Impact Damage Formation on Composite Aircraft Structures

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FAA Joint Advanced Materials and Structures Center of Excellence Meeting
NIAR/WSU, Wichita KS

FAA Sponsored Project Information

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- Principal Investigators & Researchers
  - Hyonny Kim, Associate Professor, UCSD PI
  - *Prof. Tom Hahn, UCLA PI – sending subcontract to UCSD*
  - Gabriella DeFrancisci, Graduate Student, UCSD
  - Daniel Whisler, Graduate Student, UCSD (completed MS June 09)
  - Jennifer Rhymer, Graduate Student, UCSD
  - Zhi Chen, Graduate Student, UCSD (starting Aug 09)
- FAA Technical Monitor
  - Curt Davies
- Other FAA Personnel Involved
  - Larry Ilcewicz
- Industry Participation
  - Airbus, Boeing, Bombardier, Cytec, Northwest Airlines, San Diego Composites, United Airlines
  - Govt lab: Sandia National Labs

Project Focus: Blunt Impacts

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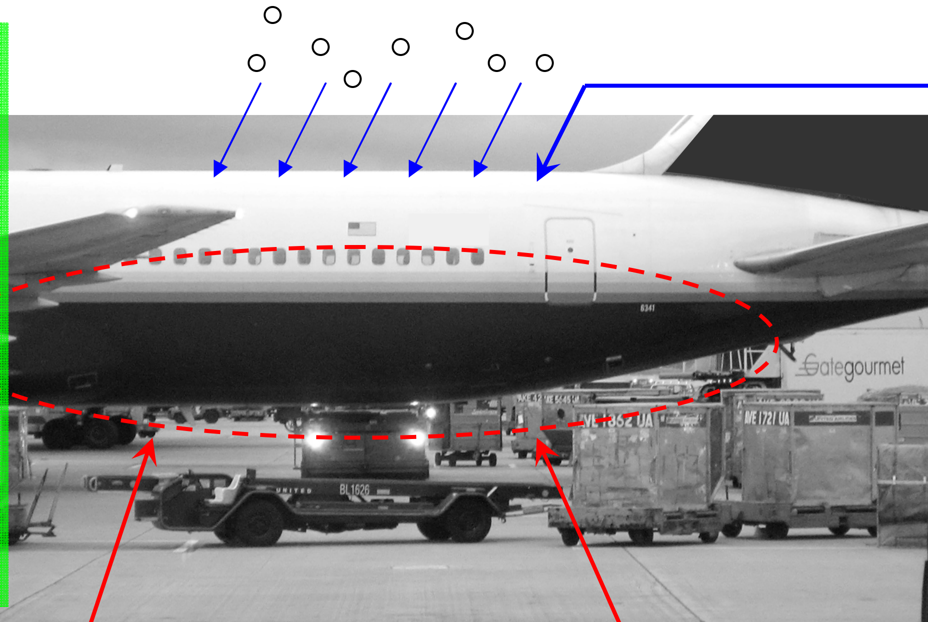
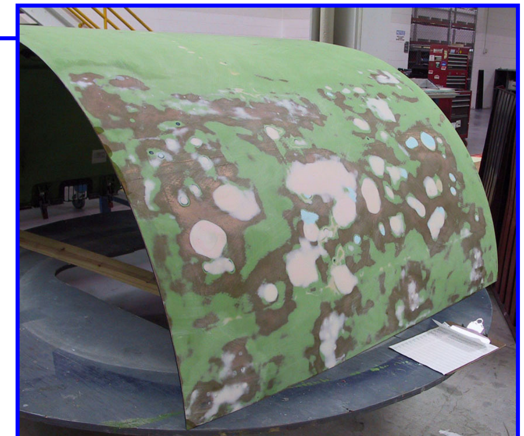
<u>Blunt Impacts</u>

- blunt impact damage (**BID**) can exist with ***little or no exterior visibility***
- sources of interest are those that affect *<u>wide area</u>* or *<u>multiple structural elements</u>*





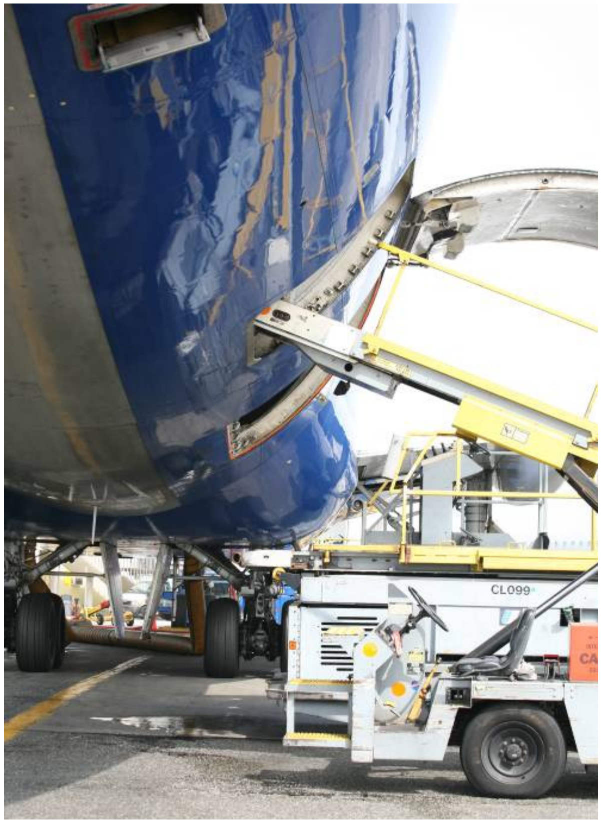
<u>Hail Ice Impact</u>

- upward & forward facing surfaces
- low mass, high velocity

Ground Vehicles &
<u>Service Equipment</u>

- side & lower facing surfaces
- high mass, low velocity
- wide area contact
- damage possible at locations away from impact

Parallel Project Activities



Low-Velocity High-Mass Wide-Area Blunt Impact

- ground vehicles and ground service equipment (GSE) impacts

High Velocity Hail Ice Impact

Low-Velocity High-Mass Wide-Area Blunt Impact Project Overview

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- **Project Partners**
  - **Team Members: Bombardier, Cytec, Sandia, San Diego Composites**
  - **Consultants: JC Halpin (aircraft), Jack Bish (automobile crash)**
  - **Other Participants: Airbus, Boeing, Northwest Airlines, United Airlines**

- **Overarching Objectives of Blunt Impact Project** *(Multi-Year Effort)*
  - **Identify which blunt impact scenarios are:**
    - » **commonly occurring**
    - » **of major concern to airlines, OEM**
  - **Develop Methodology for Blunt Impact Threat Characterization and Prediction**
    - » **establishing relationship between full-barrel vs. "small" panel BC's**
    - » **identification of key phenomena and parameters that are related to damage formation**
      - – **how affected by bluntness?**
      - – **failure initiation thresholds**
    - » **focus: what conditions relate to development of massive damage occurring with minimal or no *exterior* visual detectability?**
      - – **can this always be a *self evident* event? (self reported or system-based)**
  - **Damage tolerance assessment of blunt impact damaged structures**
    - » **loss of limit load capability?**
    - » **ID structural configurations and details more prone to this loss of capability**

More info at UCSD Blunt Impact website: http://csrl.ucsd.edu/UCSDbluntimpact/

Logic Diagram for Low Velocity High-Mass Wide-Area "Blunt" Impacts

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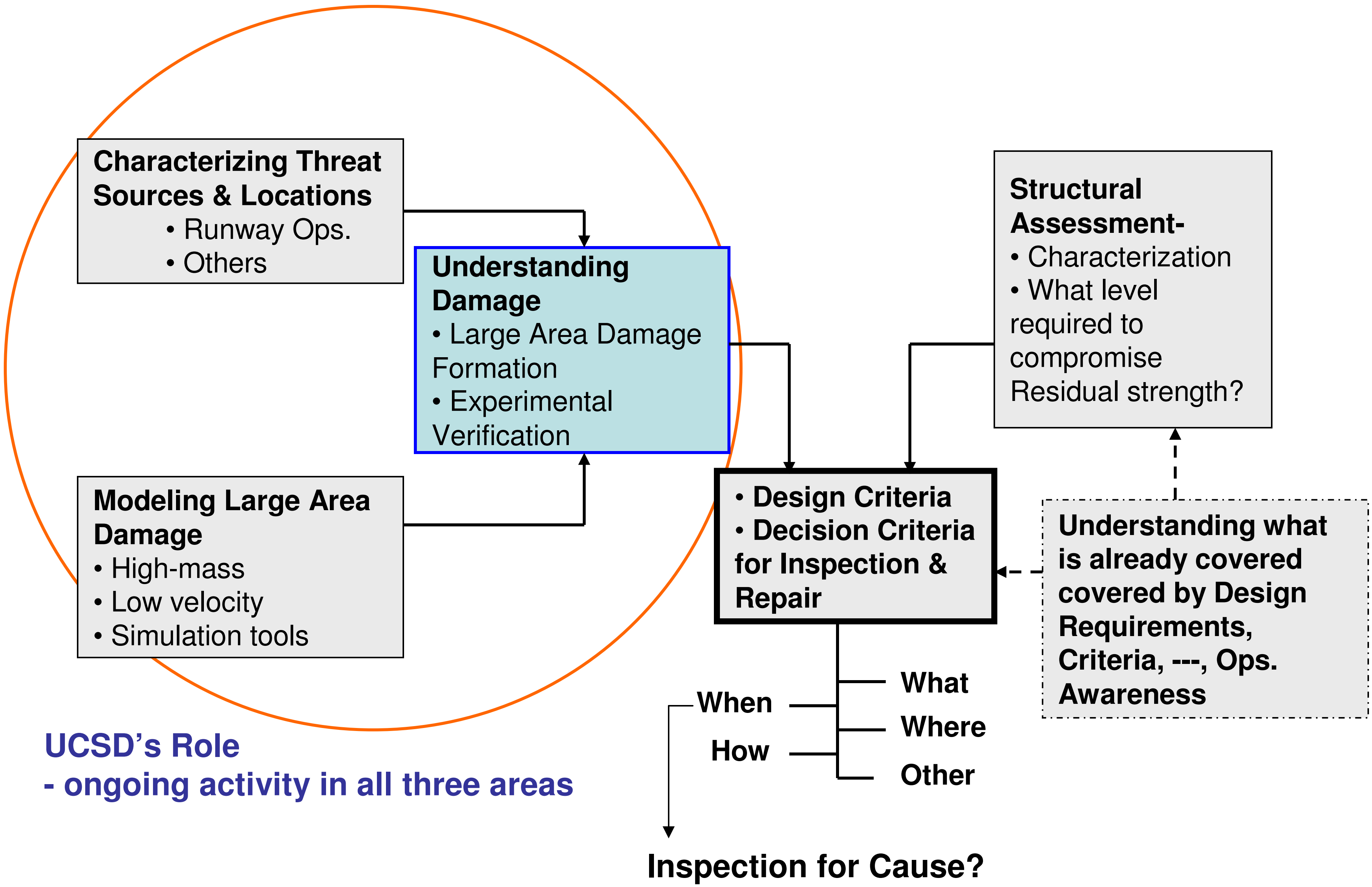

