Impact Damage Formation on Composite Aircraft Structures

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The Joint Advanced Materials and Structures Center of Excellence

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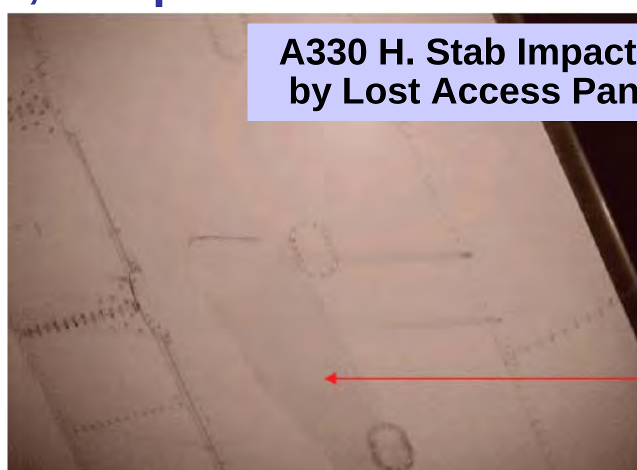
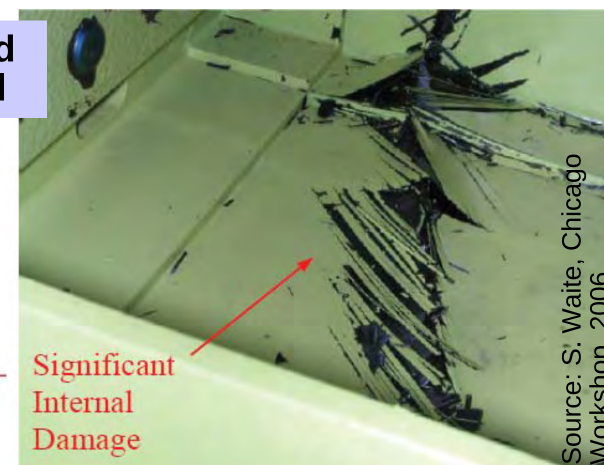
Motivation and Key Issues

- Impact damage remains major issue for composite structures
- Of interest are impact sources causing considerable internal damage with minimal visual detectability
  - Wide-area, or blunt, impact damage from collisions with ground vehicles
  - High velocity sources such as hail, bird, tire fragments, lost panel access door

Basic tools are needed for characterizing blunt impact events to aid in prediction of damage formation and its effect on structural performance.

A330 H. Stab Impacted by Lost Access Panel





Source: S. Waite, Chicago Workshop, 2006.

Impact Damage Formation on Composite Aircraft Structures

Objectives

- Identify commonly occurring wide-area "blunt" impact scenarios of major concern to airlines and aircraft manufacturers.
- Develop methodology for blunt impact threat characterization & analysis.
- Experimental identification of key phenomena and parameters governing blunt impact damage formation.

Approach – combined analytical and experimental tasks:

- Task 1. Identification of Common Impact Scenarios – conduct surveys among airlines, aircraft manufacturers, others.
- Task 2. Methodology for Impact Threat Characterization – develop accurate FE and simple low-order models describing impact threats, formulate basic parameter set characterizing blunt impact events.
- Task 3. Key Phenomena and Parameters Governing Impact Damage – conduct lab- and full-scale experiments to identify key parameters, verify models.

FAA Sponsored Project Information

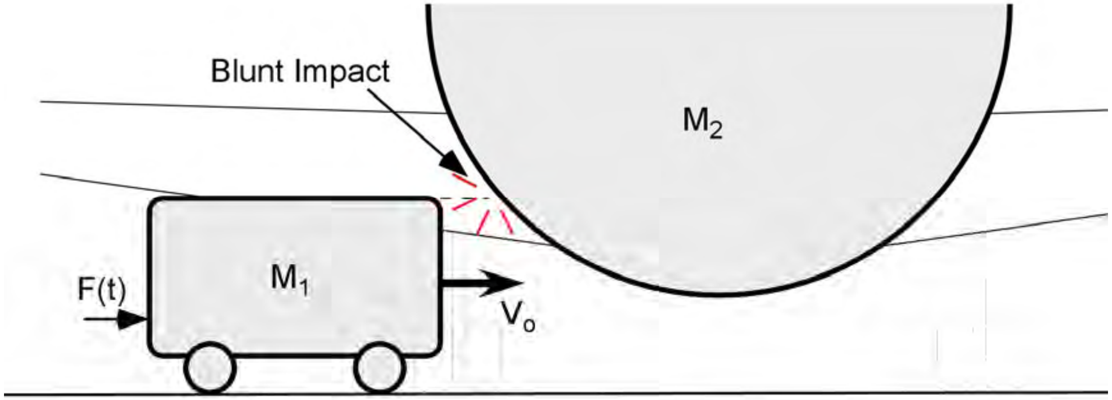
- Principal Investigators & Researchers
  - Hyonny Kim, Associate Professor, UCSD PI
  - Prof. Tom Hahn, UCLA PI – sending subcontract
  - Daniel Whisler, Graduate Student, UCSD
  - Jennifer Rhymer, Graduate Student, UCSD
- FAA Technical Monitor
  - Curt Davies
- Other FAA Personnel Involved
  - Larry Ilcewicz
- Industry Participation
  - airlines, OEM

