Damage Tolerance and the Composite Airframe

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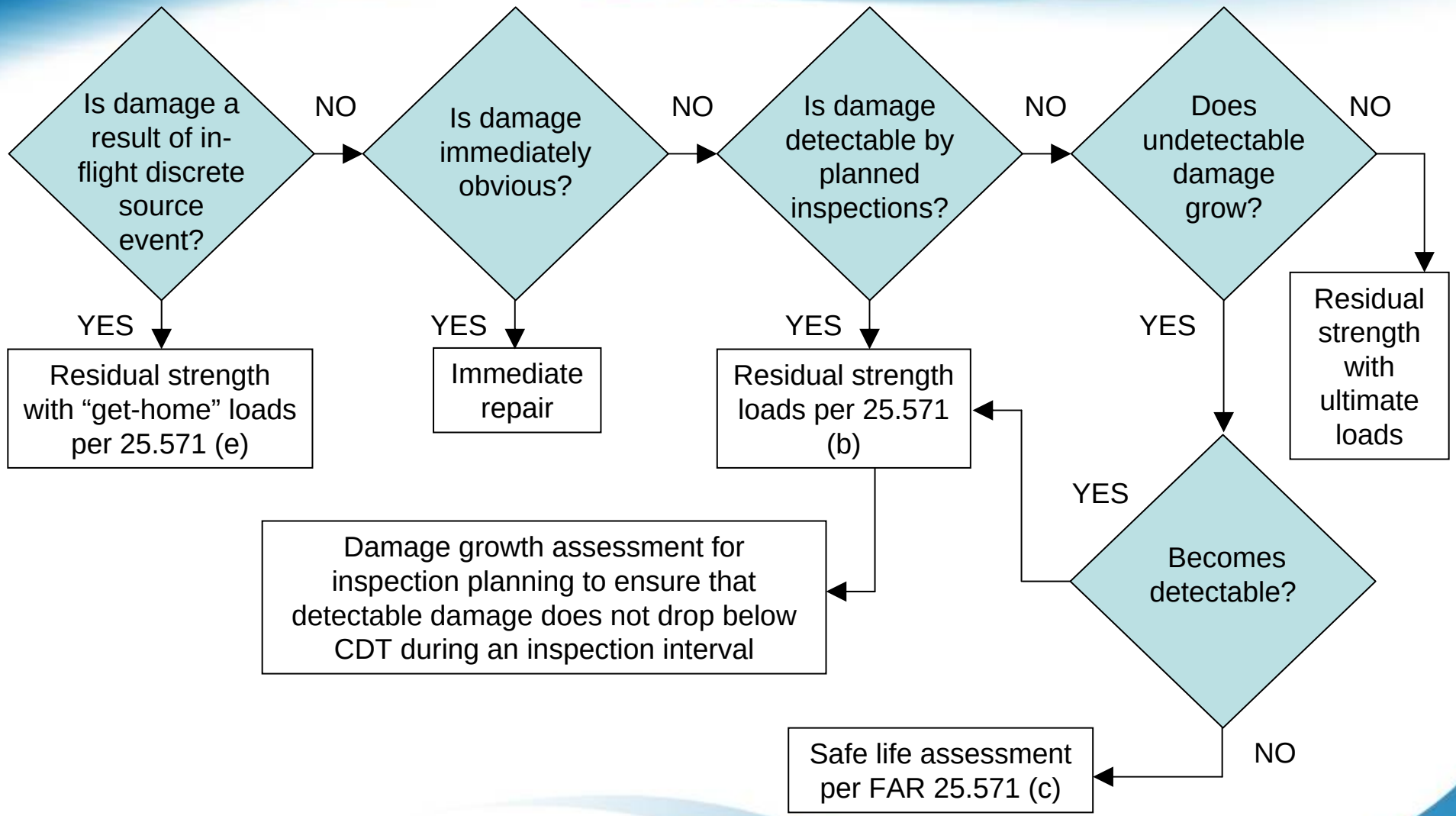
Outline

- **Deriving Composite Primary Structure Design Requirements and Criteria**
- **Testing in the Support of Damage Tolerance**
- **Service History and the Effect on Damage Tolerance Criteria**
- **Proper Maintenance Reporting in the Field**

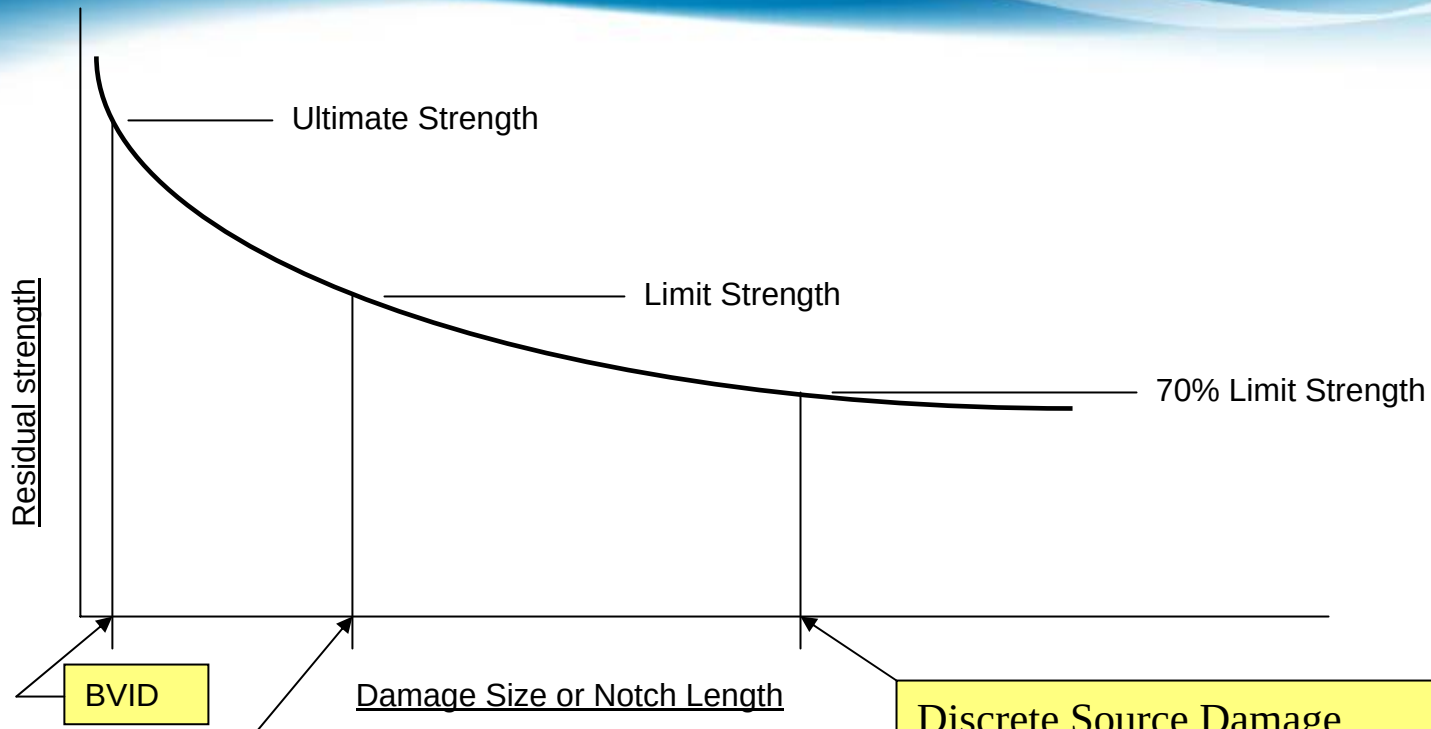
Levels of Damage Tolerance Assessment



Basic Requirements
Interpreting the FARs for CFRP Structure

- **Ultimate Load - AC20.107a**
  - Small Damages, Damage not Expected to be found
  - AC20-107a covers “no detrimental damage growth philosophy”
- **Limit Load - 25.571b**
  - Visible Damage
  - Disbonded Stringer Between Arrestment Features
  - Disbonded Facesheet Between Arrestment Features
  - Fail Safety
- **Continued Safe Flight and Landing – 25.571e & AC25.571C**
  - Unknown Source - Large Damage Applicable to all PSEs
  - Rotating Machinery
  - Bird, Hail and Tire Strike

Residual Strength Curve



Detectable Damage ~ Failed, or severely damaged, frame or stiffener with associated damage to attached skin or web (or) Failed, or severely damaged, skin panel or web with associated damage to attached stringers, stiffeners, frame or rib. Ref. FAR 25.571 (b)

