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# **Vehicle Thermal Management Simulation at TARDEC**

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| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                          | Form Approved<br>OMB No. 0704-0188                       |                                 |
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| 1. REPORT DATE<br><b>07 MAY 2010</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE<br><b>N/A</b>        |                                          | 3. DATES COVERED<br><b>-</b>                             |                                 |
| 4. TITLE AND SUBTITLE<br><b>Vehicle Thermal Management Simulation at TARDEC</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 5a. CONTRACT NUMBER                                      |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 5b. GRANT NUMBER                                         |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 5c. PROGRAM ELEMENT NUMBER                               |                                 |
| 6. AUTHOR(S)<br><b>TARDECScott Shurin</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                          | 5d. PROJECT NUMBER                                       |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 5e. TASK NUMBER                                          |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 5f. WORK UNIT NUMBER                                     |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 8. PERFORMING ORGANIZATION REPORT NUMBER<br><b>20802</b> |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><b>US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    |                                     |                                          | 10. SPONSOR/MONITOR'S ACRONYM(S)<br><b>TACOM/TARDEC</b>  |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                          | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)<br><b>20802</b>   |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release, distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                          |                                                          |                                 |
| 13. SUPPLEMENTARY NOTES<br><b>The original document contains color images.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                    |                                     |                                          |                                                          |                                 |
| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                          |                                                          |                                 |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                          |                                                          |                                 |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>SAR</b> | 18. NUMBER OF PAGES<br><b>17</b>                         | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                          |                                                          |                                 |

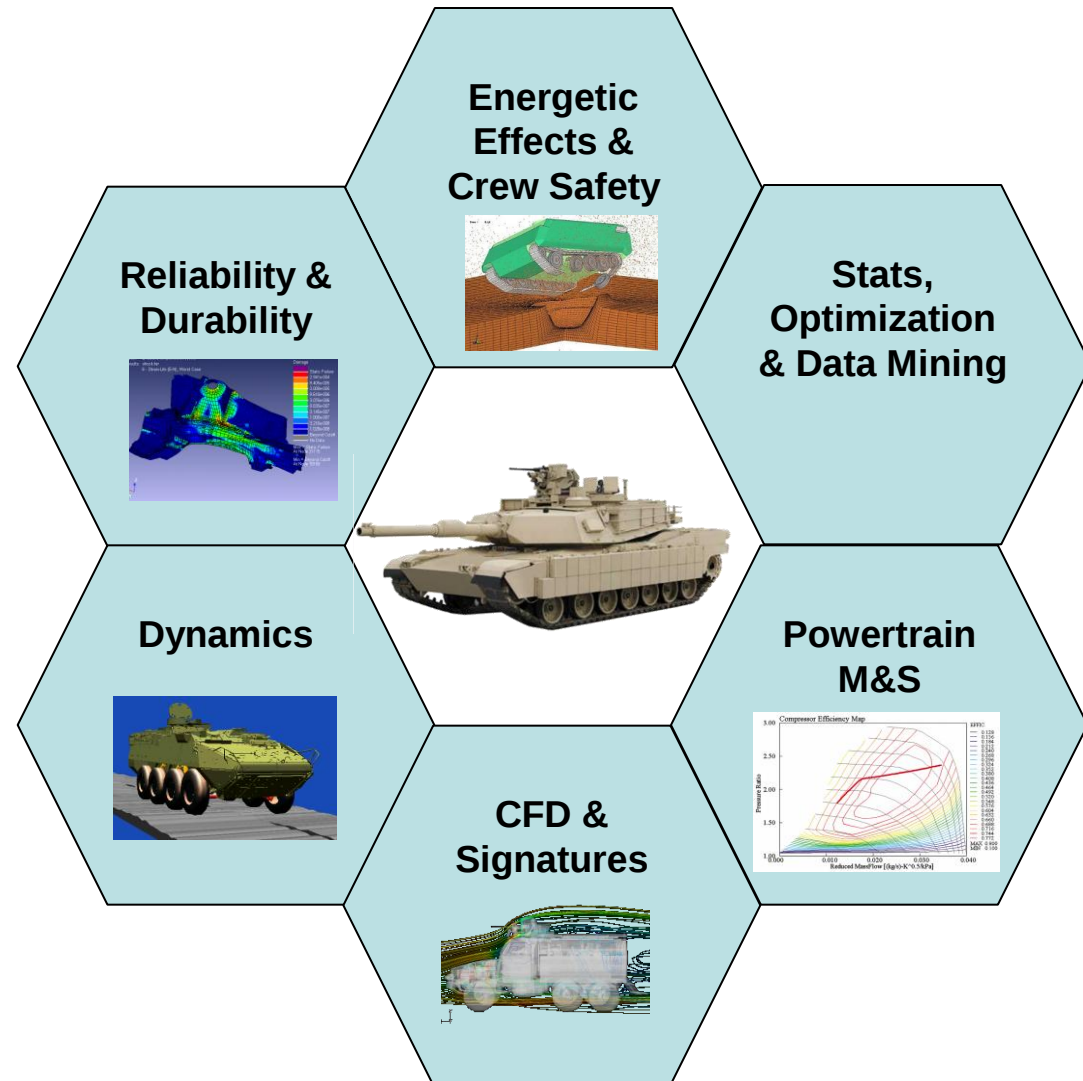
- TARDEC/CASSI Introduction
- Why TARDEC Performs Simulation
- Interior Cooling Analysis
- Engine/Underhood Cooling Analysis
- Conclusion