1st Year Progress Overview

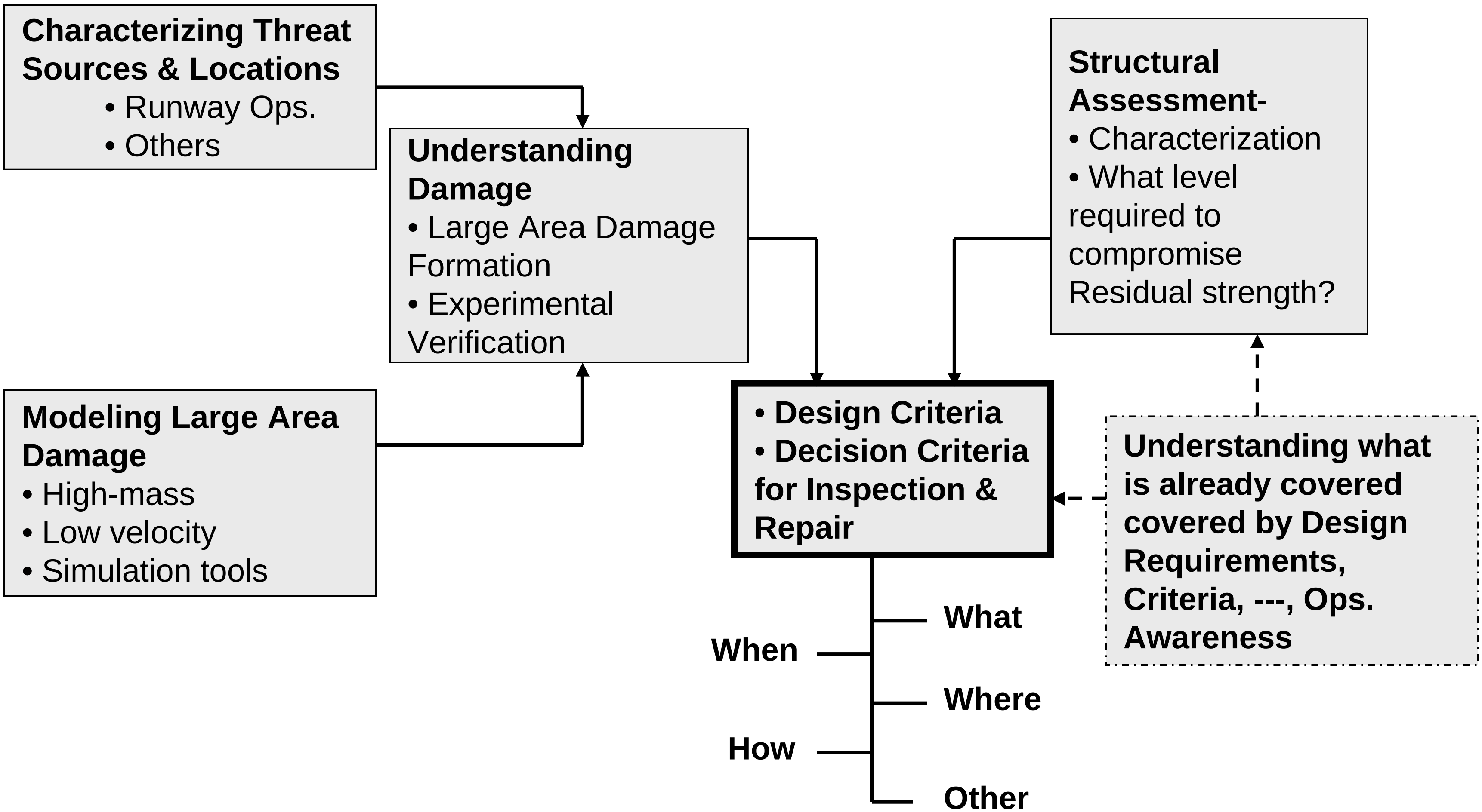
- Year 1 focus has been on high-mass low-velocity wide-area impact – a.k.a. blunt impact
- Task 1 executed & ongoing
  - surveys sent out and responses received
  - would still like additional participants
- Task 2 started

Wide-Area Blunt Impact Problem

- problem very complex due to many variables that are important
- "impactor" can be different types of ground vehicles or equipment (and various locations on these equipment, e.g., corner, long edge, or flat face) or buildings, etc.
- "target" can be the many locations of the aircraft exposed to contact with ground vehicle/ equipment or other sources
  - fuselage, nacelles, wing skins, control surfaces, etc.
  - impacts can be near or away from internal stiffeners (greatly affects local contact stiffness)
  - incidence angle between "impactor" and surface plays major role in nature of contact force history



Logic Diagram for Low Velocity High-Mass Wide-Area “Blunt” Impact



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Task 1. Summary of UCSD Blunt Impact Surveys

- From 10 Industry survey responses received
  - 11 definitions of blunt impact provided
    - Hemispherical impactor (3) and specify a radius>0.5” (1)
    - Damage that occurs on the surface, not through the thickness of laminate; crack through the thickness or partially through the thickness (2)
    - Definition depends on the source (2)
  - 16 ways damage is described
    - Damage reports specifying size, location, parts affected (6)
    - Specified by source of damage (5)
    - Non destructive evaluation of damage area employed (2)

Task 1. Summary of UCSD Blunt Impact Surveys

- From 10 Industry Survey Responses Received
  - 19 sources of damage described
    - Ground service vehicles (GSV) 1-12mph (7)
    - Technician stepping/kneeling outside design area or technician tool drop (4), tool drop into rubber mat "protecting" cover
    - Fence/hanger hit by moving aircraft (3)
  - 12 damage areas of common occurrence
    - Wing leading edge near winglets and the wing horizontal surfaces (4)
    - Fuselage around passenger entry door (3)
    - Door (2)

Task 2 Progress

- **Task 2. Methodology for Impact Threat Characterization**
  - develop models describing impact threats
    - detailed FEA models
    - simple low-order models
  - identify via models key parameters that govern aspects of interest for blunt impact events

Initial Model Development: Validated Impact Simulation & Lab-Scale Tests Analysis

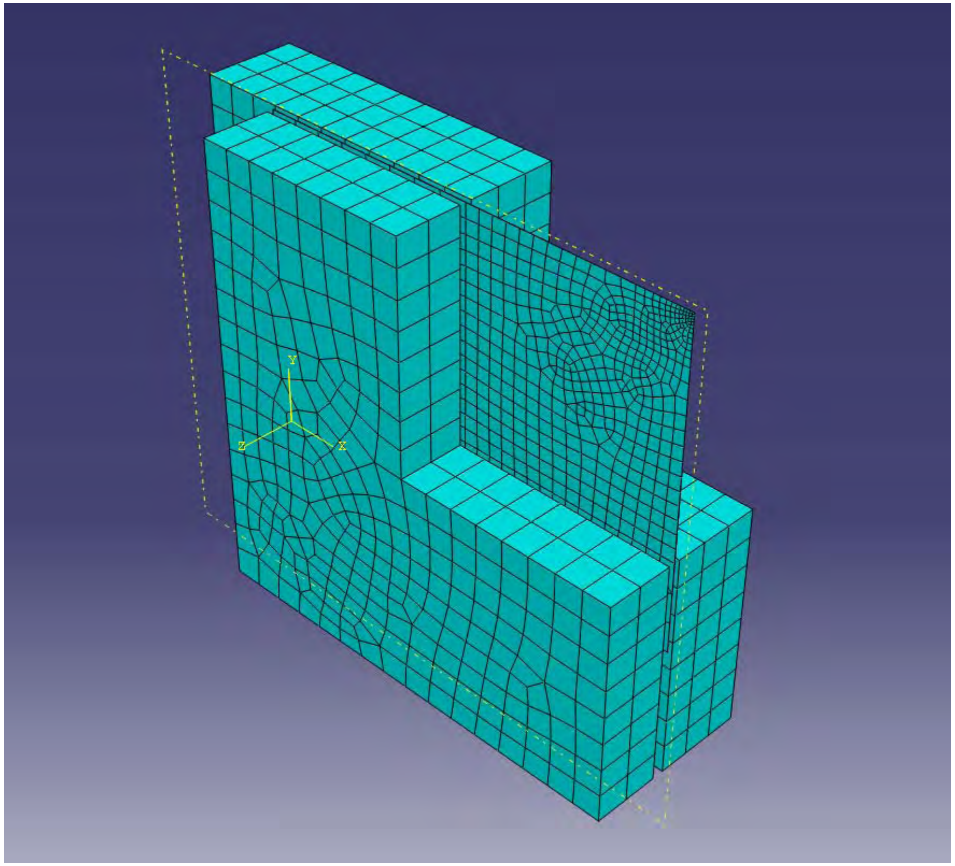
- ANY new series of FE models must 1st be validated with experimental data – use Air Force Low Velocity Impact data set*
- Replicate test No. H28: 1” diameter impactor
- Model description: quarter-symmetry
  - Laminate (shell elements): $[90/0]_{6s}$ AS4/3501-6
  - Impactor (solid elements): 3.10kg mass with 4.61J of energy

