



RDECOM

Army, Tank-Automotive RD&E Center, System Level Fuel Economy Analysis



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Army Material
Command (AMC)



Assistant Secretary of the Army
for Acquisition, Logistics &
Technology ASA(ALT)



RDECOM



TACOM LCMC



PEO
I

PEO
GCS

PEO
CS & CSS

PEO
Soldier

NSC

ARDEC

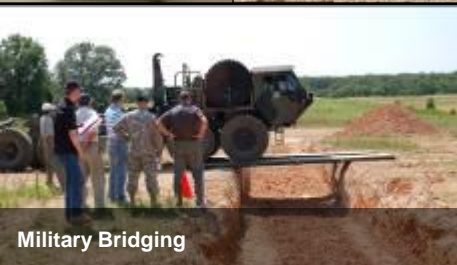




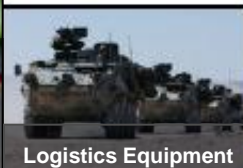
Army, Tank-Automotive RD&E Center, System Level Fuel Economy Analysis



MISSION: Provide full service life cycle engineering support to our TACOM LCMC customers (PEO GCS, PEO CS&CSS) and to develop and integrate the right technology solutions to the effectiveness for the current force and realize the superior capability of the future force to facilitate army transformation.



VISION: Be the first choice of technology and engineering expertise for ground vehicle systems and support equipment - today and tomorrow.



TARDEC is responsible for research, development and engineering support to more than **2800** Army systems and many of the Army's and DoD's top joint warfighter development programs:

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Ground Vehicle Power & Mobility

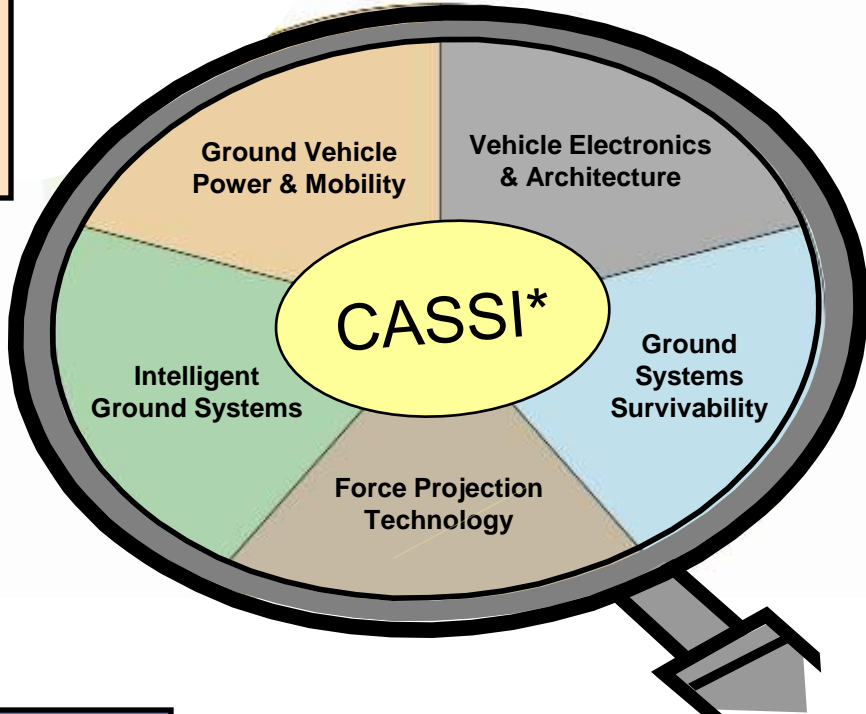
- Hybrid Electric
- Pulse Power
- Engines
- Fuel Cells
- Suspension
- Tracks

Vehicle Electronics & Architecture

- Power Architecture/Management
- Electronics Integration
- Data Architecture
- Condition Based Maintenance (CBM)
- Diagnostics/Prognostics

Intelligent Ground Systems

- Robotic Systems Technology
- Human-Robot Interaction
- Crew Interface and Automation
- Robotic Follower ATD



Ground System Survivability

- Active Defense
- Signature Management
- Laser Vision Protection
- Ballistic Protection
- Crew Survivability