- Tank Automotive Research, Development and Engineering Center (TARDEC)
  - Develops, integrates, and sustains the technology for all manned and unmanned DOD ground systems
  - The main Research and Development Engineering (R&DE) organization for ground systems integration and technology
- Consists of Three Major Business Groups:
  - Engineering Business Group
  - Product Development Business Group
  - Research Business Group
    - Includes CASSI (Next Slide)



# CASSI ANALYTICS

**C**oncepts  
**A**nalysis  
**S**ystems  
**S**imulation  
**I**ntegration



- 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
- Direct R&DE efforts through cooperation with industry and universities
  - Form partnerships to direct development efforts in areas of interest to the Army

- Objective: Determine environment in crew cabin during extreme hot conditions
  - Size A/C System
  - Evaluate electronics cooling (will components fail?)
  - Evaluate crew effectiveness/comfort
  - Optimize HVAC Duct Design
- Potential Analysis Scenarios
  - Steady-state
  - Pull down
  - Diurnal cycle (24+ hours)
- Environmental conditions
  - Extreme High Temperatures
    - >125 °F ambient temperature
    - 1120 W/m<sup>2</sup> solar load
  - Environment: Tunnel or Outdoor

## Diurnal Cycle: Ambient Solar Load and Temperature

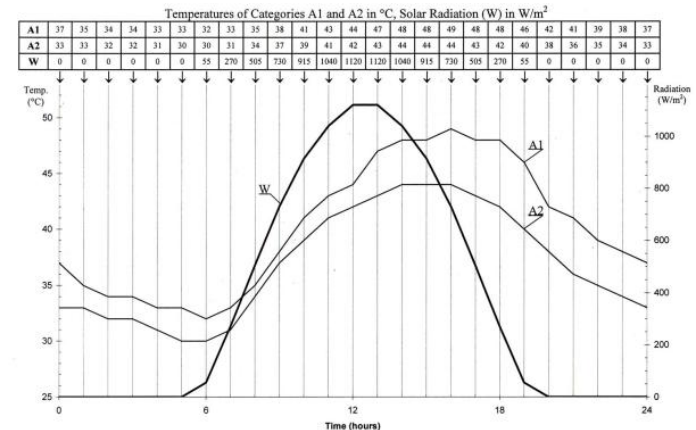
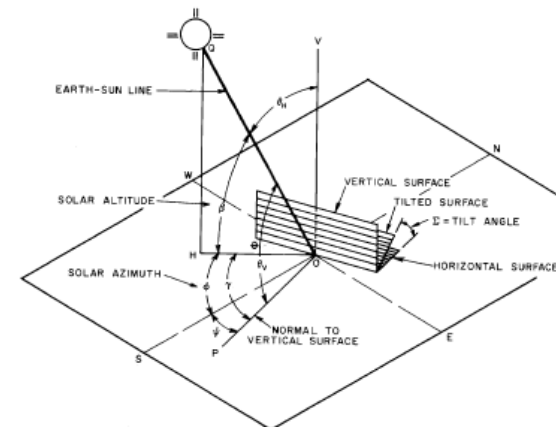


