Volpe Center Support in FRA Hazardous Materials Tank Car Safety Research Program

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U.S. Department of Transportation

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Volpe Center Support to FRA Research Programs

- Vehicle Systems
- Track Systems
- Vehicle-Track Interaction
- Human Factors
- Highway Railroad Grade Crossing Safety

NTSB Accident Investigation Support

- Tank Car Integrity
  - Bridgeport, CT
    - May 17, 2013
- Crashworthiness
  - Columbus, OH
    - July 11, 2013
- Rail Integrity
  - Bronx, NY
    - July 18, 2013
- Train-Track Dynamics
Timeline of FRA/Volpe Hazmat Tank Car Research

1980: Switchyard Impact Tests
1986-87: Investigation of Stub Sill Tank Car Failures
1992: Chlorine Tank Car Puncture Resistance
1993: Stress Analysis of Stub Sill Tank Cars
1997: Residual Stresses Near Weld Ends
2001: Engineering Analyses for Tank Car Head Puncture
2004: Research Addressing NTSB Recommendations from Minot, ND Derailment
2007-2008: Next-Generation Rail Tank Car (NGRTC) Project
2008-2011: Research on Shell Protection
2007-present: Full-scale Testing and Analysis of Tank Car Shell Impacts

Head impact testing conducted by Government and Industry in 1970s and '80s

Toxic by Inhalation Hazard (TIH) Tank Cars

Crude Oil and Ethanol
Generalized Head and Shell Impact Scenarios

**Head – Code of Federal Regulations (CFR) § 179.16**

- Moving Ram Car (286,000 lb.)
- Stationary Tank Car with Brakes Released (263,000 or 286,000 lb)
- Three Backup Cars with Brakes Applied (263,000 lb each)

**Shell – Ongoing Research**

- Moving Ram Car
- Stationary Tank Car
- Rigid Barrier
- Tank Centerline
Development of Generalized Shell Impact Scenario

- Based on Results from
  - Train Derailment Dynamics Research
  - Accident Data and Forensic Evidence
- Idealized Impact Condition
  - Repeatable
  - Analyzable
  - Results in Failure Mode(s) Similar to Accidents
  - Represents Essential Accident Characteristics
  - Safe/Controlled
- Provides Means of Comparing Alternative Designs
- Provides Means for Qualifying Designs
- Approach Parallels Automotive 30-mph Barrier Test

Macdona, Texas on June 28, 2004

Automobile Side Impact Test
Video of Puncture Test and Analysis

Impact Test of a DOT-105 Tank Car
Impact Speed: 15.1 mph
Tank Punctured

Tests Performed at Transportation Technology Center
Pueblo, CO

Simulation Performed by the Volpe Center
Cambridge, MA
Predicted Damage to Tank Shell
Relative Effect of Various Factors on Puncture Speed

- Strong
  - Ram Car Weight
  - Internal Pressure

Moderate

Weak

+ Indenter Size

Steel Type
Shell Thickness
Jacketed
Tank Diameter
Summary

- The Volpe Center provides technical support to all of the agencies within the US Department of Transportation.

- The Volpe Center has provided technical support to the Federal Railroad Administration since the late 1970s.

- Support to the FRA Tank Car Safety Research entails both long-term research and as-needed assistance.
Contact Information

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Backup Slides
Derailment Pile-Ups

Minot, North Dakota on January 18, 2002

Oneida, New York on March 12, 2007

Macdonia, Texas on June 28, 2004

Lac-Mégantic, Quebec on July 5, 2013
Semi-empirical Method for Head Puncture

- Based on extensive head testing conducted in 1970s and ‘80s
  - RSI-AAR
  - FRA

- Forces and deformations based on Hertz contact

- Failure based on transverse shear stress criterion
Correlations with Test Data and Engineering Analyses

• Semi-empirical method gives reasonable but conservative estimates for head puncture speed.

• Conservative means
  – Lower-bound estimate
  – Actual or true puncture speed is most likely to be somewhat higher than estimate

http://www.fra.dot.gov/eLib/details/L04134
http://www.fra.dot.gov/eLib/details/L04135
Semi-analytical Method for Shell Puncture

- Based on results from finite element analyses
- Validated with limited full-scale testing

http://ntlsearch.bts.gov/tris/record/ntl/37910.html
http://ntlsearch.bts.gov/tris/record/ntl/47391.html
Building Block Approach

Full-scale Level

Component Level

Coupon Level

Correlation

Test

Analysis

NON GENERIC SPECIMENS

CLOSED FORM ANALYSES AND COMPUTATIONAL MODELING

GENERIC SPECIMENS
Verification for Head and Shell Deformations

**Head**

![Graph showing indentation vs. force for Head.

**Shell**

![Graph showing indentation vs. force for Shell.


