Blunt Impact Damage Formation on Composite Aircraft Structures

FAA Supported Research Project

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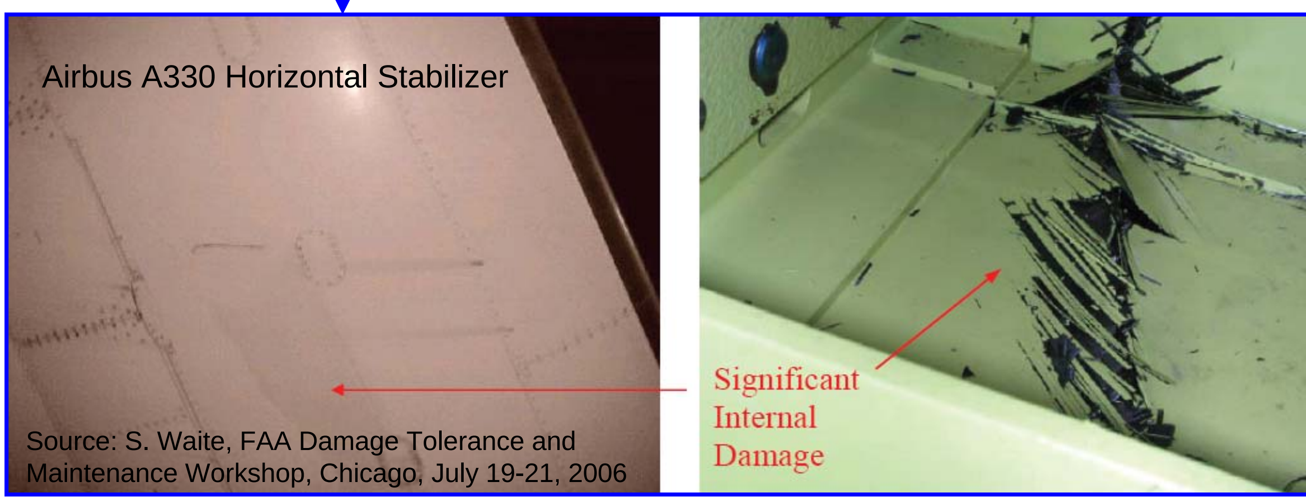
Background

- incidental contact / collisions with ground vehicles and equipment can result in blunt impact damage
  - a significant source of damage to commercial aircraft
  - extensive sub-surface damage is often not externally visible
- new all-composite fuselage transport aircraft are coming into service
  - significantly more composite skin surface area is exposed to ground vehicles and equipment

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



Source: S. Waite, FAA Damage Tolerance and Maintenance Workshop, Chicago, July 19-21, 2006

Objectives

Newly-starting research project has three objectives:

- identify blunt impact scenarios that are
  - commonly occurring
  - of major concern to airline maintenance organizations and aircraft manufacturers
- develop methodology for blunt impact threat characterization and modeling
- experimental identification of key phenomena and parameters governing blunt impact damage formation

Expected outcome upon accomplishment of these objectives (along with proper dissemination of the results) are "simple" modeling tools that can aid in:

- assessing whether incident could have caused damage
- improving the resistance and tolerance of composite aircraft structures to damage from blunt impacts
- establishing practical design criteria for damage resistance and tolerance

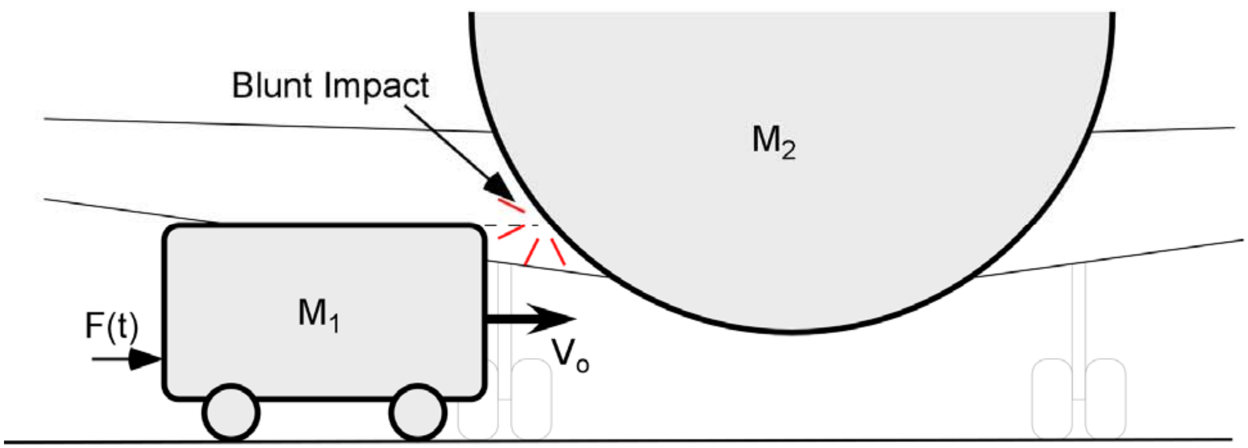
Plan of Work

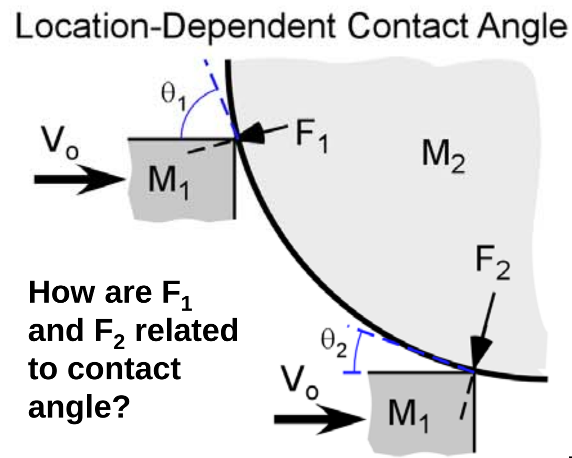
- Three tasks – addressing each of the objectives:

