September 17, 2015 Agenda

- **Session 6: Damage Tolerance (Special Subjects)**

8:30-9:00	"Composite Fatigue & Damage Tolerance Design & Service Experience" - Kevin Davis (Boeing)
9:00-9:30	"Validation of Thermal Loads for Hybrid Structure" - Jean-Philippe (Bombardier)
9:30-9:45	"Thermal Loads of Horizontal Tail Plane Structure" - Jan Waleson (Fokker)
9:45-10:00	"Perspectives on Damage Detection and Inspection" - Larry Ilcewicz and Rusty Jones (FAA)
10:00-10:15	Break
10:15-10:45	"Composite Damage Tolerance Special Topics Recap" - Led by Larry Ilcewicz (FAA), D.M. Hoyt (NSE) and Waruna Seneviratne (WSU)

Perspectives on Damage Detection and Inspection

Presented at: 2015 FAA/Bombardier/TCCA/EASA/Industry Composite Transport Damage Tolerance and Maintenance Workshop (Montreal, Quebec)

By: Larry Ilcewicz

Date: September 15 to 17, 2015

Opinions on Current State of Composite Inspection

Detect damage, monitor part quality but what about supporting residual strength predictions?

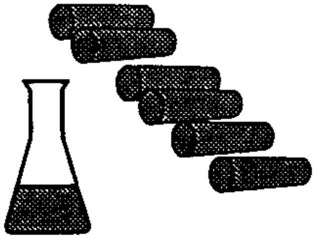
- Excellent safety management for most defects originating in the factory
  - Metal weak bonds & composite weakened bonds remain an issue
  - “Allowable damage characterization” remains a challenge (conservative and structural test extensive)
- Field practicality
  - Composite damage tolerance to facilitate practical maintenance
  - Most current field inspection procedures using NDI are triggered by visual evidence to measure the full extent of damage but are not quantitative for accurate damage tolerance assessments

Categories of Damage & Defects for Primary Composite Aircraft Structures

Category	Examples (not inclusive of all damage types)
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)	Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life
Category 2: Damage detected by scheduled or directed field inspection @ specified intervals (repair scenario)	VID (ranging small to large), deep gouges, mfg. defects/mistakes, major *local* heat or environmental degradation that retain limit load until found
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)	Damage obvious to operations in a "walk-around" inspection or due to loss of form/fit/function that must retain limit load until found by operations
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, exploding gear tires, severe in-flight hail)
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	Damage occurring due to rare service events or to an extent beyond that considered in design, which must be reported by operations for immediate action

Complexities of Foreign Object Impact

Material variables



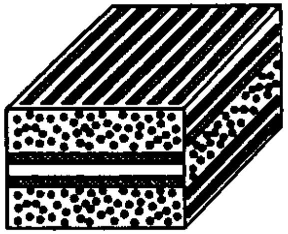
☆ Fiber
- AS4
- IM7

☆ Resin
- 938 (3501-6)
- 977-2

☆ Fiber volume
- 0.480
- 0.565

☆ Material form
- Tape
- Tow

Laminate variables

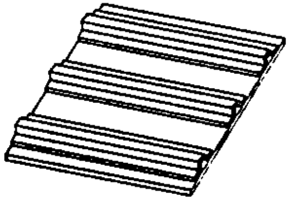


Stiffener layup
- Hard
- Soft

Skin layup
- Hard
- Soft

☆ Thickness
- Thick (approximately 0.2 in)
- Thin (approximately 0.1 in)