Figure 505.5-1. Procedure I – Cycling test.

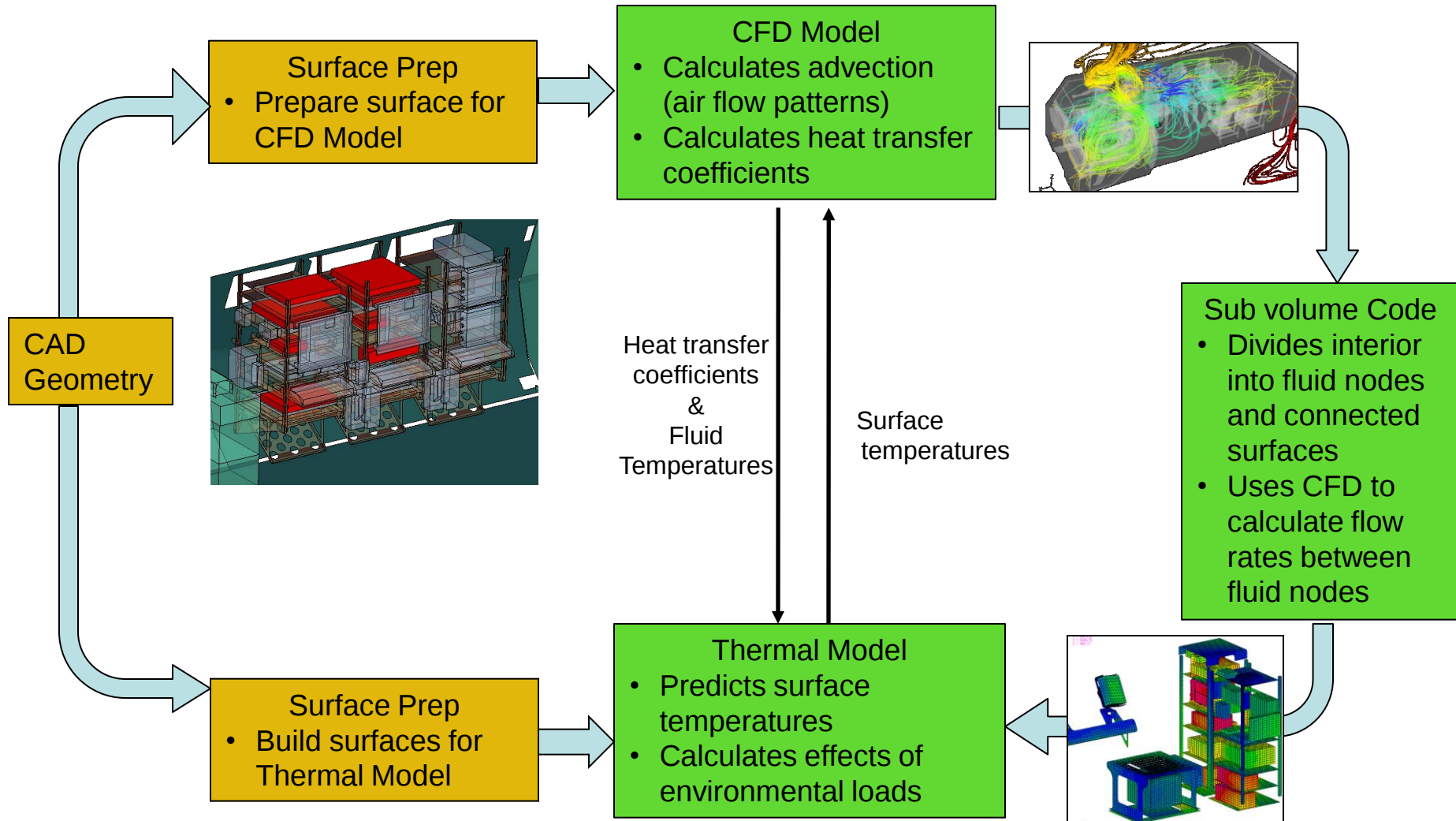
## Diurnal Cycle: Solar Position



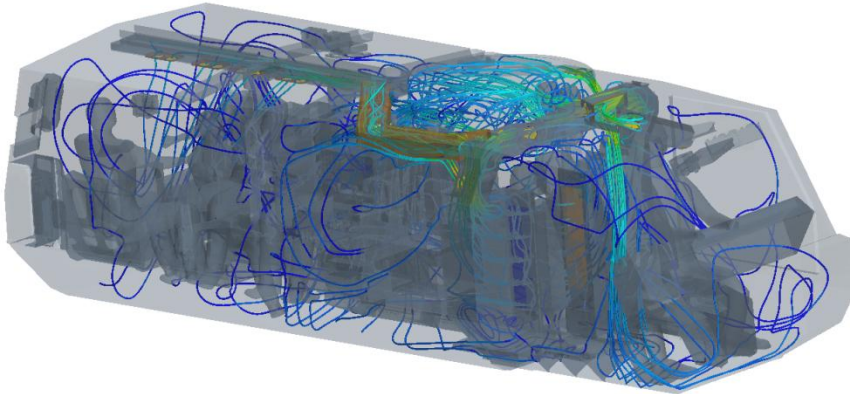
- Vehicle technical data is not always available— especially:
  - Material properties (density, specific heat, conductivity)
  - Cooling system performance specifications (HVAC capacity, flow rates, etc.)
  - Surface properties (emissivity, solar absorptivity)
  - Engine exhaust flow rates and temperatures (underbody heating)
- CAD data may be difficult to obtain or may be outdated
- Difficulties with electronic components:
  - Obtaining reasonable values for heat rejection (duty cycle)
  - Temperature limits— when does failure actually occur?
  - Modeling of internal cooling fans inside electronic enclosures boxes
- Multiple modes of heat transfer (multiple codes?):
  - Need to model environmental heat loads
    - Solar position, irradiation
  - Need to calculate internal and external convective heat transfer
  - Need to model internal advection
  - Need to model thermal conduction and thermal mass