- **Task 1. Identification of Common Blunt Impact Scenarios and Establishment of Partner Relationships**
  - initial phase of the project
  - active communication with the following organizations
    - airlines
    - aircraft manufacturers
    - OEM suppliers
    - FAA and EASA
  - identify blunt impact scenarios that are:
    - most commonly occurring
    - of major concern
    - e.g., source of impact, location, and type of damage formed
  - visits to maintenance depots
    - document findings via photographs (if permitted) and written notes
  - **outcome** of this task will be summarized in a written document/FAA report

Task 2. Methodology for Impact Threat Characterization

- focus on defining generalized methodology for describing, characterizing, and establishing blunt impact threats – e.g., assign all aircraft-adjacent ground items with threat index
- problem is 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)
  - "target" can be the many locations of the aircraft exposed to contact with ground vehicle/equipment
    - fuselage, nacelles, wing skins, control surfaces, etc.
    - impacts can be at or near internal stiffeners, or away from them, thereby greatly affecting the local stiffness of the structure – local stiffness governs the contact forces generated during impact
  - incidence angle between "impactor" and composite panel surface plays major role in nature of contact force history

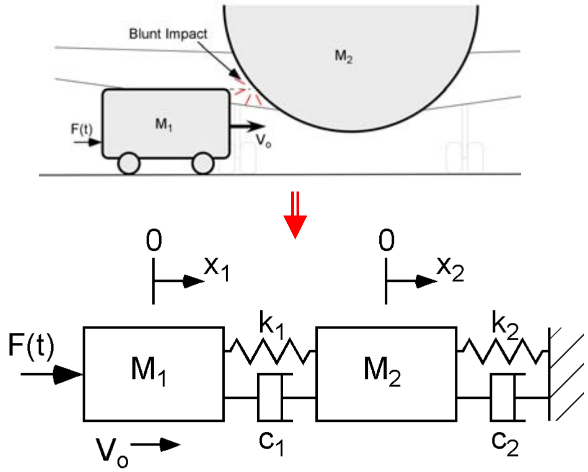




Task 2 – Contd.

- Consider: 5,500 kg vehicle at 0.5 m/s (1.1 mph) collides with an aircraft.
  - How do we describe this event? If kinetic energy based, is the entire kinetic energy of 687 J (507 ft-lb) involved in the projectile-target interaction? How much of the aircraft structure is active in reacting to the collision?
  - Alternatively, **peak contact force has been shown to be a descriptive parameter for describing damage initiation** (Jackson & Poe 1992, Schoeppner & Abrate 2000)
    - BIG ISSUE: contact force is not readily known quantity – need to estimate using blunt impact characterization model

First-Order Blunt Impact Characterization Model - similar momentum-force based tools exist for automobile impact simulation – *SMAC, EDSMAC, CRASH,* etc.



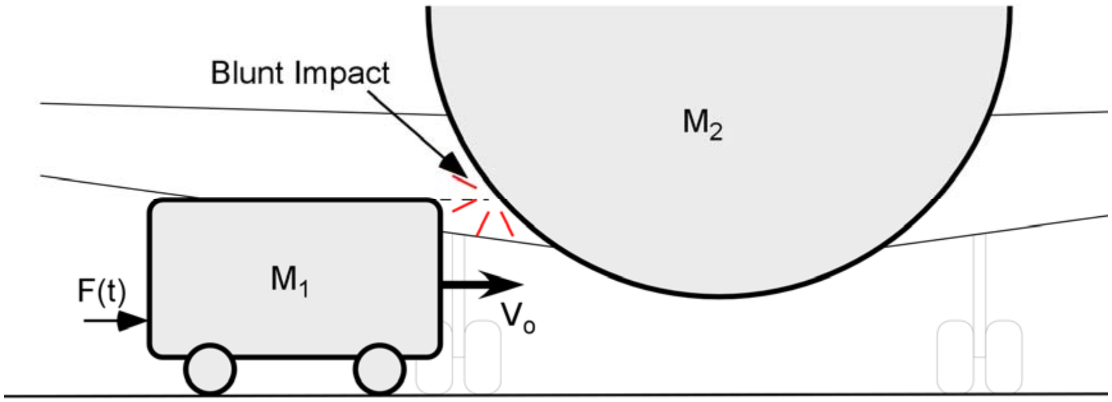
- k_1 and c_1 represent impactor-target interaction – k_1 could be nonlinear
- k_2 and c_2 represent stiffness supporting target, or portion of target active in the problem represented by mass M_2
- applied force F(t) allows additional forcing input after initial contact
- parameters measured experimentally or determined via numerical simulation

