Federal Railroad Administration

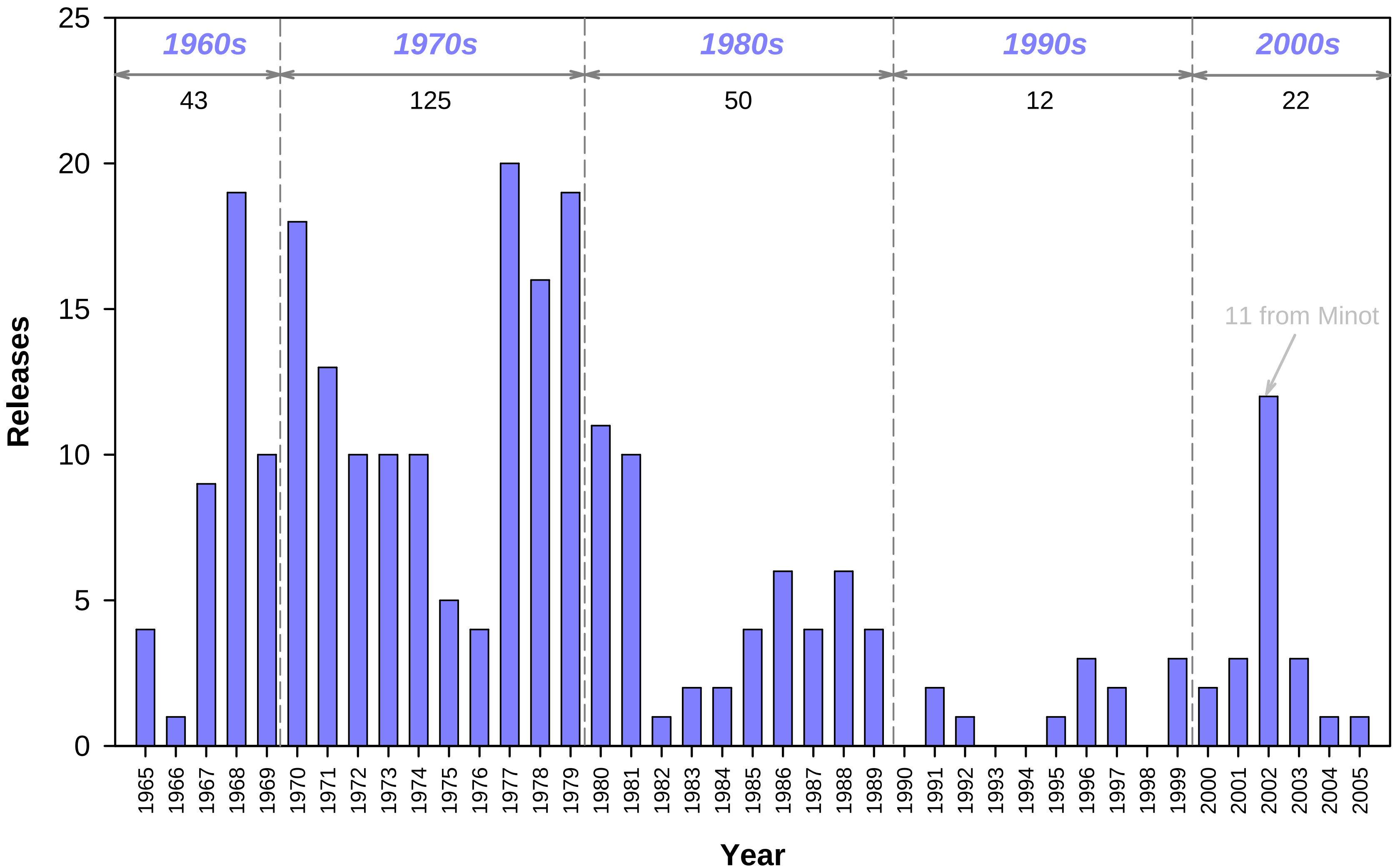
Update on Ongoing Tank Car Crashworthiness Research: Research Overview

