TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Ground Vehicle CFD at TARDEC

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Report Documentation Page

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Outline

- TARDEC/CASSI Introduction
- Why TARDEC Performs Simulation
- Examples of typical CFD problems
- New CRES Program
- Questions

TARDEC's Impact on Ground Vehicle Community

TARDEC - Tank Automotive Research, Development and Engineering Center

- Develops, integrates, and sustains technology for all manned and unmanned DOD ground systems
- R&D for ground systems integration and technology

What We Do

- Provide information to make acquisition decisions
- ⅔ of Engineers are embedded support to programs
- ⅓ of Engineers are performing cutting edge R&D
- Modeling and simulation, including HPC processes are core to acquisition support

Fuel Efficiency Demonstrator

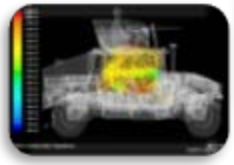
We support a diverse set of product lines through their life cycles, from combat and tactical vehicles, watercraft, to fuel and water distribution equipment.

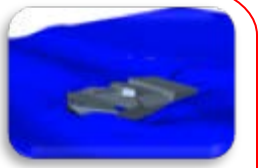
CASSI Commercial Tool Based CAE

***System-centric* Modeling and Simulation to integrate and assess the impacts of new concepts/technologies and changes to existing systems.**

Concepts
Analysis
Systems
Simulation
Integration

Dynamics and Durability





Thermal / CFD/ Acoustics

TARDEC HPC

Unclassified

- *512 Node Unclassified*
- *6 TFlops*

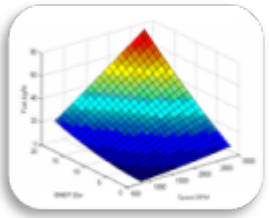
Classified

- *768 Node Classified: 9 TFlops*
- *Infiniband Interconnects*

DOD HPC Centers

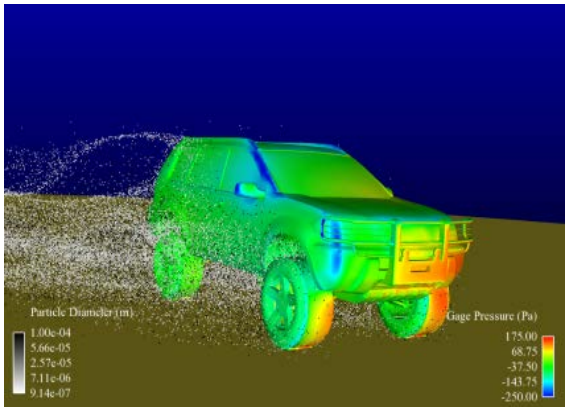
Energetic Effects and Crew Safety

Powertrain / Operational Energy



Data Analysis and Multidisciplinary Optimization

- Why TARDEC uses mainly commercial codes
  - Build a repository of vehicle models
  - Reuse of models for multiple purposes
  - Mesh wrapping capabilities shave weeks off the pre-processing time
- Issue: Scalability
  - Even w/ Inifiband, scale to 200,000 elements per node up to around 32 nodes.
  - Beyond 32 nodes, communications starts to dominate
  - Typical 16 million cell models we only use 64 nodes
  - Dust modeling, fire suppression, blast solid modeling have particular scaling problems because of the use of Lagrangian particles



Example: Dust modeling for engine durability does not scale on commercial code!

Question

Given - contractors design and build vehicles…

Why does the government do CAE?