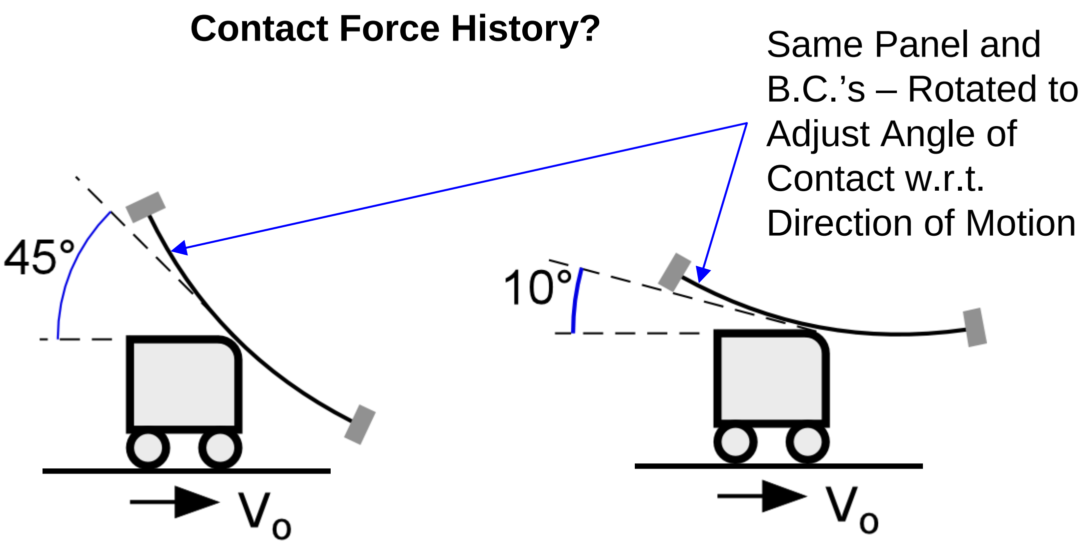
- expected outcome:
  - user-friendly analytical tool that estimates peak contact force and max deflection
  - assess whether failure threshold has been exceeded – if so, what type of inspection is needed
- validation needed – experiments proposed in Task 3

Task 2 Preliminary Results:

Interrogation of Contact Angle Effect via FEA

- 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 exhibit only horizontal motion
- Curved Composite Panel
  - 6.35 mm thickness (0.25 in.)
  - radius of curvature 3 m
  - clamped b.c. at top and bottom
  - oriented at 45º and 10º angle w.r.t. ground plane
- FE simulation conducted in ABAQUS/Explicit