Presentation to

Fertilizer Institute

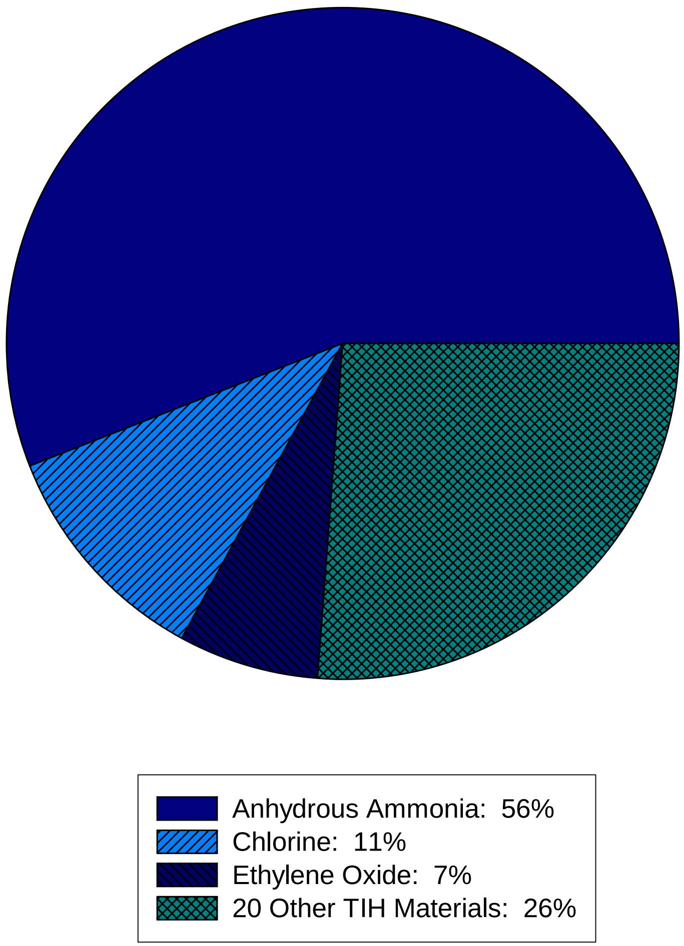
February 14, 2008

TIH Tank Cars Releases, 1965-2005
252 Releases in 176 Accidents

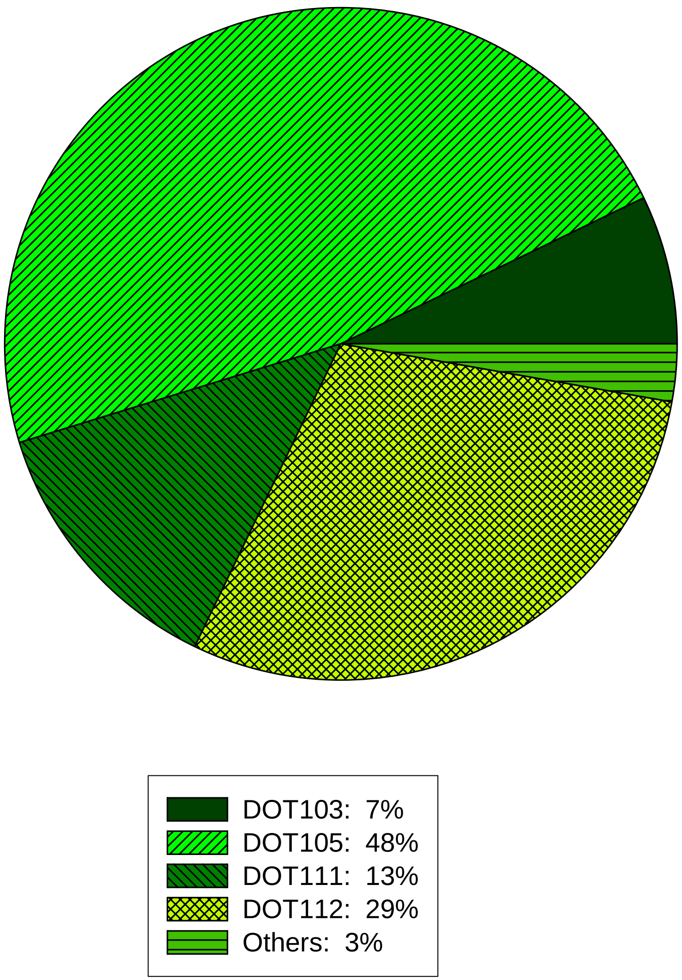


TIH Accident-Caused Releases 1965-2005 : 252 Releases

Lading

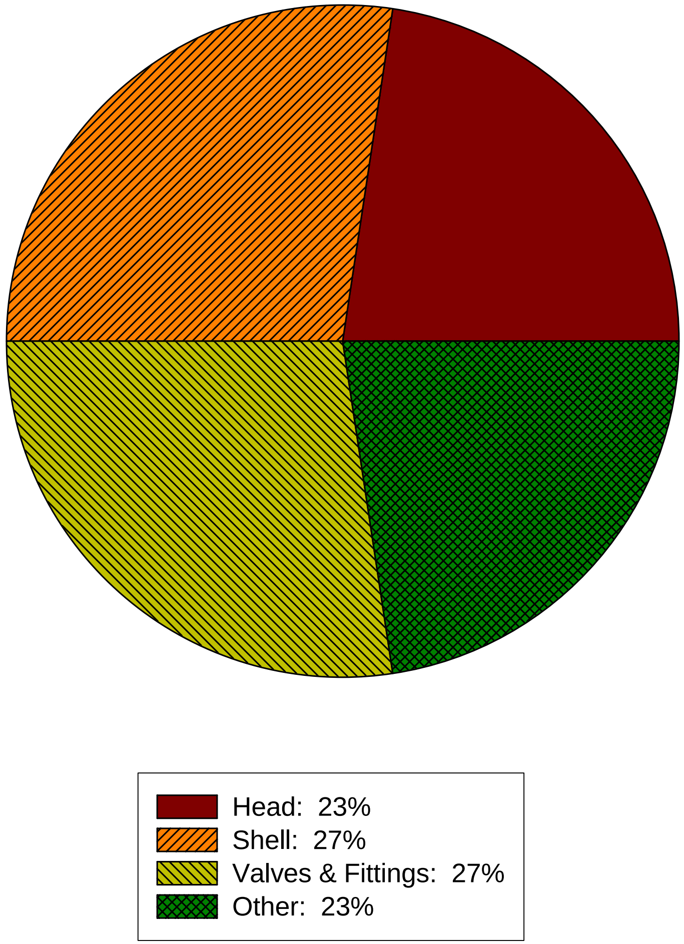


Car Specification

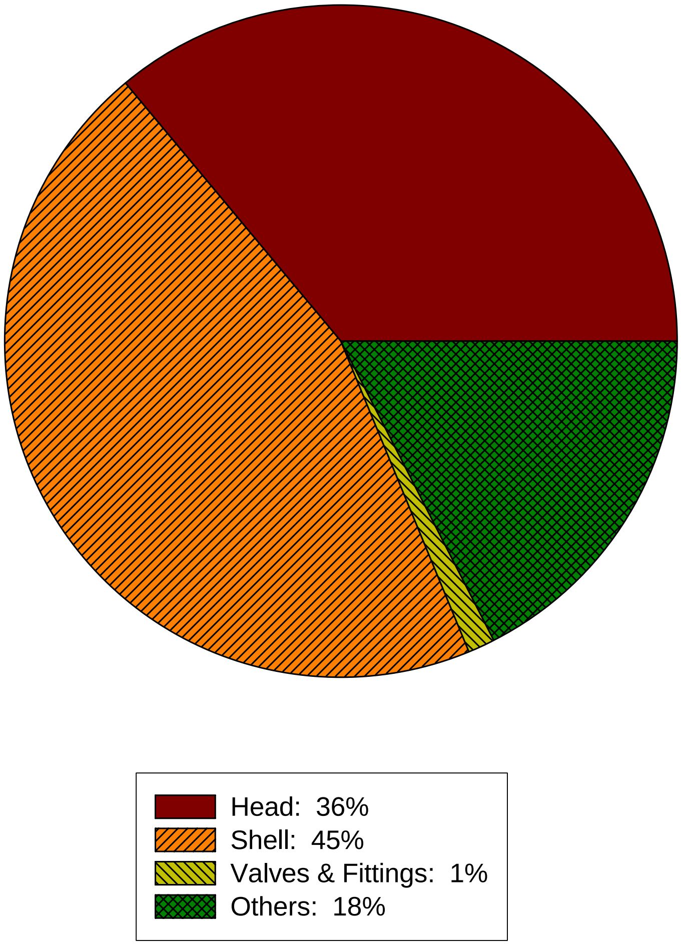


TIH Accident-Caused Releases, 1980-2005
84 Releases; 735.5 (1000's) Gallons Lost

Cause of Lading Loss



Gallons Lost



Tank Car Safety Research Objective

1980 - present

2002 - present

- **To Maintain Tank Integrity**
- Under "Normal" Operating Conditions (Prior to Minot)
  - Damage Tolerance
  - Metal Fatigue
- Under Extreme/Accident Loading Conditions (After Minot)
  - NTSB/Minot Recommendations
  - Technical Support
    1. Notice for Proposed Rule-Making
    2. Memorandum of Cooperation with NGRTC Program

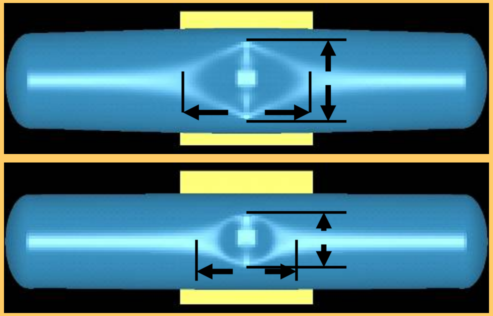
Framework

- Identify Collision Scenarios of Concern
- Adapt Existing Analysis Techniques
- Evaluate Effectiveness of Baseline Design
- Develop and Model Improved Design
- Compare Effectiveness of Improved and Baseline Designs
- Conduct Tests to Verify/Refute Modeling and Comparison

Roadmap

1. Define Problem

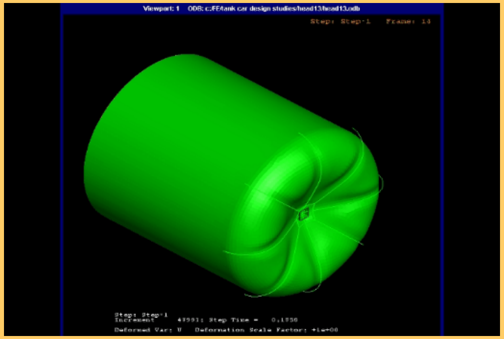
2. Analyze Problem



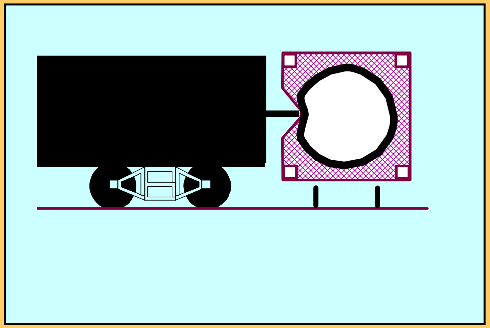
3. Test Baseline

4. Refine Simulation

5. Develop Modifications



6. Evaluate Modified Design

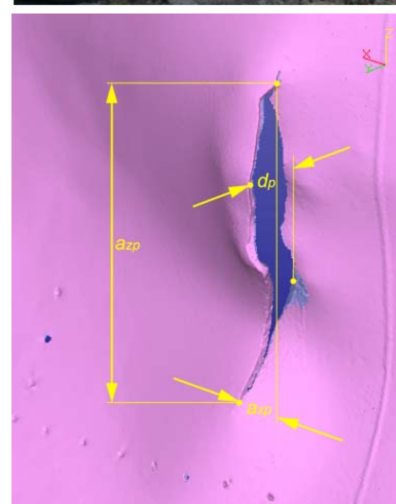


Accident Scenarios of Concern

Accident Scenario	Collision Modes	Example Accidents
Derailment	Head and Shell Impacts	*Alberton, MT, April 11, 1996* *Temagami, ON, March 14, 2000* *Minot, ND, January 18, 2002*
Train-to-Train Collision	Override, Head and Shell Impacts	*Macdona, TX, June 28, 2004* *Graniteville, SC, January 6, 2005*

Example Punctures

Head Puncture in Macdona Accident



Shell Puncture in Graniteville Accident

Problem Definition

Generalized Accident Simulation

Generalized Impact Scenario

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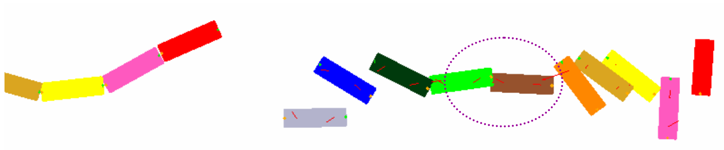