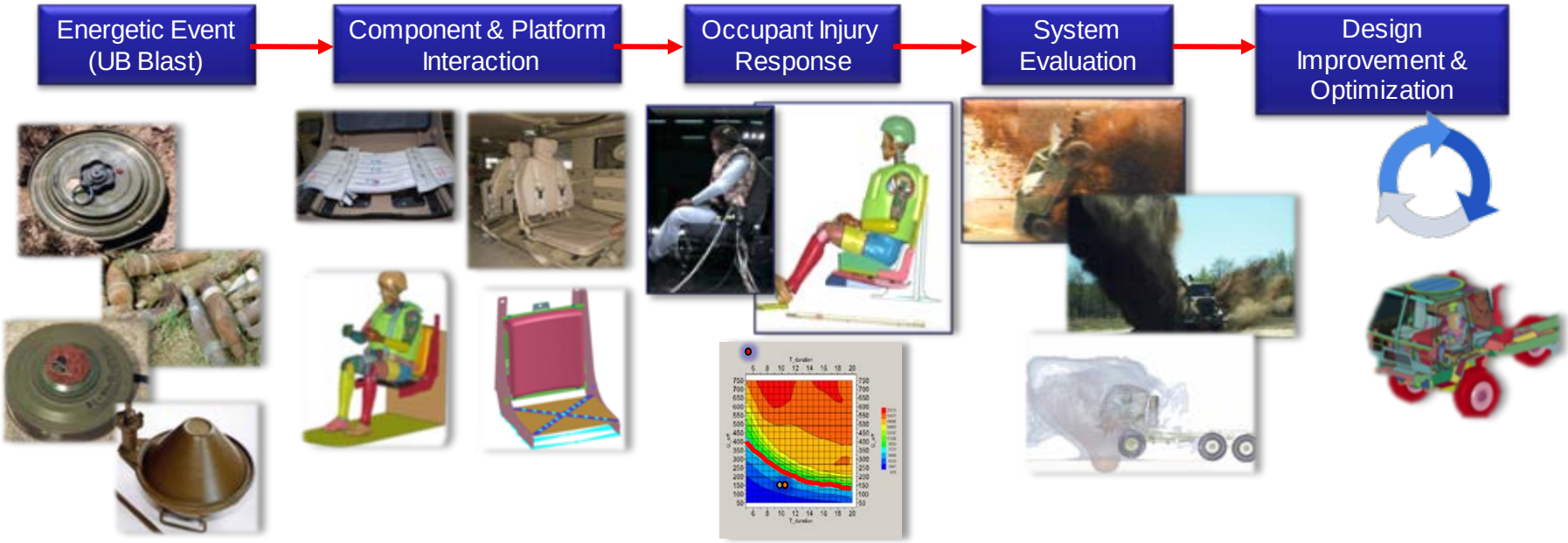
Why TARDEC Performs Simulation

- Pre-Request For Proposal (RFP) work
  - Need to ensure specifications are technically feasible before issuing RFPs
  - Analysis of Alternatives (AOA) studies
- Evaluation of proposals and oversight of supplier efforts
  - 'Honest Broker' - proposed solutions should be evaluated on a level playing field
  - Verify supplier analyses are reasonable
- Rapid response for field fixes
  - Determine how new equipment will affect vehicle performance
  - Provide initial assessment before starting formal contract process for proposed upgrades
- Analysis for technology demonstrator vehicles

Example CFD Interest Areas

- Underbody mine blast
- HVAC design / interior cooling
- Propulsion cooling
- Fire suppression modeling
- Thermal Effectiveness modeling
- Amphibious operation
- Physical testing support

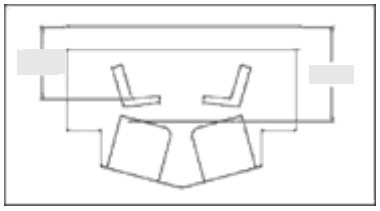
End-to-End Mine Blast Modeling



Use commercial automotive crash simulation models for blast

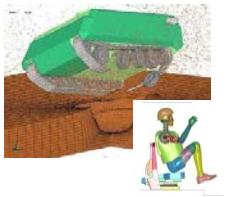
Most Modeling is Multidisciplinary: Example Amphibious Vehicle Project

Packaging / CAD



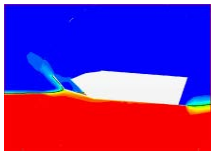
- Packaging studies
- Weight and CG tracking (key)
- Crew location (seat stroke)
- Propulsion/ waterjet locations
- Technology survey
- Level 2 drawings

Blast Full-Vehicle Analysis



- Soil, structure, and crew
- Optimize materials, ride height, and structure

CFD Water Mobility



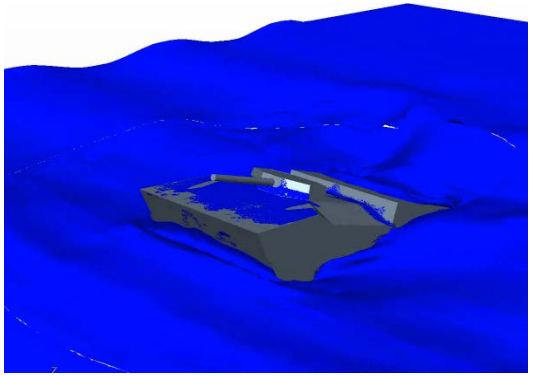
- Required thrust
- Resistance optimization
- Reserve buoyancy
- Sea stability