UCSD's Role
- ongoing activity in all three areas

Understanding Damage

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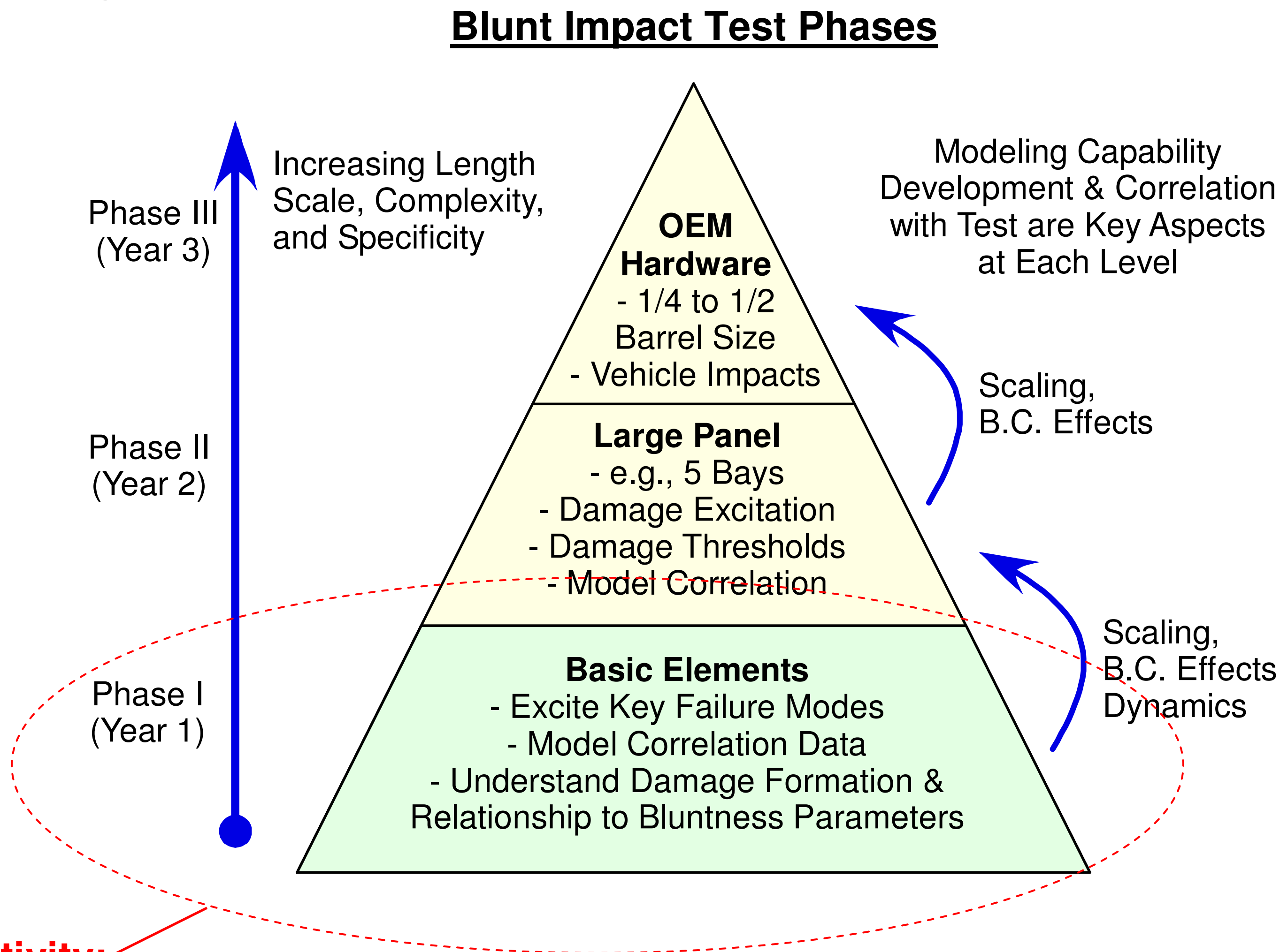
Achieved by Conducting Tests:

- **Two different specimen types defined during <u>two Workshops at UCSD</u> (1/23/09 & 7/1/09)**
  - **Frame Specimen**
  - **Stringer Specimen**
- **Specimens intended to be representative of large commercial aircraft fuselage**
  - **geometry**
  - **failure modes produced**



Current phase of activity:
Test specimens are starting to be built by UCSD & SDC

Test Specimen Types

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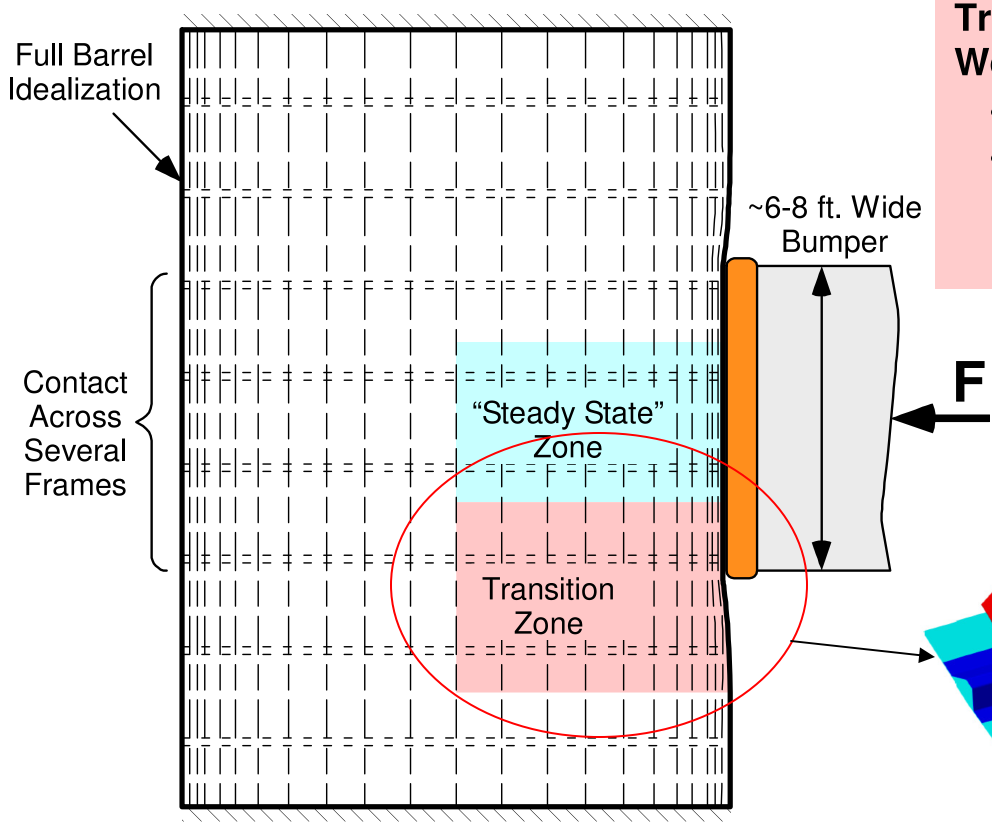
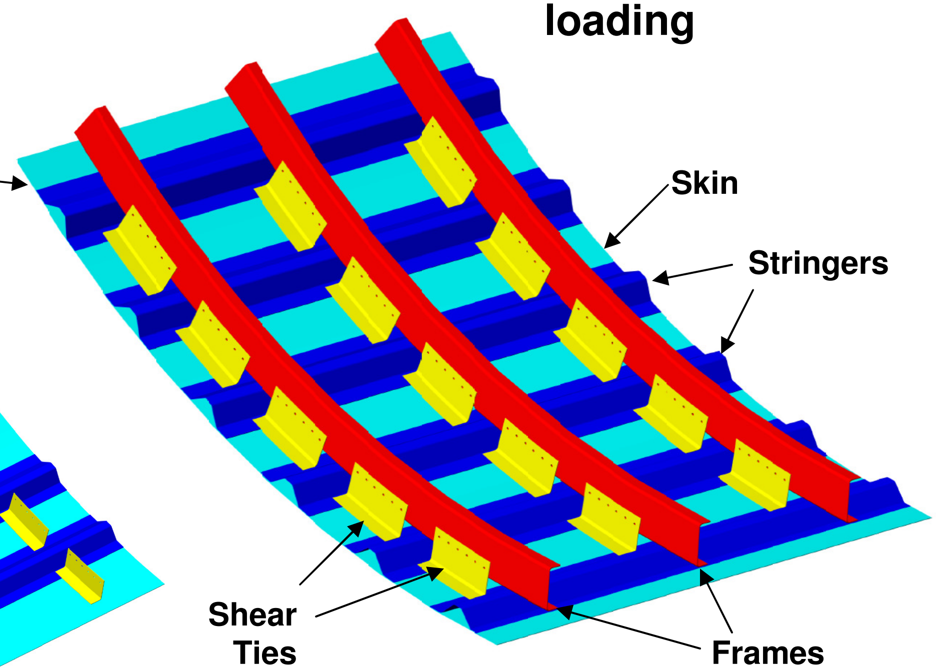
Transition Zone – focus defined in 7/1/09 UCSD Workshop by industry participants

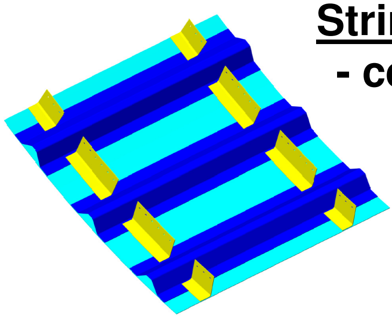
- **includes end of bumper**
- **phenomena not present in "steady state" zone**
  - » **biaxial bending in skin (affects visual detection?)**
  - » **shear in stringer-skin interface**