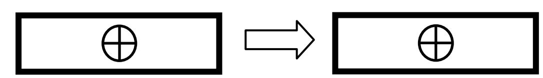

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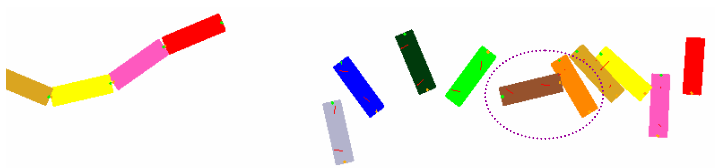
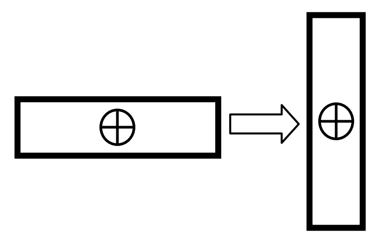
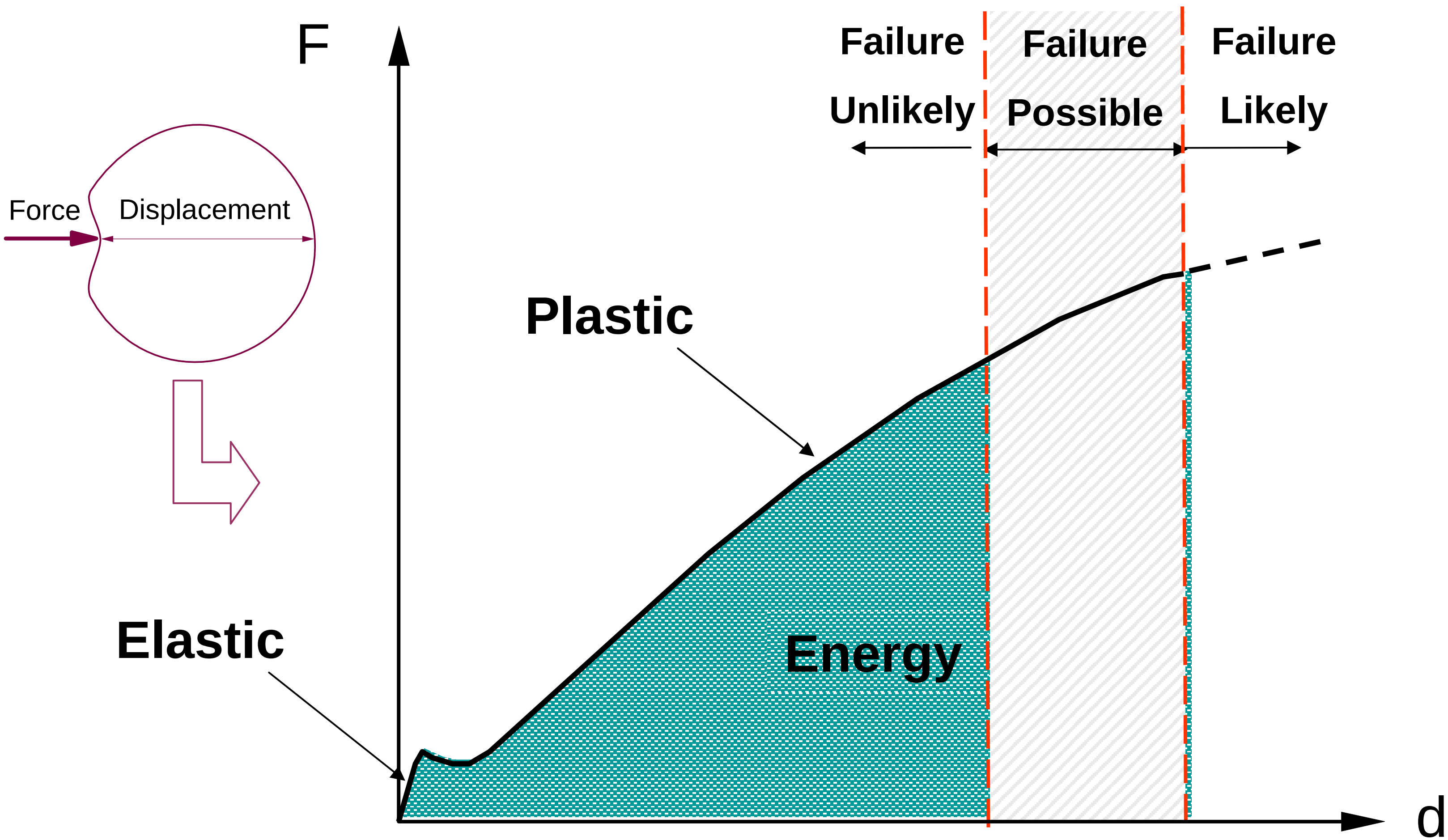




Car-to-car impacts tend to occur at about ~½ initial accident speed

Generic Force-Indentation Characteristic



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

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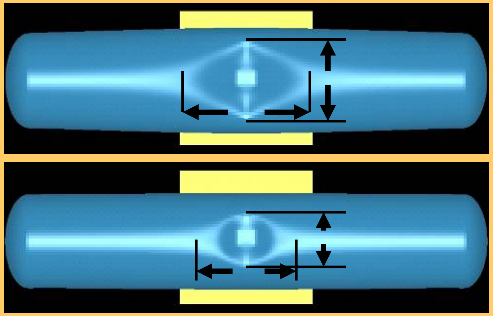

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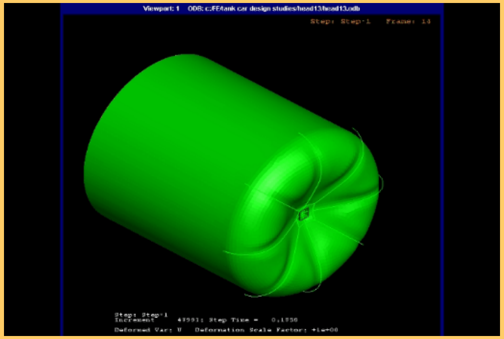

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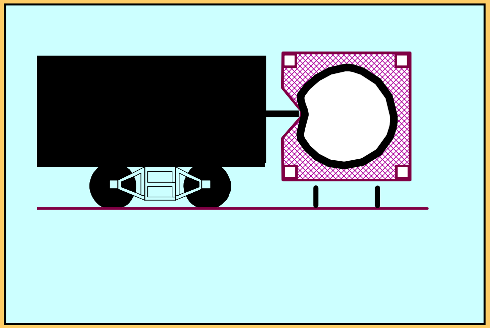


Approach to Full-Scale Testing

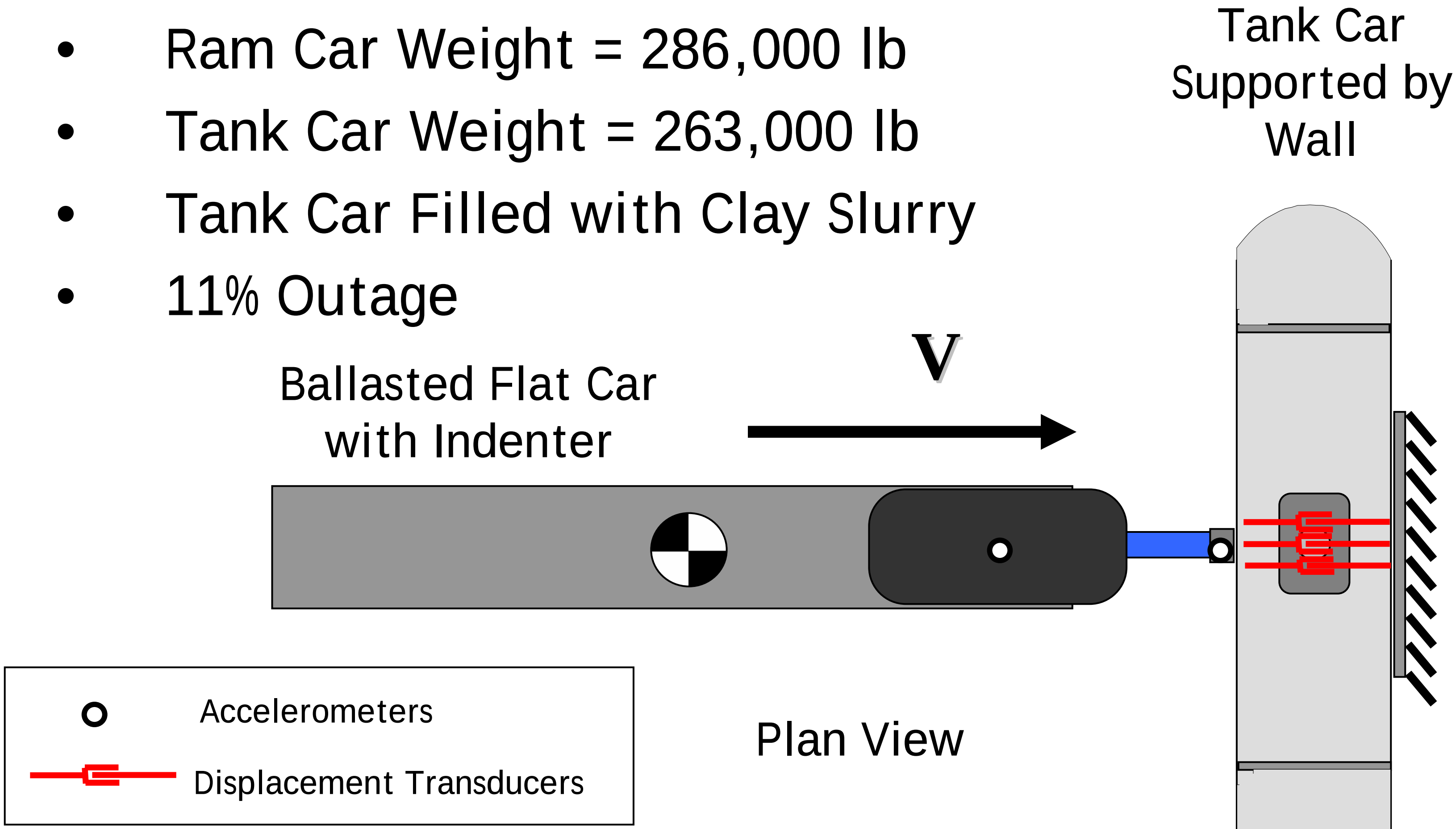
- Idealized Impact Condition
  - Repeatable
  - Analyzable
  - Not intended to replicate accidents conditions with high fidelity
  - Results in failure mode(s) similar to accidents
- Provides means of comparing alternative designs
- Provides means for qualifying designs
- Approach similar to automotive 30-mph barrier test