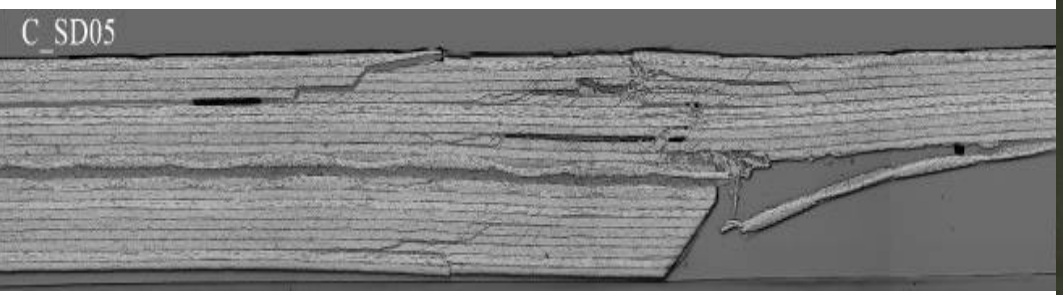
Discrete Source Damage

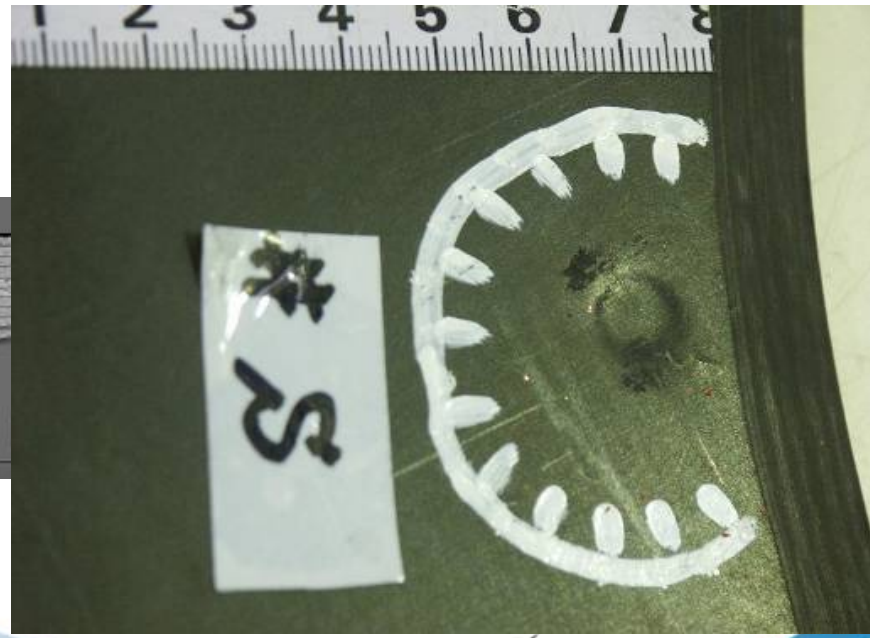
~ Failed or completely severed frame, stiffener, or chord with failed or completely severed attached skin or web. Ref. AC 25.571-1C (8c)

Residual Strength vs Damage Size or Notch Length

Understand Small Damages

- **Understand what small damages, sometimes known as BVID, can do to the structure as related to:**
  - **Ultimate Load**
  - **No Detrimental Damage Growth**
  - **Satisfying AC 20-107a**





Barely Visible Impact Damage Defined

- **BVID**

Small damages which may not be found during heavy maintenance general visual inspections using typical lighting conditions from a distance of five (5) feet

  - **Typical dent depth – 0.01 to 0.02 inches (OML)**
  - **Dent depth relaxation must be accounted for**

Wing Panel Residual Strength Test

With BVID

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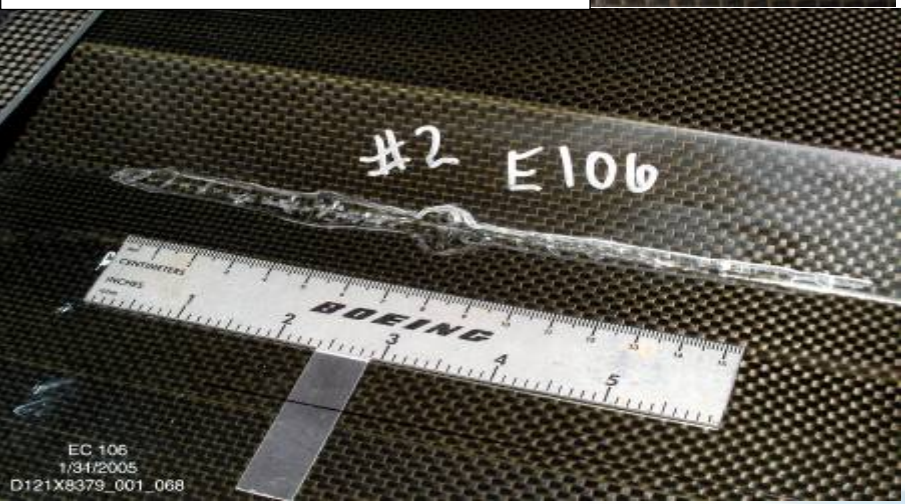
Light Skin Stringer - BVID Impacts

Stringer Cap Impact

Stringer Web Heel Impact



PANEL #

EC106

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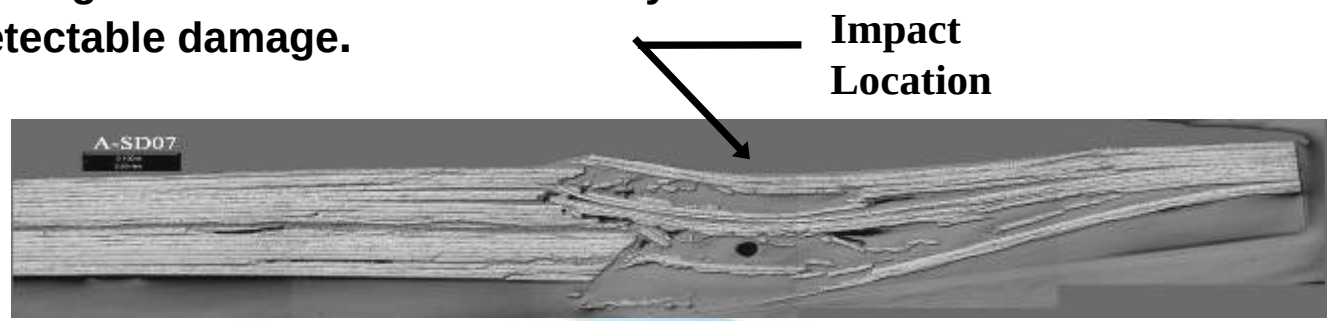
Criteria Requirements for Visible Damage

- **Airframe must support design limit loads without failure.**

- **No detrimental damage growth during fatigue cycling representative of the structure's inspection interval.**
  - **One missed inspection is assumed (two interval requirement)**
  - **Validated by testing**

- **Airframe must be able to support residual strength loads until the damage is found and repaired.**
  - **Damage state contains both visibly detectable and associated non-visibly detectable damage.**



Wing Skin Visible Impact Damage

OML Impact, 1” Diameter impactor

Impact Energy: Greater than 8000 in-lbs

Residual Limit Load

No Growth for a missed inspection interval

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Fuselage Skin Visible Impact Damage

PANEL
EC-164
FATIGUE
CYCLING
4/27/05

Residual Limit Load
No Growth for a missed inspection interval

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Criteria Requirements for Disbonded Discrete Elements

- **Check is for a disbonded stringer or facesheet**
- **Airframe must support design limit loads and residual strength flutter requirements without failure.**
- **No detrimental damage growth during fatigue cycling representative of the structure's inspection interval.**
  - **One missed inspection is assumed (two interval requirement)**
  - **Validated by testing**
- **Airframe must be able to support residual strength loads until the damage is found and repaired.**

Criteria Requirements for Discrete Source Damage

- **This check is for threats from Unknown Damage Sources, Rotating Machinery, Bird, Tire and In-Flight Hail**
- **Airframe must support continued safe flight loads and residual strength flutter requirements without failure.**
- **No repeat cycle loading required**

Criteria Requirements for Unknown Source Discrete Source Damage

- The airframe shall be capable of completing a flight during which complete failure of a structural segment, such as a frame or stiffener, with associated skin or web, occurs due to an undefined source.
- Analysis, supported by component tests, shall demonstrate required residual strength loads (“get home loads”) without failure.
- Typical basis, appropriate environmental residual strength allowables or design values.

Compression Panel – Unknown Damage Source

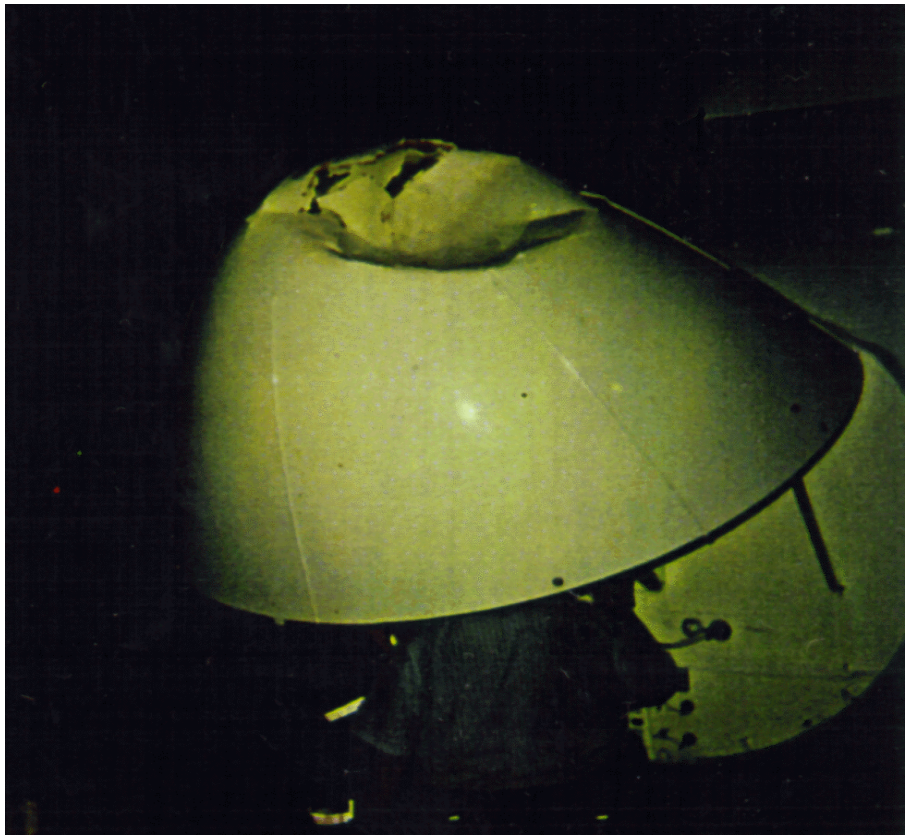
Criteria Requirements for Treats from Bird, Tire & In-Flight Hail

- **Bird**
- Continued safe flight and landing following impact of a 4 lb bird; 8 lb for empennage
- Bird impact tests on test articles or components representative of A/C design.