## Model Preparation

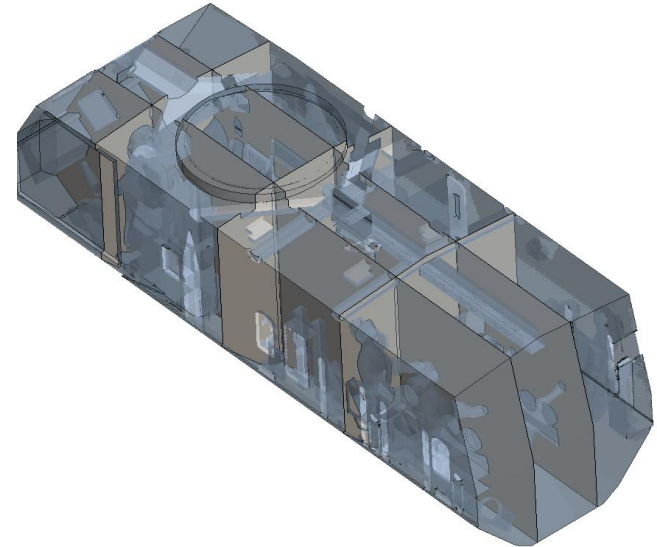
## Analysis: Iteration Required



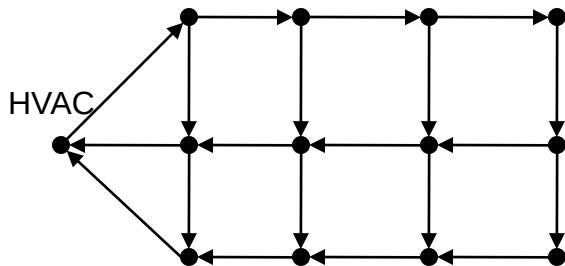
1. Calculate flow field CFD



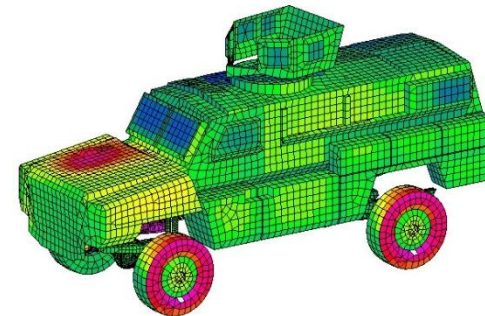
2. Divide domain into sub-volumes



3. Calculate advection between nodes



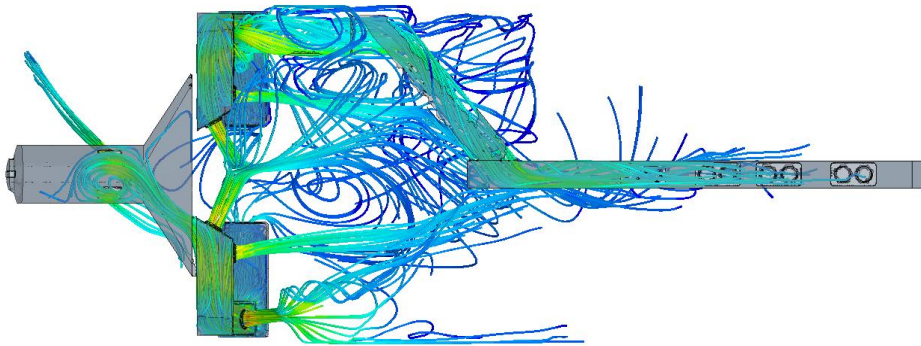
4. Add advection links to thermal model



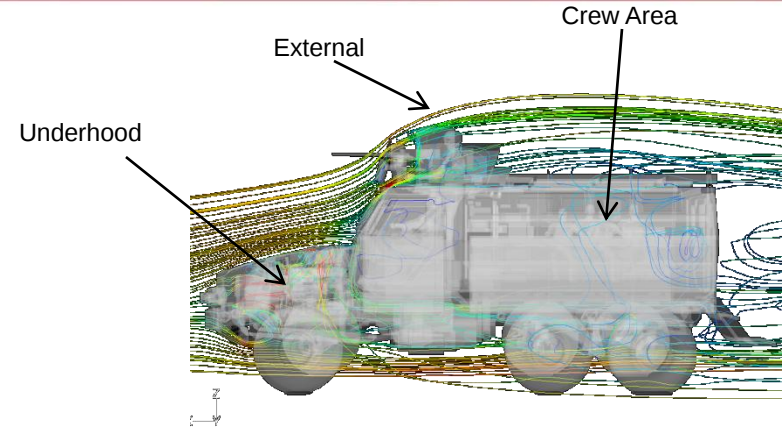
- Why couple CFD with a Thermal Code?

| Category | CFD Model                                                                                                                                                                                                                     | Thermal Model                                                                                                                                                                                                                     |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Geometry | Uses volume elements<br>Models actual geometry<br>Quick surface preparation (with wrapping)                                                                                                                                   | Uses surface elements (shells)<br>Geometry adjusted to model heat paths<br>Surface preparation takes a long time (can't use wrapper)                                                                                              |
| Setup    | Limited material and surface property database                                                                                                                                                                                | Extensive material and surface property database                                                                                                                                                                                  |
| Physics  | Calculates advection<br>Calculates surface heat transfer coefficients<br>Cannot perform IR signature analysis<br>Manual setup for weather model<br>Requires manual setup of solar angle<br>Does not calculate terrain effects | Advection must be manually setup<br>Convection coefficients based on handbook values<br>Can be extended to perform IR Signature Analysis<br>Incorporates weather model<br>Calculates solar angle<br>Calculates terrain reflection |
| Run Time | Long run time for transient simulations                                                                                                                                                                                       | Transient simulations run quickly                                                                                                                                                                                                 |