Force Projection Technology

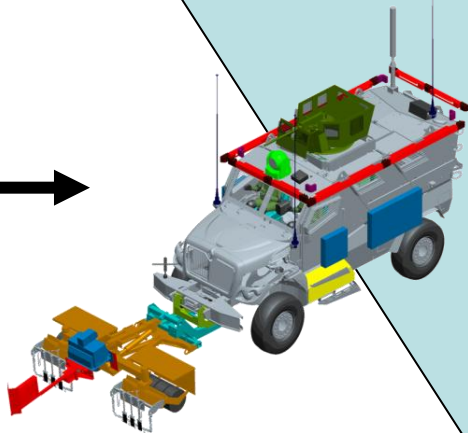
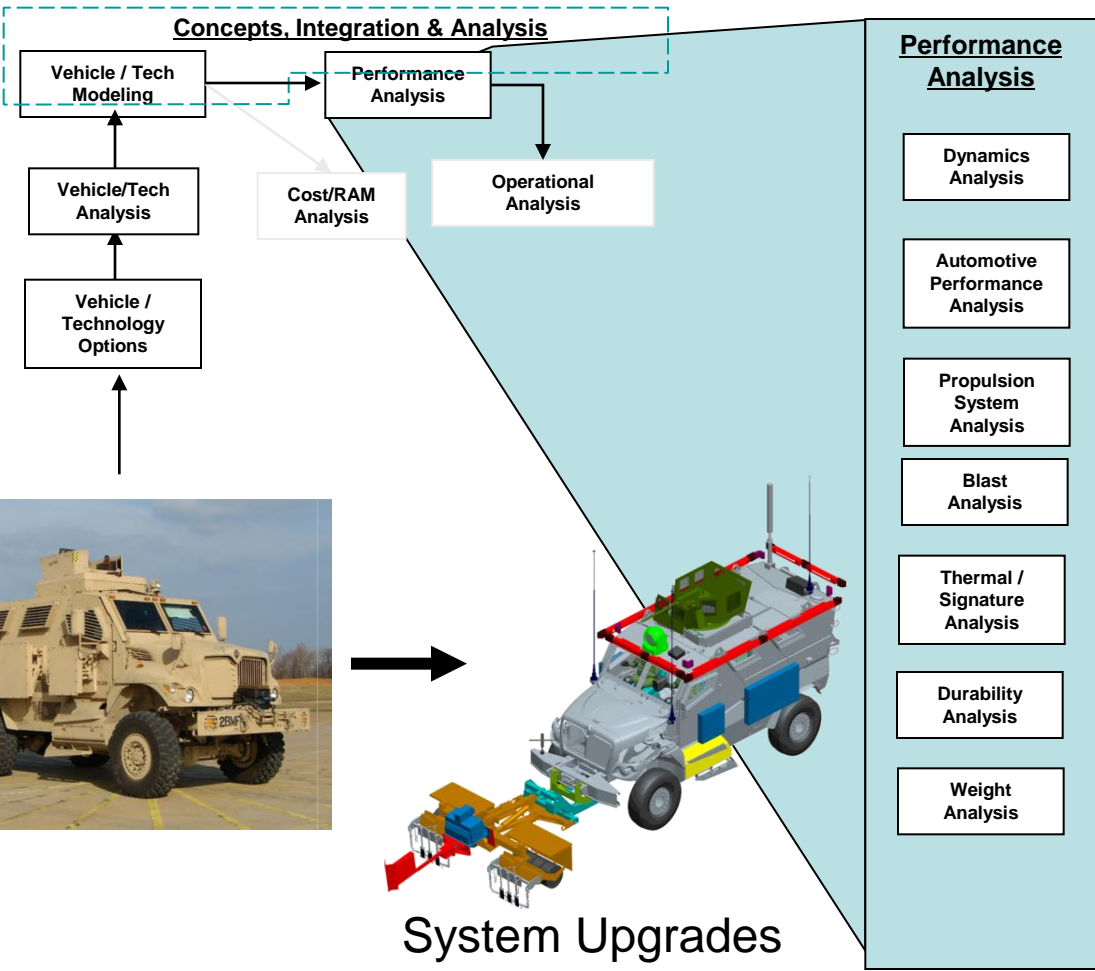
- Water Generation & Purification
- Petroleum, Oils & Lubricants
- Mechanical Countermine
- Combat Engineering/Bridging
- Gap Crossing
- Future Truck System

*** Concepts, Analysis, System Simulation & Integration**

- Requirements Capture, Concept Development, Program Formulation
- Dynamic/Structural Performance, Mathematical Modeling, Data Analysis
- Physical Validation, Systems-Level Validation
- High Performance Computing, Product & Program Data Management
- Integrated System-Level Demonstrators



HPC / Tools

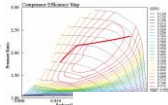


System Upgrades

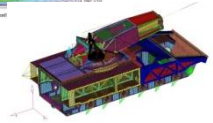
Dynamics Analysis ...