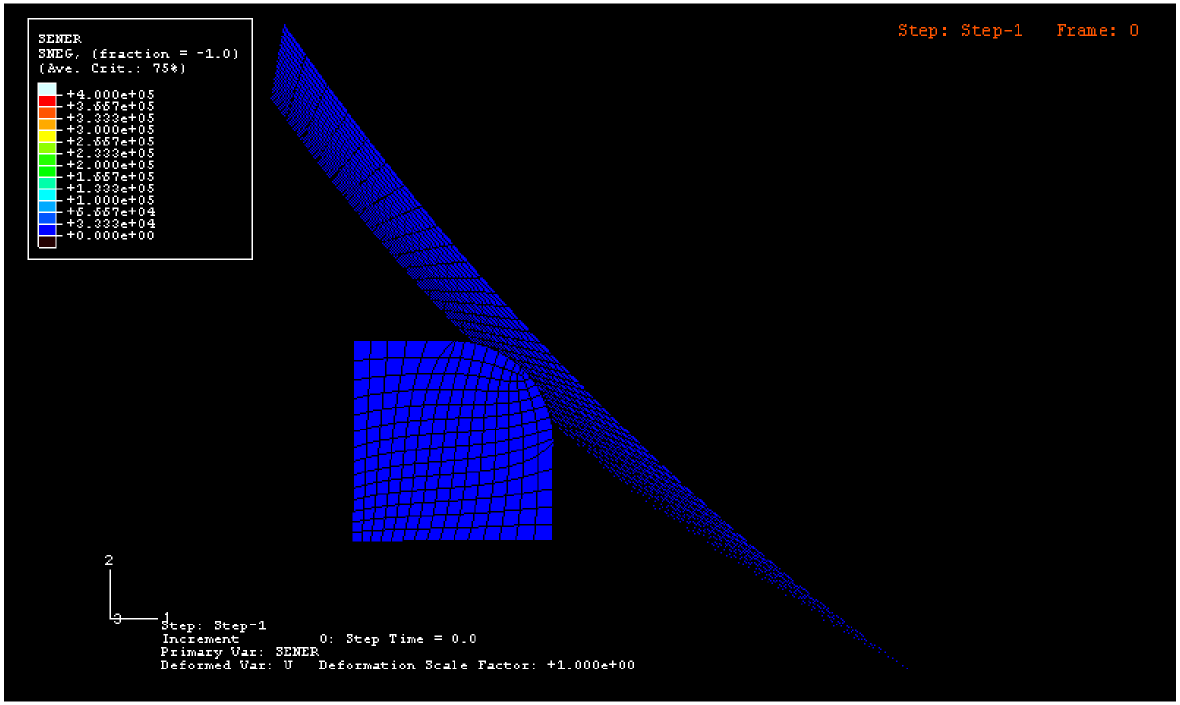


High Mass Impact Simulation Results

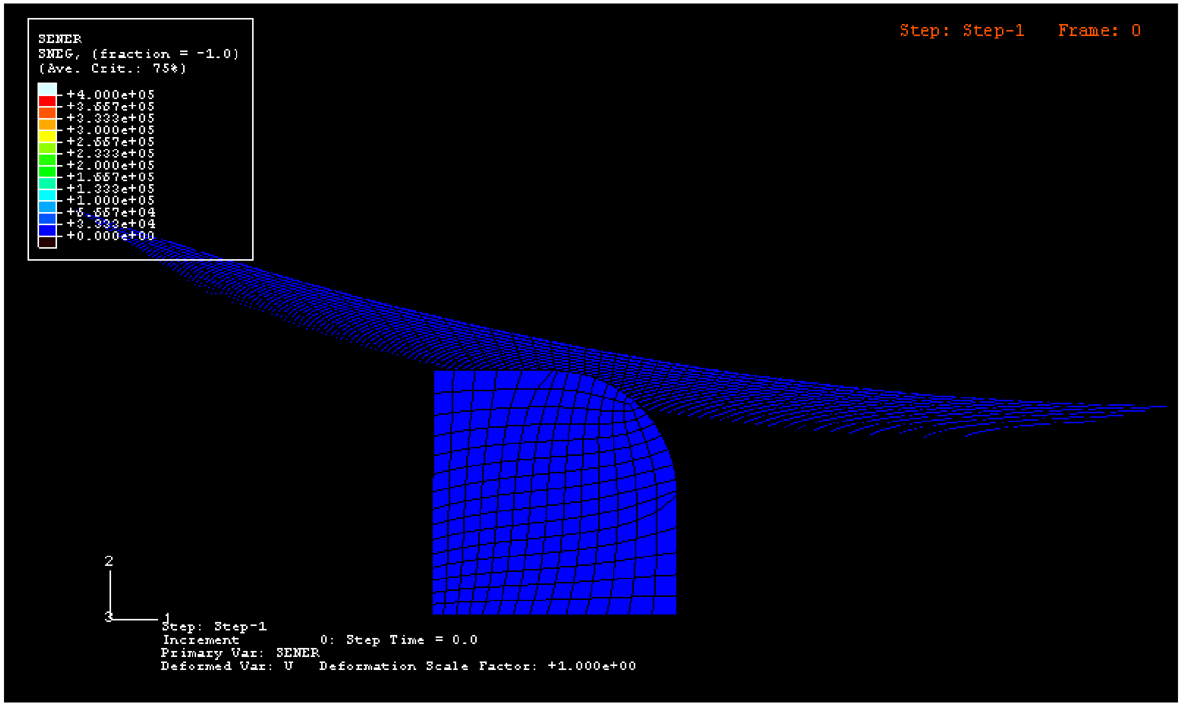
Observations: for lower contact angle,

- Increased contact duration
  - for 45°: 94 ms
  - for 10°: 376 ms
- Contact spread across more elongated area