Land Mobility / Automotive Performance Analysis

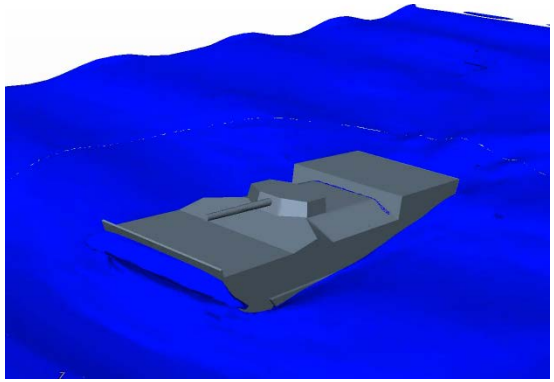
- Stress/ fatigue analysis
- Mobility
- Propulsion analysis
- Suspension optimization

Bow Shaping Study Example

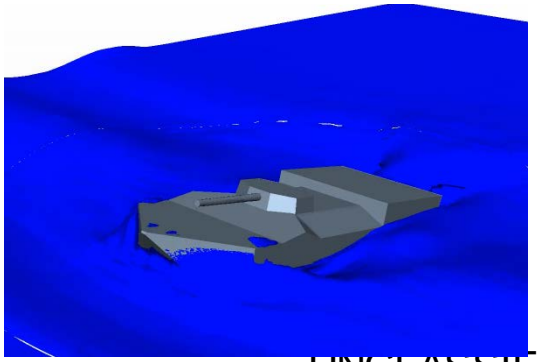
Fully Transient Computational Fluids



Baseline
0% increase in volume
0% improvement in resistance



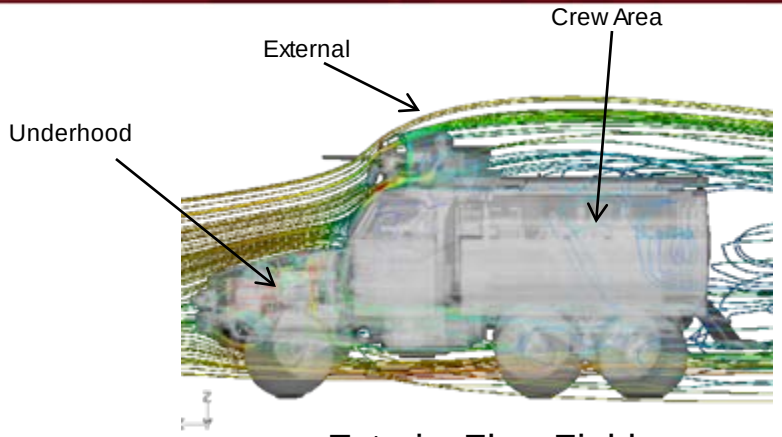
Shape I
10.8% increase in volume
28.2% improvement in resistance



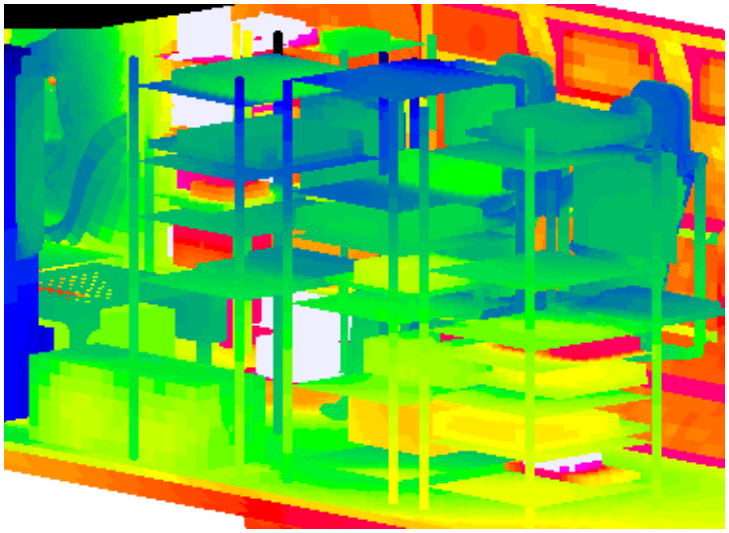
Shape II
8.7% increase in volume
12.9% improvement in resistance