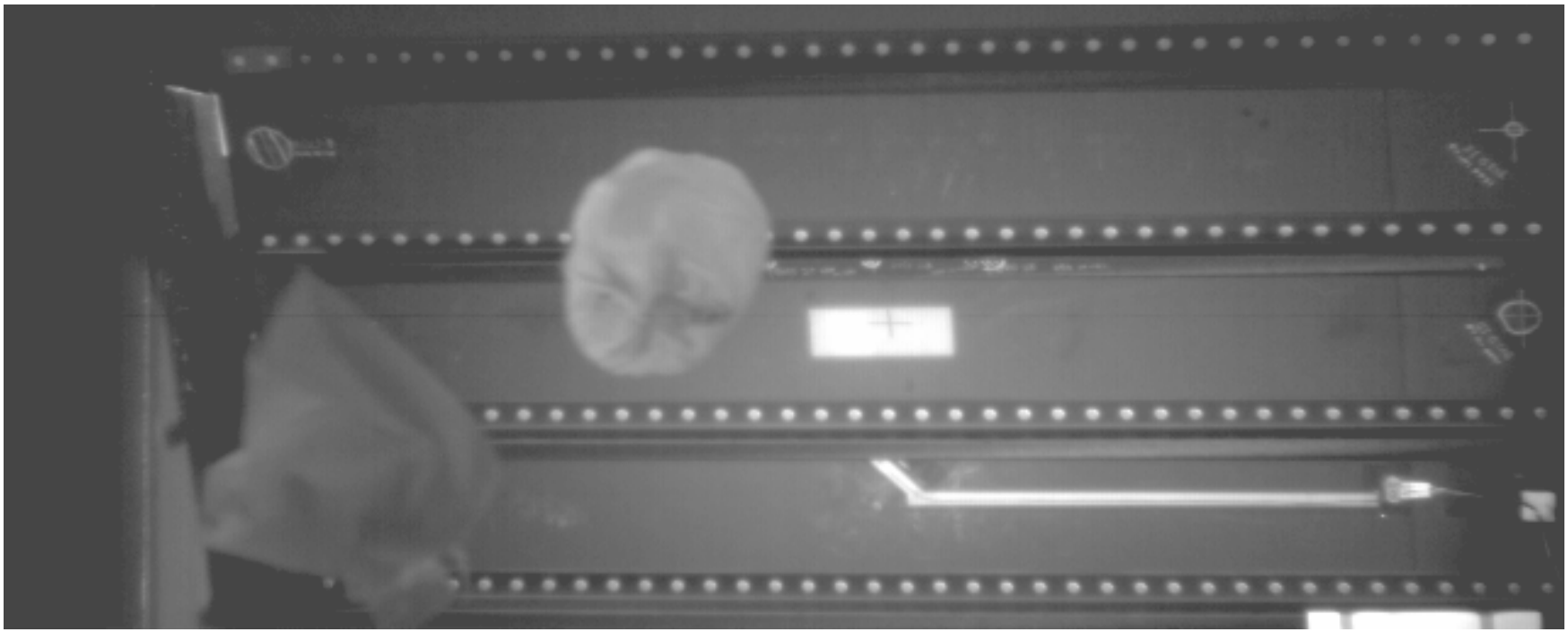
- **Tire**
- No single tire / wheel threat may prevent continued safe flight and landing.
- No single tire / wheel threat may cause leakage of hazardous fuel quantities.
- Analyses supported by test evidence

- **In-Flight Hail**
- Large dia hail @ cruise for continued safe flight and landing.
- For typical dia hail @ cruise: no moisture intrusion, maintain ultimate strength for full DSO, include effects of environments.
- Applies to all airframe primary structure with exposed frontal area in level flight
- Tests representative of A/C design details of surface panels and supporting structure.

Bird Strike



Simulated Bird Gel-Pack Impact Video



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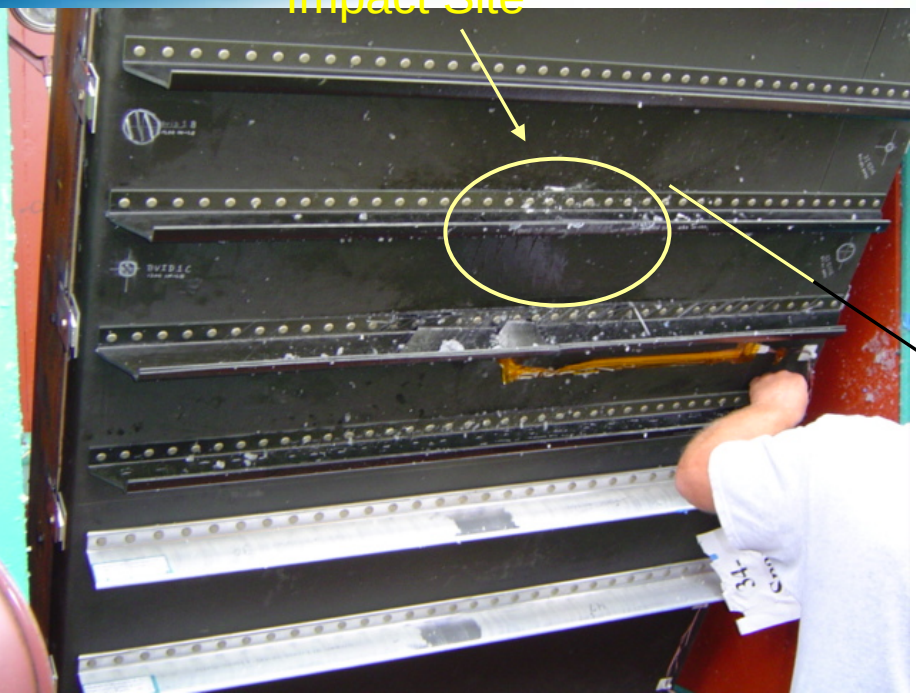
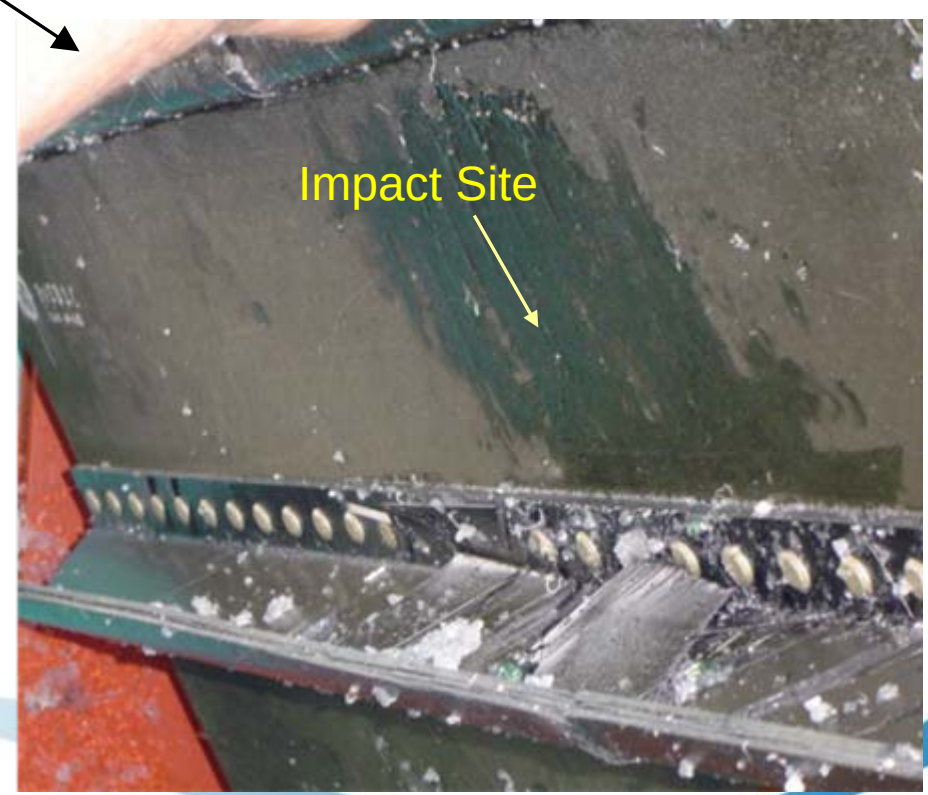
Damage from 4# Gel Pack Impact