Full-Scale Tank Car Shell Impact Tests

- Test Objectives
  - Impact, Deform and Puncture Shell, Away from Sills
  - Observe Evolution of Deformation and Failure Modes
  - Measure Force-Indentation Characteristic
- Target Information
  - Shell Deformation Time-History
  - Impact Load Time-History

Full-Scale Tank Car Shell Impact Tests

- VTest 1 = 14 mph; 17” x 23” (Large) Punch
- VTest 2 = 15 mph; 6” x 6” (Small) Punch
- Ram Car Weight = 286,000 lb
- Tank Car Weight = 263,000 lb
- Tank Car Filled with Clay Slurry
- 11% Outage



Full-Scale Shell Impact Test 1
(14mph with 17 by 23 inch Impactor)

TANK CAR SHELL IMPACT TEST 1

APRIL 26, 2007

OVERHEAD VIEW OF IMPACT

AND

FINITE ELEMENT ANALYSIS OF IMPACT

Finite Element Modeling

- Simplified Geometry
  - No Manway, Body Bolster, or Draft Sill
- Fluid
- Internal pressure: 100 psi
- Selective Mesh Refinement
- Failure: Bao-Wierzbicki with Progressive Damage
- Solvers
  - ABAQUS (with Failure Criterion)
  - LS-DYNA (without Failure Criterion)

Results from Full-Scale Shell Impact Tests

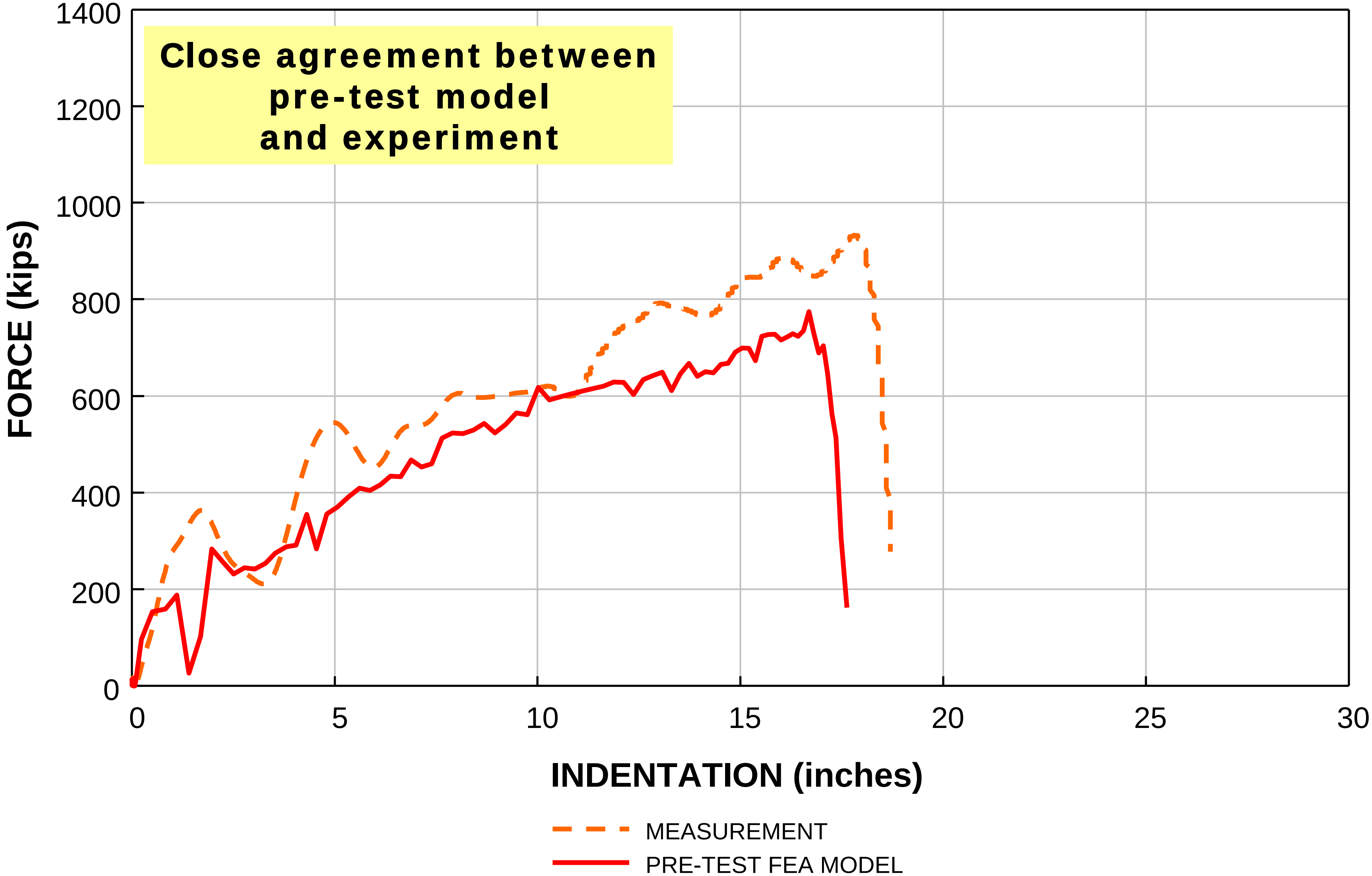
Test 1

14 mph
23” x 17” Punch
No Rupture

Test 2

15 mph
6“ x 6” Punch
Rupture

Test 2 Force-Indentation: Measurement & Analysis



Full-Scale Tank Car Shell Impact Tests: Lessons Learned

- Failure Mode Similar to Accidents
- Modeling of Structural Response Validated with Test Data
- Robust Techniques Can be Used to Evaluate Alternative Designs

Roadmap

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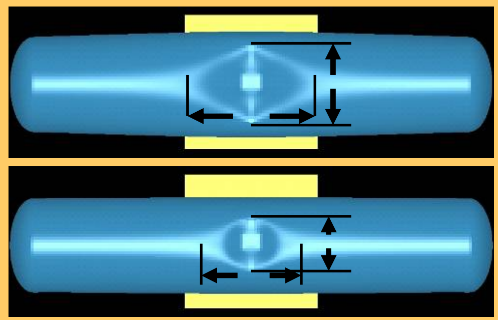
2. Analyze Problem



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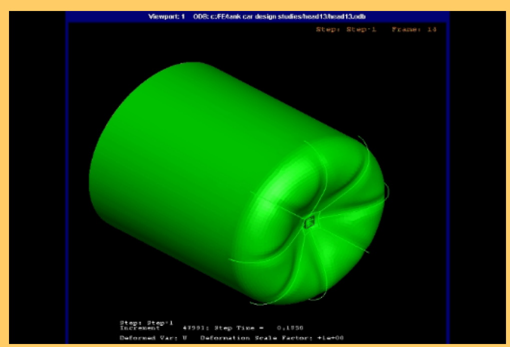

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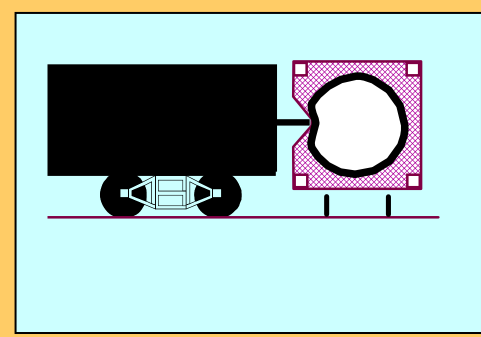


Improved Design Development

- Approach
  - Define Desired Performance
  - Develop Strategy for Meeting Performance
  - Develop Tactics (Evolve a Conceptual Design)
- Engineering Methods
  - Collision Dynamics
  - Structural Collapse
  - Material Selection