Structural variables

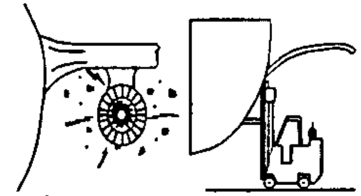


☆ Stiffener type
- Blade
- Hat

Stiffener spacing
- 7 in
- 12 in

☆ Stiffener adhesive layer
- With
- Without

Extrinsic variables



Impact mass
- 0.5 lbm
- 12.0 lbm

☆ Impact energy (skin/stiffener)
- 80 in-lb/200 in-lb
- 1,200 in-lb/2,000 in-lb

Impact temperature
- 70°F
- 180°F

☆ Impact diameter
- 0.25 in
- 1.0 in

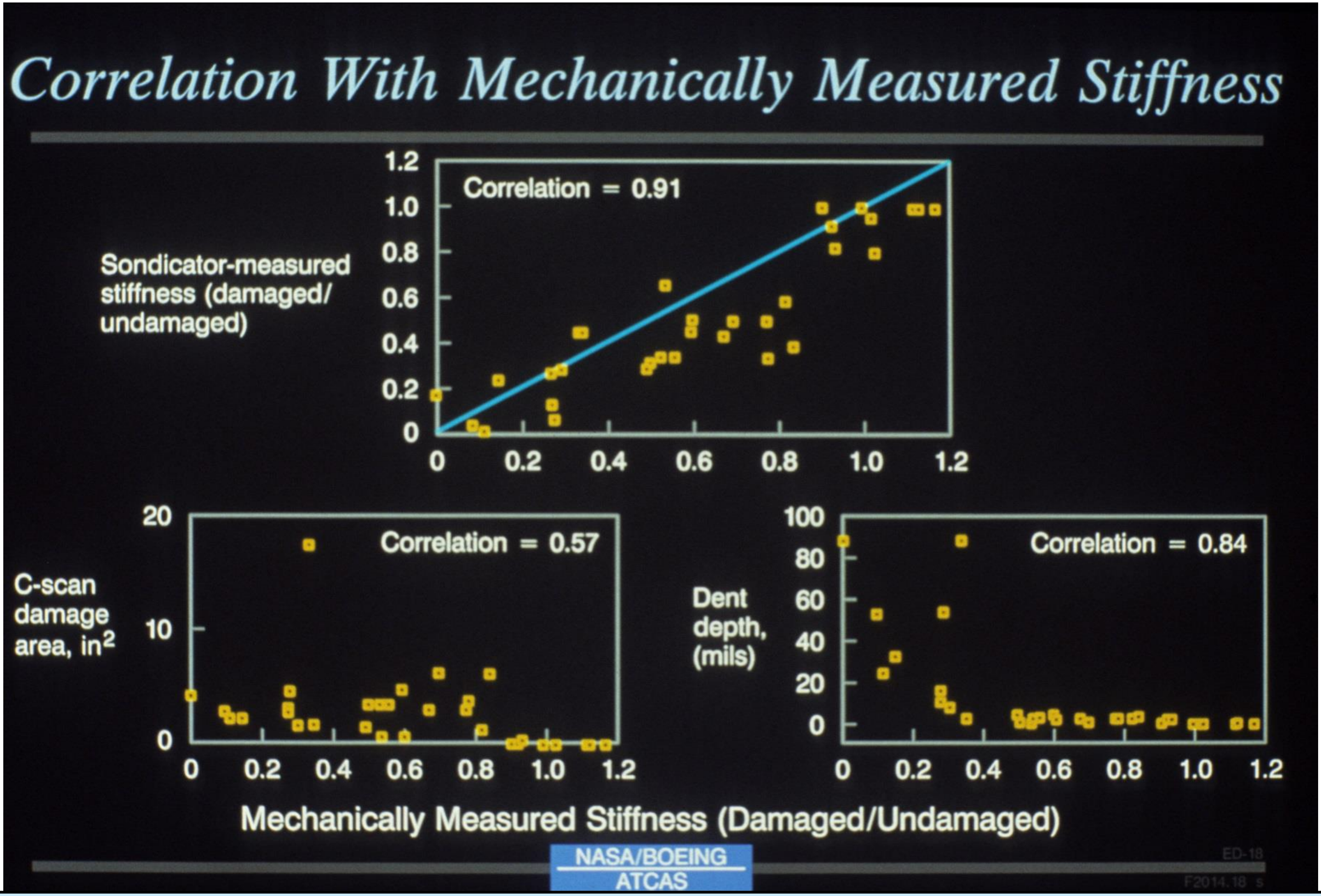
☆ Impactor tup shape
- Flat
- Spherical

Impactor stiffeness
- 0.5 Msi
- 30 Msi

☆ Factors critical to type and extent of damage, as well as its detectability. Note there were many interactions, which were as important as the main effects.

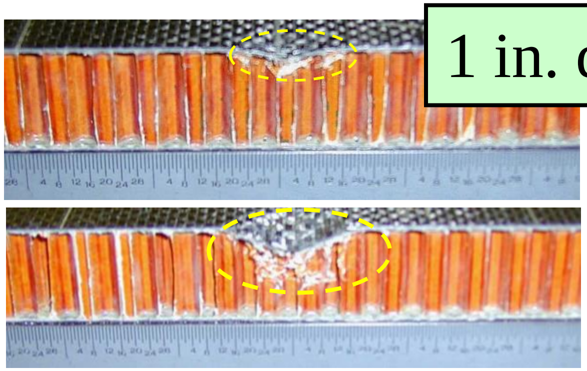
"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