45° Relative to Horizontal



10° Relative to Horizontal

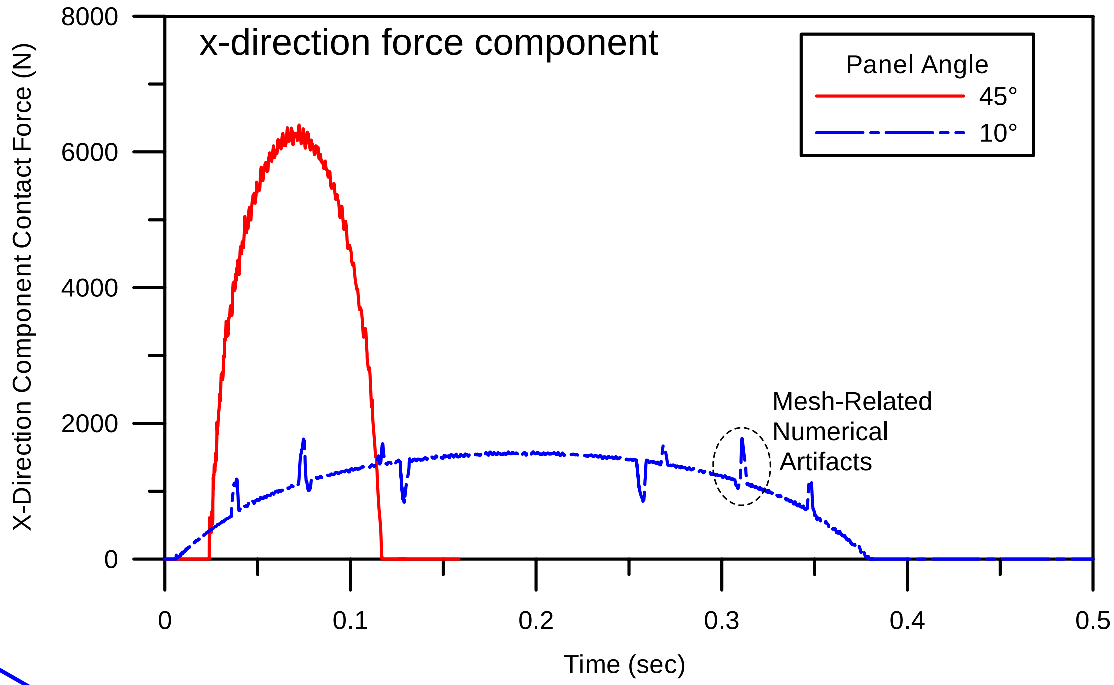


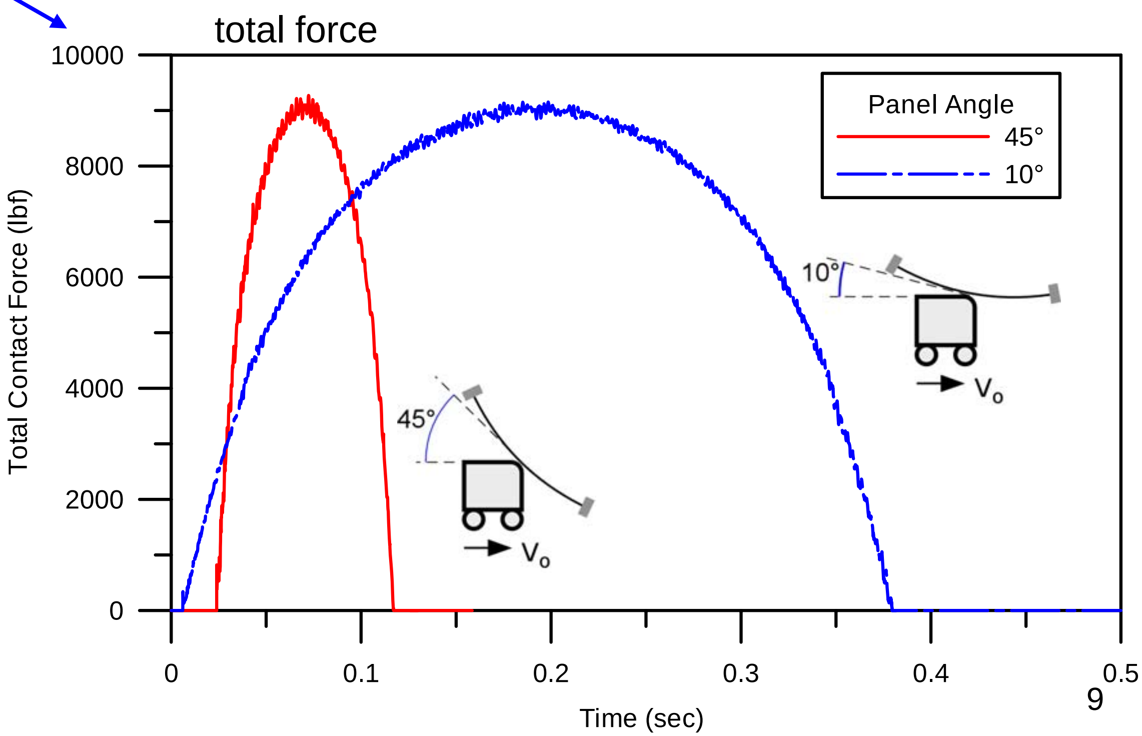
Additional model info:

- linear material behavior – i.e., damage not modeled
- geometric nonlinearity
- contact defined as friction-less

Contact Force History

- 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)
- Longer duration pulse can be more damaging
- Notes:
  - same peak force only for projectile having constrained motion
  - if x-direction force applied behind projectile, peak contact forces will NOT be the same (trigonometric balance)
    - e.g., driving force from vehicle wheel torque





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Momentum Transfer

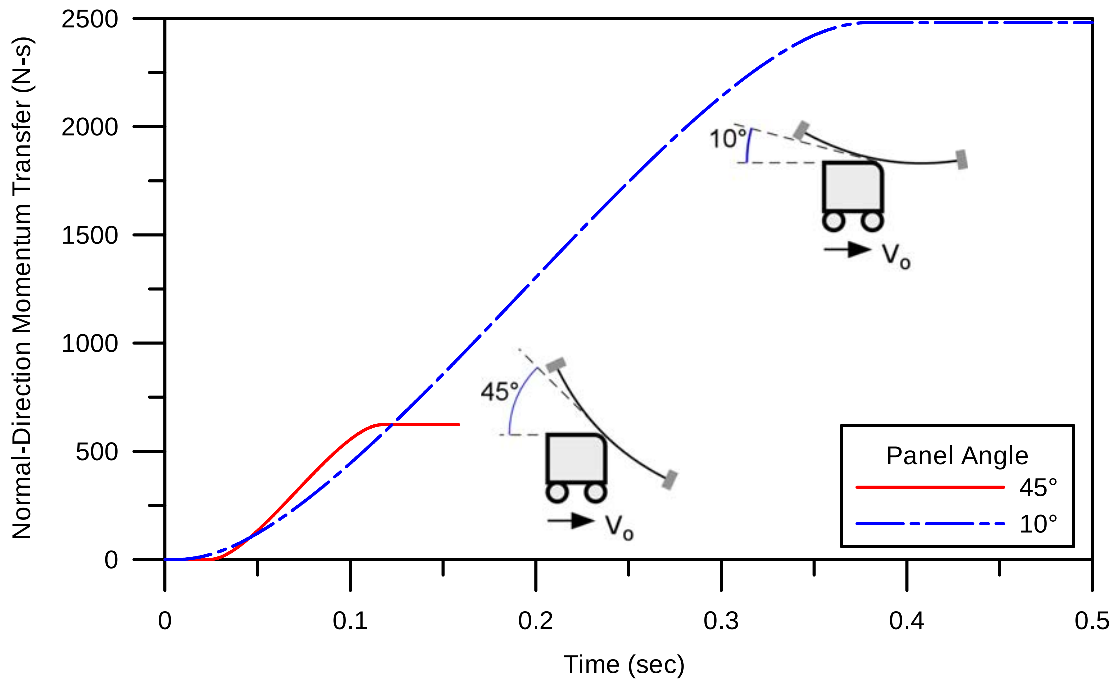
- Momentum of projectile imparts impulse to structure during impact event
  - projectile initial momentum is 500 kg x 0.447 m/s = 223.5 kg-m/s (or N-s)
  - total momentum change is 2X due to projectile "bouncing" off target and returning with equal but opposite velocity: 447 N-s