Tank Improvement Strategies

- Reinforce the commodity tank
  - Increases capacity for energy absorbing structure
- Distribute the load
  - Blunt the impact
- Absorb collision energy
  - Reduces energy absorption demands on the tank
- Carry service loads in exterior structure
  - Controls the load path to the tank

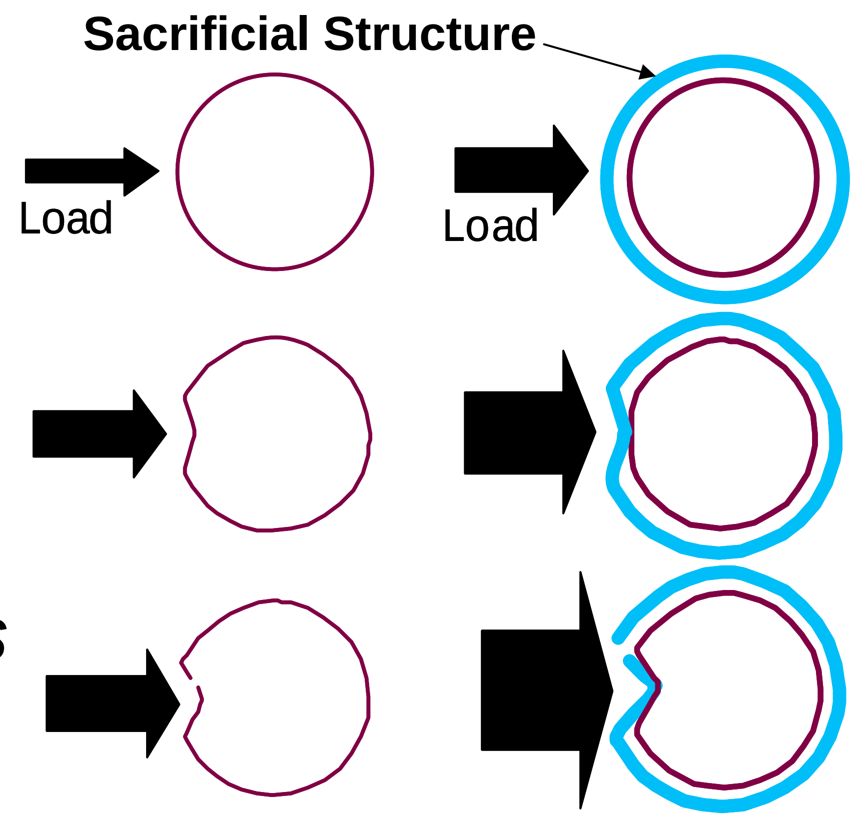
Reinforce Tank

Make tank stronger than sacrificial layer so that energy absorbers crush before tank collapses

Absorb Collision Energy

- Sacrificial structure can absorb significant portion of impact energy
- Energy absorption reduces demand on tank