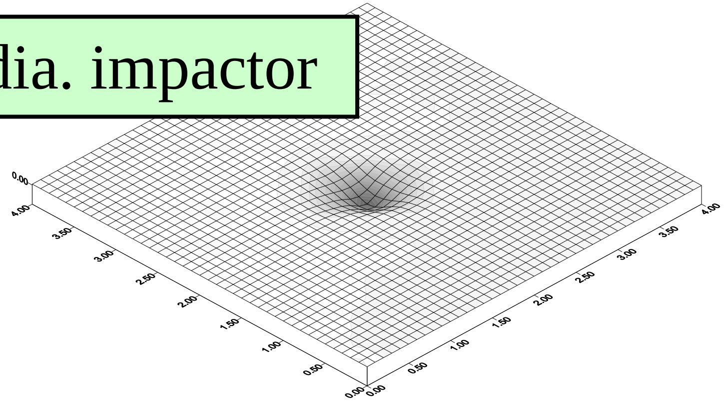
Impact Design Experiment Results



"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

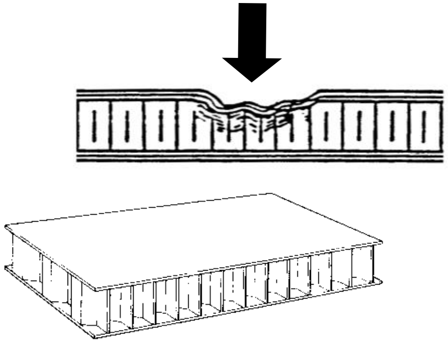
Wichita State Univ. Sandwich Impact Studies