* Data Sources:

1. Schoeppner, G. A. and Abrate, S. Delamination threshold loads for low velocity impact on composite laminates. *Composites: Part A.* 31 (1994) 903-915
2. Personal communications with G. Schoeppner

Development of Accurate Finite Element Model

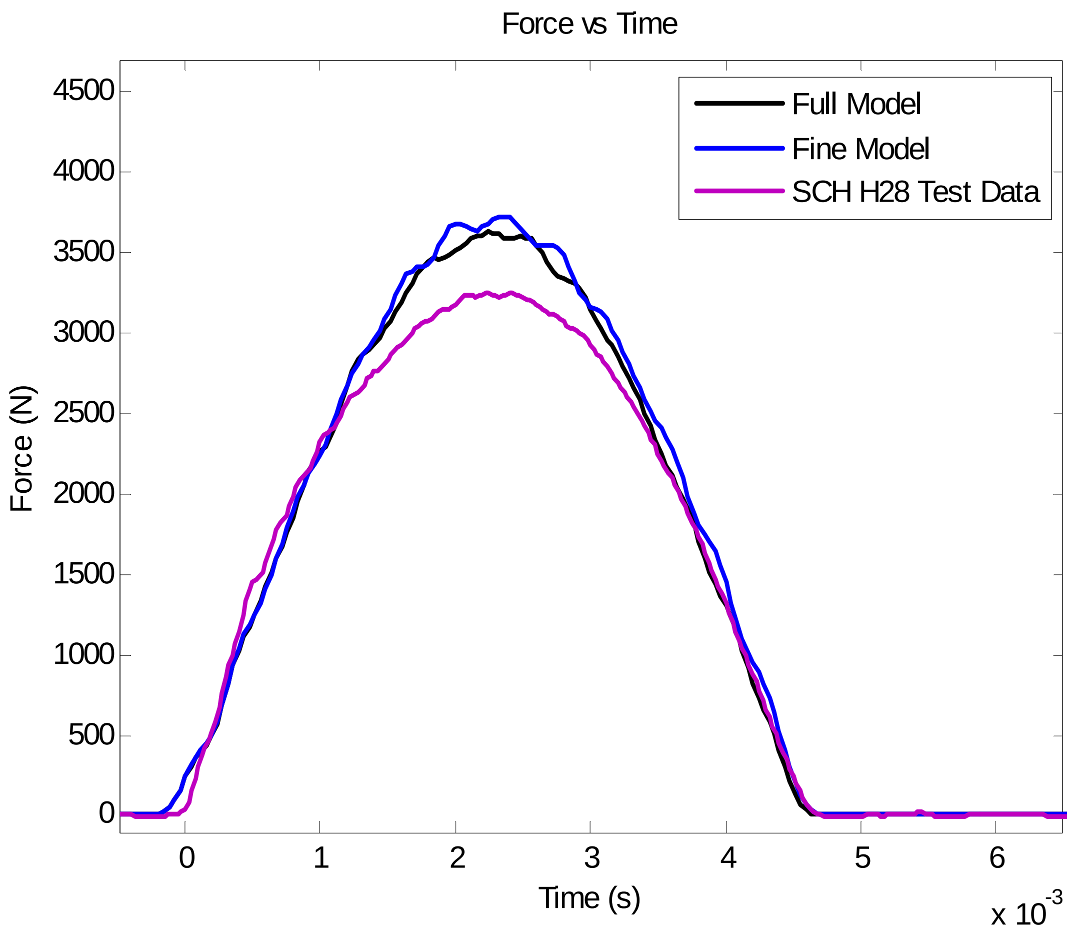
- **Quarter model**
  - 7 x 10 x 0.13 in. plate
  - Held by fixture with 5 x 5 in. opening
    - 0.75 in. thick Al top plate
    - 1.0 in. thick SS bottom plate
    - four bolts
  - Exact boundary conditions must be modeled to get accurate correlation – including fixture plates and bolt connections



Test Model Results: Contact Force History

- Peak forces ~13% higher than test
- Contact duration same as test
- Mesh refinement indicates convergence

- This test-problem used to establish methodology for accurate impact analyses.