Interior Cooling Analysis: Examples

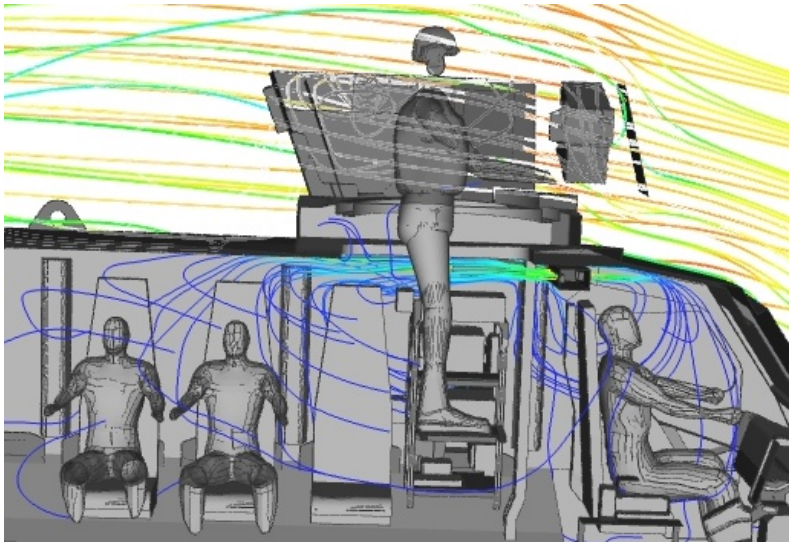
HVAC Duct Design / Cooldown Sizing



Exterior Flow Field



Component Temperatures



Simulation: Hatch Open

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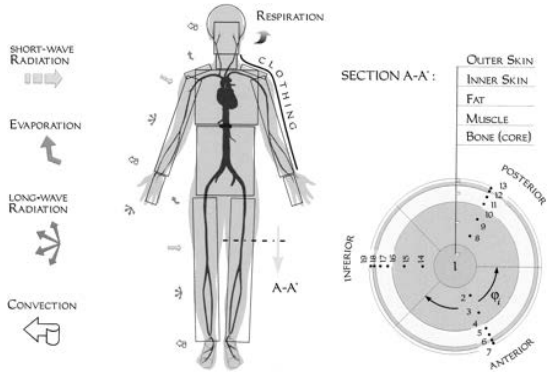
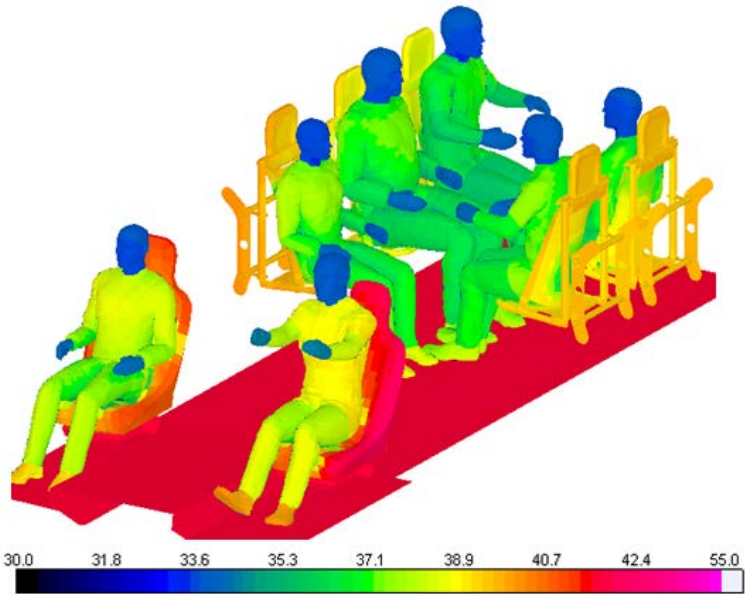
Crew Comfort/Effectiveness Modeling

Objective:

- Assess crew's ability to perform mission based on interior environment CFD
  - Based on Fiala's Physiology Model
  - 20 body segments
  - with 4 to 5 tissue layers per segment
  - Define metabolic heat rates by role (driver, gunner, commander)
  - Shivering
  - Respiration
  - Sweating
  - Peripheral Vasomotion
  - Sweating, clothing, etc all accounted





Shown: Various physiological builds (ranging fromm 5th Percentile to 95th Percentile)