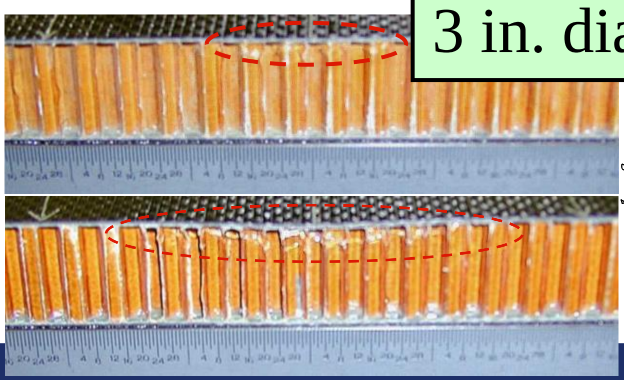


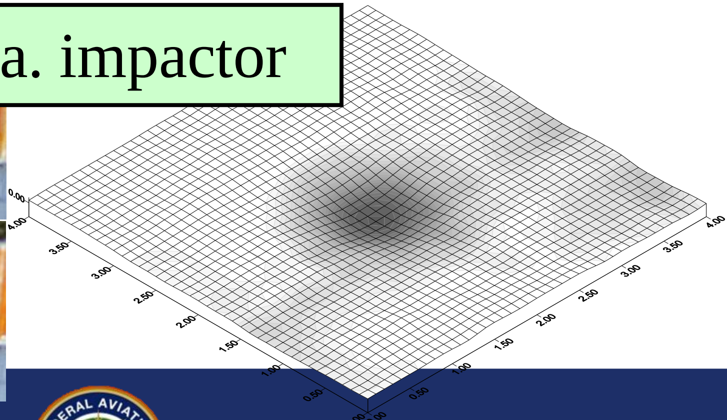
1 in. dia. impactor

Foreign-Object Impact is Complex



Some NDI may be needed to place damage shown below into Category 2

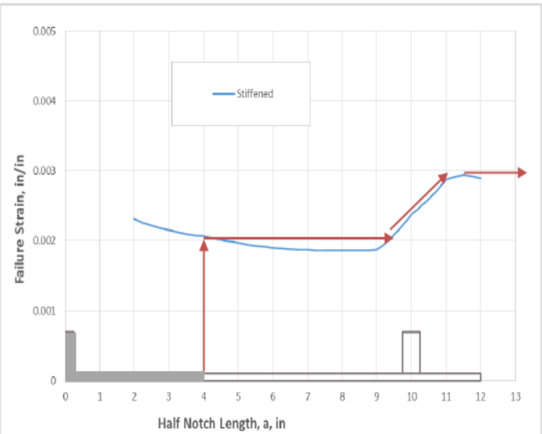


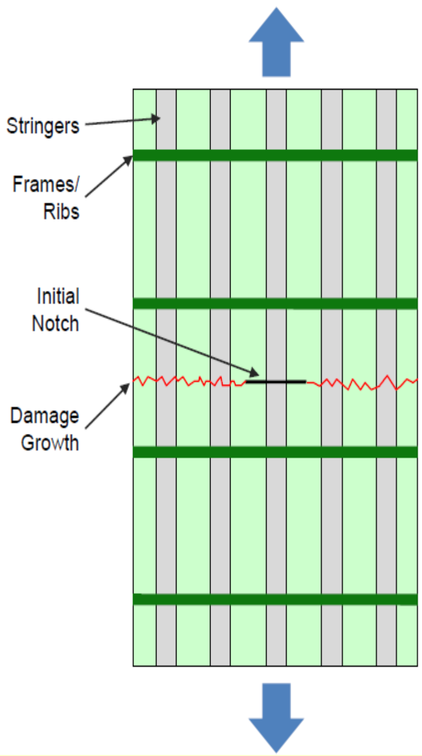


3 in. dia. impactor

Large Damage Capability/ Residual Strength Curve Shape

- General response for uniaxial loading of a notch severing a central stiffener
  - Damage growth in the skin
  - Arrest at intact stiffener
  - Failure of stiffener and/or skin/stiffener attachment
  - Unstable damage growth in the skin





Notch damage details For a large notch tensile residual strength test

The uncertainties of impactor variables versus the visual detectability of relatively small impact threats like Category 1 (e.g., BVID) and small Category 2 damage can effectively be balanced by “large damage capability” such as Category 3 damage.

Tom Walker, CMH-17, Damage Tolerance TG Mtg., SLC, UT (March, 2015)

Recommended Composite NDI Research

(towards a goal for measuring useful damage metrics)

- **Composite damage tolerance assessments should include NDI measurements to identify the most reliable and accurate methods of determining the effects of given damage states on growth and residual strength**
- **NDE to determine "weakened composite bonds" should measure local stiffness and attenuation that suggest lost load paths and reduced strength**
- **More work on the structural integrity of composites exposed to fire and locally high temperatures**
- **More work on the NDE of aged composite structures, with some focus on bonded joints and repairs, followed by destructive testing and inspection**

Recap for Damage Tolerance (Special Subjects)

- **Further consideration of service experience**
  - As discussed by Boeing (Kevin Davis presentation)
- **Thermal loads**
  - Validation of temperature distributions and thermal loads
  - Importance to metal fatigue and composite static strength
  - Practical considerations for the LOV assessment
- **Related field inspection procedures**
  - Protocol for scheduled maintenance
  - Conditional inspection for severe damage that is not clearly visible on the exterior of an aircraft
  - Improved characterization of the effects of damage on structural strength

September 17, 2015 Agenda

- **Session 7A: Smarter DT Testing**

10:45-11:00	"Smarter DT Testing - Boeing Perspectives" - Kevin Davis (Boeing)
11:00-11:15	"Smarter Testing - Airbus Approach" - J-l Leon Dufour, S. Rabois, and John van Doeselaar (Airbus)
11:15-11:30	"Smart Testing - Bombardier Thoughts" - Salamon Haravan (Bombardier)
11:30-11:45	"Smarter DT Testing - Summary" - Kevin Davis (Boeing)

- **Session 7B: Use of Probabilistic Methods**

12:30-1:30	Intro (J. van Doeselaar Airbus) 5 min Bombardier thoughts - Salamon Haravan- 10 min with Q&A Boeing thoughts - Alan Fawcett- 15 min with Q&A Airbus thoughts - Emilie Morteau; Chantal Fualdes- 15 min with Q&A WS participant experiences/closing remarks + Q&A (Airbus led) - 15 min

September 17, 2015 Agenda

- **Session 7C: Major Structural Modifications, Alterations & Repairs**

1:30-2:00	"Issues Associated with Modification and Repair of Primary Aircraft Composite Structures " - Steve Forness (Air Flight Technical)
2:00-2:30	"Examples of Substantiation Testing and Documents to Support Large Areas of Composite Repair" - John Welch, Jim Epperson (Spirit Aerosystems)

- **Near-Term Emerging Technology Recap**

2:45-3:45	"Near-Term Emerging Technology Recap" - Led by Boeing (TBD), Airbus (TBD), Bombardier (TBD) and Cindy Ashforth (FAA)

Session 7 Recaps

- **Session 7A: Smarter Damage Tolerance Testing**

- **Session 7B: Use of Probabilistic Methods**

- **Session 7C: Major Structural Modifications, Alterations and Repairs**