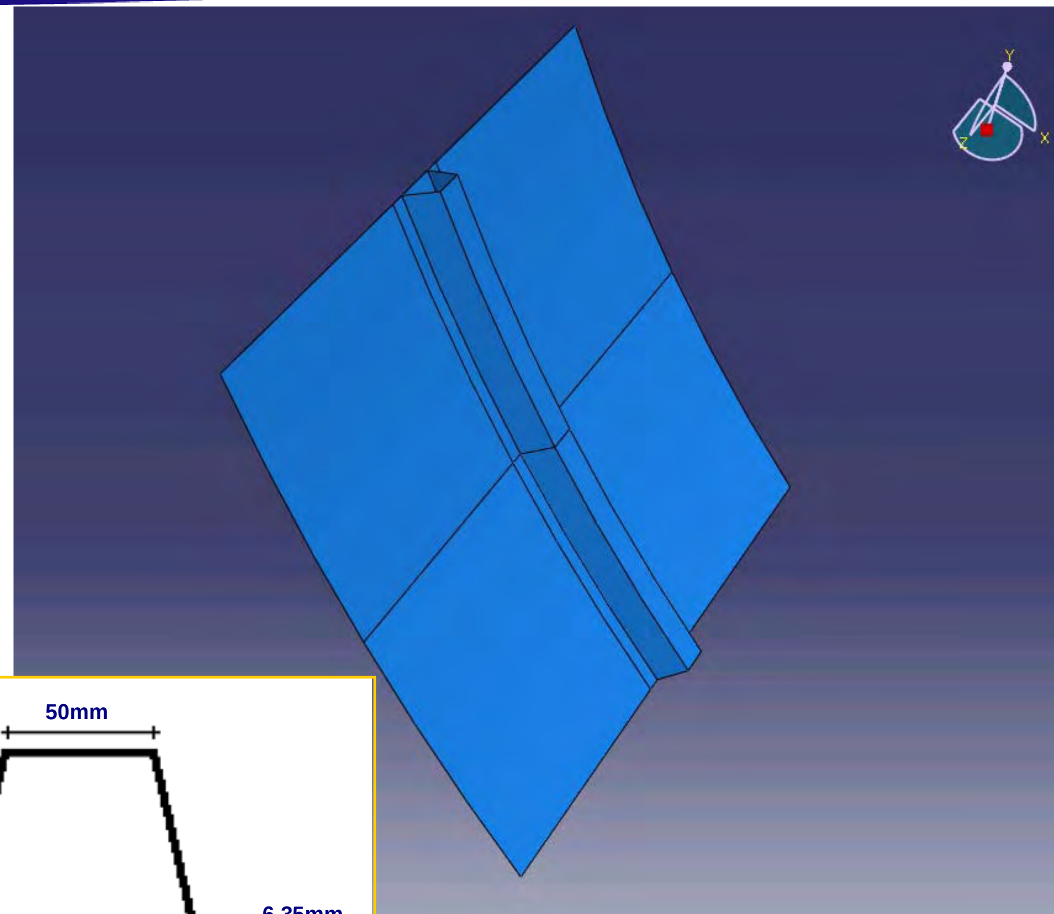
Wide-Area Impact Visual Detectability

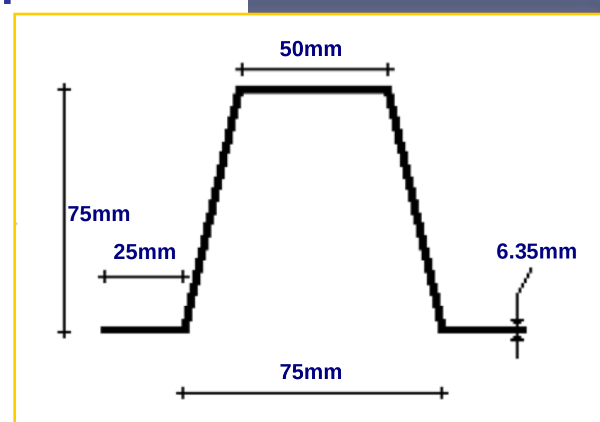
- Investigate factors that can produce maximum damage with minimum visual detectability
  - what mechanical quantities affect visual detectability? (i.e., visible mark left on surface)
    - wide-area contact (or padded contact) less likely to leave dents
    - surface scuffing or “bruising” due to high surface tractions: pressure, shear, or ???
    - cracking due to bending moments, transverse shear
- Study large curved panels with stiffener reinforcements

Wide-Area Impact FE Model

Stiffened panel

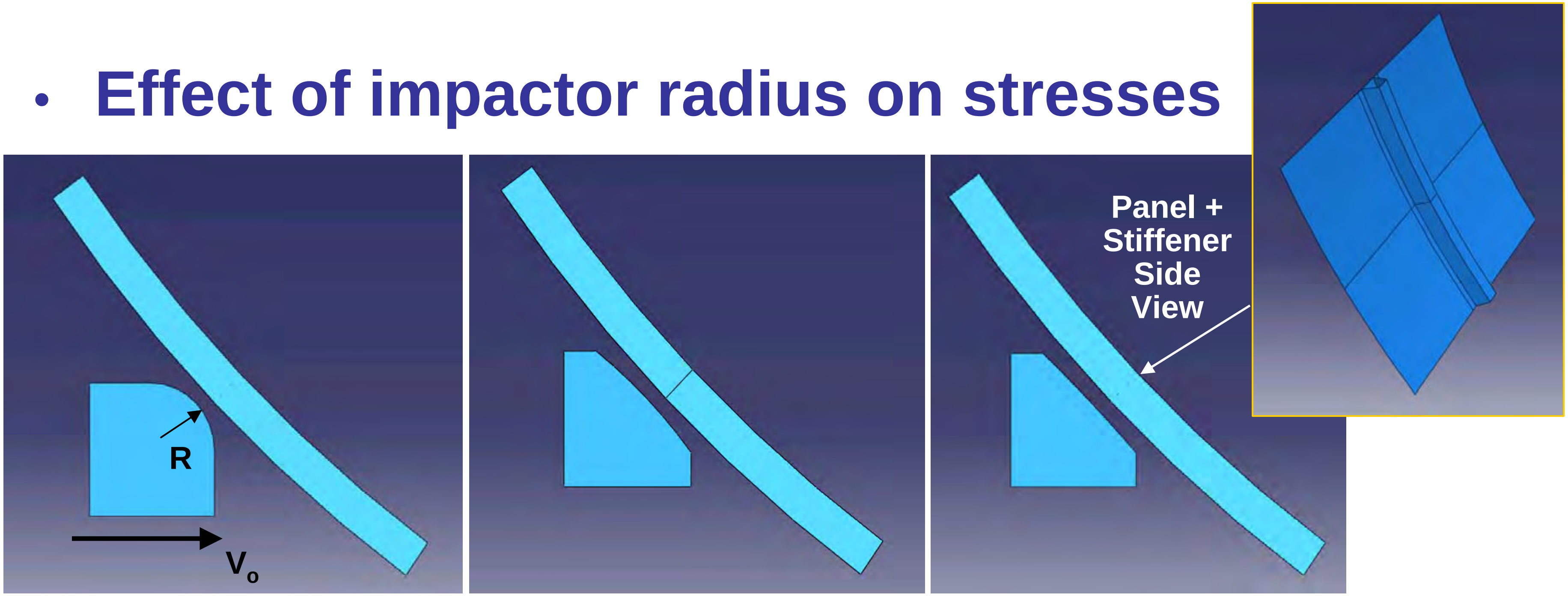
- panel details
  - 1m x 1m x 6.35mm
  - singly-curved: 3m radius
  - Quasi-Isotropic Carbon/Epoxy
    - E= 70 GPa, ν = 0.3
    - ρ = 1600 kg/m³
  - clamped b.c. at top & bottom
- stiffener details
  - quasi-isotropic carbon/epoxy