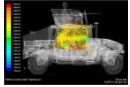
Powertrain Analysis...



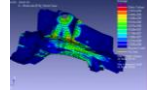
Crash Analysis.....



Thermal Analysis....



Structural Analysis.....



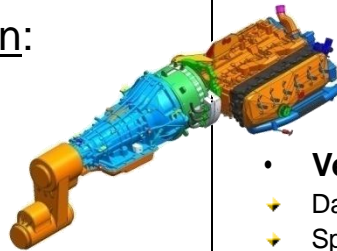
CAD



Analytical Tool Description:

Complex Analyses - Primary Modeling Software

- Driveline Components
- Alternative Power Plants
 - Battery, Fuel Cell, Motor/Gen
- Controls
- Expert Systems _ Automated Design of Experiments



VPSET – Vehicle Propulsion System Evaluation Tool

- Developed by TARDEC and Industry Partners
- Government Owned
- Ideal for SSEB Evaluations
- Quick Evaluation of Multiple Platforms and Architectures
- Scalable components

Potential Analysis Projects:

• Vehicle Upgrade Evaluations

- Dash Speed
- Speed on Grade
- Step Climb
- Drawbar Pull
- Fuel Economy
- Range
- Cooling
- Quantify on/off road mobility

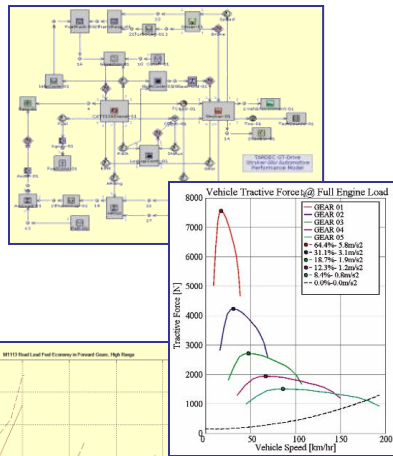
• Acquisition Support

- Virtual Tech Demonstrators
- CDD -> Automotive Performance Req'ts
- Section C, L & M M&S RFP Language
- SSEBs

Analysis Inputs/Outputs:

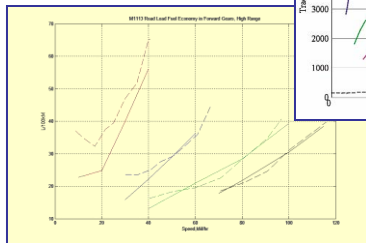
Inputs:

- Engine Torque/Horsepower
- Engine Fuel Map
- Engine Friction/Motoring
- Torque Converter
- Shift Schedule
- Transmission/Driveline Efficiencies
- Accessory Loads
- Mass/Inertia Properties



Outputs:

- Automotive Performance



Recent Analysis:

Propulsion System Models

- Bradley – Power Pack Upgrade
- Paladin – Bradley Power Pack Insertion
- MRAP – Weight and Accessory Load
- Abrams (Full Throttle Performance)
- Stryker
- Joint Light Tactical Vehicle
- FMTV
- HMMWV



GT SUITE - Vehicle and Driveline Simulation

Commercial Tool

Engine: map-based (general maps w/ scattered data) or higher-level models.

Torque converter: capacity factor/coeff. of perf., torque ratio, lockup clutch

Clutch: actuator, max. torque; “bristle” friction-based model, lockup

Transmission: discrete or CVT, inertias, efficiency, friction, shift strategies

Driveshaft: rigid or flexible

Differential, transfer case: Ratios, inertia, efficiency, friction

Planetary: ratios, inertias, friction

Axles: Inertias, friction

Brakes: actuator, torque map or friction-based model (like clutch)