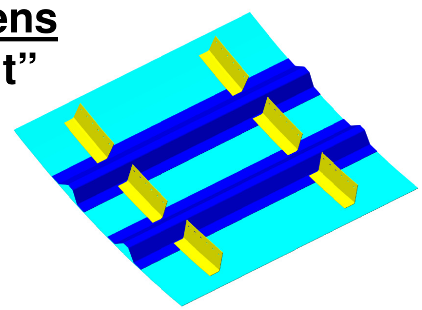


Frame Specimens
- half-width line loading



Stringer Specimens
- centrally "point" loaded





Frame Specimen Loading

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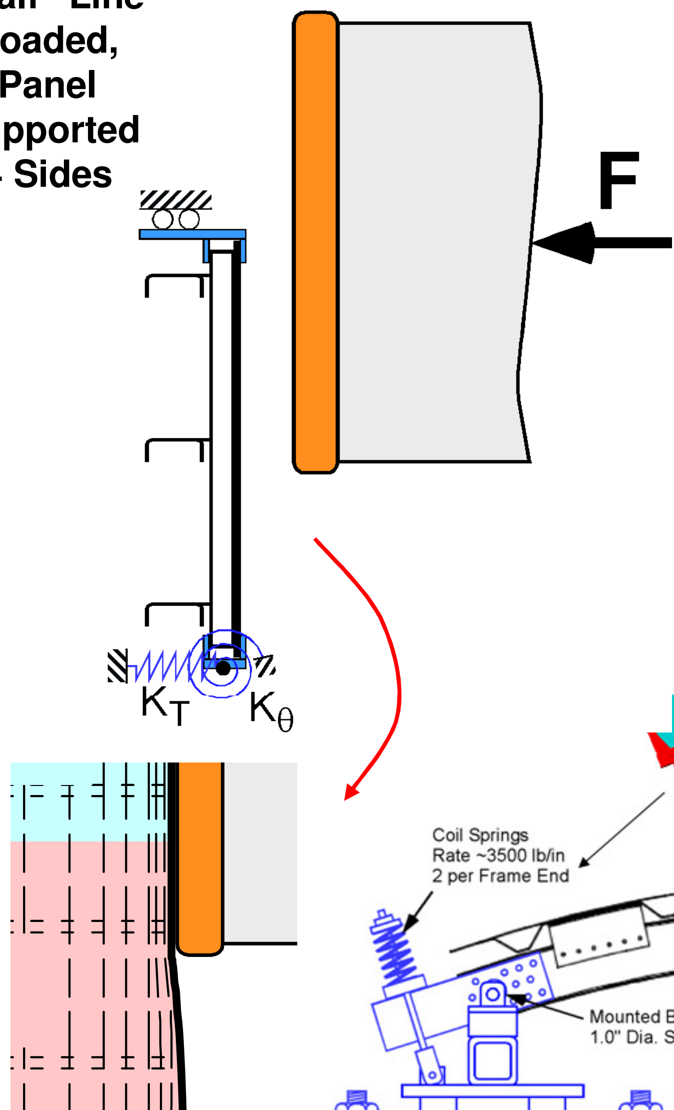
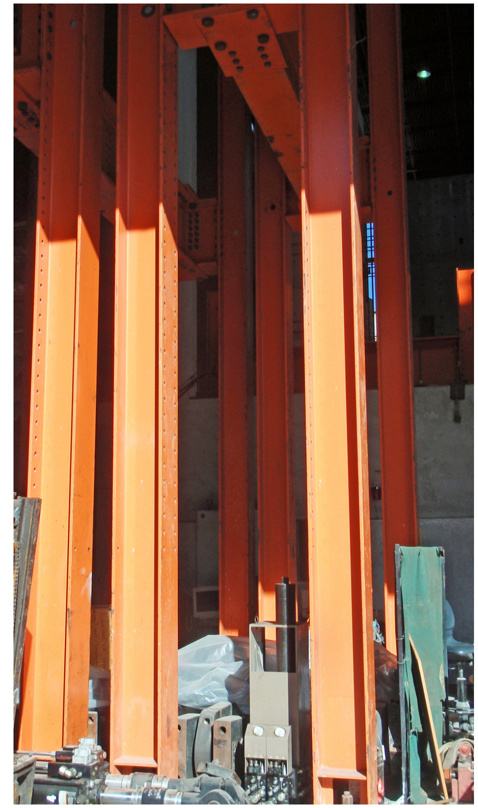
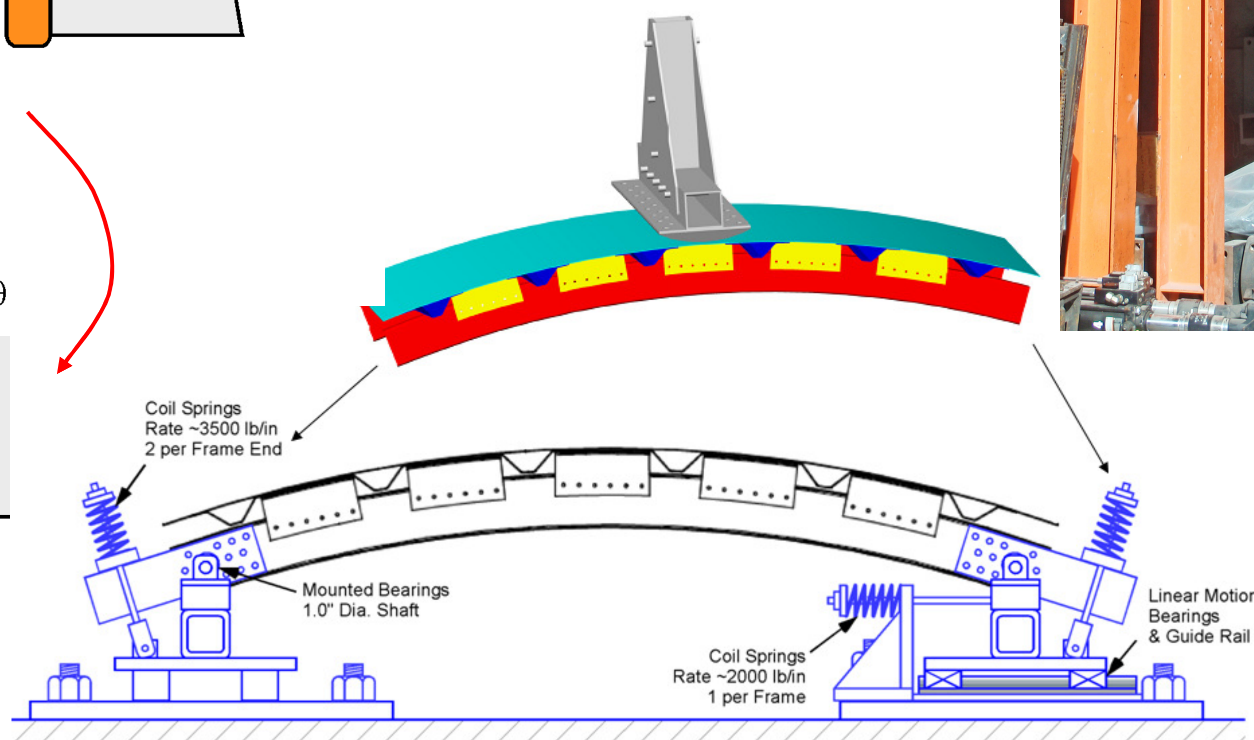
"Half" Line Loaded, Panel Supported 4 Sides



Tests to be conducted at UCSD's Large-Scale *__Powell Structural Research Labs__*





Frame Specimen Details

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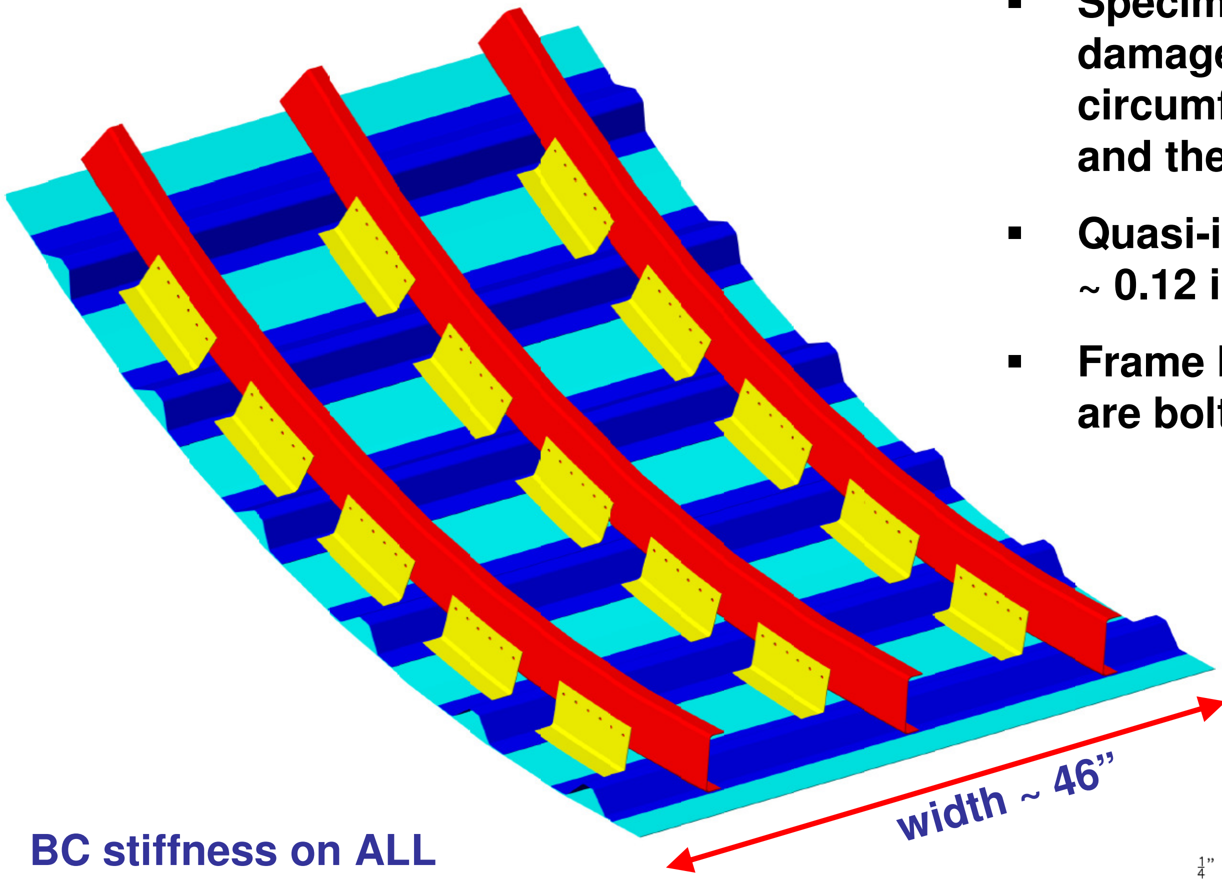
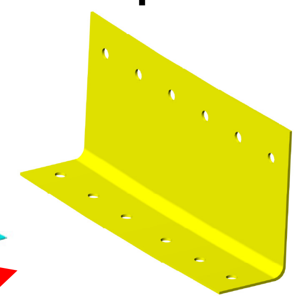
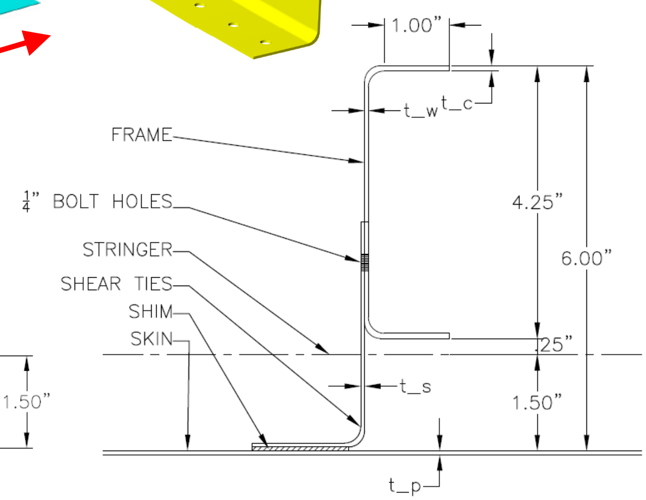
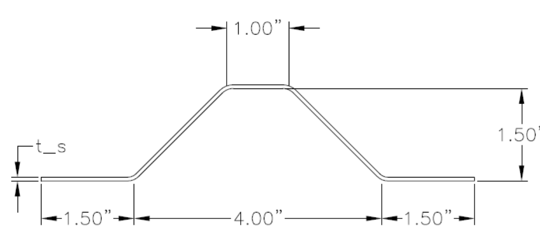
- Specimens primarily focused on damage development to circumferential frame members and their connection to the skins
- Quasi-isotropic layups, thickness ~ 0.12 in.
- Frame bolted to shear ties which are bolted to panel skin







BC stiffness on ALL FOUR sides to be determined via full barrel FE models (ongoing activity)