Varying Impactor Radius

- Effect of impactor radius on stresses

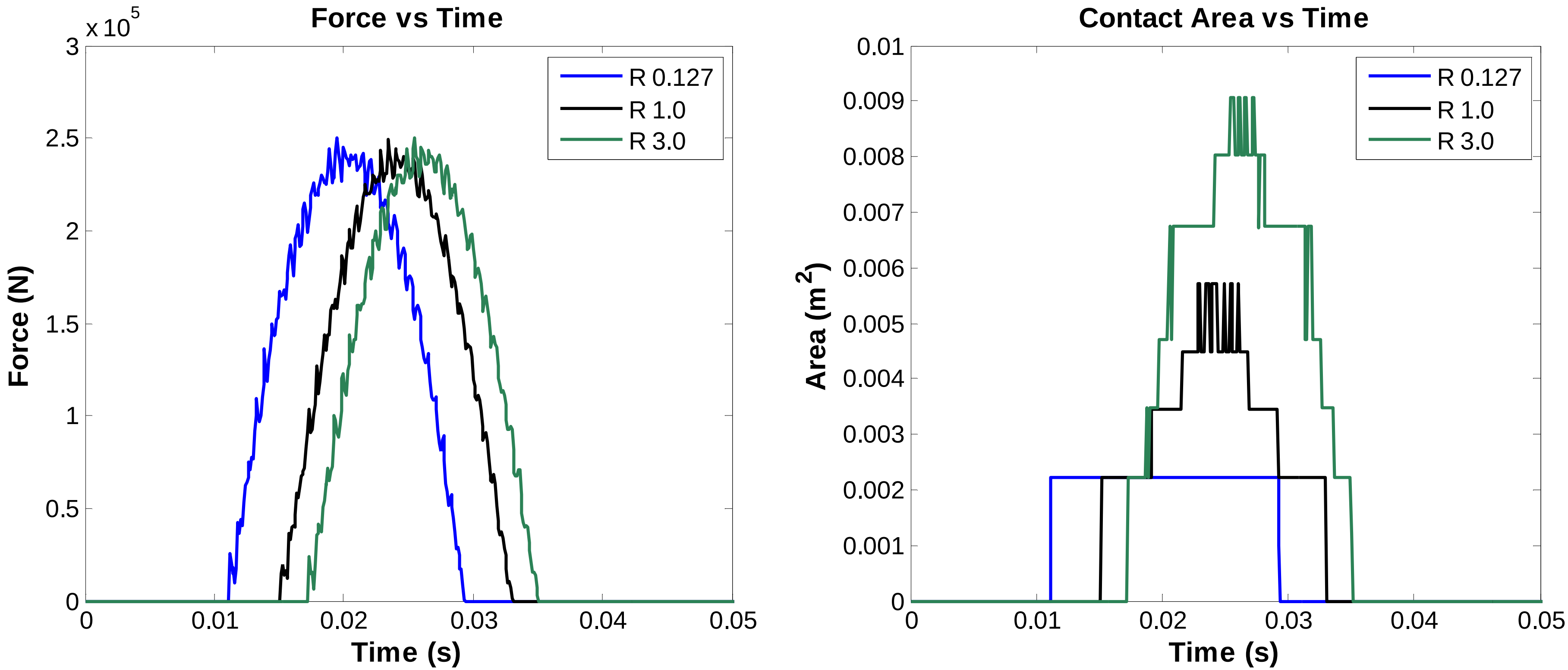


R = 0.127m R = 1m R = 3m

Projectile mass = 483.5 kg, velocity = 2 m/s, KE = 967 J

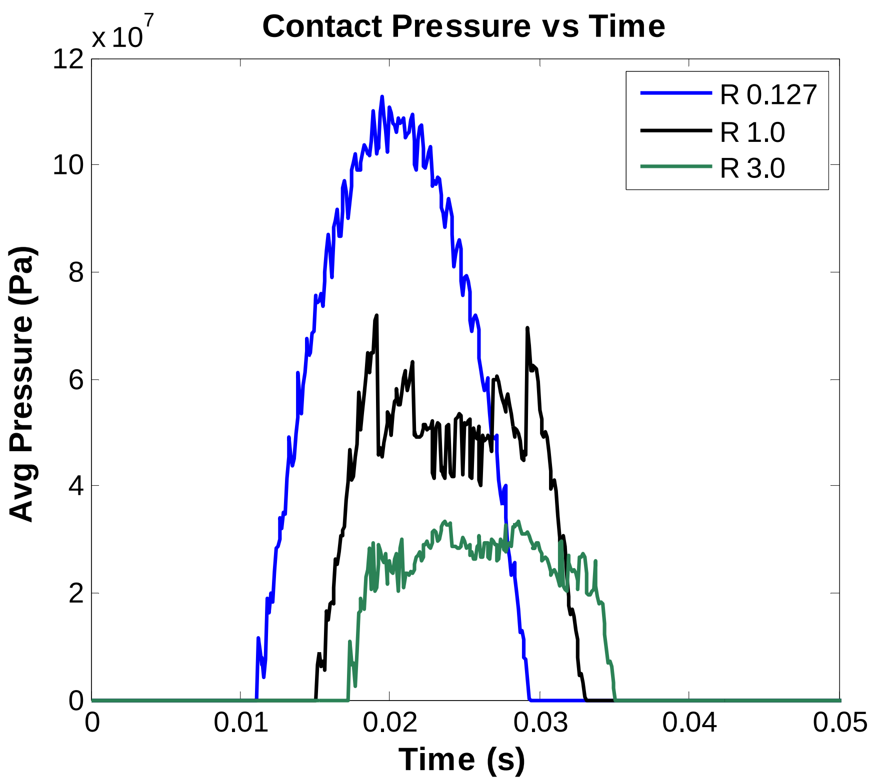
Results: Contact Force

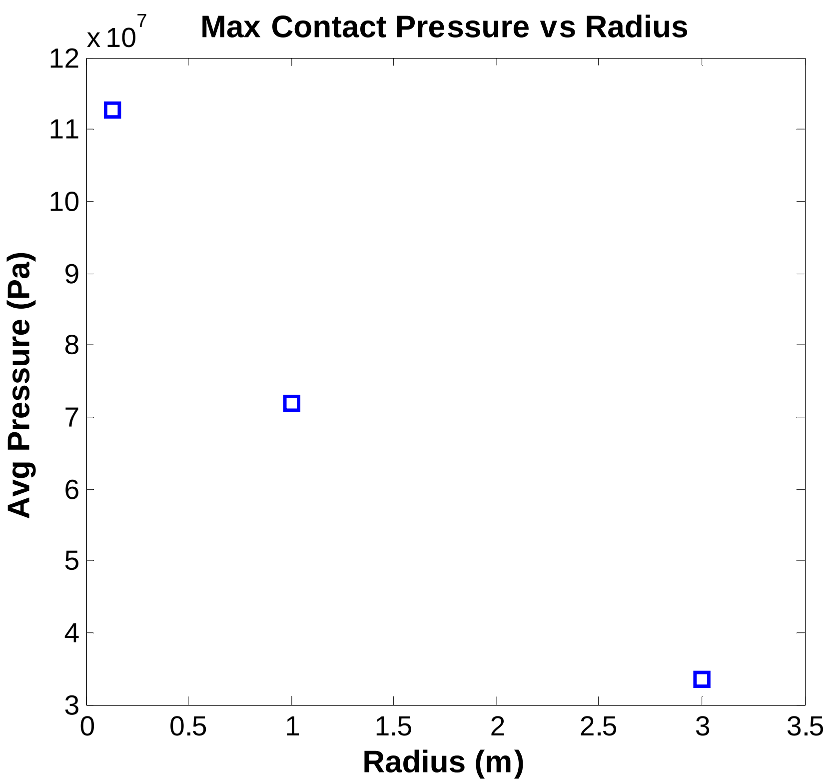
- Same contact force history
- Increasing contact area with R