Larger force and longer distance required to rupture protected tank



Use sacrificial components to absorb energy

Blunt Impact Loads

Large Impactor Face
Does Not Rupture Tank

Small Impactor Face
Ruptures Tank

Use Shielding to Increase Effective Impact Area on Tank

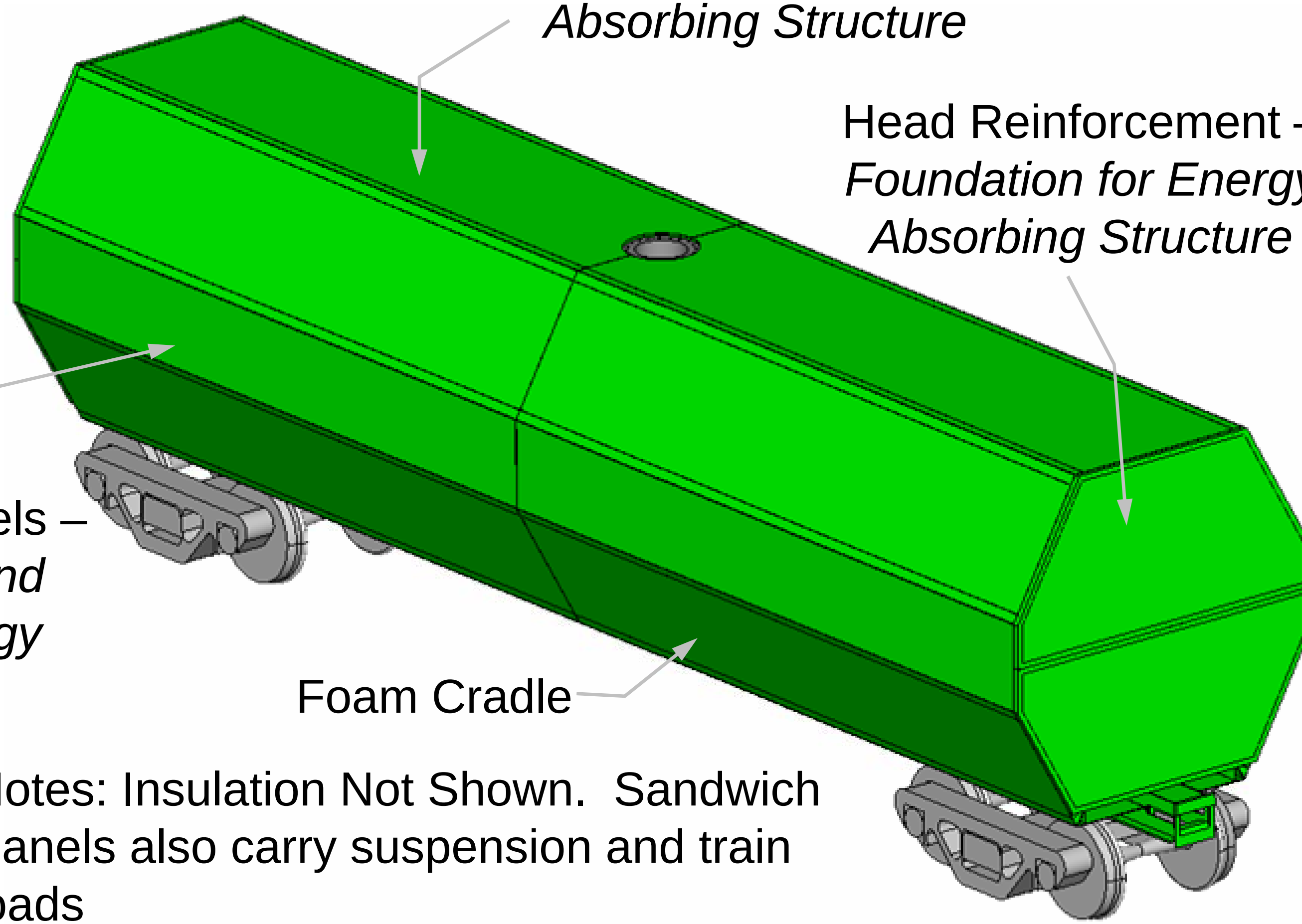
Tank Loads

Shield entire tank and absorb collision energy before impacting tank

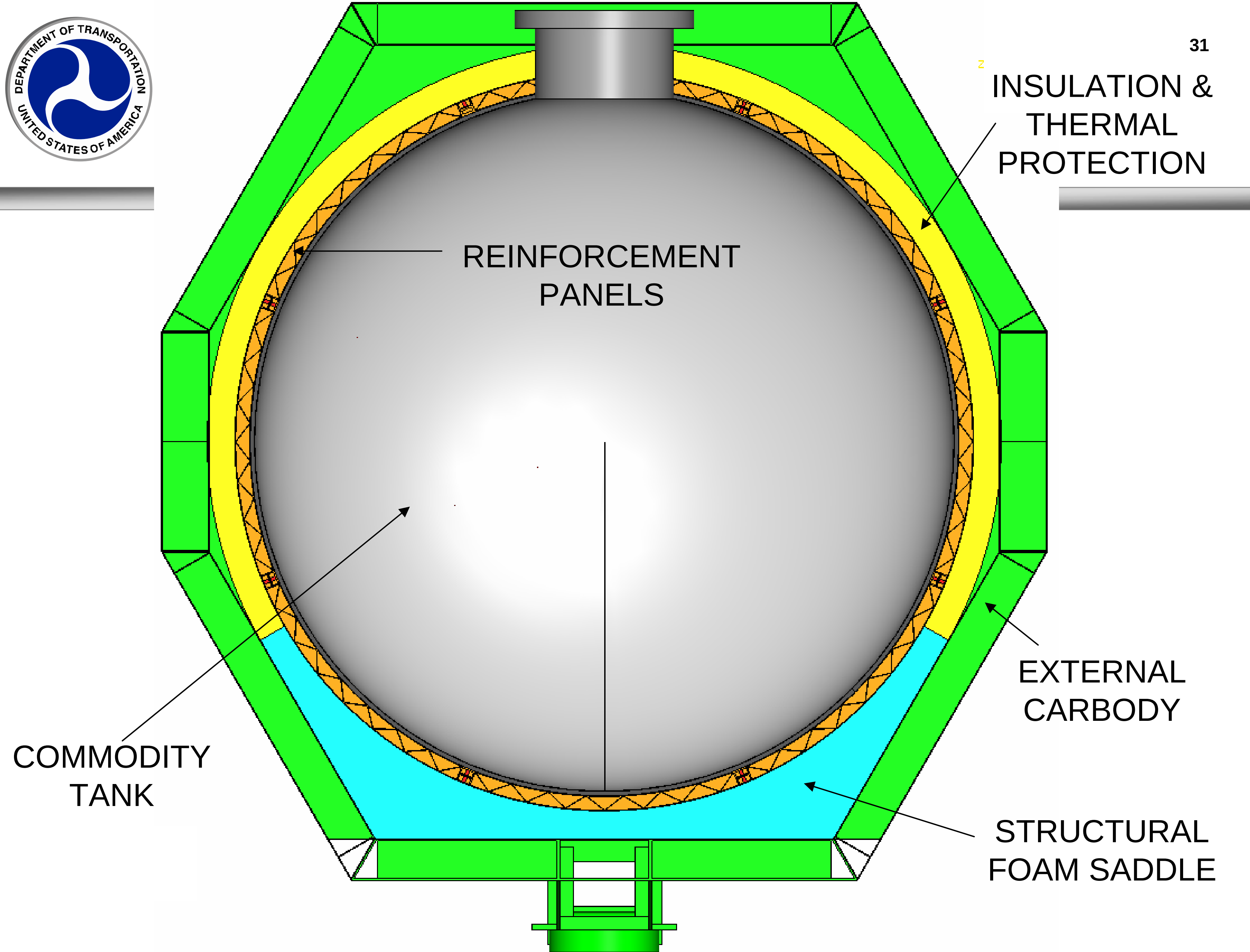
Tank Car Conceptual Design Functions, Features, Forms

Functions	Features	Forms
Blunted impact loads	Sacrificial structure that shields tank and absorbs energy	Dual-purpose sandwich structures
Collision energy absorbed		
Stronger tank	Reinforcement of head and shell	Ribs on head, sandwich panels over shell
Control load path to tank	Detach tank from service loads	Separate carbody

Conceptual Design



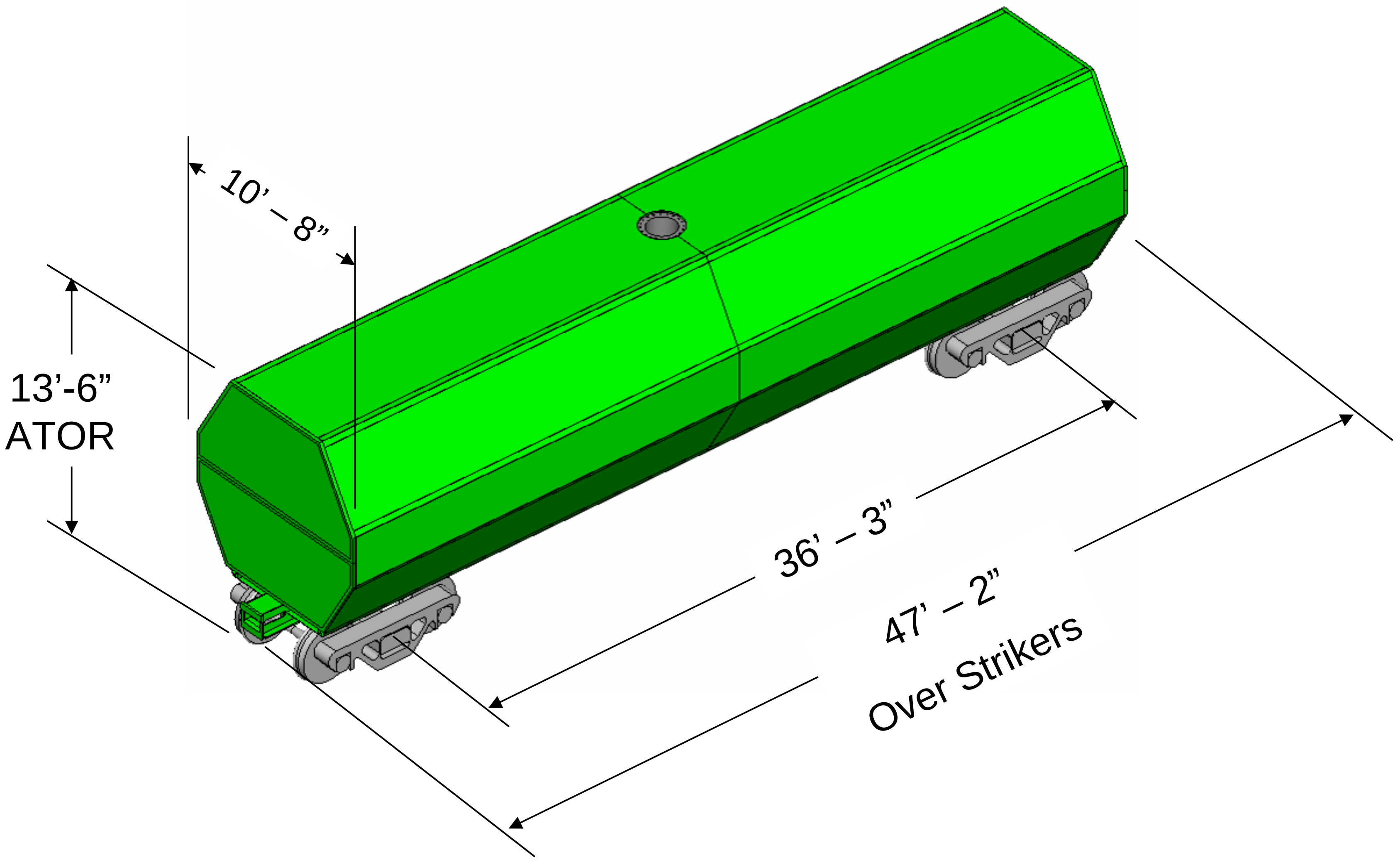
Notes: Insulation Not Shown. Sandwich Panels also carry suspension and train loads


INSULATION &
THERMAL
PROTECTION
REINFORCEMENT
PANELS
EXTERNAL
CARBODY
COMMODITY
TANK
STRUCTURAL
FOAM SADDLE

Design Considerations

- Clearances
  - AAR Plate B
  - Swingout Clearance
- Static Loads
  - Static End Strength
  - Standing Weight
  - Diagonal Jacking
- Weight
  - 286,000 lb Maximum Weight-on-Rail
  - 180,000 lb Commodity Capacity

Clearances



Improved Design Constrained to fit AAR Plate B

Static Load Requirements

- Static Loads Evaluated
  - Static End Strength
  - Standing Weight
  - Diagonal Jacking
- Additional Load Cases Required for Detailed Design

Weight Budget

Assembly	Weight (lbf)
Reinforced Tank	45260
Structural Carbody	33500
Marriage Components	24410
Lading	180000
Total Weight	283170

Note: This weight budget uses a 0.625” thick tank

Head and Shell Impact Analyses

Objective

- Evaluate Effectiveness of Tank Reinforcement and Sacrificial Structures

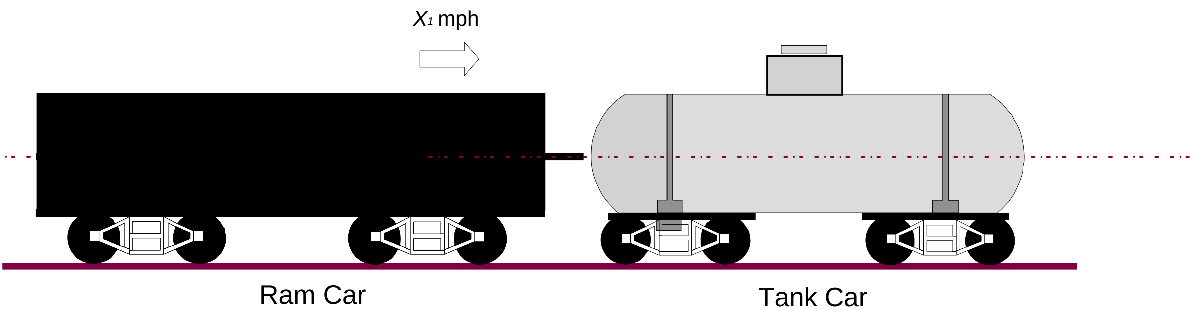
- FEA Modeling
  - Simplified Geometry, No Fluid, No Pressure
  - Estimate of Material Failure