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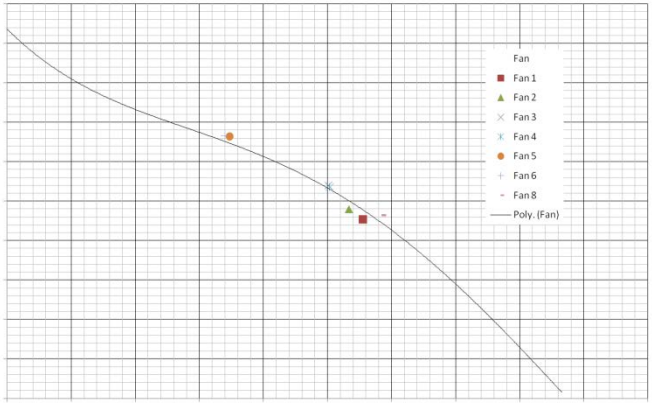
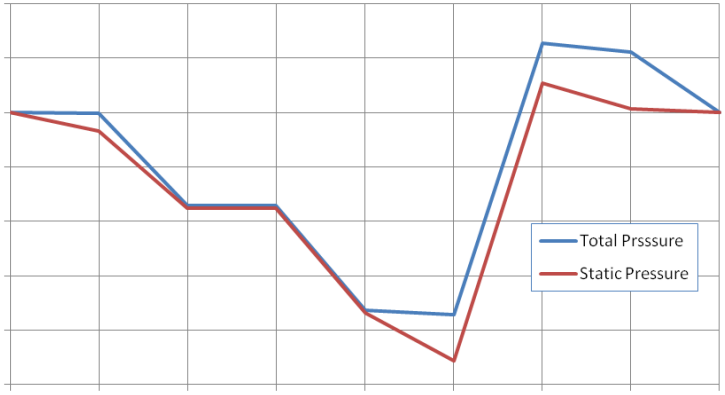
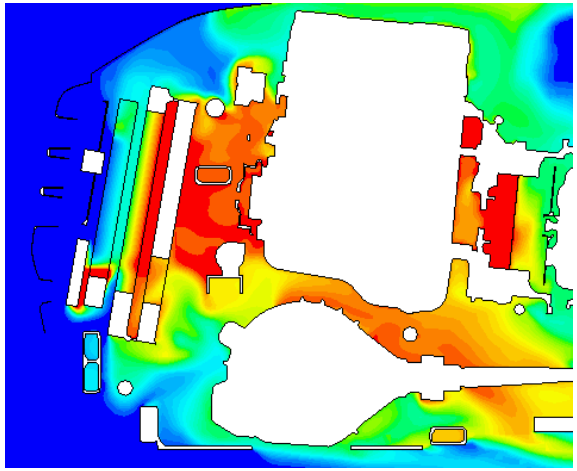
Underhood/Engine Cooling Examples

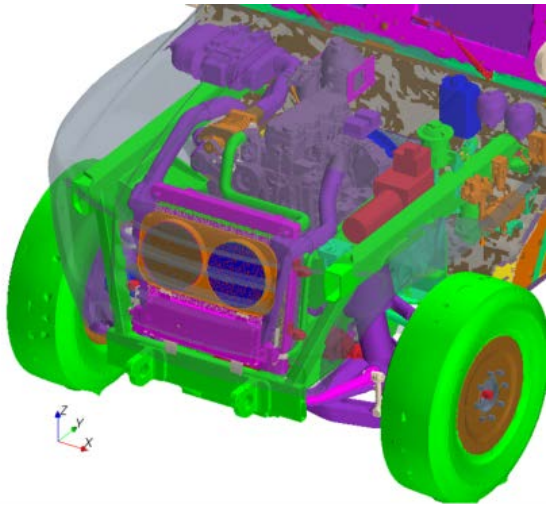


Fan Operating Points/Power Prediction



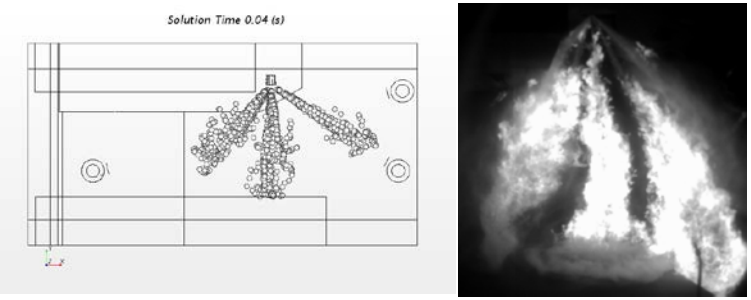
Pressure Trace Through System





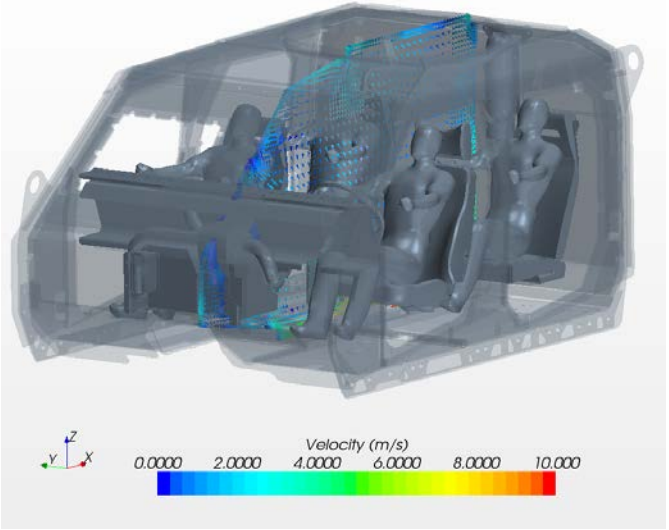
Fire Suppression Modeling (< 1 second, subsonic)