Results: Contact Pressure

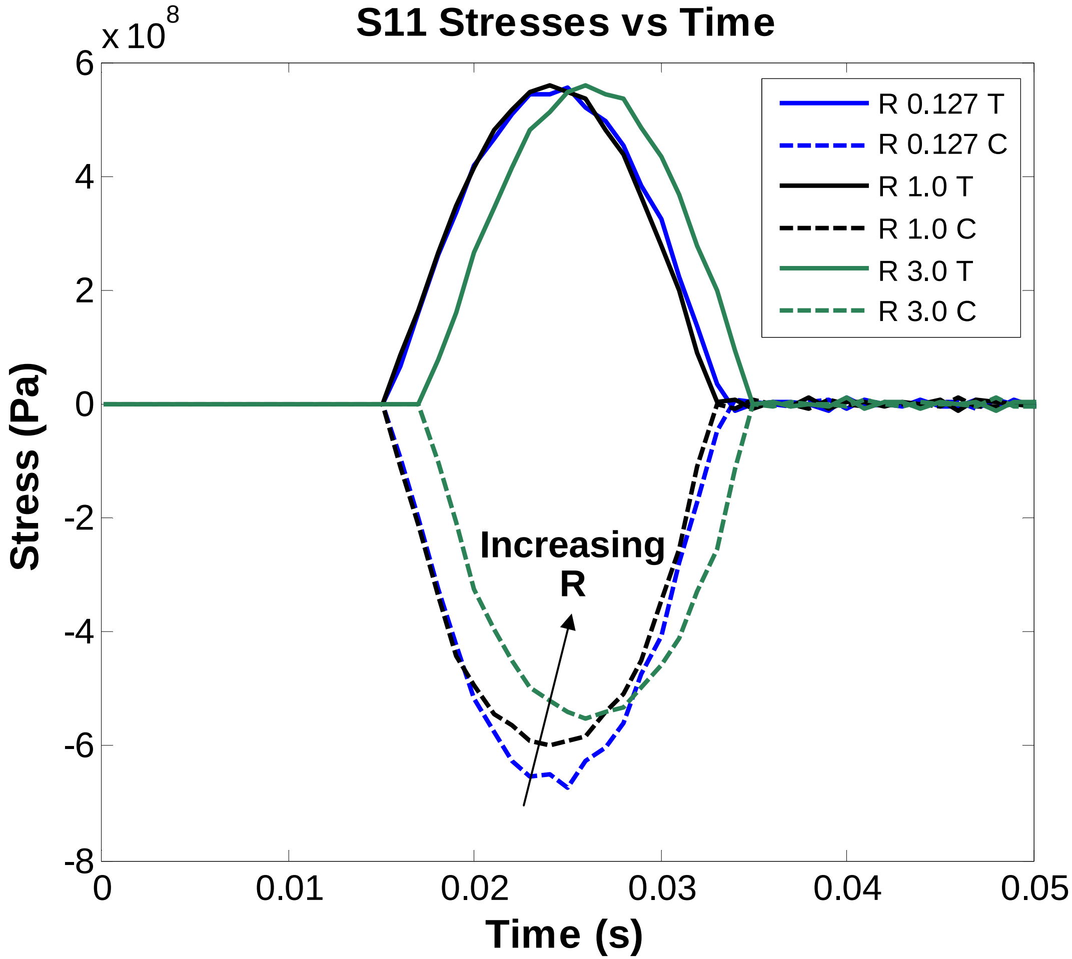
- Decreasing contact pressure with increasing impactor radius – implications on "bruising"





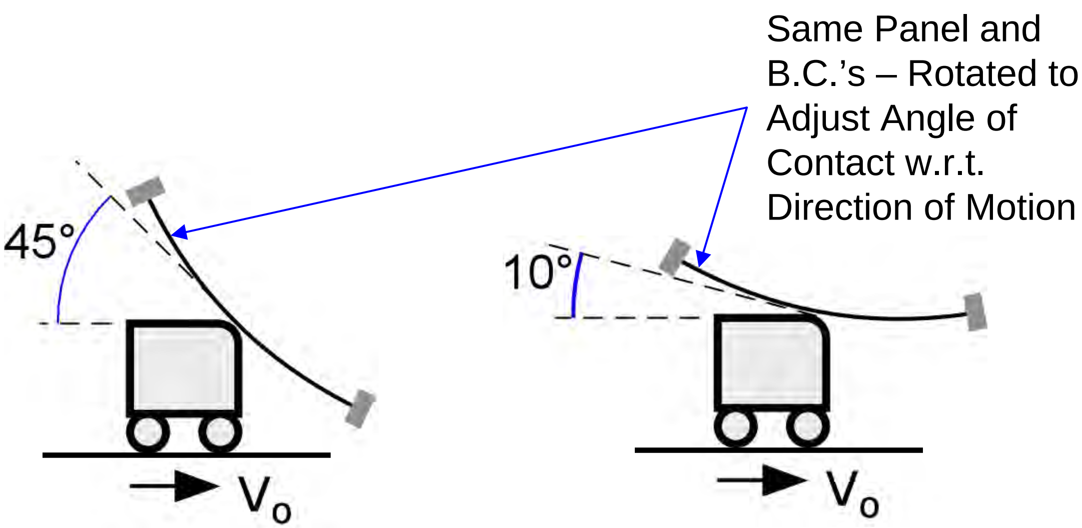
Results: Bending Stress

- **Decreasing compressive σ_{11} stress magnitude with increasing impactor radius**
- **Tensile σ_{11} stress remains same**
- **Failure at backside (tensile) possible before impact-side (compressive)**



Effect of Contact Angle

- High-mass "projectile"
  - 500 kg (1103 lb)
  - 127 mm (5 in.) corner radius
  - initial velocity 0.447 m/s (1.0 mph) to right; KE = 50 J
  - no applied external force
  - ***constrained*** to only horizontal motion
- Curved Composite Panel
  - clamped b.c. at top and bottom
  - oriented at 45º and 10º angle w.r.t. ground plane
  - no stiffener
- FE simulation conducted in ABAQUS/Explicit



