Vehicle Thermal Management Simulation at TARDEC

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The original document contains color images.
Outline

- 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 ANALTICS

Concepts
Analysis
Systems
Simulation
Integration

Energetic Effects & Crew Safety
Stats, Optimization & Data Mining
Reliability & Durability
Powertrain M&S
Dynamics
CFD & Signatures

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
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
• Direct R&DE efforts through cooperation with industry and universities
  – Form partnerships to direct development efforts in areas of interest to the Army
Interior Cooling Analysis

- **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/m² solar load
  - Environment: Tunnel or Outdoor
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
Internal Cooling Analysis Methodology

Model Preparation

- **Surface Prep**
  - Prepare surface for CFD Model

- **Surface Prep**
  - Build surfaces for Thermal Model

- **CAD Geometry**

Analysis: Iteration Required

- **CFD Model**
  - Calculates advection (air flow patterns)
  - Calculates heat transfer coefficients

- **Thermal Model**
  - Predicts surface temperatures
  - Calculates effects of environmental loads

- **Heat transfer coefficients & Fluid Temperatures**

- **Sub volume Code**
  - Divides interior into fluid nodes and connected surfaces
  - Uses CFD to calculate flow rates between fluid nodes

- **Surface temperatures**
Internal Cooling Analysis: Sub-Volume Approach

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?

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

• 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
Interior Cooling Analysis: Examples

HVAC Duct Design

Component Temperatures

Exterior Flow Field

Crew Area

Underhood

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/Engine Cooling Analysis
Challenges/Considerations

• 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
Underhood/Engine Cooling Examples

Fan Operating Points/Power Prediction

Pressure Trace Through System

Underhood Cooling

Fan Pressure/Power Budgeting
Conclusion

• 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?