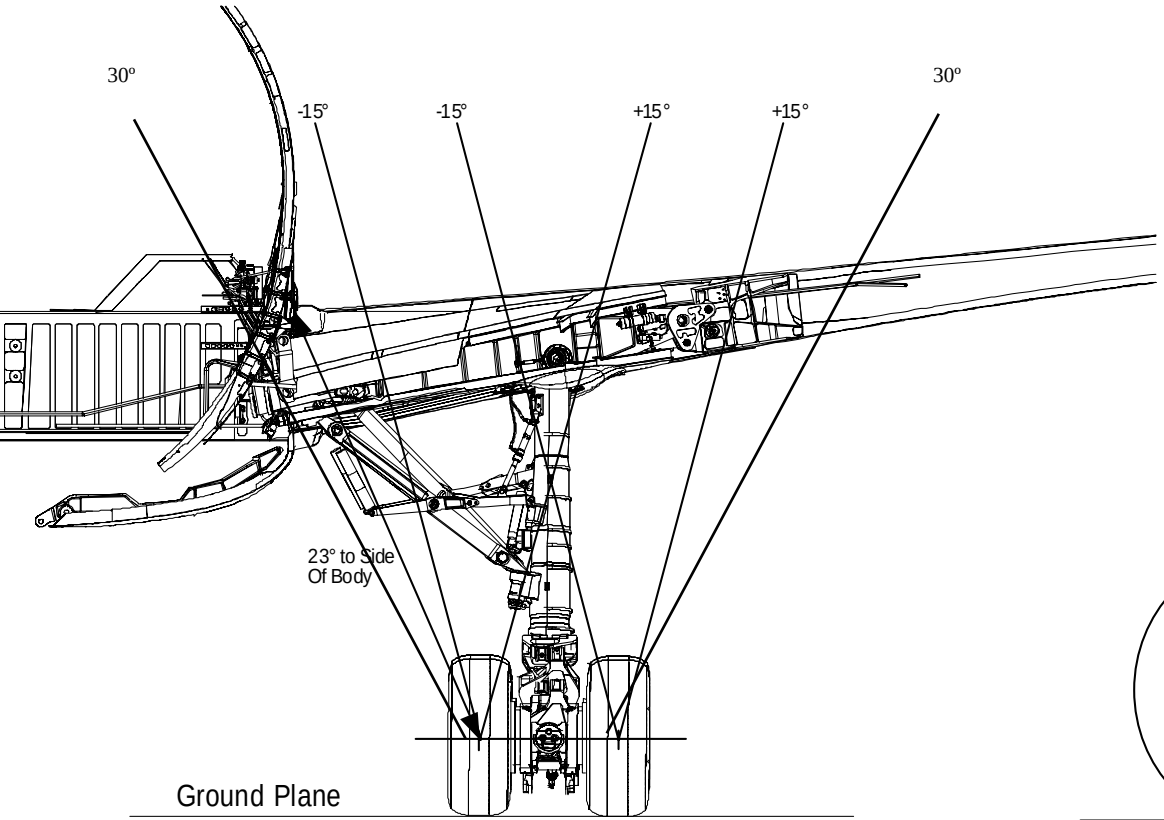
- Stiffener damage at impact sites

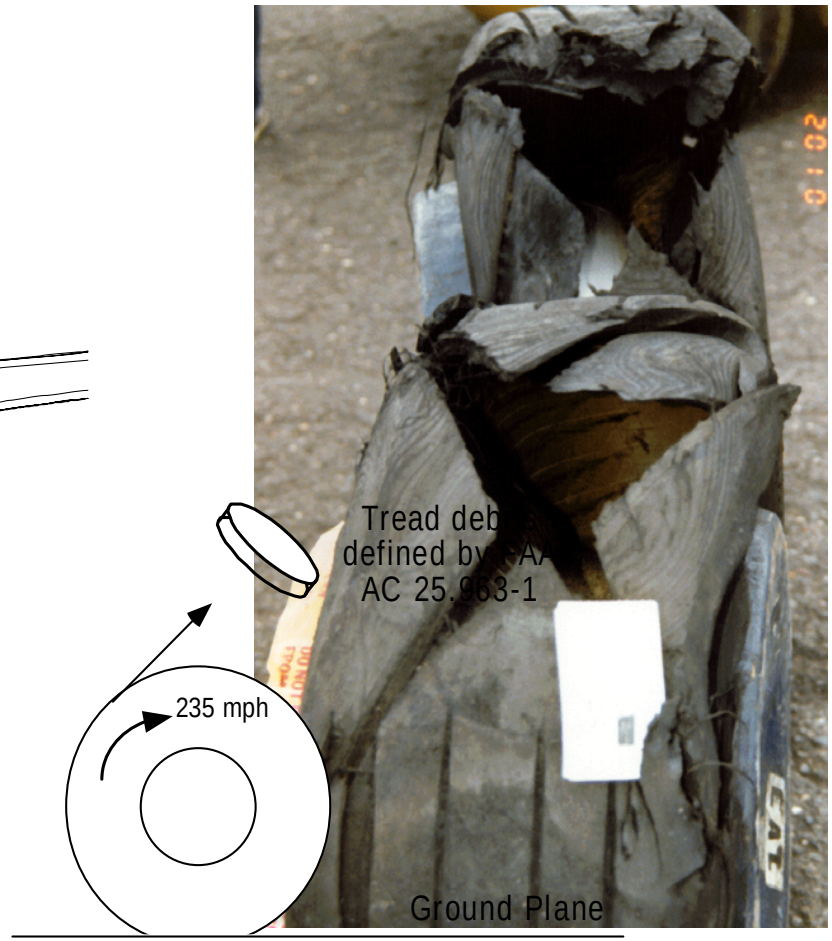


NO spar web damage

Tire Impacts

- **Runway Debris**





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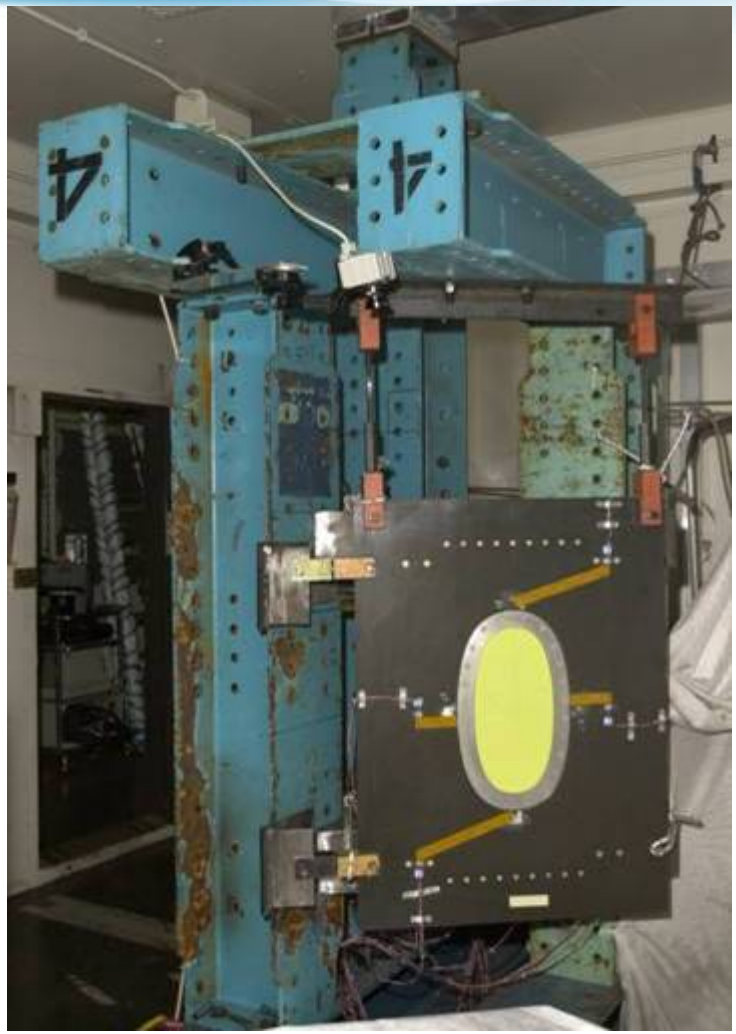
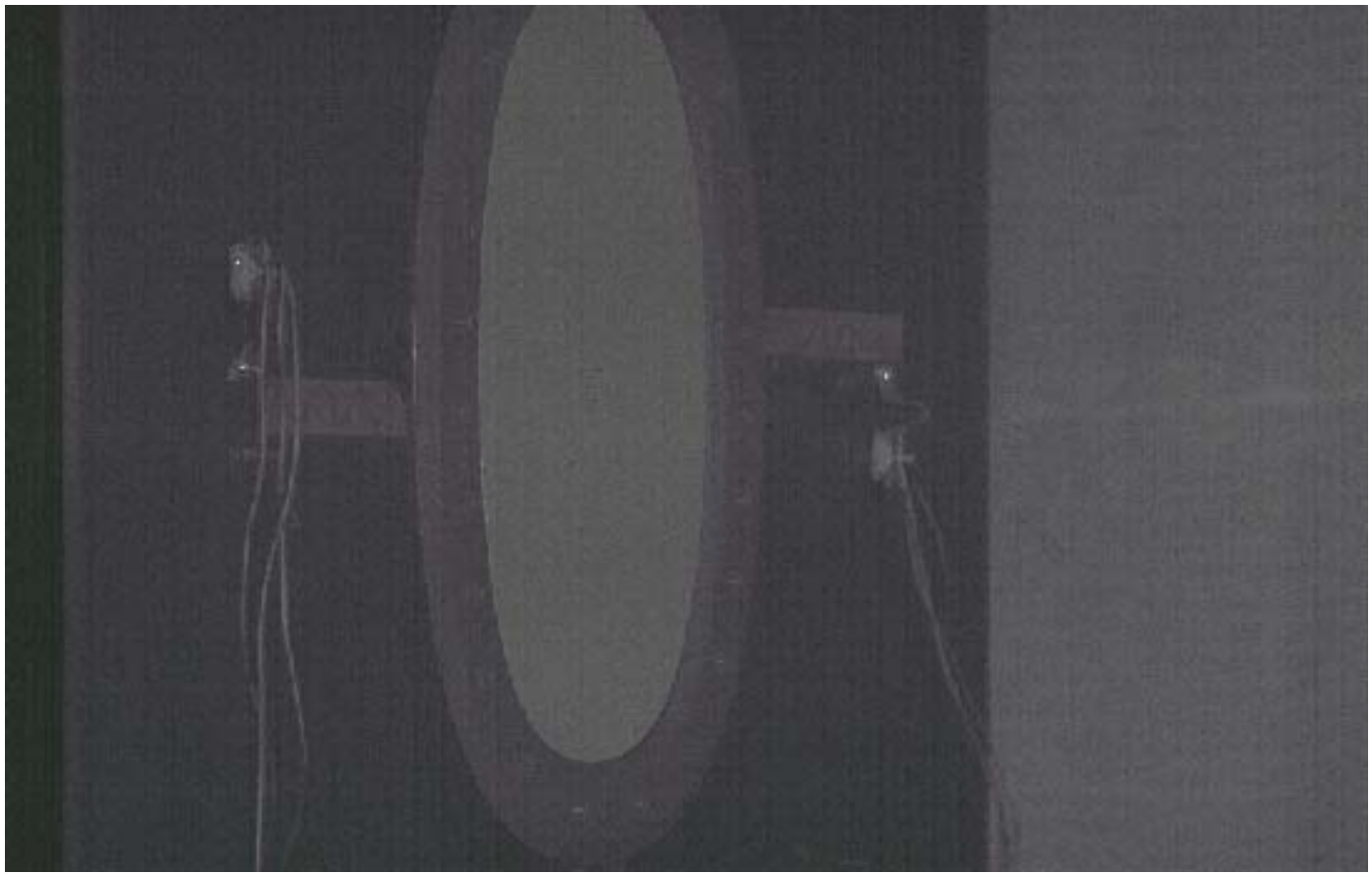
Tire Impact Test Setup