Frame Specimen Details

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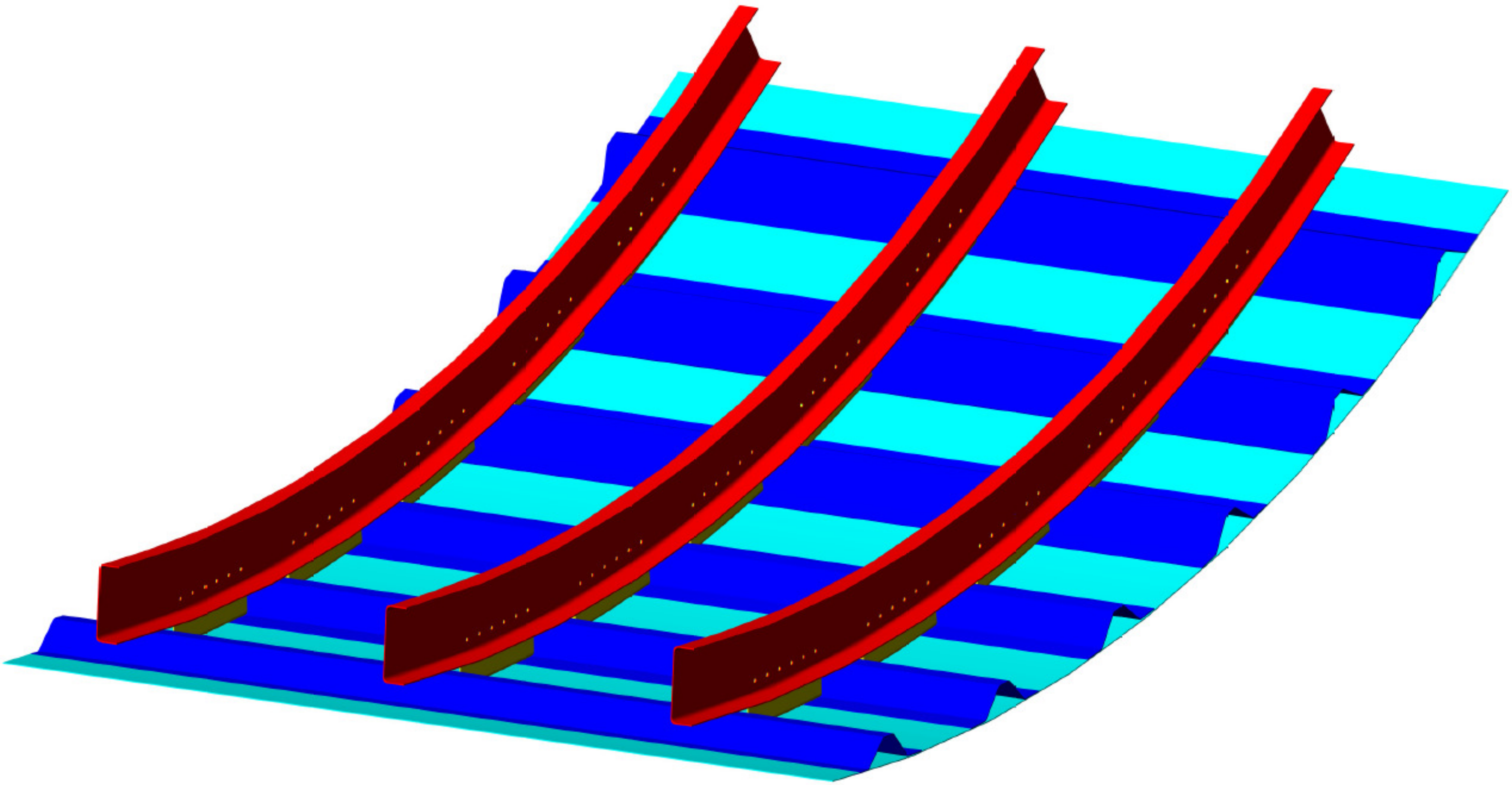

Stringer Specimens

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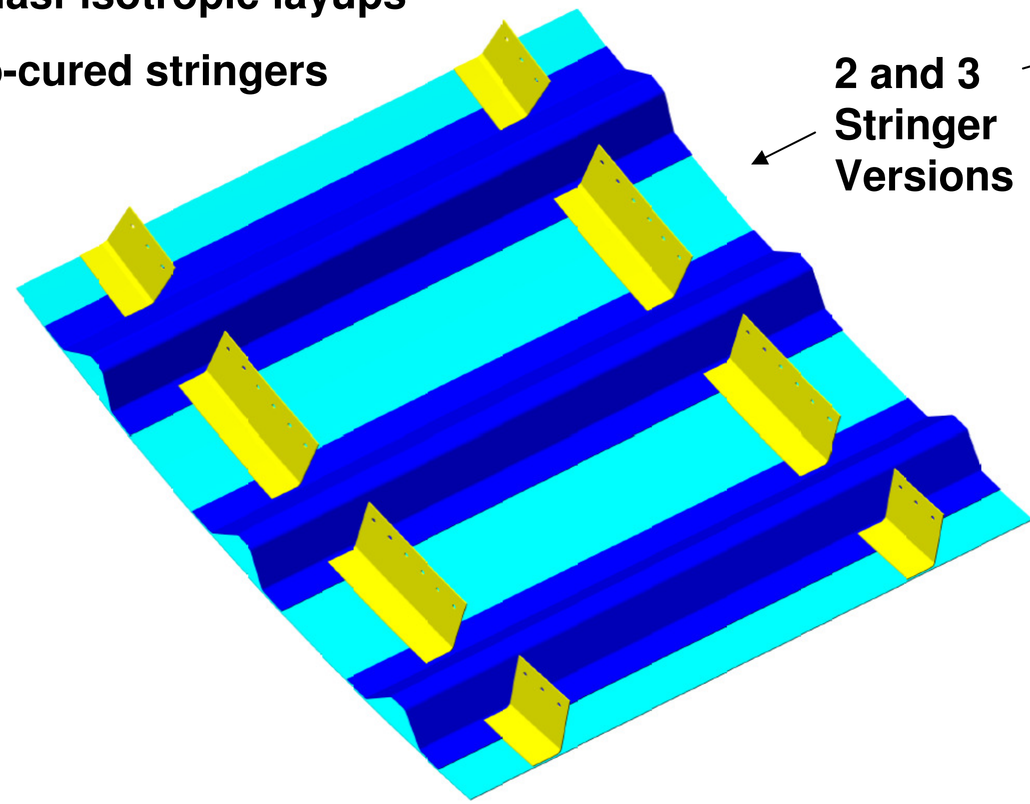
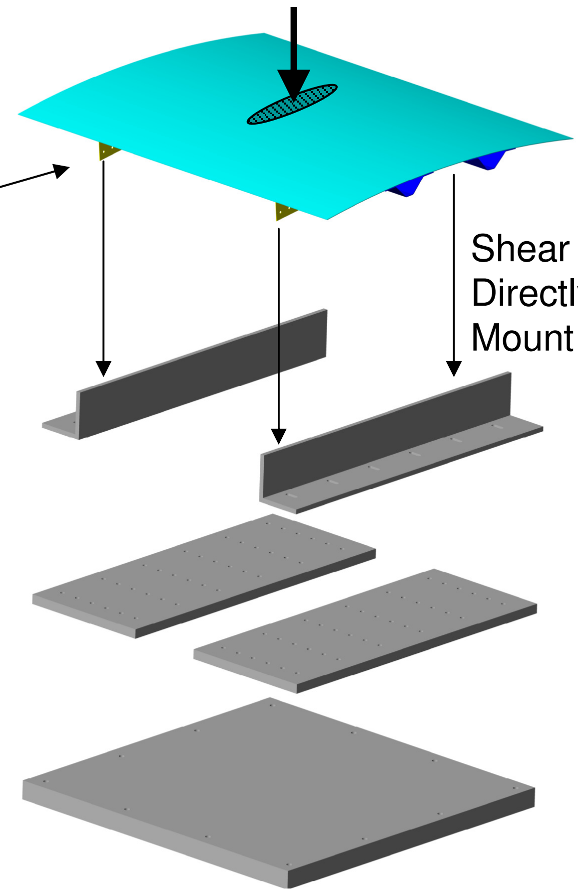
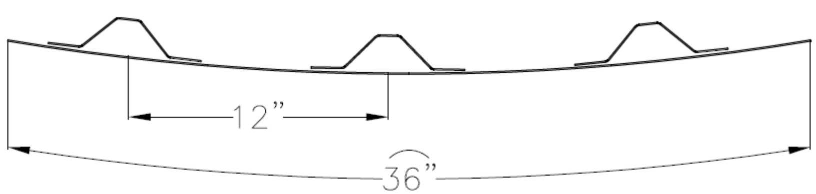
- **Specimens focused on damage formation to stringers and their connection to the skins**
- **Quasi-isotropic layups**
- **Co-cured stringers**