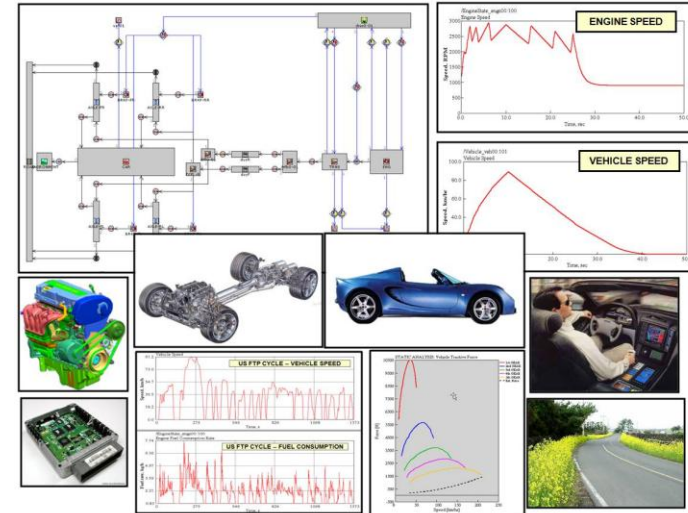
Vehicle: drag, lift, suspension and load distribution to axles

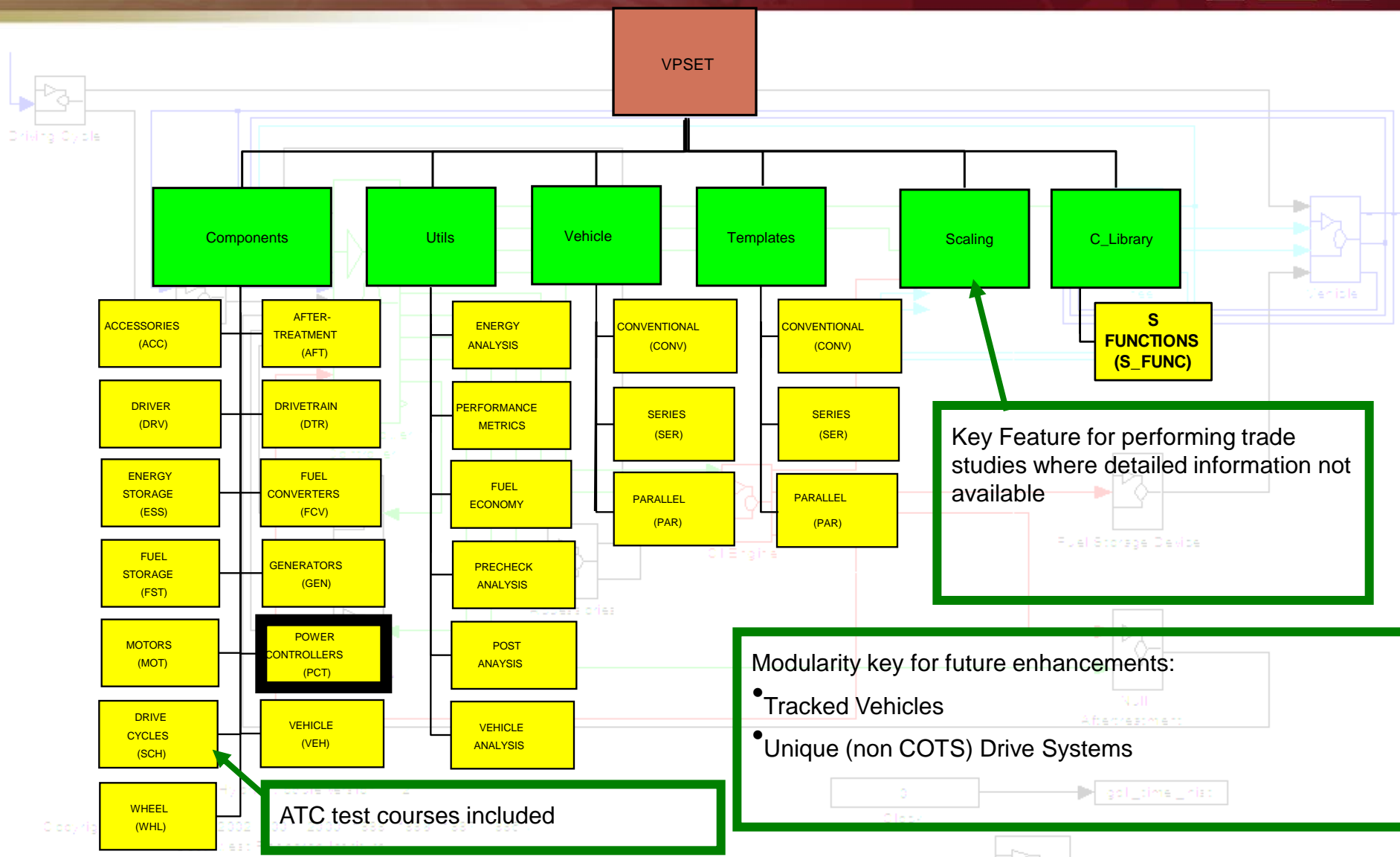
Tire: radius, rolling resistance, rigid or slipping tire (traction) model