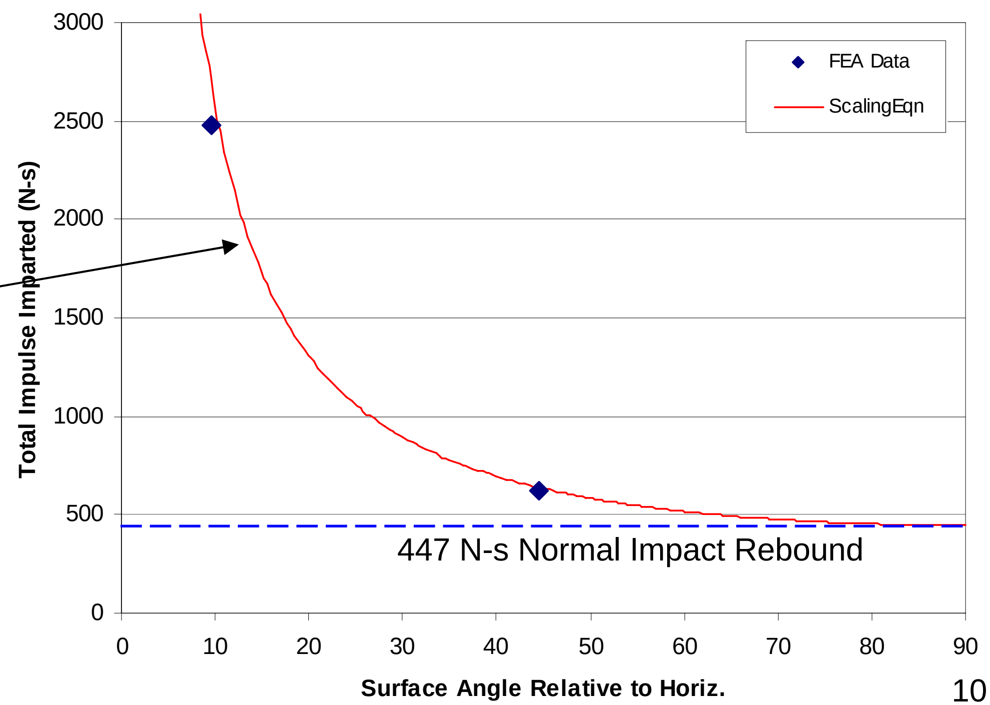
- Total impulse on structure
  - computed by integration of total force over time (area under f vs. t curve)
  - dependent on panel orientation
    - for 45°: 2,480 N-s
    - for 10°: 623 N-s (4X higher than 45°)
  - acts normal to panel surface

- Impulse found to scale by trigonometric relationship

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

  - where θ is angle between panel surface and direction of projectile motion (constrained)
  - good match-up with FEA