Key Result

- Estimate of Energy to Puncture

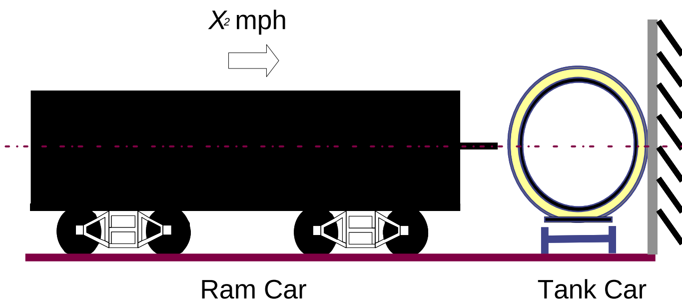
Desired Performance

Head Impact



Elevation View

Shell Impact

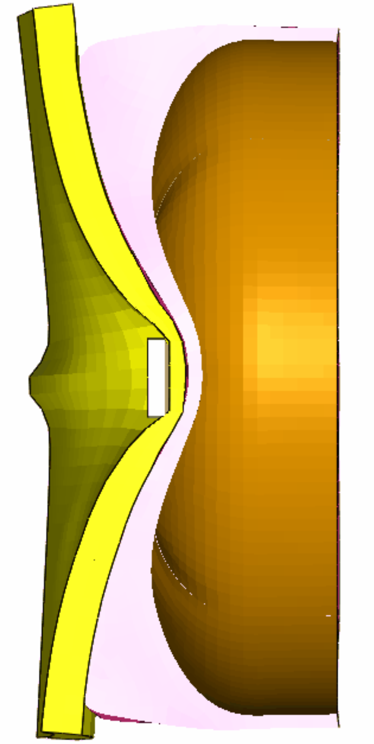


Elevation View

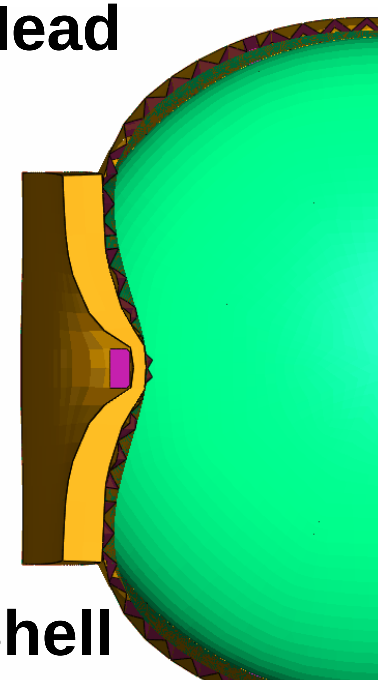
<u>Quadruple</u> Impact Energy for which Commodity is Contained

Modes of Deformation at Estimated Puncture

- Head and Shell Reinforcement and Sacrificial Structure Blunt Load and Absorb Energy
    - Blunting Spreads the Load and Increases Puncture Displacement
    - Energy Absorption Reduces Impact Experienced by Tank



Head



Shell

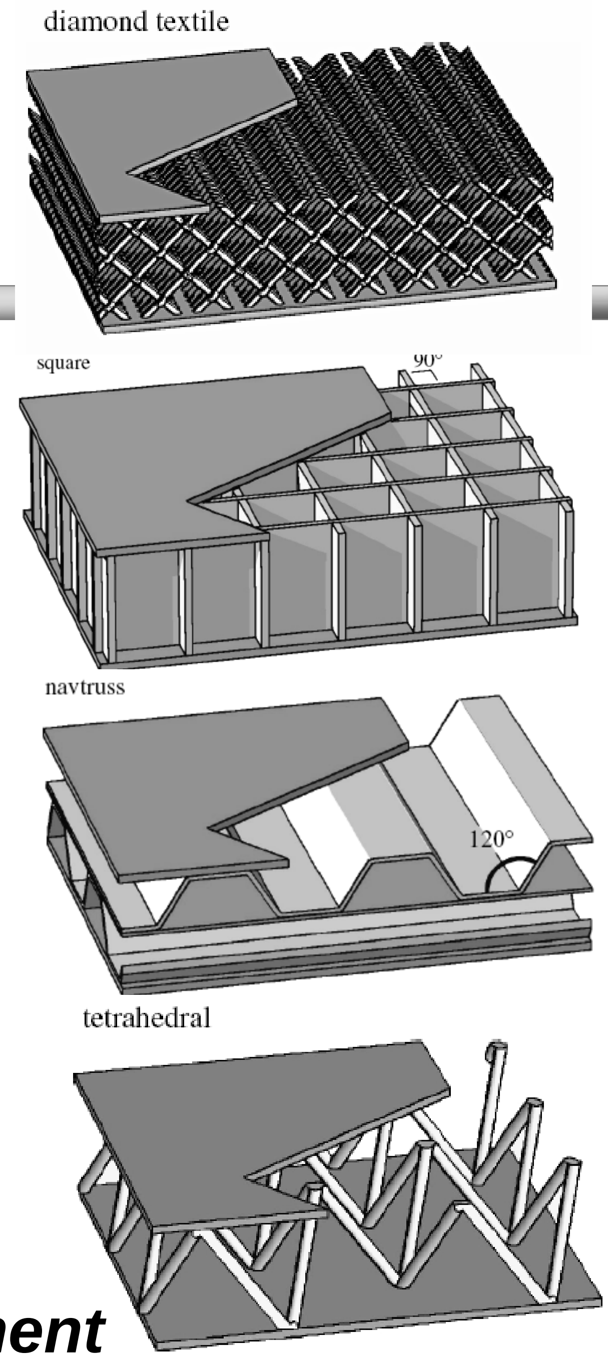
Head and Shell Impact Analysis Summary

- Estimated Head Impact Energy to Rupture
  - Increased by ~10 Times Over Baseline Bare Head
  - Increased by ~5 Times Over Baseline Head with Shield (expected)
  - Comparable Improvement for Offset Impacts
- Estimated Shell Impact Energy to Rupture Increased by ~4 Times
- Tank Reinforcement and Sacrificial Structure Effective in Absorbing Energy and Blunting Impact Loads

Construction

- Conceptual Design Can Be Fabricated Using Mature Technologies
- Tank Car Manufacturing Facilities
  - Fabrication of Tank
  - Installation of Reinforcement
  - Assembly of Carbody
  - Integration of Tank and Carbody
- Marine Facilities
  - Sandwich Panels

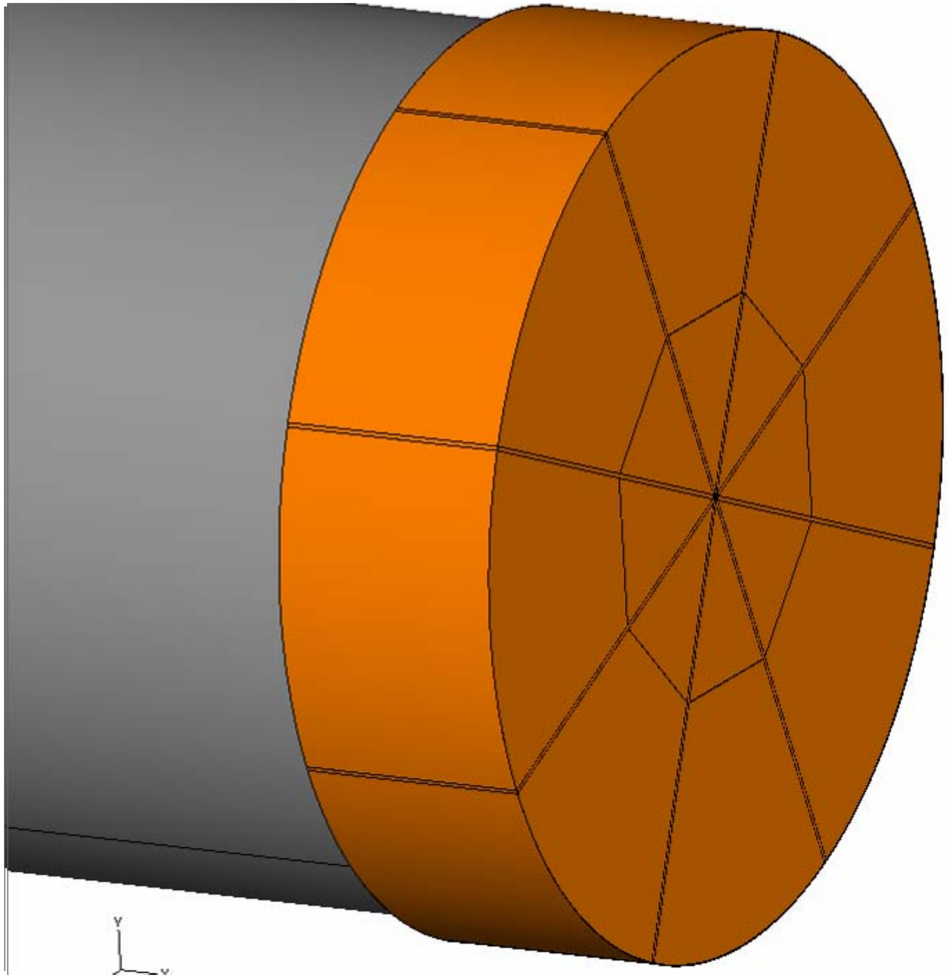
Sandwich Panels



- Characterized By Facesheets and Inner Core
  - Facesheets up to ½ Inch Thick
  - Wide Range of Core Geometries
- High Bending Stiffness and Strength, Compared with Equal Weight/Area Solid
- Absorb Energy When Crushed