Significant Factors in Shell Impact Test

Tank Car Specification

Impact Speed

Indenter Size

Ram Car Weight
<table>
<thead>
<tr>
<th>Indenter (W x H)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6” x 6” (½-inch radii)</td>
<td>• Similar to coupler shank with broken head</td>
</tr>
<tr>
<td>12” x 12” (1-inch radii)</td>
<td>• Similar to standard coupler</td>
</tr>
</tbody>
</table>
| 17” x 23” (1-inch radii) | • Smaller than draft sill  
| | • Larger than standard coupler  
| | • Similar to shelf coupler on car rolled onto side |
Major Railroad Accidents Involving HAZMAT Release
Composite Summaries for 1969 to 1978

• Total of 75 accidents in this time period

• 22 accidents in which probable impacting object was reported
  – 13 couplers
  – 5 drawbars
  – 2 rails
  – 1 wheel
  – 1 end sill

• Probable cause of these accidents
  – 16 Derailments
  – 6 Collisions
Generic Force-Indentation Characteristic

For a given tank car specification and indenter size

Elastic

Plastic

Energy

Failure Unlikely

Failure Possible

Failure Likely

DENT ZONE

Increasing impact Speed

PUNCTURE ZONE
Force-Time Histories in Full-Scale Shell Impact Test 1
(14 mph, 17” x 23” Indenter)

Force-Indentation in Full-Scale Shell Impact Test 2
(15 mph, 6” x 6” Indenter)

- Processed Test Data
- Pre-Test Finite Element Analysis

Energy

Failure Possible

Force (kips)

Indentation (inches)
Comparison Between DOT 111 Test and FEA
(14 mph, 12” x 12” Indenter)
## DOT111 and 112 Cars in Full-scale Tests

<table>
<thead>
<tr>
<th>DOT111A100W1</th>
<th>DOT112J340W</th>
</tr>
</thead>
<tbody>
<tr>
<td>General purpose</td>
<td>LPG service</td>
</tr>
<tr>
<td>Built in 1974</td>
<td>Built in 2001</td>
</tr>
<tr>
<td>7/16” shell thickness</td>
<td>0.618” shell thickness</td>
</tr>
<tr>
<td>7/16” head thickness</td>
<td>11/16” head thickness</td>
</tr>
<tr>
<td>ASTM 515 Grade 70</td>
<td>TC128 Grade B, Normalized</td>
</tr>
<tr>
<td>Sloping bottom rings; 106 to 110¼” diameter</td>
<td>117⅞” diameter</td>
</tr>
<tr>
<td>4” insulation</td>
<td>½” insulation</td>
</tr>
</tbody>
</table>
Comparison of Full-scale Tank Car Shell Impact Test Results

<table>
<thead>
<tr>
<th>Car Type</th>
<th>Test Impact Speed (mph)</th>
<th>Kinetic Energy (M ft-lb)</th>
<th>Estimated Puncture Speed (mph)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOT111</td>
<td>14.0</td>
<td>1.95</td>
<td>12</td>
<td>PUNCTURE</td>
</tr>
<tr>
<td>DOT112</td>
<td>14.7</td>
<td>2.14</td>
<td>16</td>
<td>Tank Integrity Maintained</td>
</tr>
</tbody>
</table>
Applications of Force-Indentation Characteristic

• Automotive Crashworthiness (to Analyze Wall Test)
• General Aviation and Transport Aircraft (to Analyze Failed Takeoff/Landing)
• Building Protection Barriers
• Passenger Rail Equipment Crashworthiness
• Locomotive Crashworthiness
Strategies for Improved Puncture Performance

- Blunting the Impact
- Managing Collision Energy
- Providing Support Structure for Load-Blunting and Energy-Managing Features
Framework for Improved Designs

1. Impact Scenario
2. Existing Design
3. Potentially Improved Design
4. Evaluate
5. Develop Evaluation Techniques
6. Compare Effectiveness of Potentially Improved and Existing Designs
7. Revise
Developing Evaluation Techniques

Develop Evaluation Techniques

Modeling and Simulation Activities

Experimental and Testing Activities

Confirm

Y

Evaluate

N
Development of Protective Panel

Quasi-static Crush Tests

| 5" Pipe Core | X X X X X |
| 3" Pipe Core | X X X X X X X |
| 2" Pipe Core | X X X X X X X X X |
| X-Core | X X X |
| Diamond Core | X X X X X X X X X |

Quasi-static Three-point Bend Tests

1. Face Sheet Yield or Fracture
2. Local Indentation
3. Core Shear

Schematic of Protective Panel

<table>
<thead>
<tr>
<th>Material</th>
<th>AISI 1010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>803 lb (21 psf)</td>
</tr>
</tbody>
</table>

OUTER FACESHEET
0.12” thickness

3” OD pipes
0.086” thickness

INNER FACESHEET
0.12” thickness
Strips 3” wide, 3” spacing

6 ft
Correlating Engineering Analyses and Conditional Probability of Release

This slide has been removed from the presentation at the request of the Dr. David Jeong (May 1, 2014)
Impact Scenarios with Equivalent Kinetic Energy

Kinetic Energy = 1 Million ft-lb

Impact Speed (mph)

- Ram Car: 10.1 mph
- Passenger Car: 13.7 mph
- Empty Tank Car or Semi-trailer Truck: 19.1 mph
- 3 Sport Utility Vehicles: 20.0 mph
Estimated Shell Puncture Speeds for Other Cars

This slide has been removed from the presentation at the request of the Dr. David Jeong (May 1, 2014)