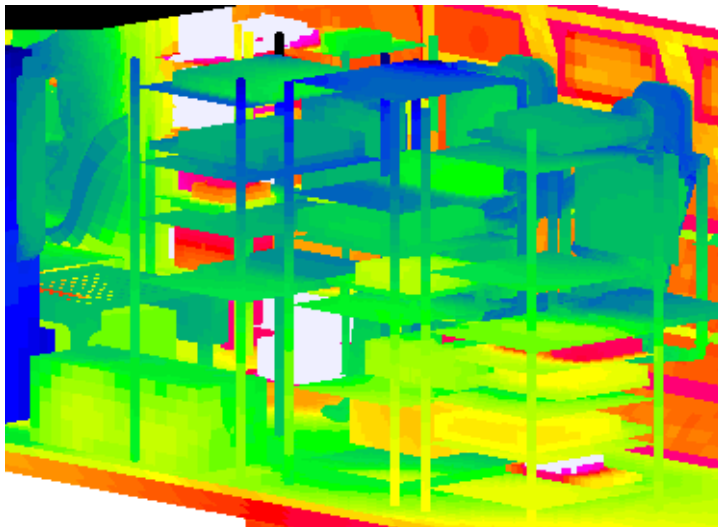
- Coupling allows each code to use it's particular strengths
  - CFD to calculate advection and convection
  - Thermal for environment and radiation effects
- Disadvantage to Coupling:
  - Thermal model requires clean surface with manual cleanup
- Modeling both solids and fluids in one model may resolve this issue, but long transients may still be a challenge