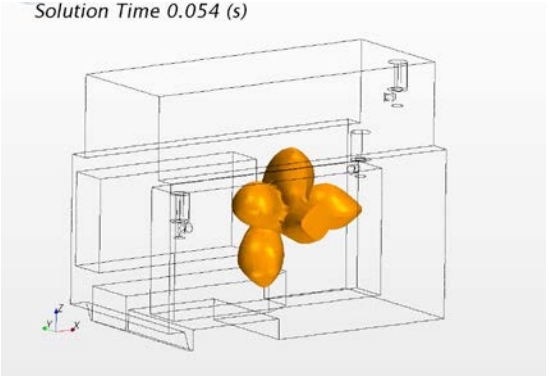
- **Types of suppressants**
  - **Evaporating liquid or liquid+solid**
- **Challenges**
  - **Multiphase + Lagrangian particles**
  - **Combustion (~9 reaction steps)**
  - **Initial fireball**
  - **Suppression chemistry**
  - **Soot radiation**
  - **Evaporation of droplets**
  - **Droplet interaction with wall**
  - **Droplet/ droplet collision**



Example: Testbed Fireball Generation - 10 Hole Showerhead

Leverage HVAC model (non-static air)





Iso-surface of Temperature 800K, FM200 Parcels

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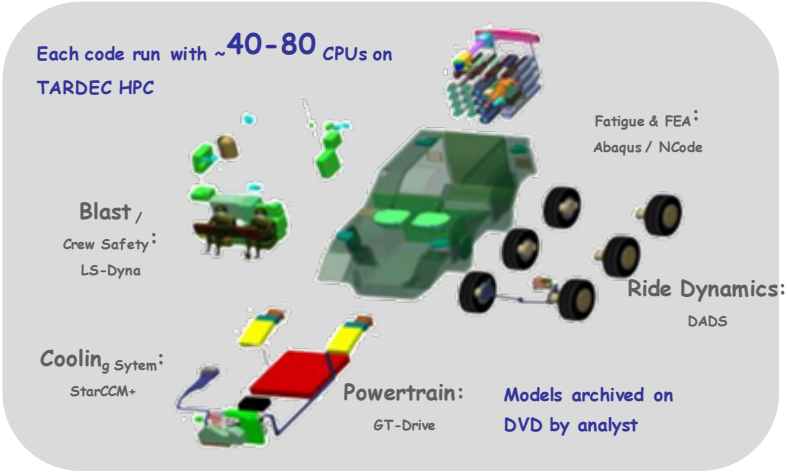
Current Army Ground Vehicle M&S Approach

- Traditional analysis evaluates a specific design for a specific performance objective for each discipline.
  - TARDEC using commercial codes, which don't scale up to real HPC capacity
  - Large commercial software budget
  - 2-3 month turn around