Road: variable grade or elevation, curvature, rolling resistance and traction

Vehicle Driver: accelerator, brake, shift base controls and shifting behavior

Event Manager: user-friendly time, distance or event-based scheduling of successive driving events





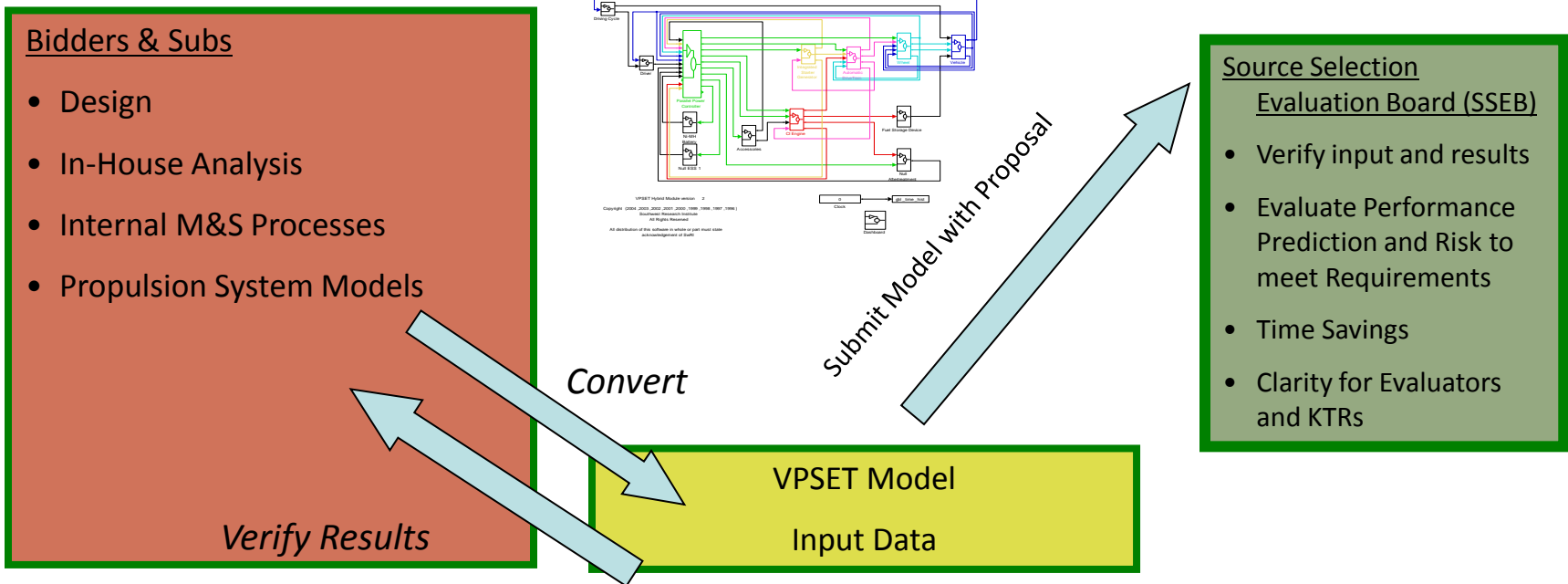
Key Feature for performing trade studies where detailed information not available

ATC test courses included

Modularity key for future enhancements:

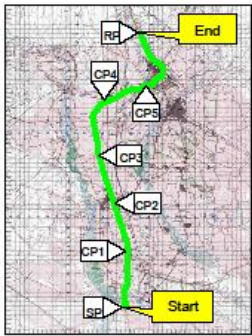
- Tracked Vehicles
- Unique (non COTS) Drive Systems

- Goal: Establish a standard for propulsion system analysis for Army vehicle system acquisitions
- Automotive performance analysis and fuel economy prediction
- Evaluation of multiple platforms and architectures (*conventional, parallel, series*)
- Realistic ???