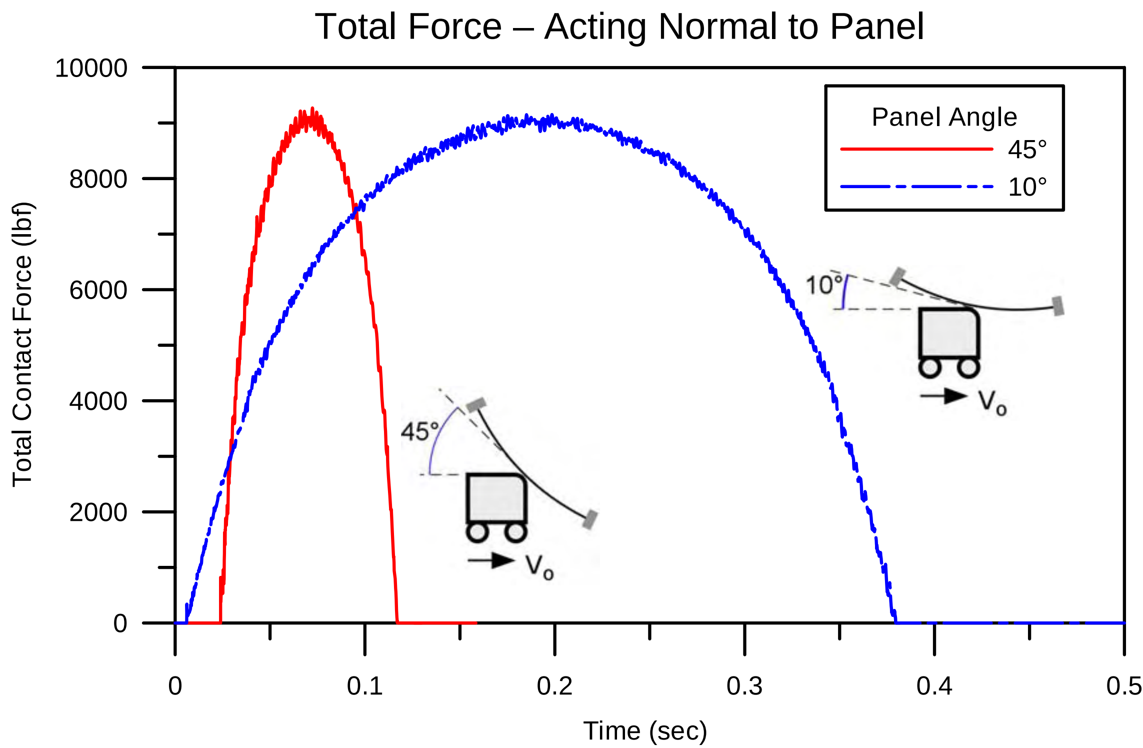
Contact Force Comparison

Total contact force

- vector sum of x- and y-direction force components
- acts in direction normal to panel surface (frictionless contact defined)
- peak force NOT dependent on panel orientation
- panel target has identical stiffness thus same maximum displacement (quasi-static like event)

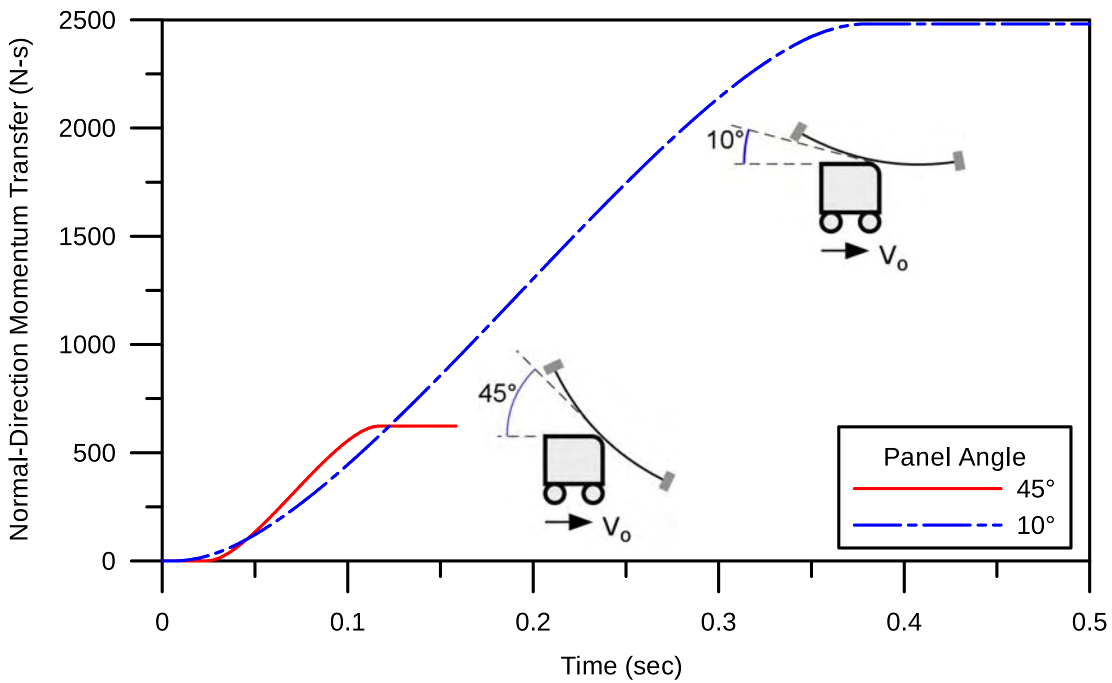
For lower contact angle,

- Increased contact duration
  - 94 ms for 45˚, 376 ms for 10˚
- Contact spread across more elongated area
- Longer duration pulse can be more damaging



Momentum Transfer

- Momentum of projectile imparts impulse to structure during impact event
  - projectile initial momentum is 500 kg x 0.447 m/s = 223.5 kg-m/s (or N-s)
  - total momentum change is 2X due to projectile “bouncing” off target and returning with equal but opposite velocity: 447 N-s
- Total impulse on structure
  - computed by integration of total force over time (area under f vs. t curve)
  - dependent on panel orientation
    - for 45˚: 623 N-s
    - for 10˚: 2,480 N-s (4X higher than 45˚)
  - acts normal to panel surface