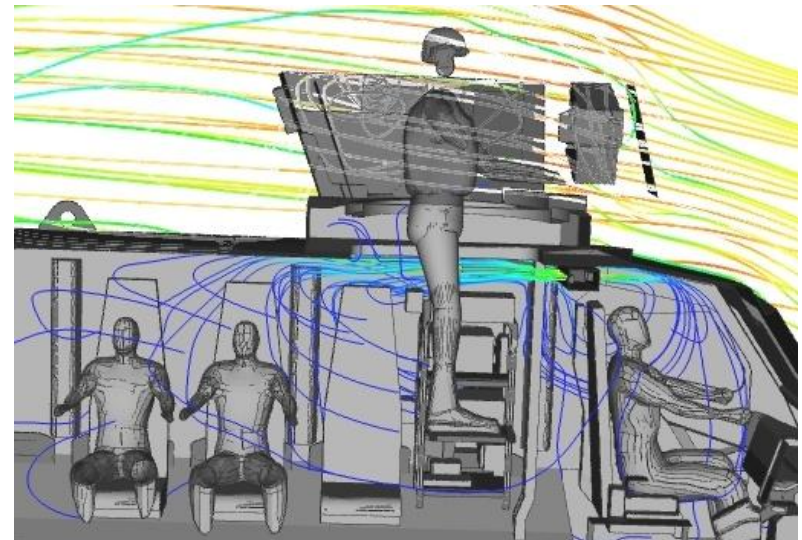
HVAC Duct Design



Exterior Flow Field



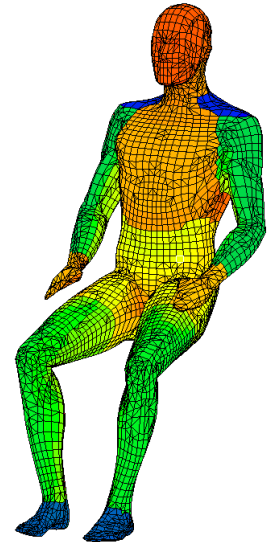
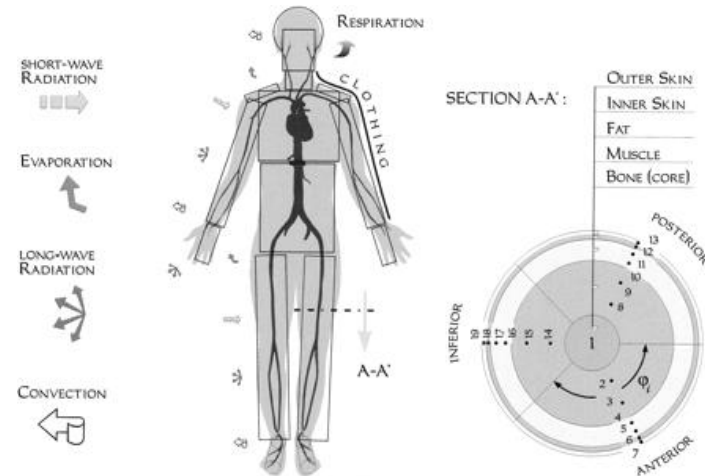
Component Temperatures



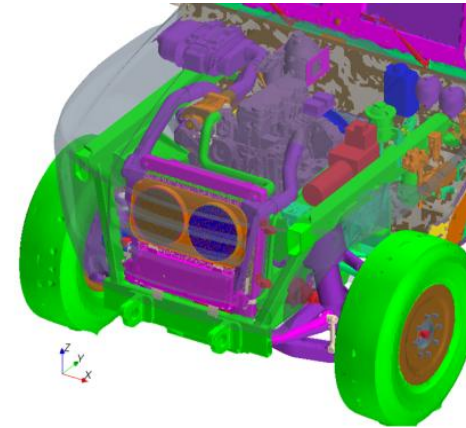
Simulation: Hatch Open

## Enhancement to Interior Cooling Analysis

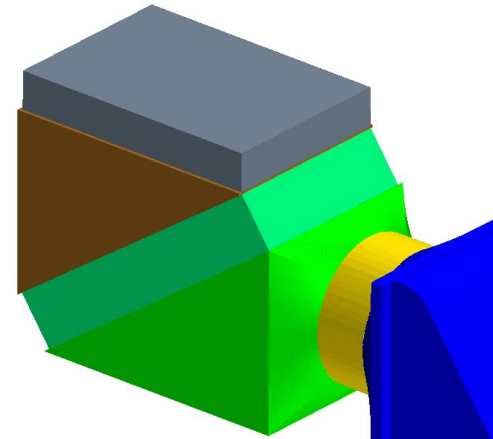
- Objective: Assess crew's ability to perform mission based on interior environment
- On-going CRADA (Cooperative Research And Development Agreement)
  - TARDEC oversees development and provides some funding
  - GM shares experience and lessons learned
  - Small business develops code and sells commercially
- Soldier Thermal Fatigue Model
  - Based on University of California Berkley model
  - Define metabolic heat rates by role (driver, gunner, commander)
  - "Comfort" index generated from local skin temps and body core temp



- Objective: Assess cooling performance of vehicle
  - Determine ability of system to operate at high ambient temperatures
    - Predict performance
  - Fan Sizing/System Resistance
    - Reduce power requirement
- Analysis Geometries
  - Underhood
  - Cooling Tower
- Extreme operating conditions
  - 125 °F Ambient temperature
  - High engine and transmission load
    - Full engine power
    - High tractive effort or steep grade