Tire Fragment Impact Test



Criteria Requirements for Threats from Rotating Machinery

- The airplane should be able to complete a flight during which damage occurs due to uncontained:
  - Fan blade impact or engine failure.
  - Failure of rotating machinery

- Analyses, supported by large component testing, shall demonstrate ability to predict containment of dynamically imposed penetration damage to the pressurized fuselage, and will be used to show compliance with residual static strength requirements for design.

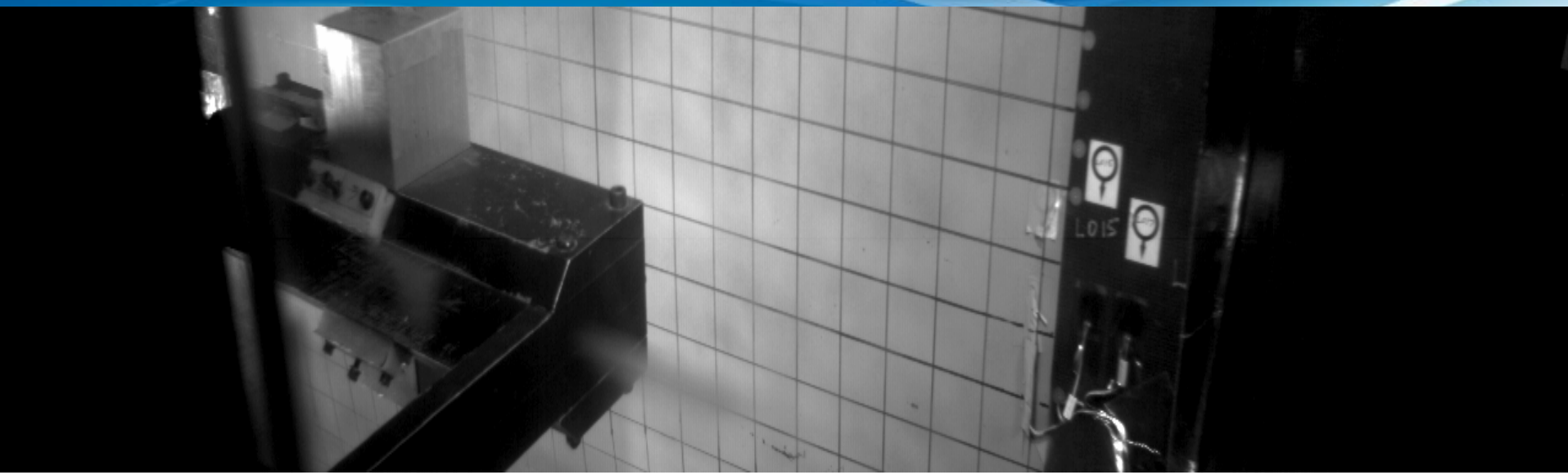
- Within the zones the airframe is subject to damage from these events, required residual strength loads are considered as part of aircraft level failure analyses that produce an aircraft probability of loss equal to, or less than, 1 in 20.

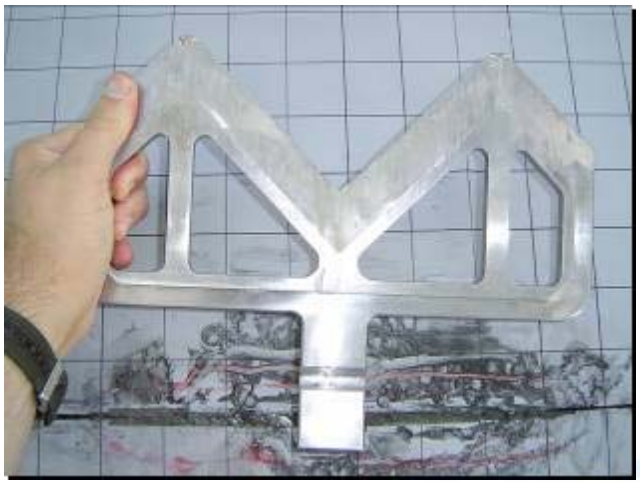
- Use typical basis strength accounting for appropriate environmental effects.