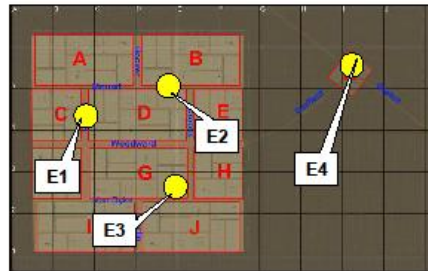


TARDEC Duty Cycle Experiments

Convoy Escort Example

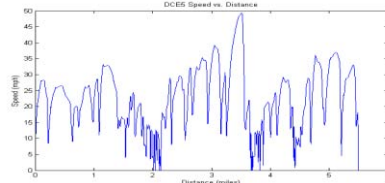
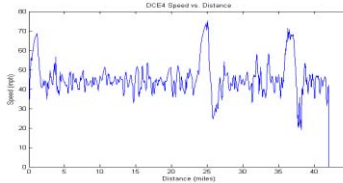


Urban Patrol Example



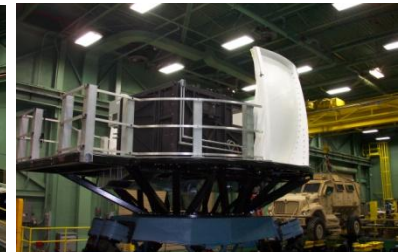
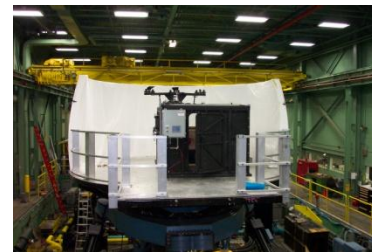
Future Vehicle Model
Predict Automotive Performance

Duty Cycles Defined Used for Design and Optimization



Model Integrated with Motion Simulator
Realistic Motion Feedback to Crew

Warfighter-in-Loop
Crew Executes Mission





Fuel/Energy Efficiency Requirement Samples

- The JLTV shall meet a fuel efficiency of 60(T), 90(O), ton-miles per gallon based on maximum GVW, including armor. Fuel efficiency will be measured over the Munson Standard Fuel Consumption course per TOP 2.2.603.
- The GCV IFV, with Level 2 armor, using standard JP8 fuel, shall have a fuel consumption at or better than identified for a specific platform weight in the table in 3.1.2.1.3.3.2 when evaluated at sustained speeds of thirty (30) mph on primary roads while providing power at 45KW sustained loads. (T=O)
- The MPC shall achieve 70 (T), 90(O), ton-miles per gallon measured at GVWR over the Munson Combo Fuel Cycle consisting of the Munson28 and Munson14 fuel course cycle run back to back.

- Mission Profile
 - Wartime **xx/xx/xx** Primary/Secondary/Trails
 - 20 Hour Duration; **x hrs moving/ x hrs Idle**
 - Peacetime **xx/xx/xx** Primary/Secondary/Trails
 - 20 Hour Duration; **x hrs moving/ x hr Idle**

Combined Drive Cycle

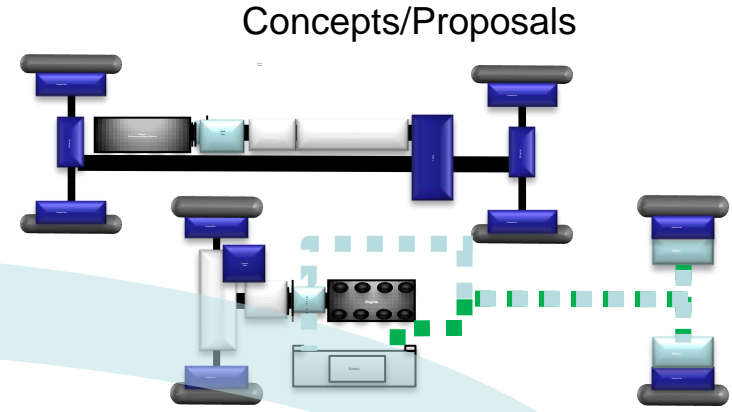
- Primary – Harford Loop Profile (paved)
- Secondary – Munson Standard Fuel Course Profile (paved/gravel)
- Trails – Churchville Test Area B- Course (dirt)

Additional Analysis Drive Cycles

- TARDEC Drive Cycles (Derived from HEVEA Duty Cycle Experiments)
 - Speed Traces (minimal elevation change)
 - Urban Assault Mission
 - Convoy Protection Mission