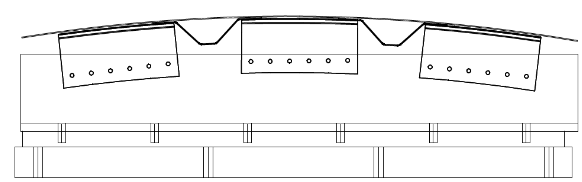


2 and 3 Stringer Versions

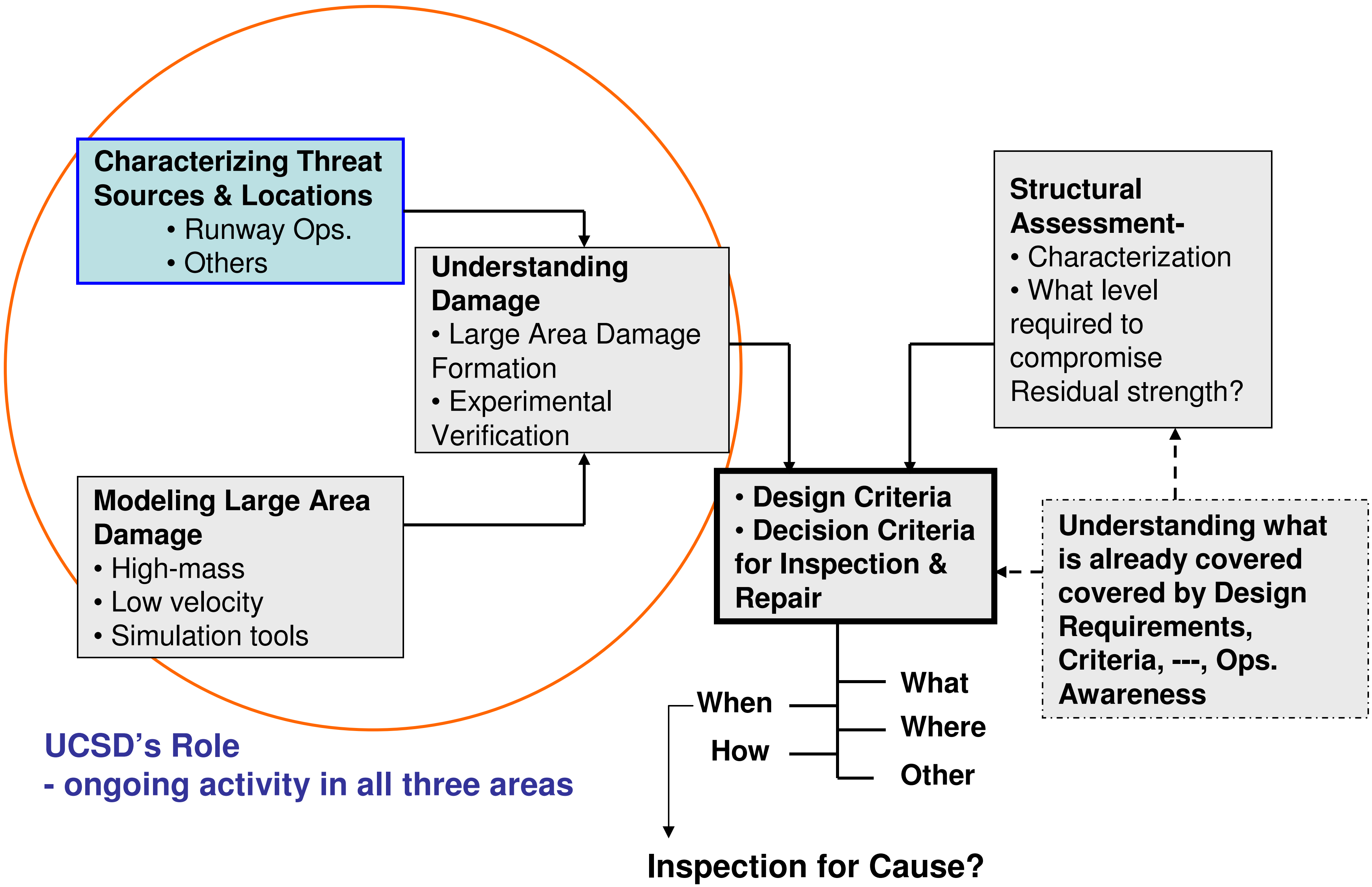


Shear Ties Directly Mount Here





Logic Diagram for Low Velocity High-Mass Wide-Area "Blunt" Impacts



UCSD's Role
- ongoing activity in all three areas

Blunt Impact Threat Characterization

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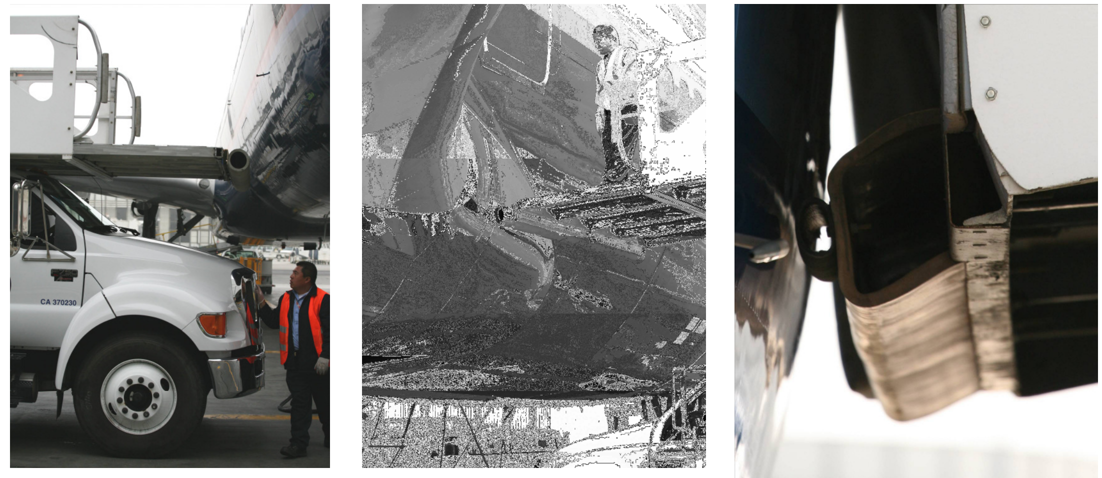
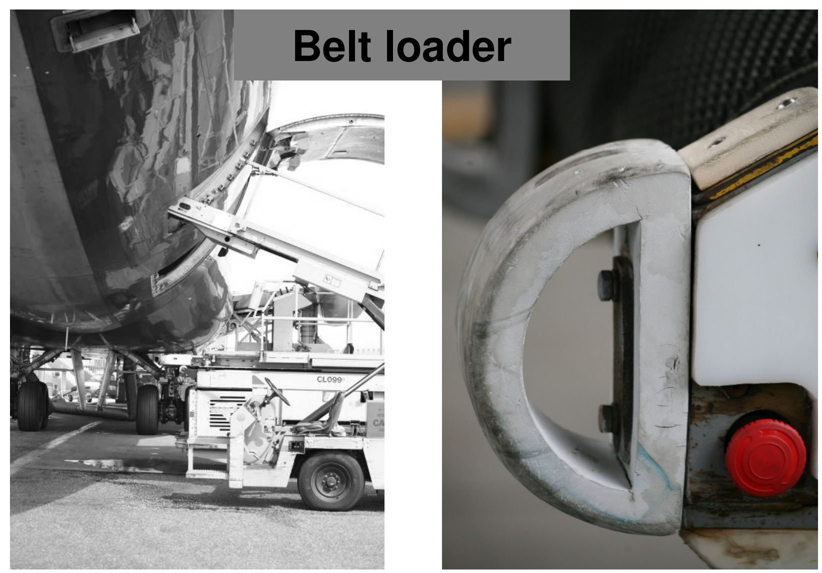
- Surveys to industry – conducted in 2008
- Blunt Impact Workshop held at UCSD campus January 23, 2009
  - presentations from airlines identified ground service vehicles as key source
- LAX observation – March 19, 2009
  - direct observation of ground operations at United Airlines ramps
    - quantitative information extracted from photos, video documentation
    - discussion with personnel
  - much thanks to Eric Chesmar and United Airlines for hosting activity



GSE bumpers and walkway bumper



Belt loader

LAX Video Analysis: TUG Belt Loader Approach

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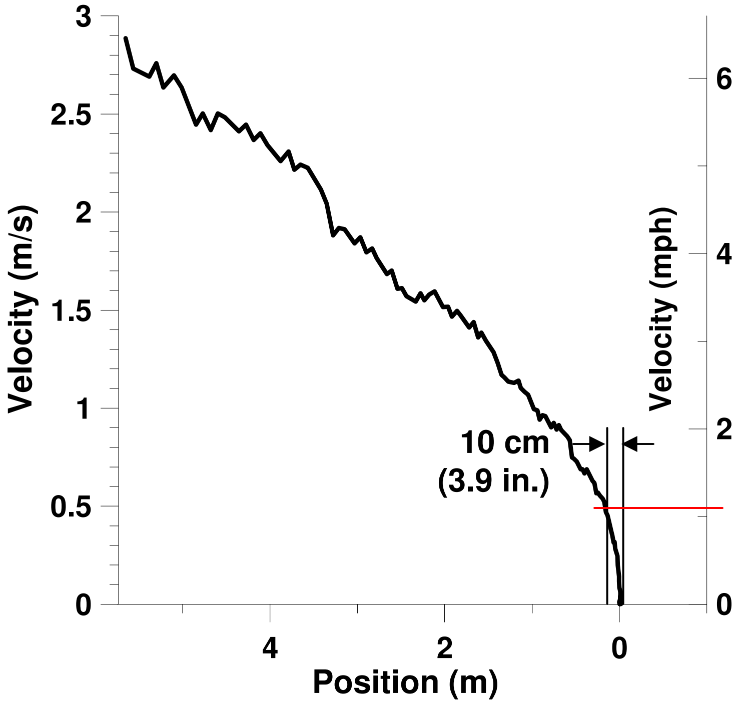
TUG Belt Loader Approaching B757



TUG Vehicle Weight: 6680 lb (3030 kg)

Velocities as high as 2 mph are realistic within close proximity of the aircraft

Kinetic Energy:

- **1515 J at 1 m/s (1117 ft-lbf at 2.24 mph)**
- **379 J at 0.5 m/s (280 ft-lbf at 1.12 mph)**

Impactor Geometries to be Tested

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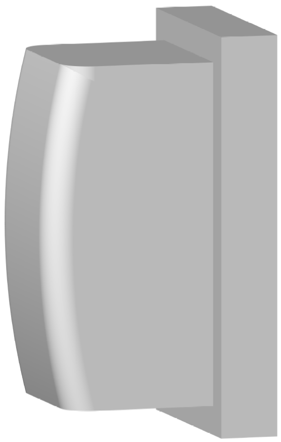
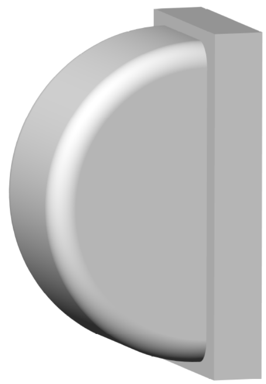
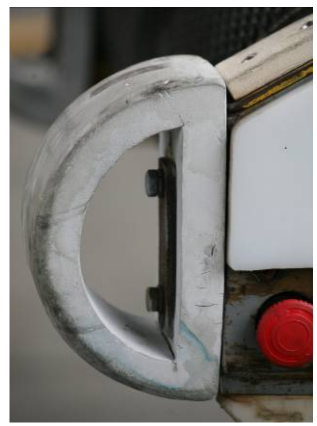


Rigid 12" radius impactor

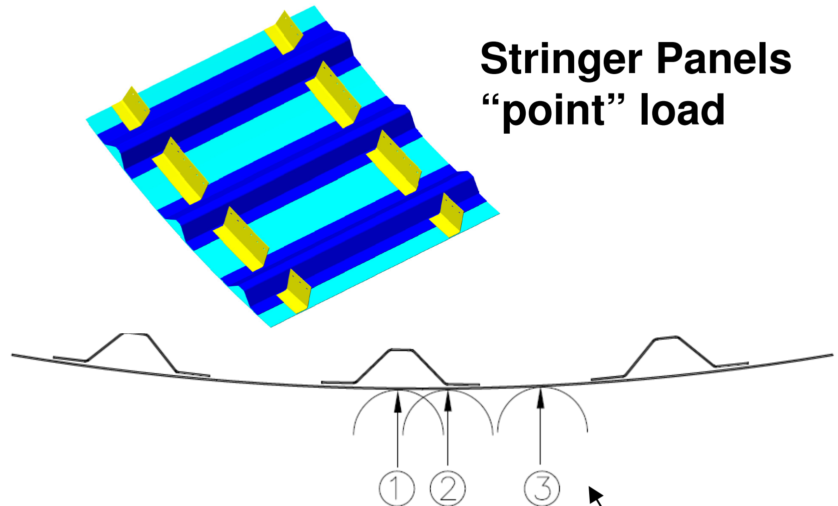


Rigid 3" radius impactor

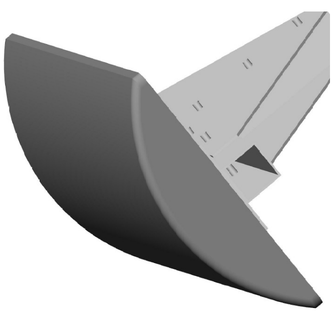


Soft Bumper (actual product)