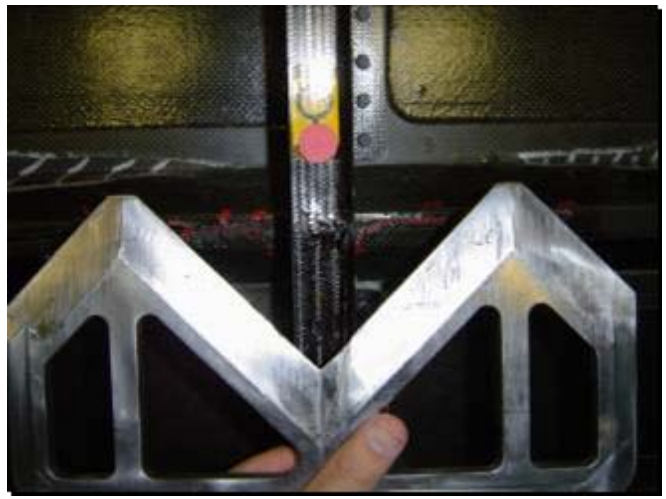
Rotorburst

Blade Impact

Large Damage Arrestment







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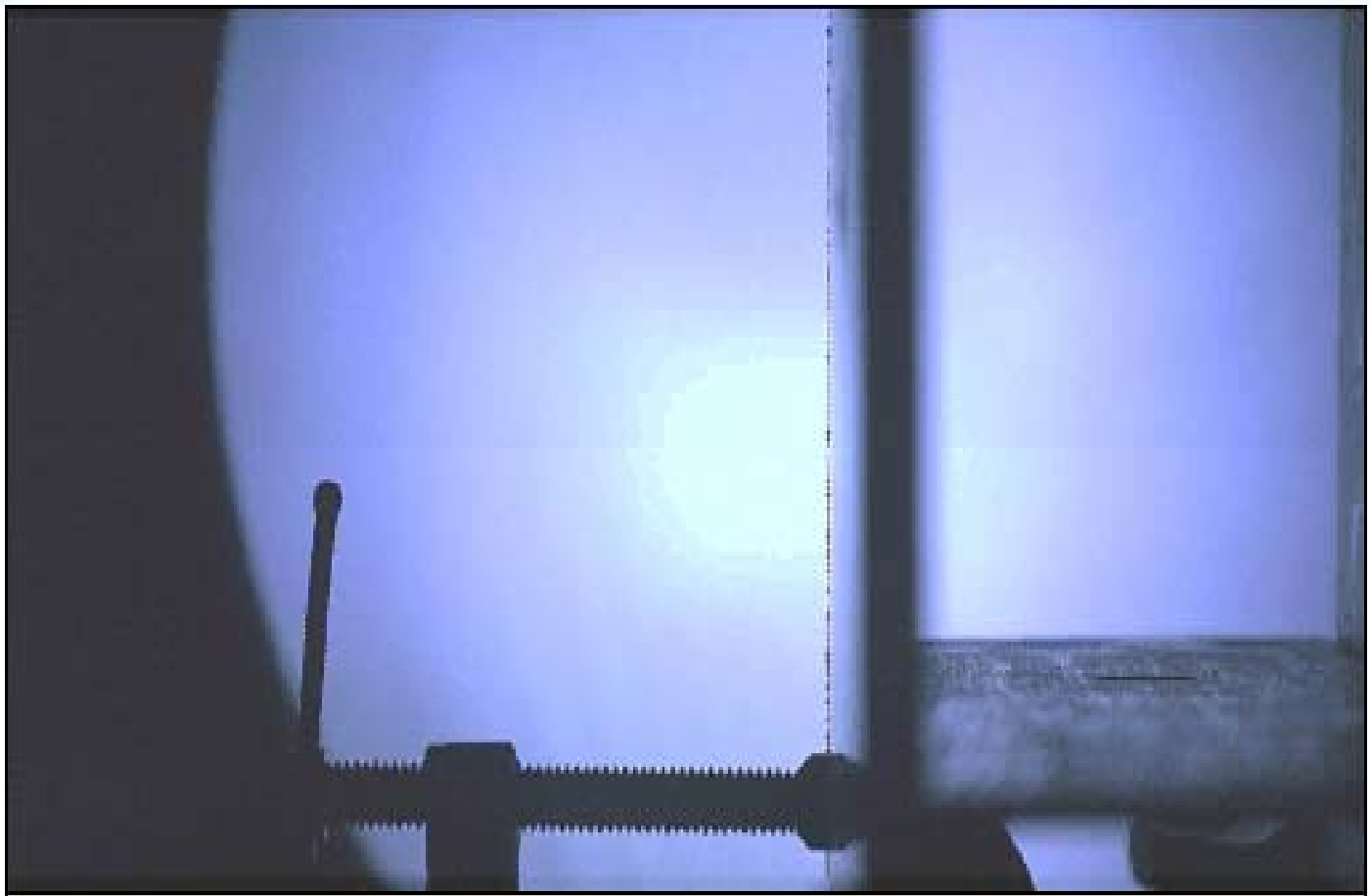
Engine Debris

Engine Debris Testing

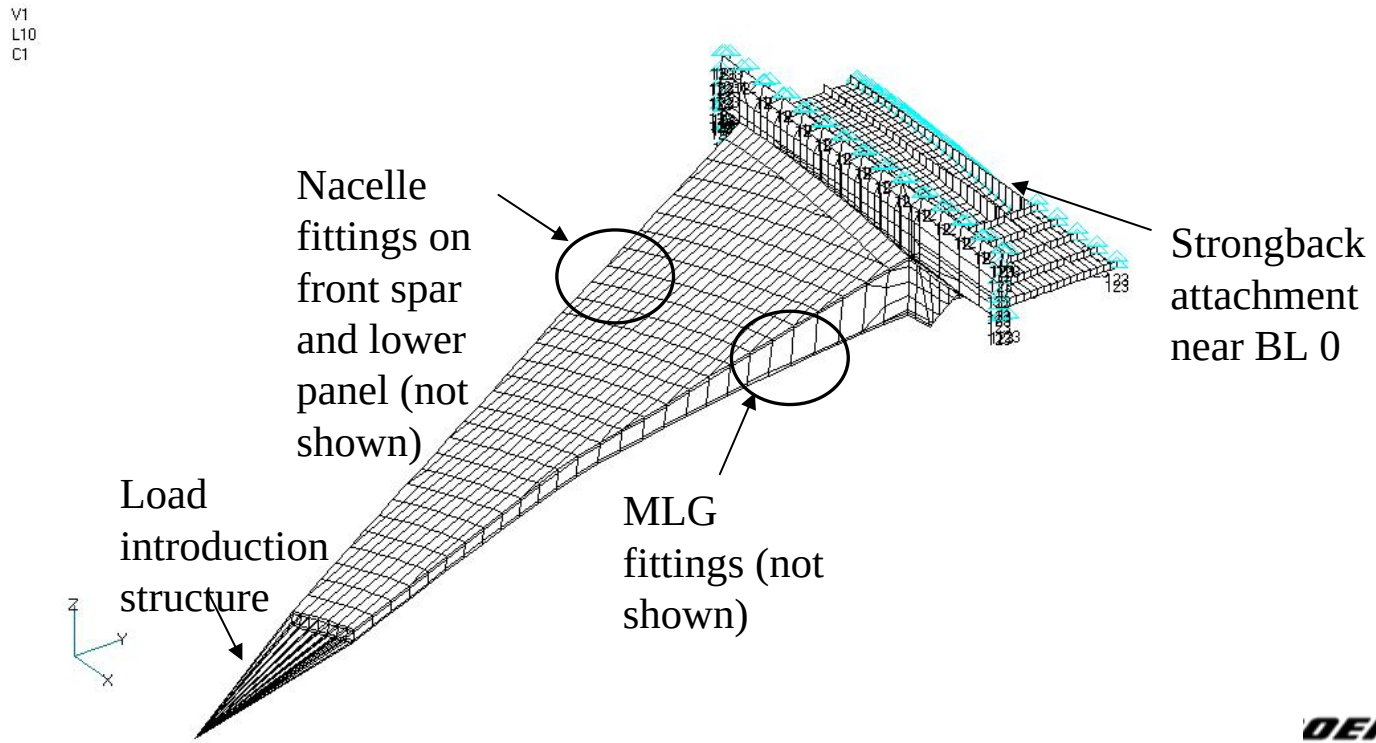


In-Flight Hail

Criteria Realized Through Pre-Production Testing

Wing Structural Development Test Plans

- Pre-production Wing Test Box
  - Major component level testing to provide validation of the analysis tools for certification credit and risk reduction.
  - Testing will validate finite element models, and provide certification data for wing box fatigue (no growth with LEF), damage tolerance (VID and large cuts) and static strength (after repair) certification.



Pre-Production Test Article

Lower Panel in Trim

Wing Box Assembly

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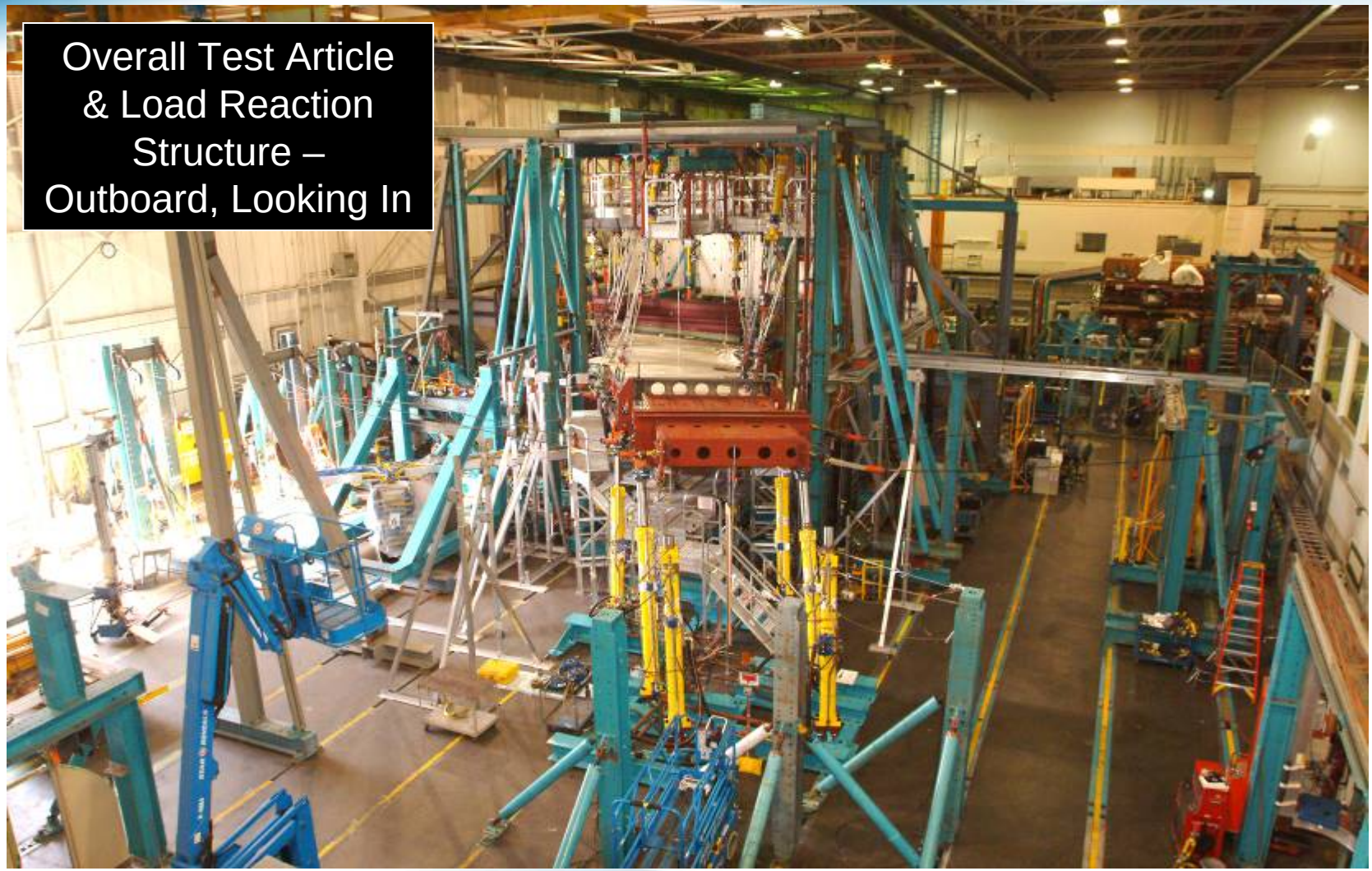
Pre-Production Wing Testing