Mission Profile

- Wartime **xx/xx/xx** Primary/Secondary/Trails
 - 20 Hour Duration; **x hrs moving/ x hrs Idle**
- Peacetime **xx/xx/xx** Primary/Secondary/Trails
 - 20 Hour Duration; **x hrs moving/ x hr Idle**



Concepts/Proposals

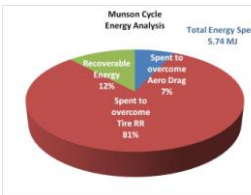
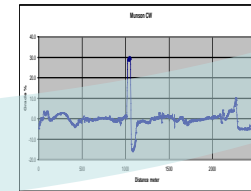
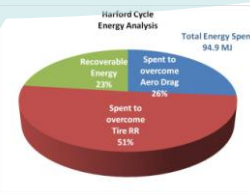
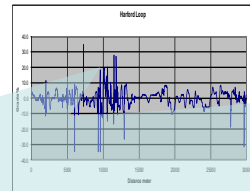
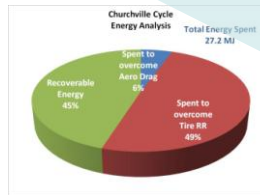
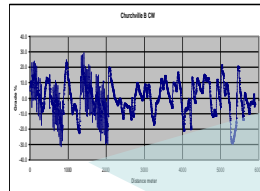
Component Sizing (Engine, Trans, Torque Converter, Driveline Motors, ISG, Battery)
 Auxiliary Load
 Cooling Requirements

Analysis

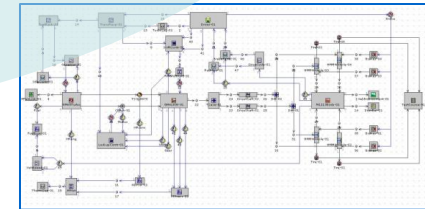
Drive Cycle Definition

TARDEC FED Concepts Fuel Economy Summary

	Baseline M1114 18,000 lb GVW No 10 MW OTM	Conv. ISG 18,000 lb GVW	Series Hybrid 18,000 lb GVW	Parallel 18,000 lb GVW	Power Assist ISG 18,000 lb GVW	Power Assist 4 Speed Kin-Trans ISG 18,000 lb GVW	Conv. ISG CIV 18,000 lb GVW
Munson mpg	7.0	5.8	6.6	6.2	5.5	5.9	7.4
Churchill mpg	3.6	3.6	4.2	4.8	3.5	3.8	4.6
Harford mpg	5.6	5.6	5.8	6.7	5.9	5.8	6.1
DCES Convoy (mpg)	6.9	6.4	6.7	7.9	6.3	6.7	7.1
DCES Urban (mpg)	4.9	4.4	5.5	5.6	4.4	4.6	5.5
TARDEC Composite FED Cycle (mpg) - Peacetime	5.8	5.5	5.8	6.4	5.4	5.8	6.3
TARDEC Composite FED Cycle (mpg) - Wartime	5.3	5.1	5.5	6.1	5.1	5.3	5.9



Model Builds





Army, Tank-Automotive RD&E Center, System Level Fuel Economy Analysis



Delta from Baseline 18,000 lb HMMWV No 10 kW OTM	Conv_ISG 18,000 lb GVW	Series Hybrid 18,000 lb GVW	Parallel 18,000 lb GVW	Power Assist ISG 18,000 lb GVW	Power Assist 8 Speed Binary Logic ISG 18,000 lb GVW	Conv_ISG CVT 18,000 lb GVW
	Team 1 Program	Team 2 Ideal	Team2 Program	Team 3 Ideal	Team 3 Program	
Munson mpg	-17%	-5%	-11%	-21%	-16%	6%
Churchville mpg	0%	16%	33%	-3%	6%	27%
Harford mpg	0%	5%	20%	5%	5%	9%
Idle Fuel Consumption (gal/hr)	-20%	-20%	-20%	-20%	-20%	-22%
DCE4 Convoy (mpg)*	-7%	-3%	14%	-9%	-3%	3%
DCE5 Urban (mpg)*	-10%	13%	14%	-10%	-6%	12%
TARDEC Composite FED Cycle (mpg) Peacetime	-5%	2%	10%	-7%	0%	9%
TARDEC Composite FED Cycle (ton-mpg) Peacetime	-5%	2%	10%	-7%	0%	9%
TARDEC Composite FED Cycle (mpg) Wartime	-4%	3%	15%	-4%	0%	11%
TARDEC Composite FED Cycle (ton-mpg) Wartime	-4%	3%	15%	-4%	0%	11%
Gal per Peacetime Cycle	5%	-2%	-9%	6%	0%	-8%
Total Fuel Consumed Peacetime (gal)	5%	-3%	-10%	5%	0%	-8%
Gal per Wartime Cycle	3%	-3%	-12%	4%	0%	-10%
Total Fuel Consumed Wartime (gal)	1%	-4%	-13%	2%	-2%	-11%
0-30 mph sec	33%	67%	40%	19%	45%	59%
0-50 mph sec	55%	75%	57%	48%	57%	62%
Top Speed mph	13%	5%	27%	-5%	7%	13%
5% Grade mph	67%	67%	79%	21%	72%	59%
60% Grade mph	100%	100%	100%	100%	100%	100%