Used for Carbody and Shell Reinforcement

Head Reinforcement



Conventional Tank

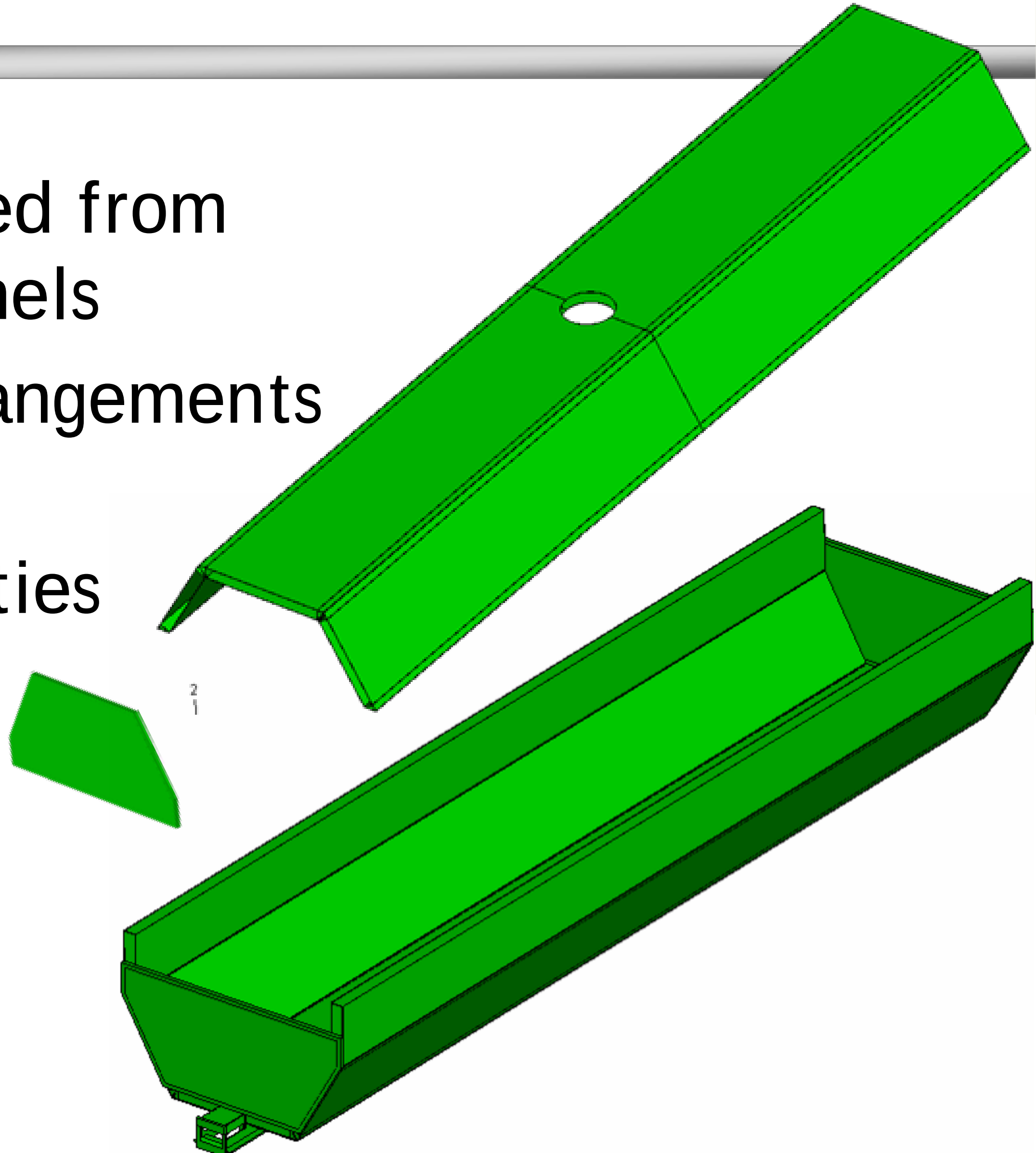
Webs Welded to Head

Face Sheet Welded to Webs

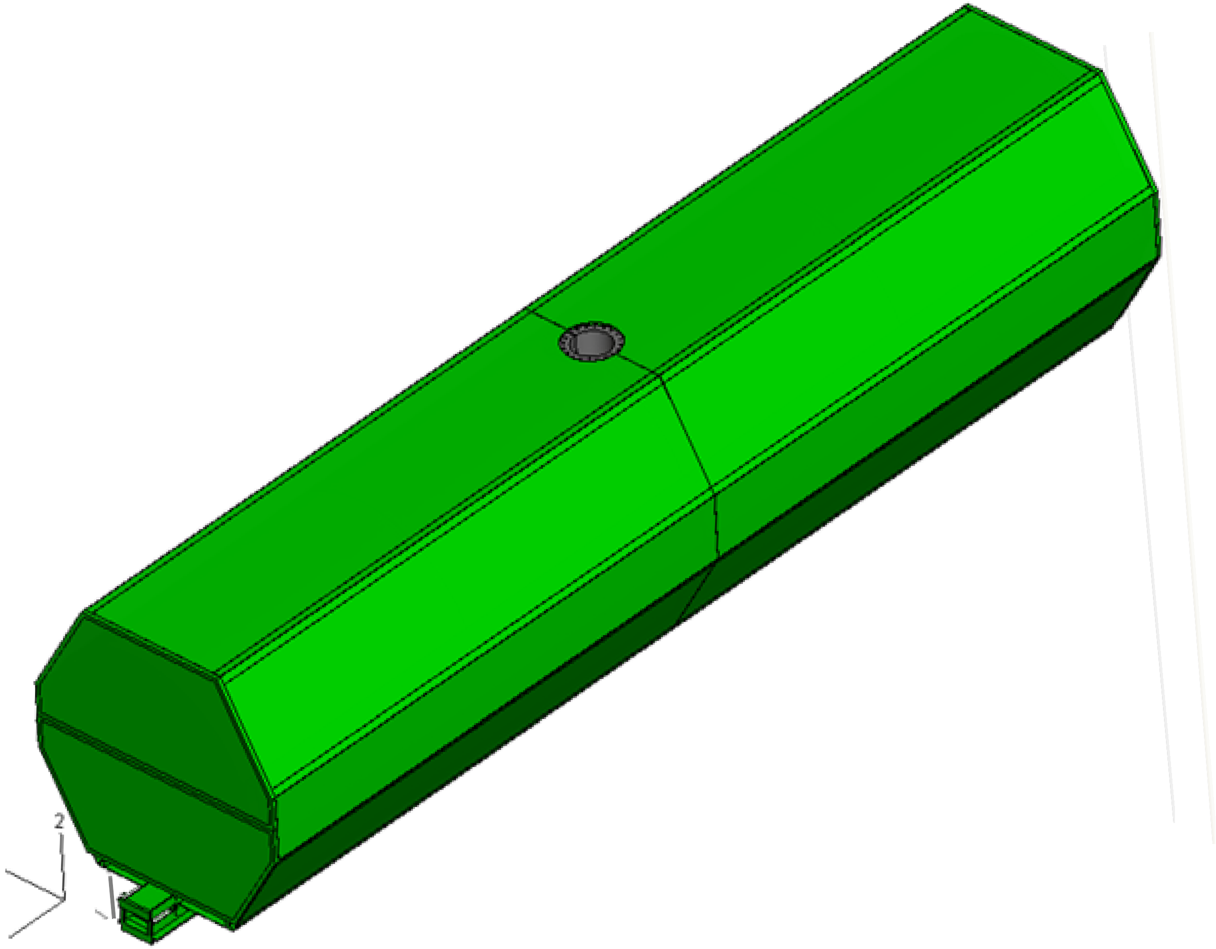
Shell Reinforcement

Carbody Construction

- Carbody Fabricated from Flat Sandwich Panels
- Multiple Core Arrangements Possible
- Fabrication Facilities Available



Conceptual Design



Reinforced Tank

Insulation and Foam Saddle

Tub

Roof

Status

- Research Status
  - Generalized Impact Scenarios Developed
  - Analysis of Baseline Shell Deformation Completed
  - Baseline Full-Scale Shell Impact Tests Completed
  - Improved Design Concept Developed

- Ongoing Activities
  - Analysis of Baseline Head Deformation
  - Refinement of Improved Design