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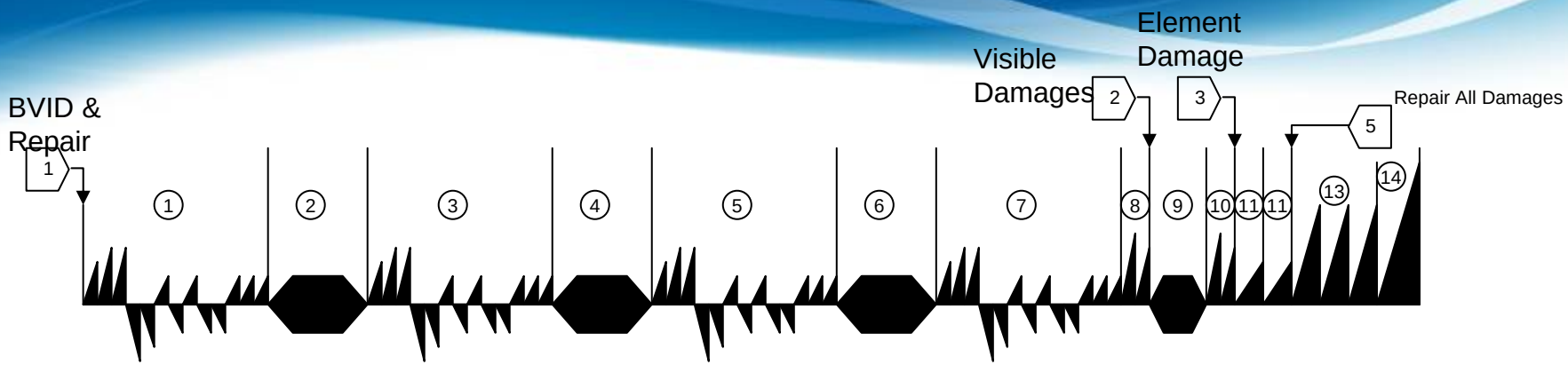
Preproduction Components
Typical Test Load Sequence



1 **Apply BVIDs**

1) Initial Strain Survey
2) Fatigue Spectrum – 1 DSO including Load Enhancement Factor
3) Strain Survey
4) Fatigue Spectrum – 1 DSO including Load Enhancement Factor
5) Strain Survey
6) Fatigue Spectrum – 1 DSO including Load Enhancement Factor
7) Strain Survey
8) Design Limit Load Verification, Multiple Conditions

2 **Apply Visible Impact Damages**

9) Fatigue Spectrum, Two Inspection Intervals – including Load Enhancement Factor
10) Fail Safe (Limit) Loads

3 **Apply Element Damages**

11) Continued Safe Flight, 70% DLL

5 **Repair Element Damages and Visible Damages**

13) Design Ultimate Load Validation
14) Destruction Test

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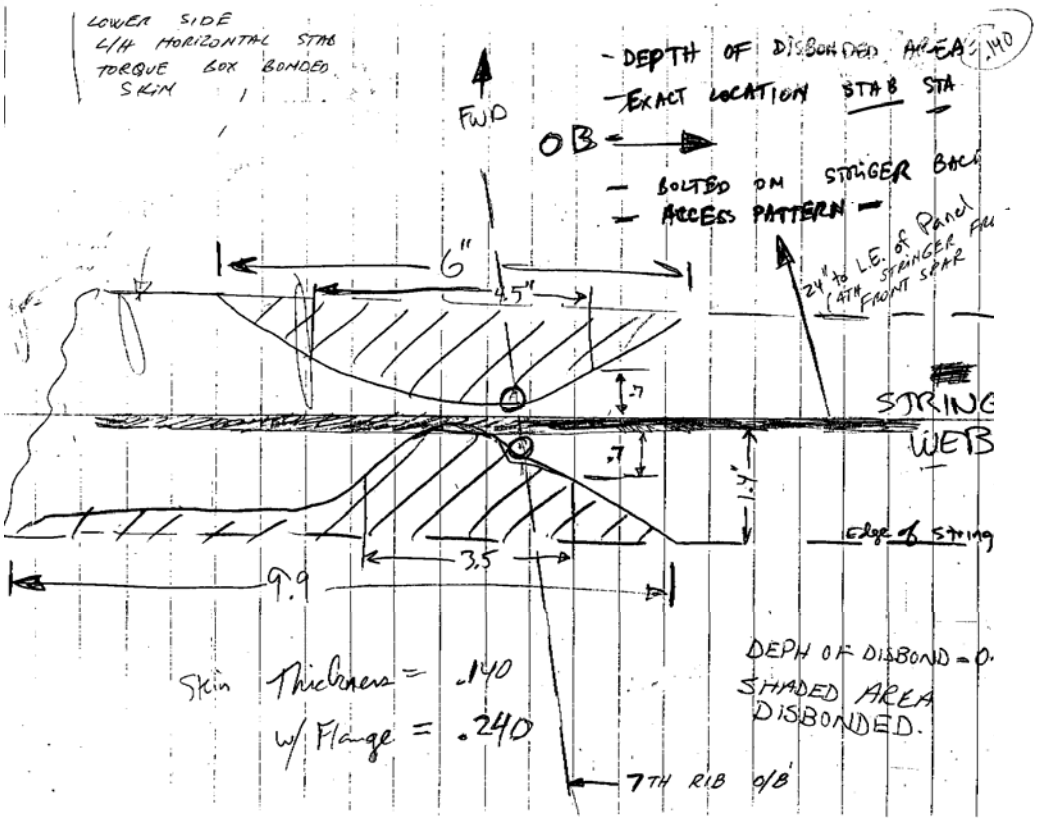
Service History
777 In-Service Experience-CFRP Empennage

- **Some reported service-induced damage incidents associated with the main torque boxes**
  - **FOD damage due to engine run-up**
    - **Area of skin/stringer disbond repaired with blind fasteners**
  - **Hailstorm damage**
    - **No damage to main torque box structure**
  - **Damage due to impact with maintenance stand**
    - **Damage to front spar, main torque box skins, aux spar and leading edges**
    - **Bolted titanium sheet metal repair on front spar, skin, other parts replaced**
  - **Damage due to impact with service truck**
    - **Damage to front spar and main torque box skin**
    - **Bolted titanium sheet metal repair on front spar and skin**
  - **Runway debris**
    - **Damage to main torque box skin and rib**
    - **Bolted titanium sheet metal repair on skin and rib shear tie**