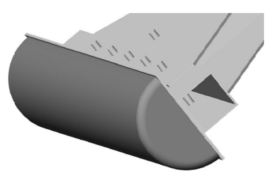
Stringer Panels "point" load



Planned Contact Locations



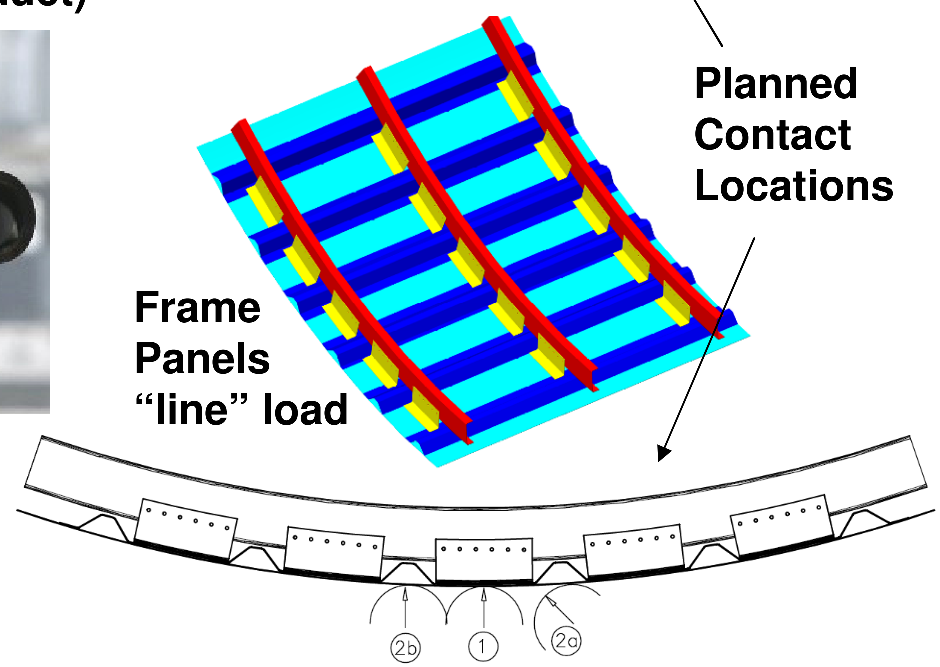
Rigid 12" radius line loading impactor



Rigid 3" radius line loading impactor

Bumper line loading impactor

Frame Panels "line" load



Logic Diagram for Low Velocity High-Mass Wide-Area "Blunt" Impacts

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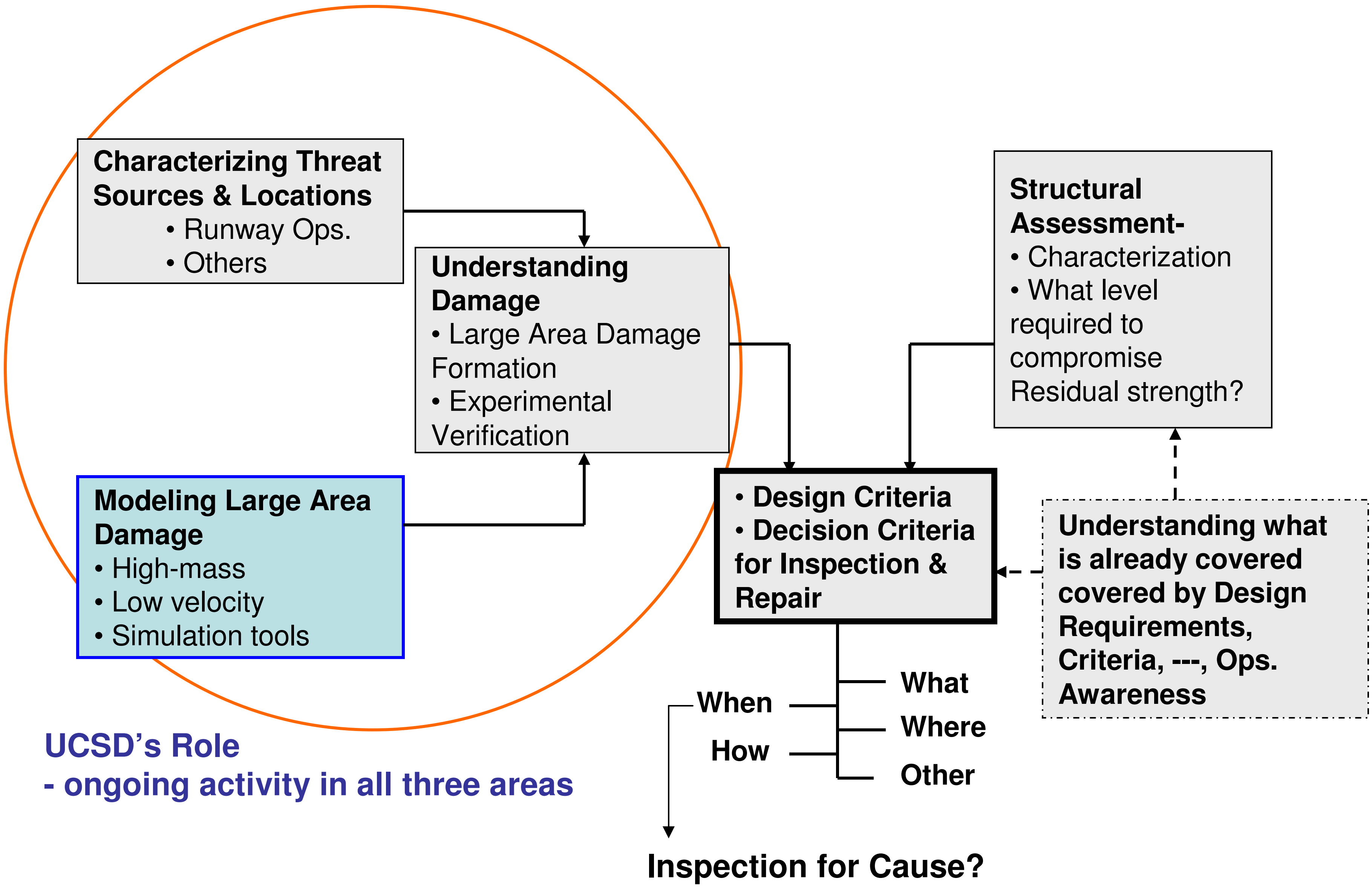

UCSD's Role
- ongoing activity in all three areas

Simulation Tools

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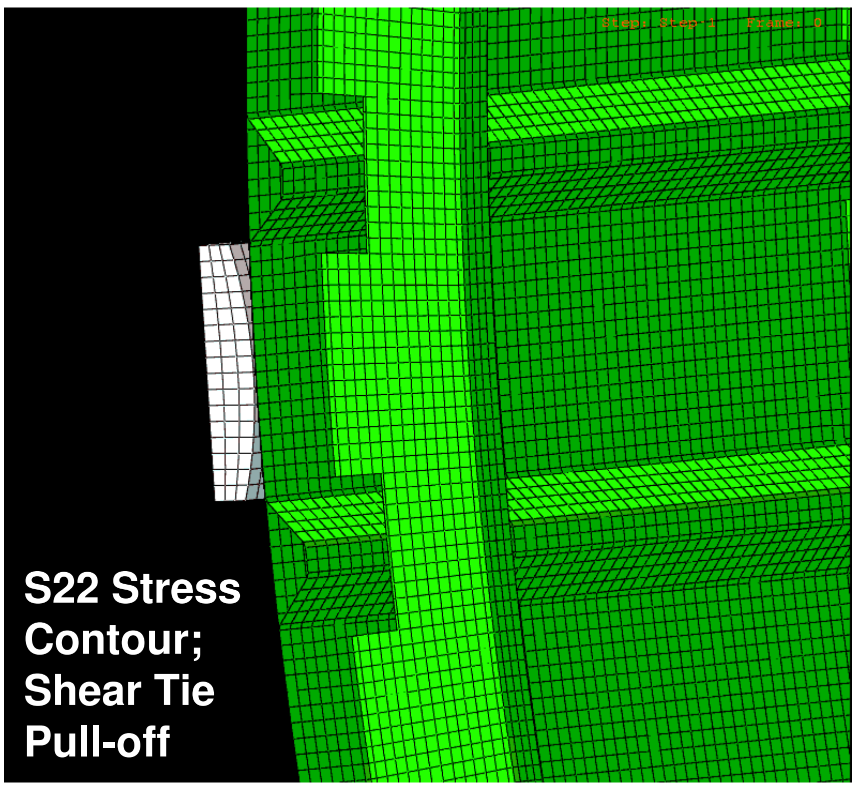
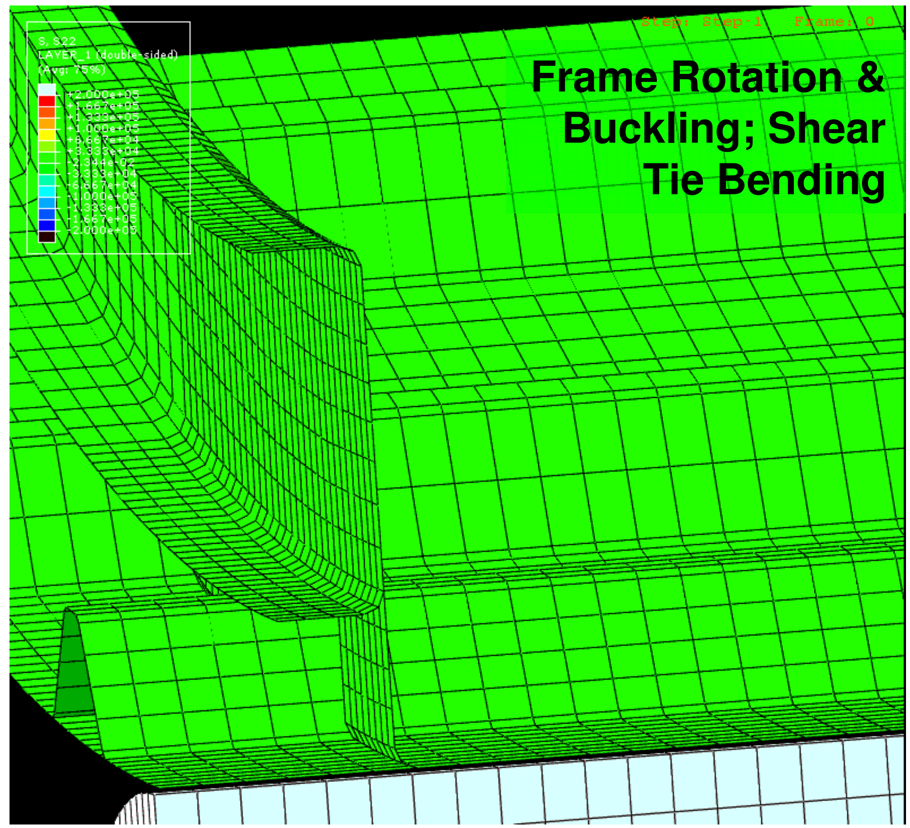
- Use of detailed FE modeling is critical for understanding
  - relationship between “small” panel vs. full barrel behavior
    - how to interpret results from “small” panel test to full barrel
    - how to scale up
  - whether failure modes are relevant and what are each test’s weaknesses
  - how to establish correct boundary conditions so that realistic stress state in “small” panel is achieved



S22 Stress Contour; Shear Tie Pull-Off



Frame Rotation & Buckling; Shear Tie Bending

Prospective Failure Modes

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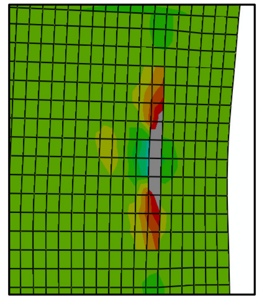
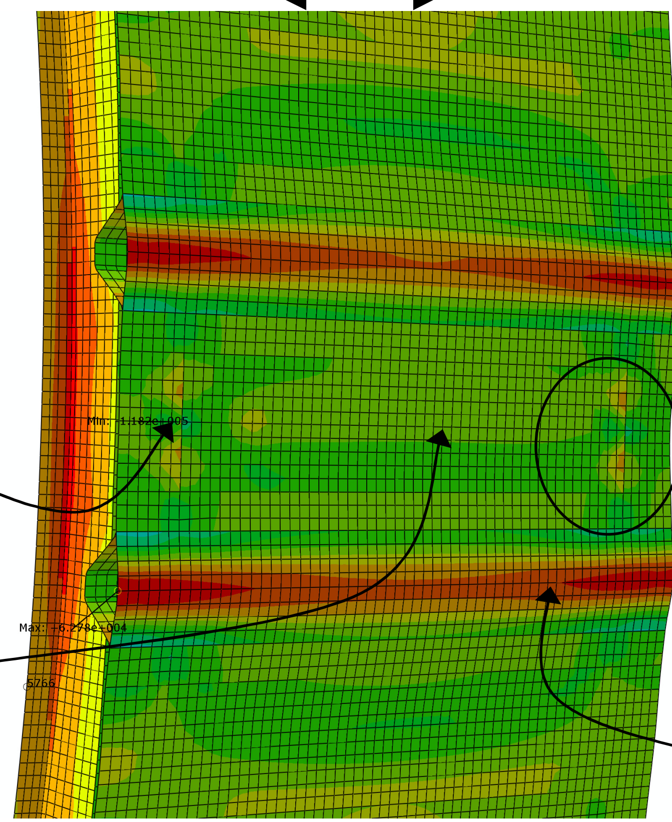
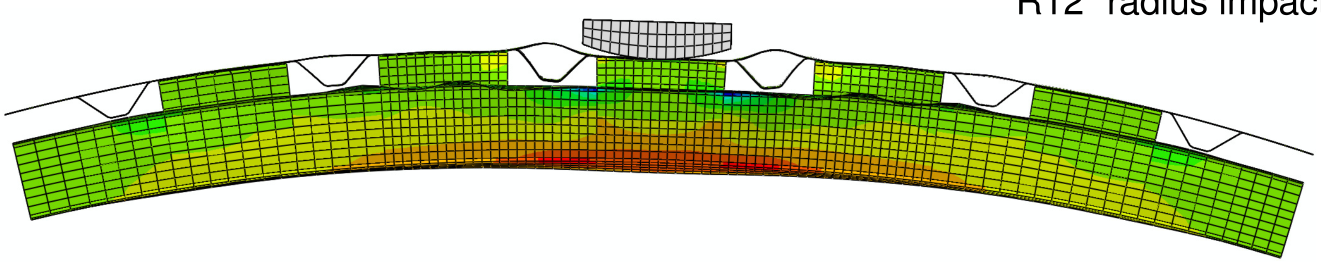
- Impactor location between stringers – similar response with R3" and R12" impactors
- Buckling and rolling of frame causes severe bending of shear tie
  - shear tie pull-off / fastener pullout from both skin and frame
  - interlaminar tension in shear tie radius due to opening moments
- Bulging of skin under stringers – mode I debonding