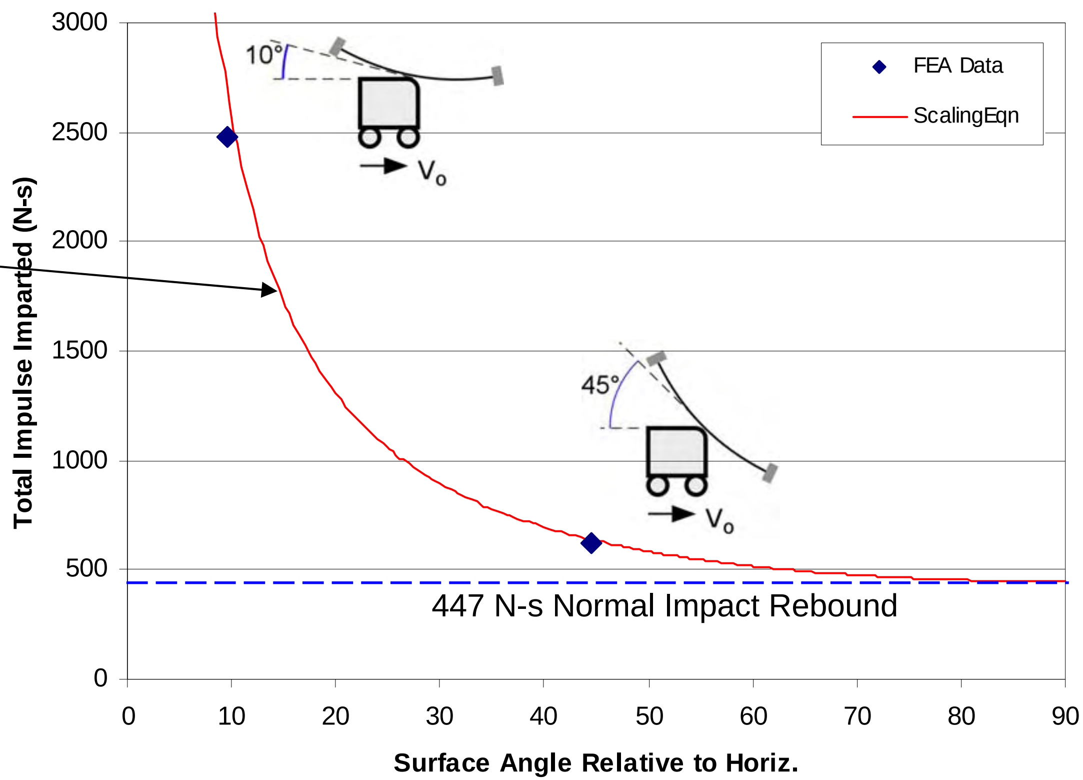


Momentum Transfer

- Impulse found to scale by trigonometric relationship

$$p_\theta = 2\frac{mv_o}{Sin\,\theta}$$

where θ is angle between panel surface and horiz. direction of projectile motion



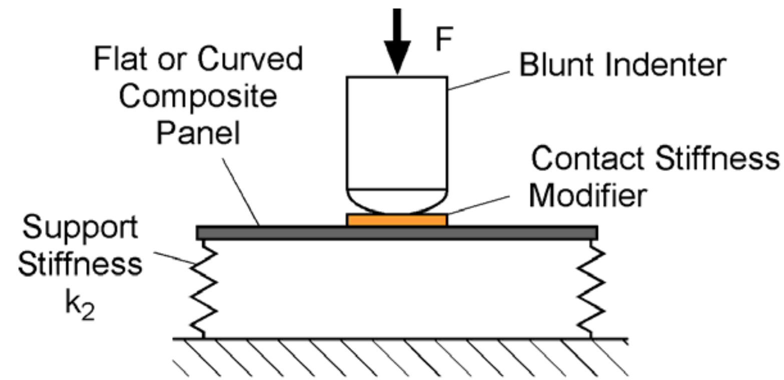
- good match-up with FEA for linearly elastic material behavior, no friction

Future FEA Investigations

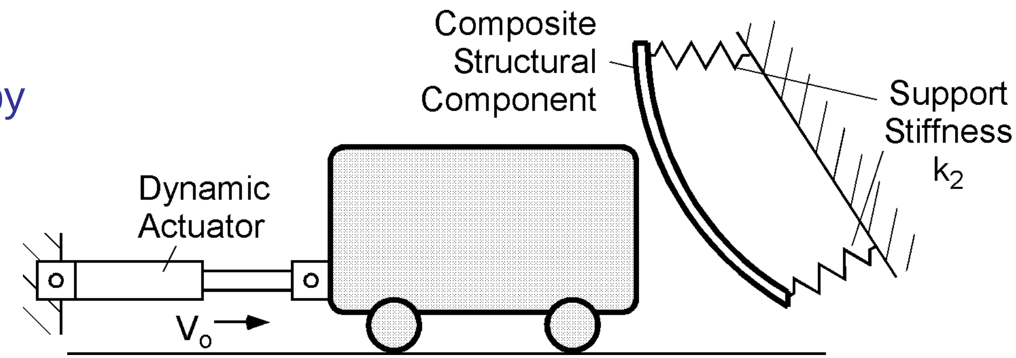
- include friction – contributes to interlaminar shear
  - include rubber bumpers commonly found on vehicle/equipment corners
- deeper look at visual detectability vs. pressure or shear traction or ??? (t.b.d. quantities)
- experiment design – use FE to design lab-scale and full-scale experiments

Task 3. Planned Experiments

- lab-scale panel tests
  - quasi-static indentation and low velocity impact
  - varying boundary support stiffness
  - measure damage metrics as function of impactor radius, contact stiffness, boundary support stiffness, etc.
  - generalization of results to encompass wide range of parameters



- full-scale wide-area impact tests
  - impact tests on full-scale structures by actual ground vehicles/equipment
  - tests conducted using large-scale tests labs at UCSD
  - validate models in Task 2



Request From Today's Audience

- feedback on proposed activities
  - what are major wide-area impact scenarios?
  - what should simple models look like? be capable of?
  - what quantities/outputs are most important to you?
- willingness to participate in survey querying about damage types and their sources, etc.
- industry participants in planned full-scale wide-area impact tests

A Look Forward

- **Benefit to Aviation**
  - can aid maintenance engineers in assessing whether an incident could have caused damage to a structure
    - if so, what inspection technique should be applied to resolve damage
  - can aid design engineers to:
    - improve resistance of composite aircraft structures to wide-area impact damage as well as a variety of other sources such as hail- and bird-strikes, runway debris, lost access panel, etc.
    - provide critical information on mode and extent of seeded damage, particularly non-visible impact damage (NVID), resulting from a wide gamut of impact threats – i.e., low to high velocity
- **Future needs**
  - large-scale test articles – stringer-stiffened skin or sandwich panels
    - either actual articles, or generic design fabricated at UCSD
  - understand relationship between visible signs of impact and surface tractions – depends on materials used on both sides, color of paint, human factors, etc., enhanced visual detection techniques (visual analytics)
  - incorporation of NDI and probability of detection (POD) into blunt impact studies (Sandia National Labs collaboration)