIPS Diesel

- 1500 rated HP @ 2600 rpm
- 12 Cylinders
- 28 Liter Displacement
- 4 Stroke / Cycle
- Single Stage VG Turbocharger
- Synthetic Oil Cooling Fluid
- 340° F Max Coolant Temp Out
- Air to Oil After Cooling
- 34 ft^3 Engine Dunk Volume

Marine Diesel

- 1500 rated HP @ 1800 rpm
- 3 Cylinders
- 7 Liter Displacement
- 2 Stoke / Cycle
- 3 Stage Turbocharger
- Water / Glycol Cooling Fluid
- 230° F Max Coolant Temp Out
- Air to H_2O Jacket After Cooling
- 20 ft^3 Engine Dunk Volume

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

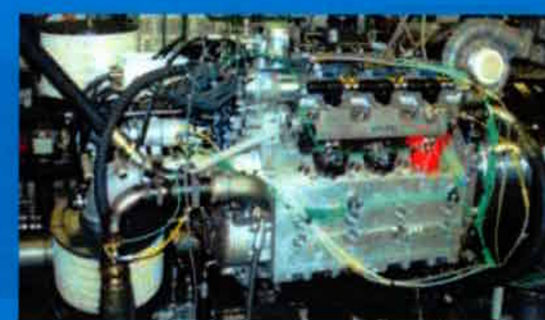
Manned Ground Vehicle Integration

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

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

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

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

Methodology Applied to 28 liter AIPS 4 Stroke vs. 7 liter Marine 2 Stroke

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

Engine	AIPS Diesel Hot Day 6 In Core	7L 2 Stroke Hot Day 5.3 In Core	7L 2 Stroke Hot Day 7.5 In Core
Engine / Application Characteristics			
Engine [hp]	1500	1500	1500
Engine Dunk Volume [ft^3]	34	20	20
Engine Specific Heat Rejection [Btu / hp·min]	20	40	40
Engine Induction Air Flow [lbs / hr]	14400	18500	18500
BSFC at Full Power [lbs / hp·hr]	0.37	0.39	0.39
Engine Heat Rejection [Btu / min]	30000	60300	60300
Vehicle Weight [tons]	60	60	60
Cooling System Size / Parasitic (Fan) Power Sizing			
Heat Exchanger Type: Oil to Air or H_2O to Air	Oil to Air	H_2O to Air	H_2O 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 [ft^3]	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

Engine	AIPS Diesel Hot Day 6 In Core	7L 2 Stroke Hot Day 5.3 In Core	7L 2 Stroke Hot Day 7.5 In Core
Engine Application Characteristics			
Engine [hp]	1500	1500	1500
Engine Dunk Volume [ft^3]	34	20	20
Engine Specific Heat Rejection [Btu / hp·min]	20	40.2	40.2
Engine Induction Air Flow [lbs / hr]	14400	18500	18500
BSFC at Full Power [lbs / hp·hr]	0.37	0.39	0.39
Engine Heat Rejection [Btu / min]	30000	60300	60300
Vehicle Weight [tons]	60	60	60
Inlet and Exhaust System Impact			
Air filter System Size [ft^3]	10	12.85	12.85
Inlet and Exhaust System Volume [ft^3]	2.06	2.64	2.64
Installation Loss (Intake and Exhaust Loss) [hp]	50.00	50.00	50.00

Methodology Applied to 28 liter AIPS 4 Stroke vs. 7 liter Marine 2 Stroke

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

Engine	AIPS Diesel Hot Day 6 In Core	7L 2 Stroke Hot Day 5.3 In Core	7L 2 Stroke Hot Day 7.5 In Core
Engine Application Characteristics			
Engine [hp]	1500	1500	1500
Engine Dunk Volume [ft³]	34	20	20
Engine Specific Heat Rejection [Btu / hp·min]	20	40.2	40.2
Engine Induction Air Flow [lbs / hr]	14400	18500	18500
BSFC at Full Power [lbs / hp·hr]	0.37	0.39	0.39
Engine Heat Rejection [Btu / min]	30000	60300	60300
Vehicle Weight [tons]	60	60	60
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

Methodology Applied to 28 liter AIPS 4 Stroke vs. 7 liter Marine 2 Stroke

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

Engine	AIPS Diesel Hot Day 6 In Core	7L 2 Stroke Hot Day 5.3 In Core	7L 2 Stroke Hot Day 7.5 In Core
Engine Application Characteristics			
Engine [hp]	1500	1500	1500
Engine Dunk Volume [ft^3]	34	20	20
Engine Specific Heat Rejection [Btu / hp·min]	20	40.2	40.2
Engine Induction Air Flow [lbs / hr]	14400	18500	18500
BSFC at Full Power [lbs / hp·hr]	0.37	0.39	0.39
Engine Heat Rejection [Btu / min]	30000	60300	60300
Vehicle Weight [tons]	60	60	60
Propulsion System Volume Estimate			
Total Propulsion System Volume [ft^3]	177.32	224.24	212.19
Sprocket Power [hp]	1055.85	849.18	928.96
Propulsion Power Density [sprocket hp / ft^3]	5.95	3.79	4.38

Conclusions

SUPERIOR **TECHNOLOGY** FOR A SUPERIOR **ARMY**

- 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.

TARDEC
U.S. ARMY TANK-AUTOMOTIVE RESEARCH DEVELOPMENT AND ENGINEERING CENTER


TARDEC
Thank You!
SUPERIOR TECHNOLOGY
FOR A
SUPERIOR ARMY
TARDEC
U.S. ARMY TANK-AUTOMOTIVE RESEARCH DEVELOPMENT AND ENGINEERING CENTER