S22



R12" radius impactor- S11



Full Barrel Models

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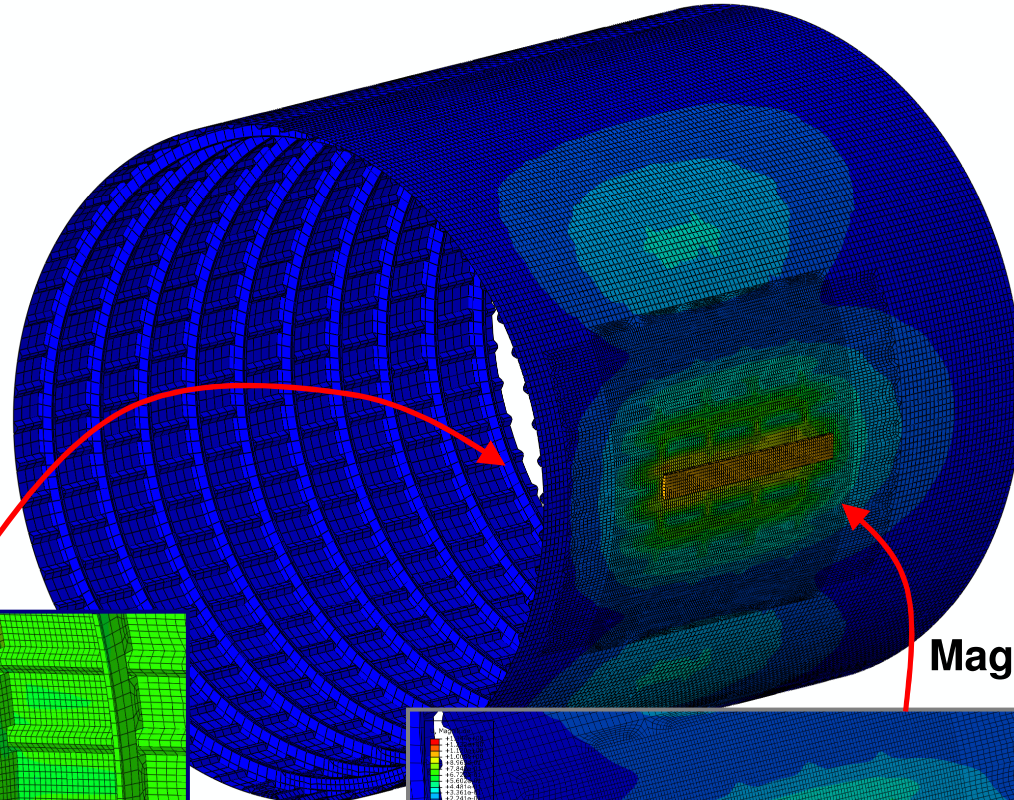
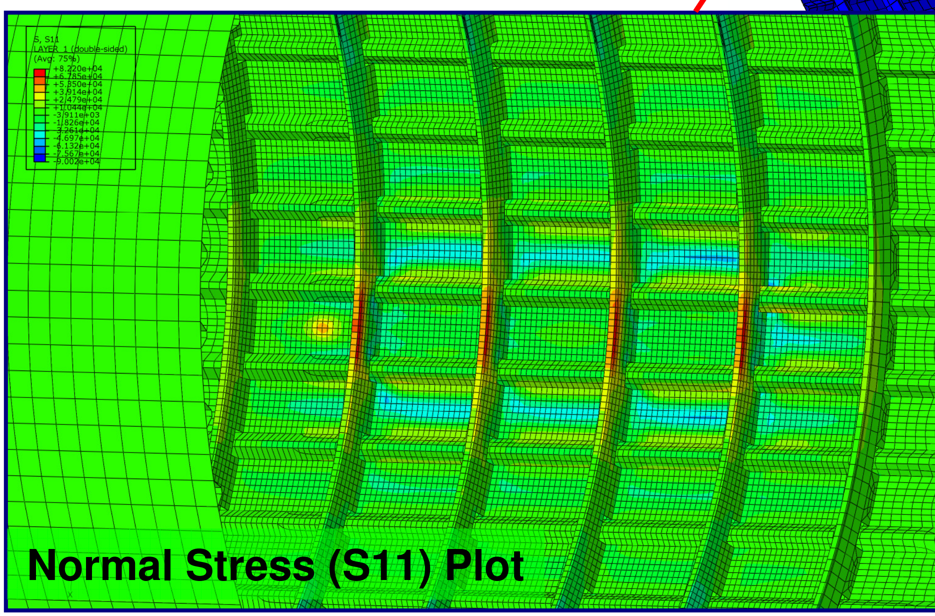
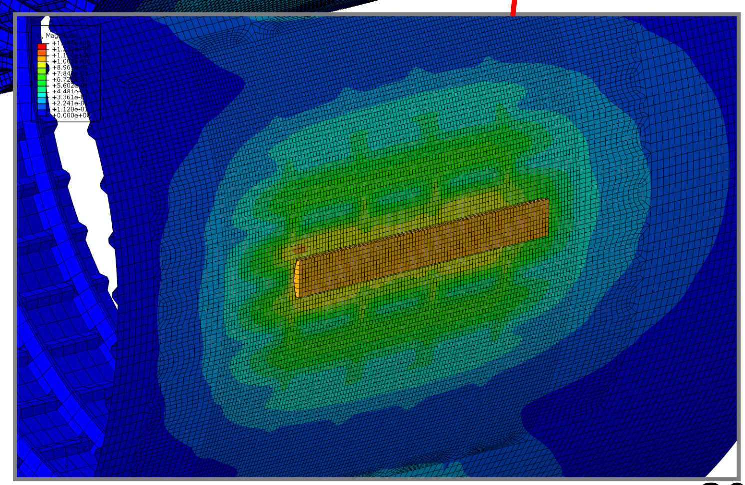
- Full Barrel Model: 19 ft. dia, 20 ft. length
- 7 ft. length blunt impactor
- Deformation localized to quadrants adjacent to impact location
- Plot of normal stress (bending-induced) in frames shows "steady state" and "transition" zones





Normal Stress (S11) Plot

Displ. Magnitude



Status of Ongoing Activities

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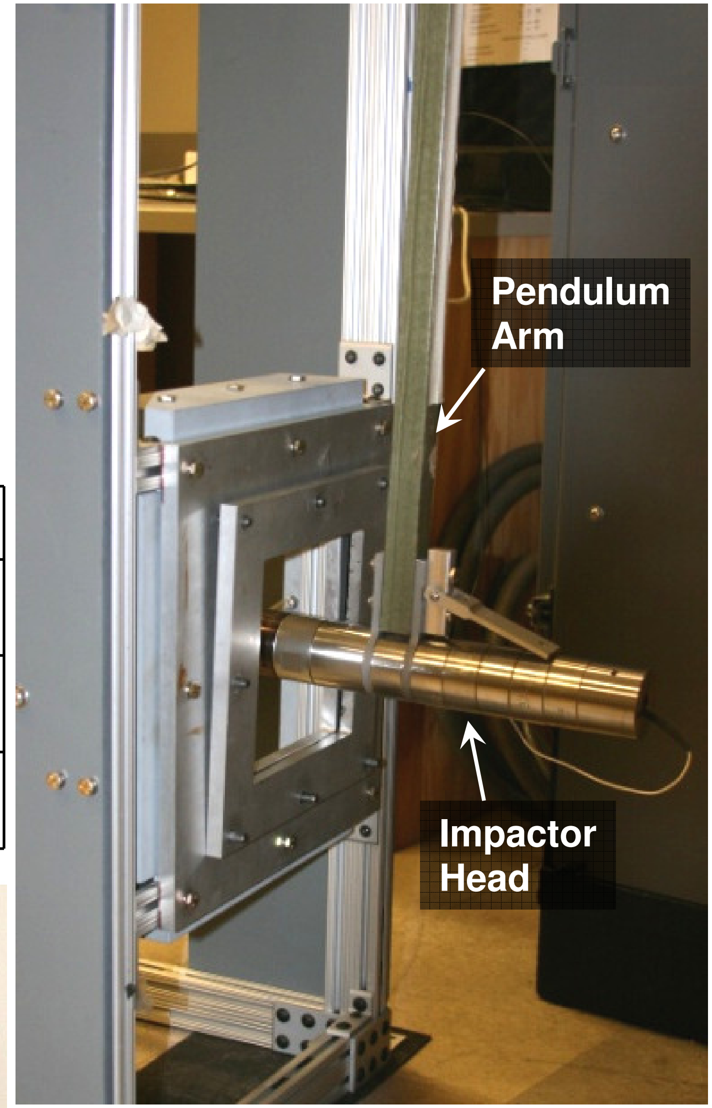
Activity	Status: Completed	Ongoing: % Complete	Not Started	Notes
Blunt Impact Threats Definition	X			Surveys. Jan09 Workshop. LAX observation w/UAL.
Lab-Scale Impact Tests		80%		Basic studies w/ 1, 4, 12 in. dia. impactors (+rubber pad) onto glass/epoxy plates.
Modeling - Blunt Impact Studies	X			Studies w/ generic geometry. Models of lab-scale impact test specimens.
Modeling - FEA of Specimens		50%		Linear matl behavior. Determine high stress & deformation regions. Definition of BCs.
Modeling - FEA of Full Barrel/BCs		50%		Linear matl behavior. Use to determine BCs for specimen.
Lower-Order Models Development		10%		3 to 4 dof spring & mass models for estimation of forces, displ.
Specimen Design	X			Phase I frame and stringer panels.
Mold/Tooling Design	X			
Mold/Tooling Fabrication		75%		Molds for: skin, frame, shear tie, stringer.
Test Fixtures Design		50%		
Test Fixtures Fabrication			X	
Specimen Fabrication			X	
Test Plan Development		80%		
Specimen Instrumentation			X	
Test Setup			X	
Conduct Tests			X	Quasi-static indentation tests for Phase I.