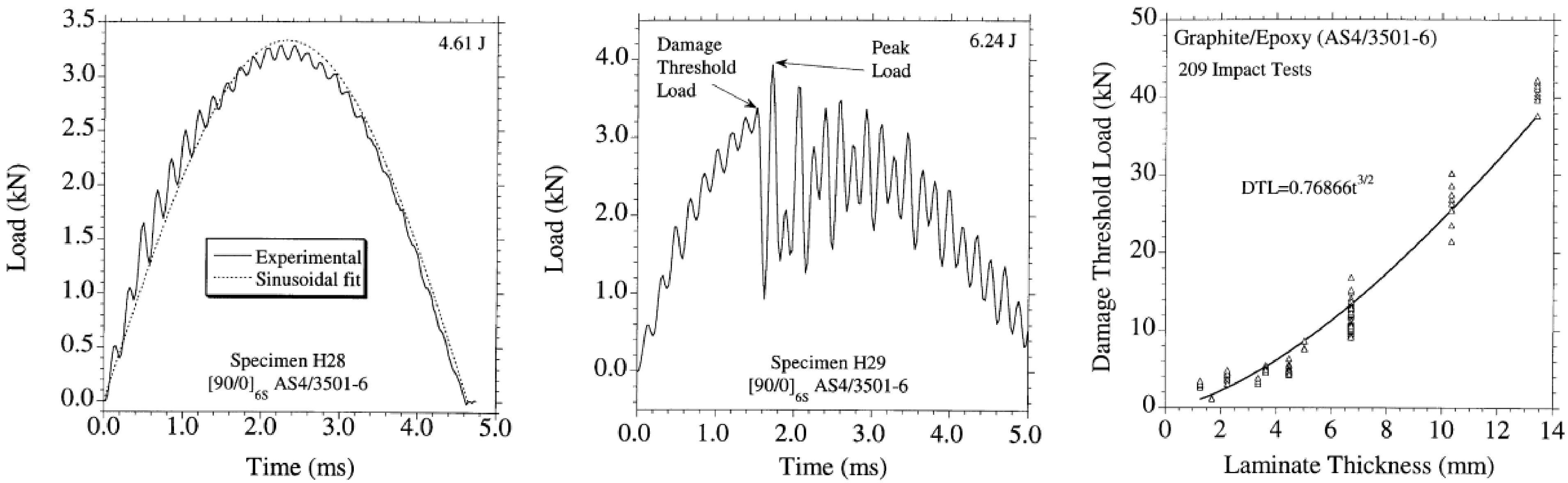




Critical Damage Threshold Force Concept

- Initiation of damage can be described by damage threshold load (DTL)*
  - can be determined from contact force vs. time and force vs. displacement plots
- DTL shown to scale with panel thickness as $t^{3/2}$: $$P_{cr}^2 = \frac{8\pi^2 E t^3 \mathcal{G}_{IIC}}{9(1-\nu^2)}$$ (relationship by Davies and Zhang**)

Impact Contact Force Histories* | Damage Threshold Load*



Refs: * *G.A. Schoeppner, S. Abrate / Composites: Part A 31 (2000) 903–915*

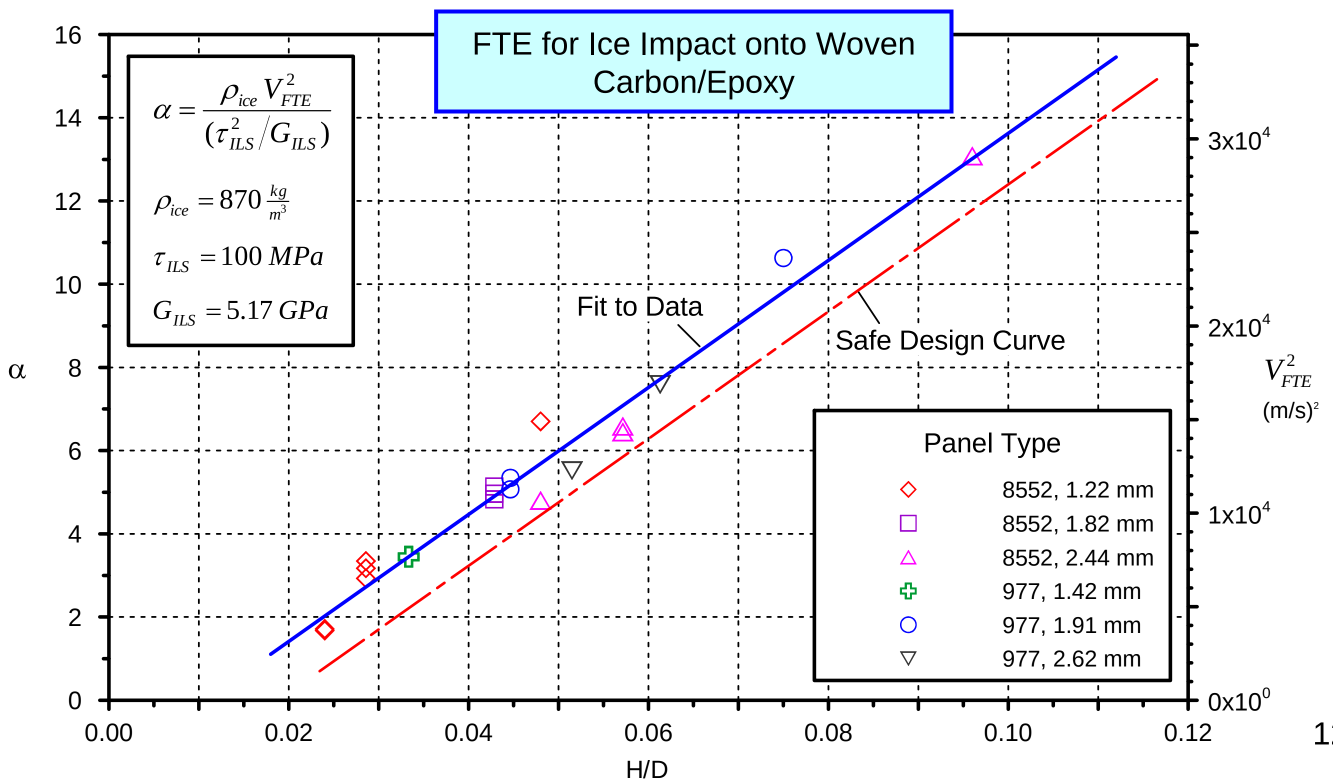
** Davies GAO, Zhang X. Impact damage prediction in carbon composite structures. International Journal of Impact Engineering 1995;16(1):149–70.

