FAST TRANSIENT 3D CABIN MODELING FOR HVAC SYSTEM SIZING AND CONTROLS ANALYSIS

Jon Juszkiewicz, ThermoAnalytics Inc.
Dan Marsh, Gamma Technologies Inc.
Outline

- Motivation and state of the art
- Introduction to simulation tools
- Problem Statement
- Model construction and basic physics
- Results
- Conclusions and next steps
## Motivation

<table>
<thead>
<tr>
<th>Number of Fluid Volumes</th>
<th>Real Time Simulation</th>
<th>Controls Simulation</th>
<th>Long Transient Simulation</th>
<th>Predictive capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>- -</td>
</tr>
<tr>
<td>1-10</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>- -</td>
</tr>
<tr>
<td>5,000-20,000</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>+ -</td>
</tr>
<tr>
<td>1M +</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>+ +</td>
</tr>
</tbody>
</table>
Introduction to GT-SUITE
Introduction to TAITherm

Radiation exchange with the sun, sky and surroundings

Automatic surface to surface radiation

Convection

Specialized Physics

Conduction through mesh
### Problem Statement

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot Weather, Face Level Vents On, Outside Air, with sun</td>
</tr>
<tr>
<td>2</td>
<td>Hot Weather, Face Level Vents On, Outside Air, no sun</td>
</tr>
<tr>
<td>3</td>
<td>Hot Weather, Face Level Vents On, Recirc, no sun</td>
</tr>
<tr>
<td>4</td>
<td>Cold Weather, Floor Vents On, Outside Air, no sun</td>
</tr>
<tr>
<td>5</td>
<td>Cold Weather, Floor Vents On, Recirc, no sun</td>
</tr>
<tr>
<td>6</td>
<td>Cold Weather, Defroster On, Recirc, no sun</td>
</tr>
<tr>
<td>Test Number</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Hot Weather, Face Level Vents On, Outside Air, with sun</td>
</tr>
<tr>
<td>2</td>
<td><strong>Hot Weather, Face Level Vents On, Outside Air, no sun</strong></td>
</tr>
<tr>
<td>3</td>
<td>Hot Weather, Face Level Vents On, Recirc, no sun</td>
</tr>
<tr>
<td>4</td>
<td>Cold Weather, Floor Vents On, Outside Air, no sun</td>
</tr>
<tr>
<td>5</td>
<td>Cold Weather, Floor Vents On, Recirc, no sun</td>
</tr>
<tr>
<td>6</td>
<td>Cold Weather, Defroster On, Recirc, no sun</td>
</tr>
</tbody>
</table>
Problem Statement

Measured Vehicle Speed

Measured Vent Temperatures

- Front Left
- Front Right
- B-Pillar Left
- B-Pillar Right
Problem Statement

- Extractors
- Driver Left Vent
- Middle Vent
- Rear B-Pillar Vent
- ...also equivalent passenger-side vents
Model Construction
Model Construction

Model Creation in TAITherm

- 48,000 elements in 24 parts
  - Parts share common properties and boundary conditions
    - $\rho$, $C_p$, $k$
    - $R_{v\lambda}$, $T_{v\lambda}$
    - Front and back $\varepsilon_{v\lambda}$
    - Front and back $H$ & $T_f$
    - Environmental loads
Model Creation in GT-SUITE

- CAD used to create voxelized grid
  - Users define
    - Inlet locations
    - Discretization level

(Internal to Solver)
Model Construction

**Vector Variables**
- Mass Flux
- Velocity
- Etc.

**Scalar Variables**
- Pressure
- Enthalpy
- Temperature
- Etc.
Model Construction

Velocity Inlet

Pressure driven flow separation

No turbulence or complex flow structures

GT-SUITE
Coupling Solution Domain

Heat Transfer Coefficient & Fluid Temperature

Wall Temperature

GT-SUITE

TAITherm by ThermoAnalytics
Structure Temperature Results

Drivers Seat

- Data is suspicious, compared to passenger seat

Passengers Seat

- Initial material temperatures varied throughout cabin structure by ~1-2 °C

Initial material temperatures varied throughout cabin structure by ~1-2 °C

Paper # 16TMSS-0024
Structure Temperature Results

Drivers Door

![Diagram of Drivers Door with temperature graphs and error percentages.]

Passenger Door

![Diagram of Passenger Door with temperature graphs and error percentages.]

Result may be location sensitive

Passenger Door Thermocouple Location
Structure Temperature Results

Windshield Exterior

Windshield Interior

Exterior Thermocouple Location

Interior Thermocouple Location
Structure Temperature Results

Drivers Front Window

Drivers Rear Window

Front Window Thermocouple Location

Rear Window Thermocouple Location
Fluid Results

Velocity in X
Conclusions

• Successfully validated a new coupling approach for cabin simulation
  – Accuracy is reasonable
    • Ranges from 0-2.4%
  – Run time is exceptional
    • Within 5 minutes of real time

• Improvements to the following could improve the correlations
  – Material properties
  – More detailed geometry
  – Precise measurement locations
  – Tighter test control
Next Steps

- Extend the physics
  - Outgassing/humidity tracking
  - Pass controller inputs back to GT-Suite
  - Incorporate virtual humans

- Accelerate the solution
  - Dynamic coupling intervals
  - Socket based data exchange

- More complex validations
  - Looking for a partner that has more and more detailed test data
    - AC system specifications
    - Precise locations
    - Material properties