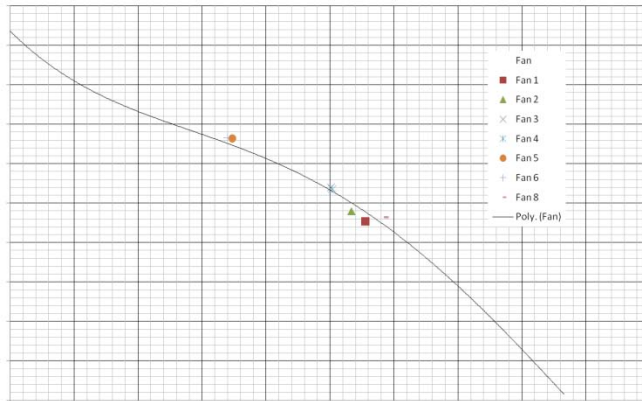


Underhood Geometry

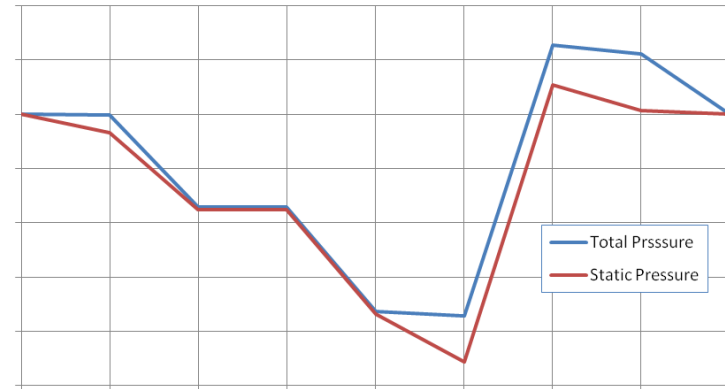


Cooling Tower Geometry

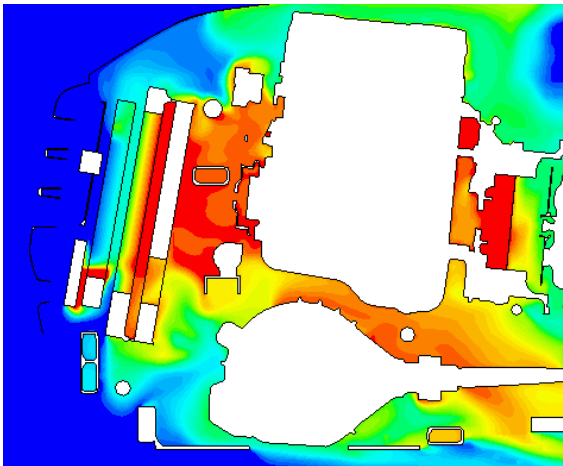
- Availability of Data
  - Vehicle Geometry
  - Heat Exchanger Performance
    - Pressure vs. Flow
    - Heat rejection map
  - Heat rejection requirements
    - Often not available early in design phase
    - May not be accurate for legacy vehicles which have been modified
  - Fan Modeling
    - Availability of fan geometry
    - Applicability of CFD code's fan model
      - May not be applicable for vane-axial fan
- Physics
  - thermal or cold flow?
    - Cold flow is useful for validation purposes
    - Including temperature provides more information, but is more difficult to validate experimentally



Fan Operating Points/Power Prediction

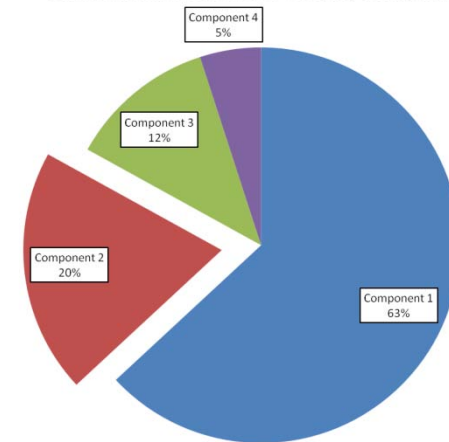


Pressure Trace Through System



Underhood Cooling

Contribution to Pressure Drop by Component



Fan Pressure/Power Budgeting

- Vehicle thermal analysis plays an important role at TARDEC
- There are two major areas of interest
  - Interior cooling
    - Predicting potential failure of electronic components
    - Sizing HVAC capacity
    - Determining Crew effectiveness/comfort
  - Underhood/Engine thermal analysis
    - Predicting vehicle performance at high ambient temperatures
    - Determining fan/cooling system size
- There are challenges
  - Obtaining reasonable performance data for system components
  - Obtaining CAD Data
  - CAD Cleanup for thermal model vs. CFD model

# THANK YOU

## Questions?