Basic Study: Lab Scale Blunt Impact Experiments

- **Objectives:**
  - **Investigate impact damage formation *as function of tip radius (i.e., bluntness)***
  - **Establish database for model development**
- **Low Velocity Pendulum Impact System**
  - **instrumented tip, 5.5 kg mass, 150 J capacity**



Test Matrix:

Glass/Epoxy Panel Thk (mm)	Number of panels tested for tip radius		
	12.7mm	50.8mm	152.4mm
3.18	9	10	8
6.35	9	7	7

Peak Contact Force

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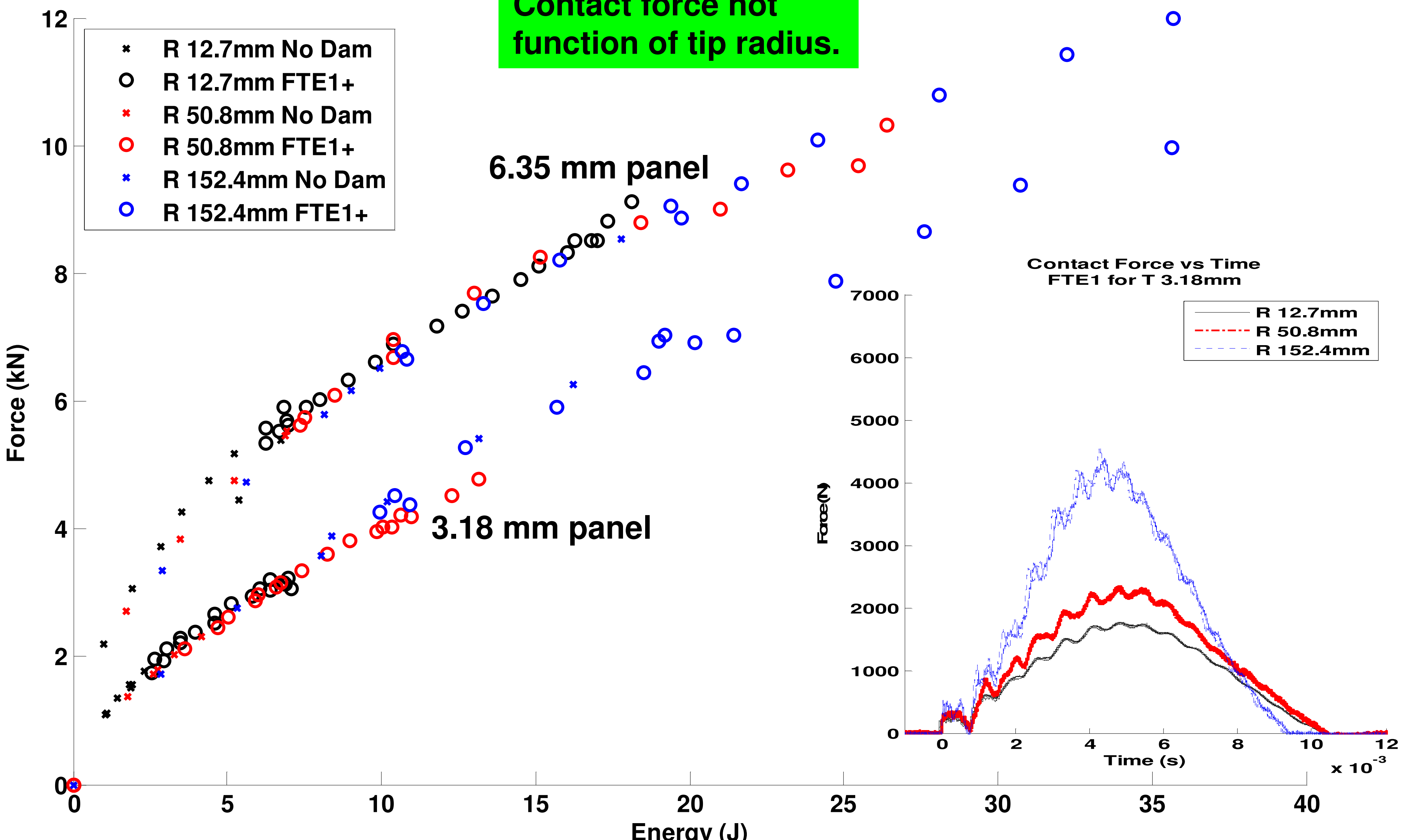
Contact force not function of tip radius.



Contact Area & Pressure

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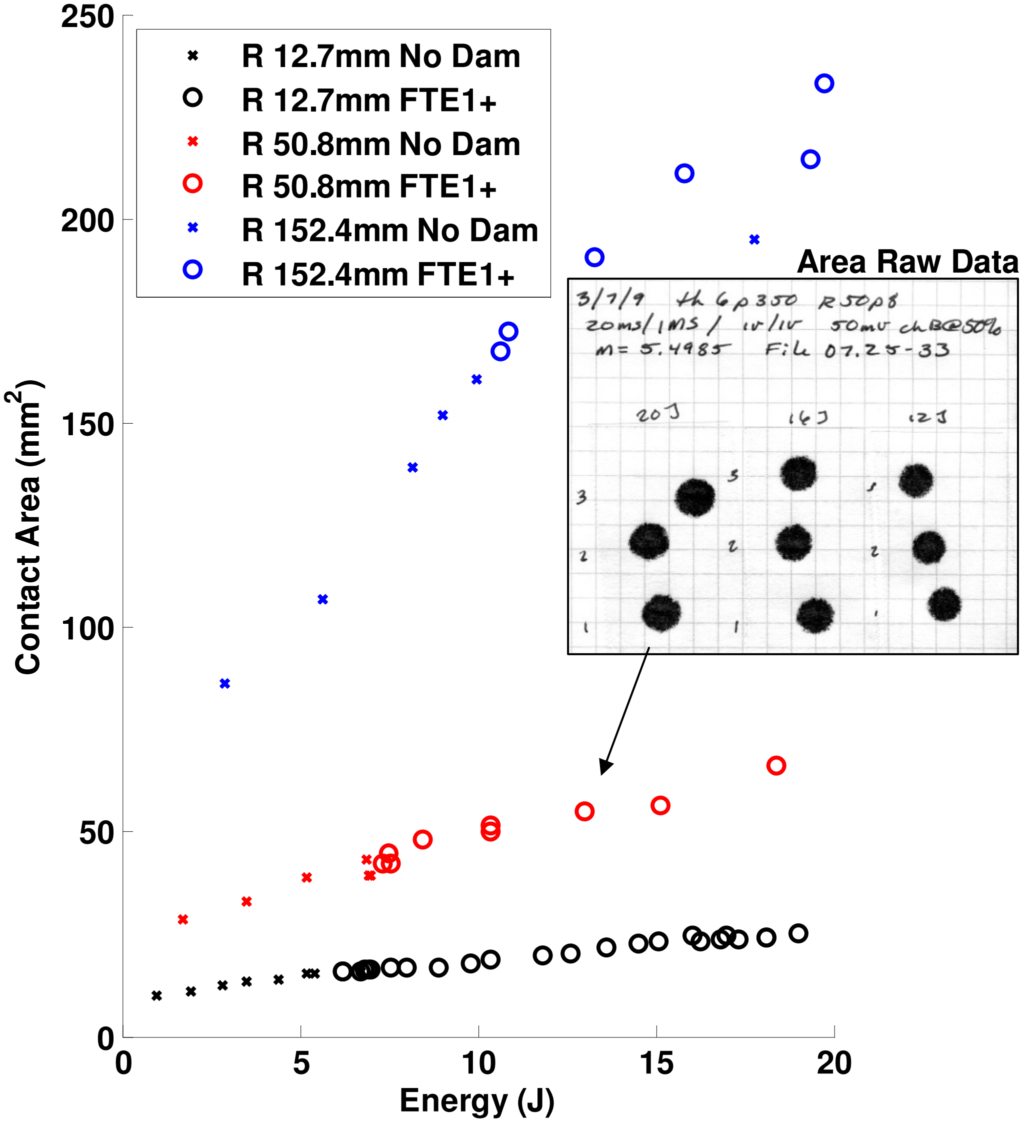
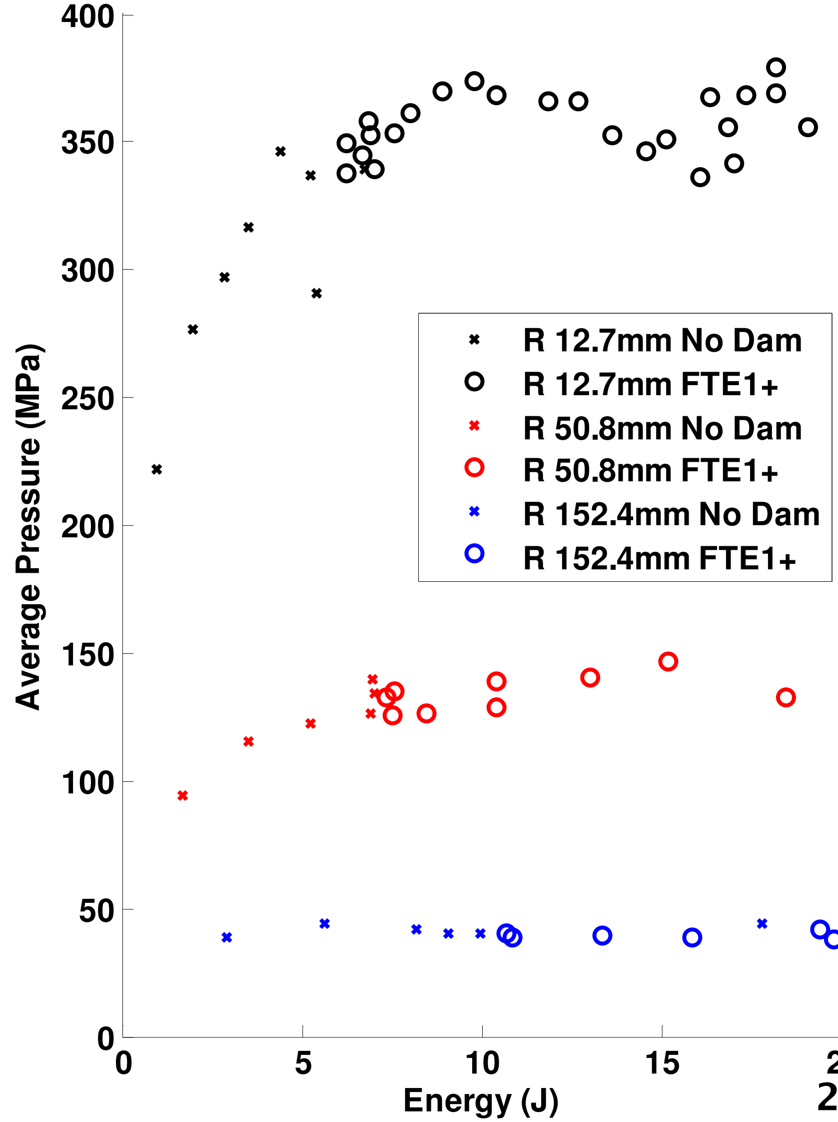
Contact area strong function of tip radius.



Contact Pressure



Lab Scale Impact Tests Summary

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Damage Initiation (Delam.) Threshold

FTE1 for each panel thickness T, impactor tip radius R			
	R 12.7mm	R 50.8mm	R 152.4mm
T 3.18mm	2.44J	4.44J	10.3J
T 6.35mm	6.47J	7.45J	10.8J

Cracking/Fiber Rupture Threshold

FTE2 for each panel thickness T, impactor tip radius R			
	R 12.7mm	R 50.8mm	R 152.4mm
T 3.18mm	7.04J	10.3J	N/A
T 6.35mm	17.0J	25.5J	N/A

> 50J

- **Blunter impactor requires significantly higher energy impact to initiate damage – must hit hit harder**
  - **higher total force (despite lower contact pressure)**
    - » **more internal deflection with higher energy**
    - » **possible to produce more internal damage?**
  - **LOWER contact pressure developed – less propensity for surface marking?**

Hail Ice Impact

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1.5 in. Dia ice at 417 ft/s on 0.032 in. 4-Ply Woven IM7/8552

High Velocity Hail Ice Impact:

- Investigate impact damage initiation and formation to composite panels, including those of skin-stiffened and sandwich construction.
- Develop unified treatment methodology for predicting damage initiation by variety of high speed impactor projectile types – e.g., bird, hail, tire fragment, runway debris, lost access panel, etc.

Project partner: Dennis Roach, Sandia Natl. Labs

Panel Thickness	Quasi-Isotropic Layup	Number of Panels Needed for Each Condition *							
		Hail Dia 1 12x12	Hail Dia 2 12x12	Hail Dia 2 (angle) 12x12	Hail Dia 3 12x12	Low Veloc Dia 1 6x10	Low Veloc Dia 2 6x10	Low Veloc Dia 3 6x10	
8 plies	[0/45/90/-45]_s	9	9	9	9	9	9	9	
16 plies	[0/45/90/-45]_2s	10	10	10	10	10	10	10	
24 plies	[0/45/90/-45]_3s	9	9	9	9	9	9	9	
Total		28	28	28	28	28	28	28	196

Material: T800/ 3900-2