Example project using TARDEC non-integrated commercial CAE tools



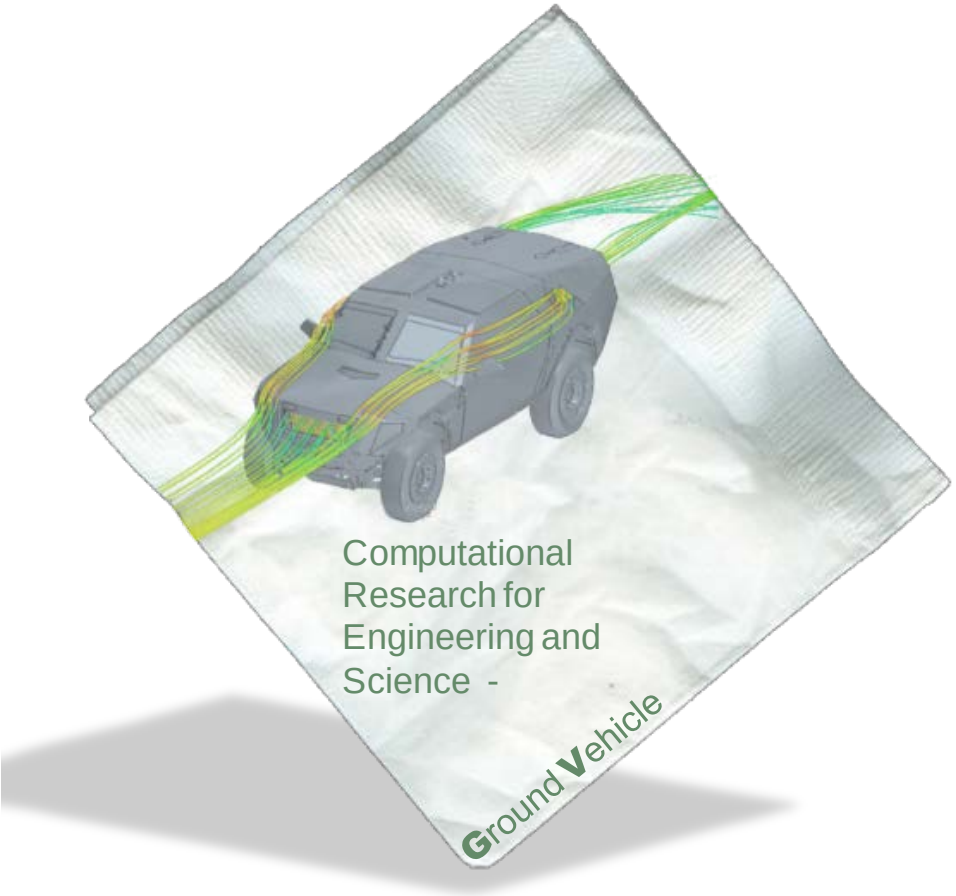
- Systems engineering trade-offs made with limited knowledge
  - Limited set of design space explored
  - As an example, force-on-force models use best available performance data
  - User/vehicle interface not physically evaluated until demonstrator vehicles
- OEMs and TARDEC do design on individual workstations and sometimes TARDEC runs on its own HPC cluster

Unique Army Modeling (and Meshing) Observations

- Government doesn't usually own the Technical Design Package
  - Geometry sources from best available
    - CAD
    - Scans
    - Hand measurements
    - Occasionally CAE which needs to be translated
  - Material properties often from measurements, etc
    - Run engines on a dyno to obtain the fuel maps
    - High strain-rate materials measurement for blast
  - Installed equipment from many sources
    - Literally many components are "black boxes"

CRES-GV Project

Goal: Provide Integrated Up-Front M&S Tools and Accelerate Process for Ground Vehicle Acquisition Support



- New program starting in HPC Modernization Office
- Commercial-Quality Government Owned Software

Preliminary CRES Product Ideas

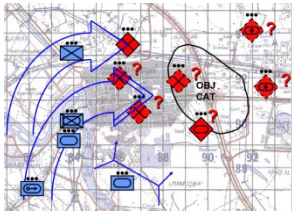
1. **Fast Multidisciplinary Physics Solver Suite**
   - Fast answer with less model preparation
   - Near realtime?
2. **Optimization Tool**
   - Focus on robustness optimization, not point solution
3. **High-Level Systems Tradespace Tool**

4. **Concept Definition Tool**
   - Goal: Computer aided brainstorming w/ physics and interface to models
   - Start with CREATE Capstone – add Back-of-Napkin 3-D sketching
   - Creativity and effectiveness depends on the whole design loop
5. **Improved Soldier-in-the-loop "Try it Before You Buy It"**

How CRES Products Might Integrate

Goal: Knowledge Based Acquisition

Physics Based = Better Informed **Requirements**



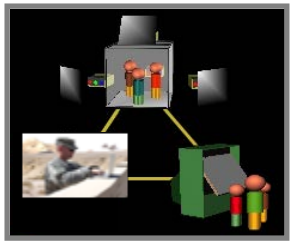
Operational Models based on accurate data

Ground Vehicle CRES

Infrastructure and Culture Change
- "Shadow Ops"
- Case studies

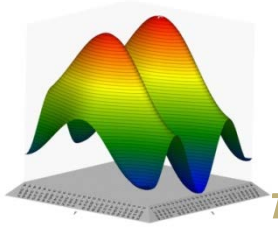
Quick Turnaround Model Based Engineering

Faster Concepting / Design Collaboration



- BETTER Concepting CAD "3-D Back of the napkin"
- Users co-design with physics-based feedback

Better Designspace Exploration



Soldier-in-the-loop
- Duty Cycle Characterization
- Key to Soldier Centric Design