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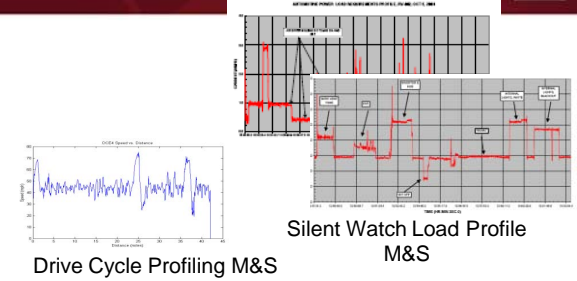
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Human-in-the-Loop Simulation



Determine Proper Duty Cycles for Design
 Involve the Soldier
 Trade-offs in Mobility and Non-mobility Power Availability
 Proper Sizing of Components

Establish Power Management Strategy



Requirements Capture, Concept Development
 Mathematical Modeling, Data Analysis
 High Performance Computing, Advanced Collaborative Environments

Integrated System-Level Simulation

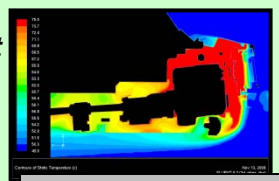
Advanced Power Management

METRICS: Rule Based – Table Lookup



Intelligent Power Management with Thermal Management Strategies

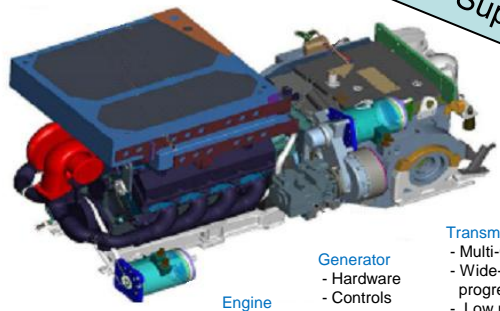
METRICS: Automated



Up-Front M&S Supports P&E Tech Investments

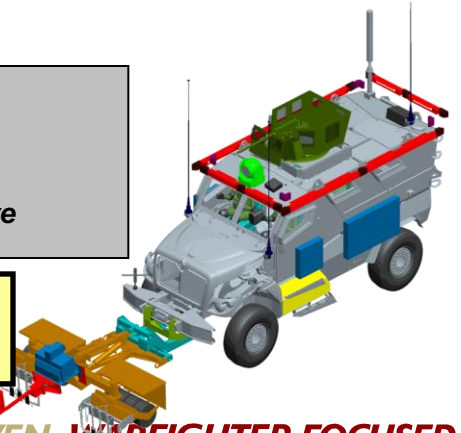
Cognitive Power and Thermal Management Control Strategy

METRICS: Cognitive/Collaborative



- Generator**
 - Hardware
 - Controls
- Engine**
 - Multiple fuels
 - Integrated Controls
 - Noise abatement
- Transmission**
 - Multi-Cone clutches
 - Wide-spread, equally progressive gear ratios
 - Low parasitic oil mgmt.
 - Variator technologies
 - Integrated controls

Making the Army a Smarter Buyer





Summary

- Many Tools Available for Assessment of Military Vehicle Energy Usage
- Energy Usage Can be Accurately Assessed at the Platform Level
- BUT -
 - Data required for Assessment often difficult to obtain, especially in pre-system acquisition (*Some success in Technology Demo Phase of JLTV*)
 - Expected usage of vehicle most critical for accurate prediction (*difficult for Army vehicles*)
 - Advanced Powertrains – Control System Logic is key, but Proprietary

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