Task 3. Key Phenomena and Parameters Governing Blunt Impact Damage

- experimentally identify key phenomena and parameters governing blunt impact damage
- correlation of global parameters to local parameters measured by test and predicted by the previously described simple models
  - global parameters: ground vehicle mass, velocity, aircraft substructure mass
  - local parameter: contact stiffness, peak contact force and deflection during impact event
- damage extent resulting from various impact force levels on a given component can be catalogued and then “looked up” when an incident occurs in service
  - can aid in making rapid maintenance/repair decisions

Example of user-friendly lookup table for complex process of high velocity ice impact, by H. Kim et al. 2003.

Panel thickness vs ice ball diameter H/D is found to be key parameter describing damage initiation.



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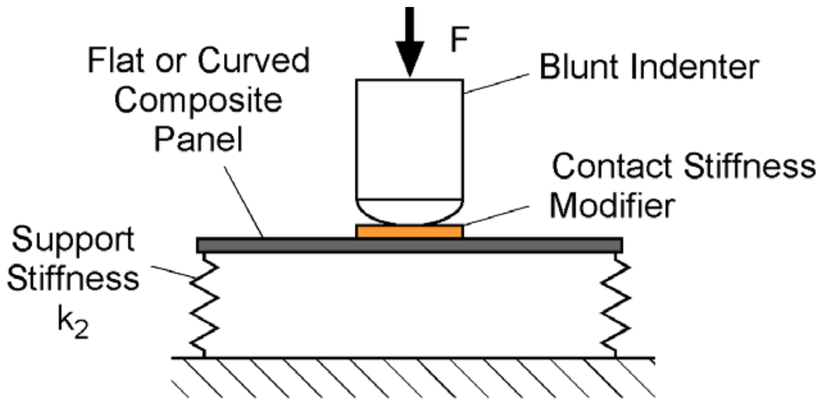
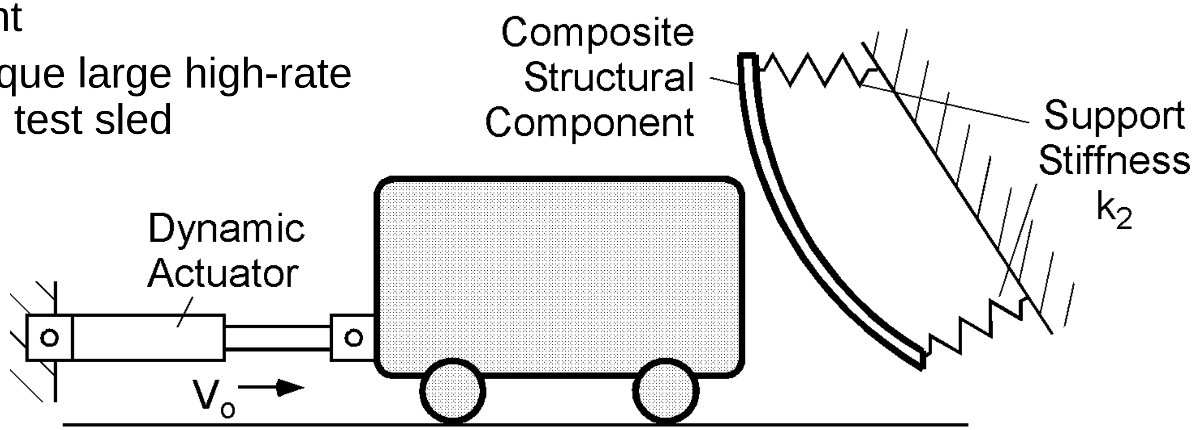
Task 3. Contd. – Planned Experiments

- lab-scale panel tests
  - quasi-static indentation and low velocity impact
  - panels having varying boundary support stiffness
  - measure initial stiffness w/out damage
  - measure critical force for damage initiation as function of indenter radius, contact stiffness, boundary support stiffness, etc.
  - generalization of results to encompass wide range of parameters



- full-scale blunt impact tests
  - impact tests on full-scale structures by actual ground vehicles/equipment
  - tests conducted using unique large high-rate equipment at UCSD or on test sled
  - validate models in Task 2



Industry/Agency Participation

- key component of this research activity is participation from industry/agency partners
  - research focus and activities should be relevant to the user community

- requested industry/agency participation broken down into three levels:
  - **Level 1. Initial Guidance.** Contribution to Task 1. Hyonny Kim will communicate and/or visit the facility to learn and see first hand about the companies' experiences in this topic and document experiences.
  - **Level 2. Advisory.** Provide initial guidance, as well as ongoing advisement, particularly in Task 2 methodology development, and in defining parameters for experiments to be conducted in Task 3.
  - **Level 3. Provide material support for Task 3.** Make available test panels, substructure components, and/or "impactors" (e.g., a cargo cart) for full-scale blunt impact investigations.

Request From Today's Audience

- feedback on proposed activities

- "wish list" from industry/agency perspective
  - what should analytical tool look like? be capable of?
  - what quantities/outputs are most important to you?

- willingness to participate in survey to be issued querying about damage types and their sources, etc.

- additional participants

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