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Summary

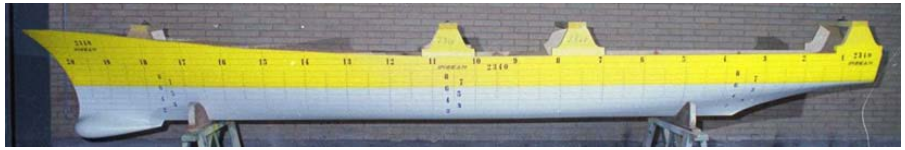
- CFD modeling at TARDEC is done using commercial codes
  - Scalability issues
- Problems are usually very multidisciplinary
- Reuse the models a lot
- Large challenges in getting data
- New CRES-GV program looking into how to improve the vehicles that wind up in soldiers hands

THANK YOU

Questions?

Validation: CFD and Test for Naval Destroyer

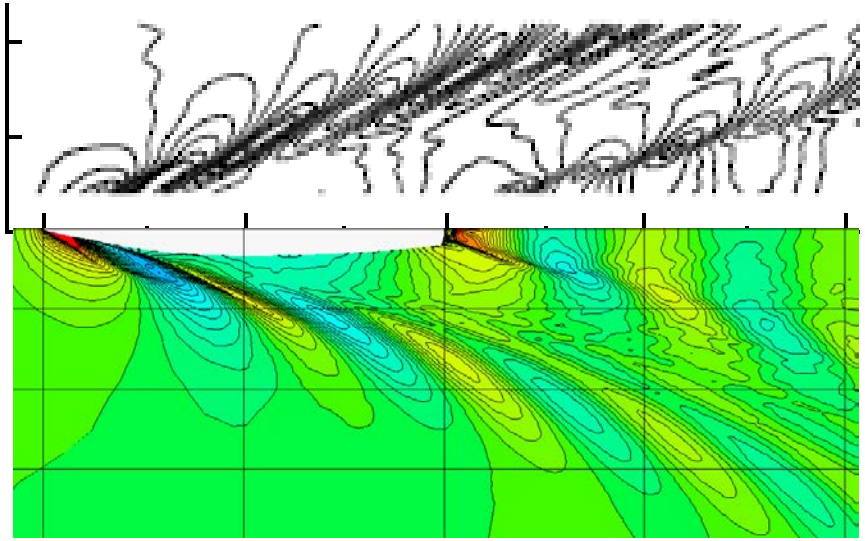
Tow Tank Model



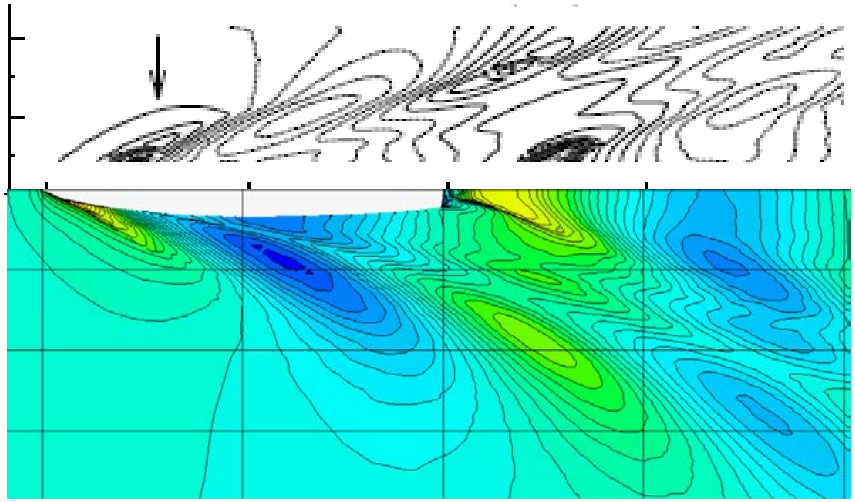
Resistance

Model Speed			Resistance (N)		
Fr	Knots	m/s	Test	CFD	Error
0.280	4.076	2.097	45.14	45	-0.32%
0.410	5.970	3.071	152.60	150	-1.70%

Wave height contours at 2.097 m/s (Fr=0.280)



Wave height contours at 5.97 m/s (Fr=0.410)



Data from: A. Olivieri, F. Pistani, A. Avanzini, F. Stern, R. Penna. 2001.
"Towing Tank Experiments of Resistance, Sinkage and Trim, Boundary Layer, Wake, and Free Surface Flow Around a Naval Combatant INSEAN 2340 Model"
IHR Technical Report No. 421

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