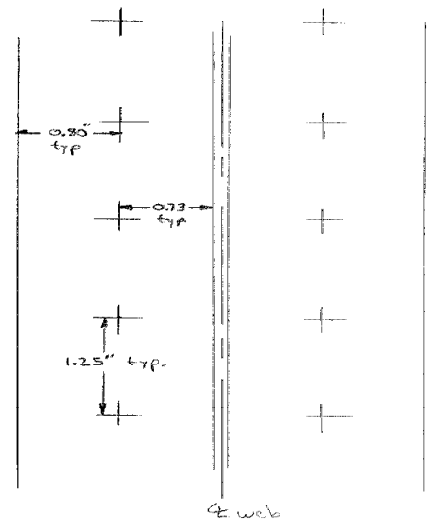
777 In-Service Experience-Details

Empennage Stringer Disbond - Engine Thrown Debris



AOG Damage Description

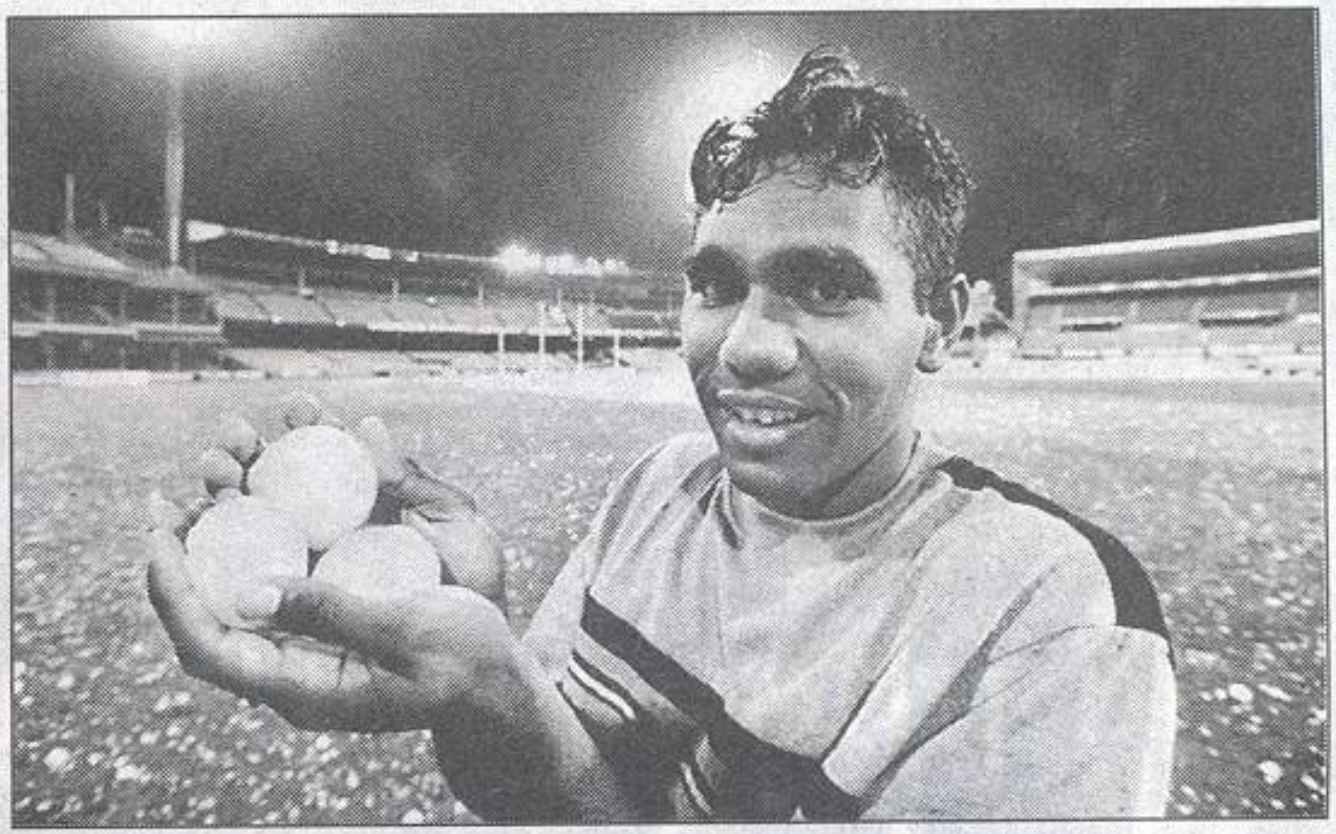
Straight-forward, effective repair



¼" dia fasteners
Extend fastener pattern 4" (approx 3 fast.) beyond any disbonded area

777 In-Service Experience
Sydney Hailstorm

Downed . . . a seagull, above, injured by hailstones at Bondi. Below, Fred Campbell shows why the Swans' SCG training was doomed.



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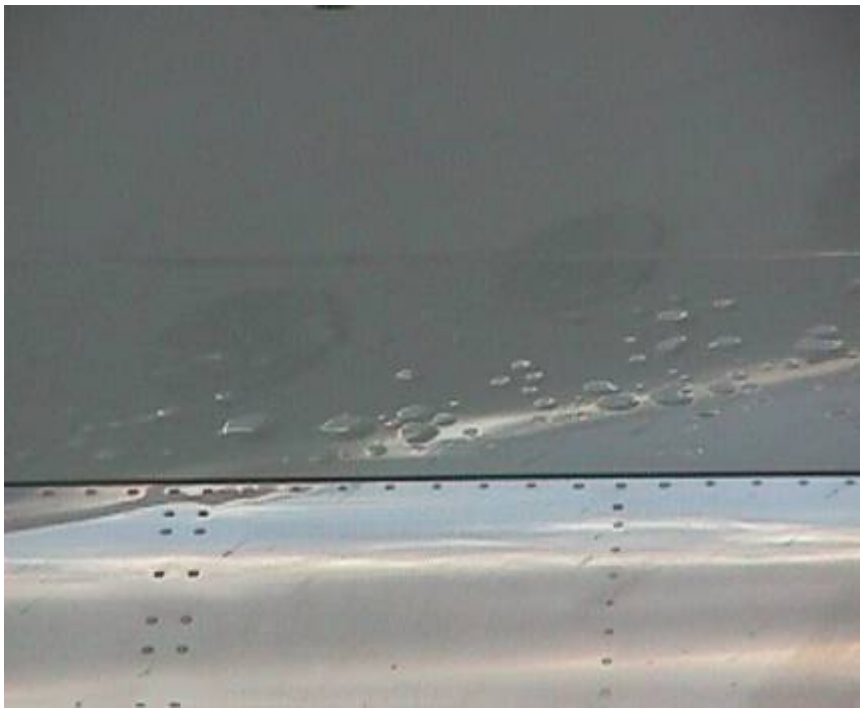
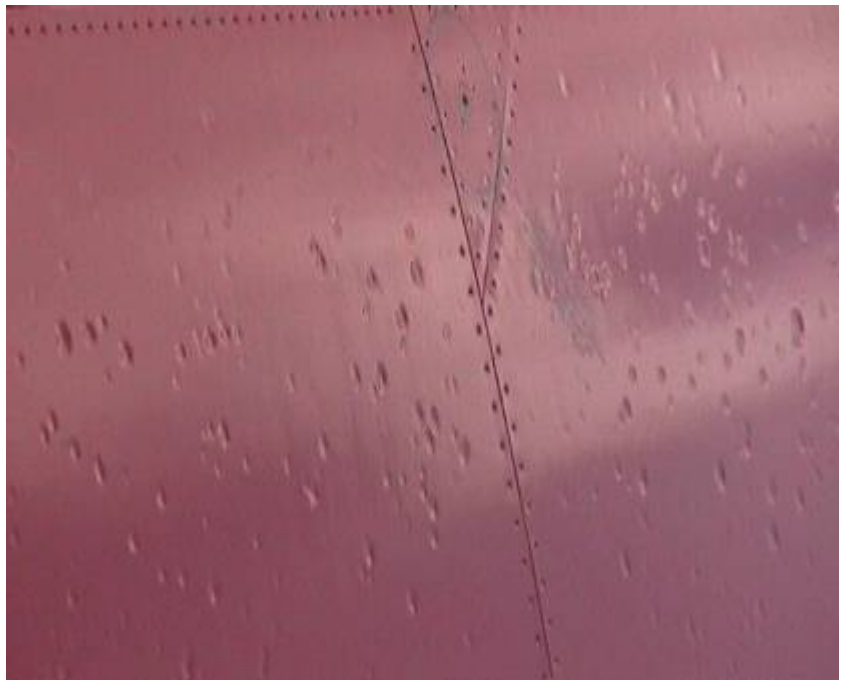
777 In-Service Experience
Sydney Hailstorm

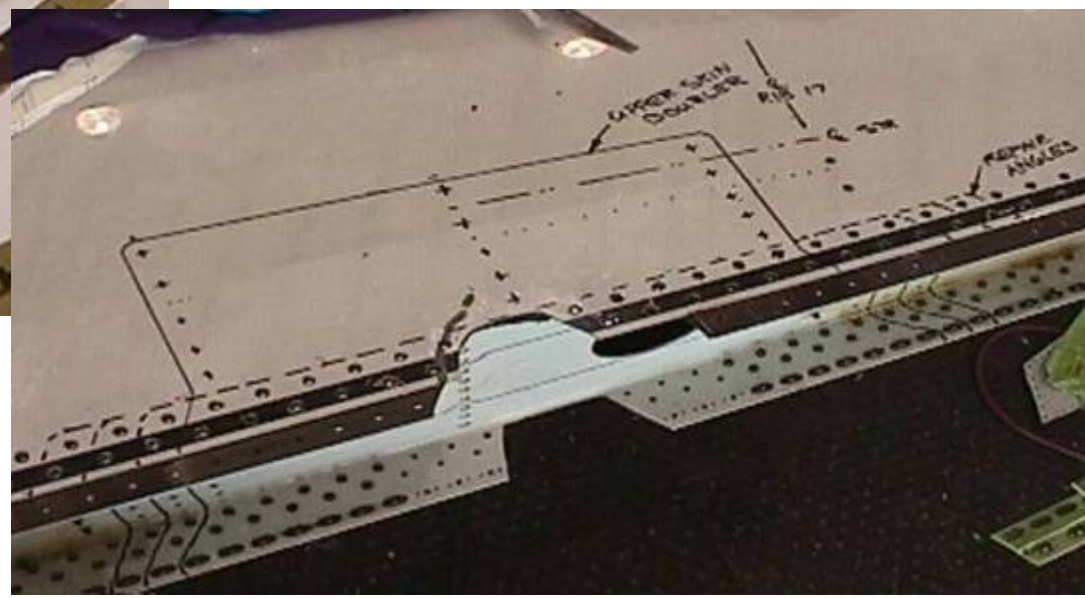
2.5” to 3.0” hail dented the fixed 5 ply honeycomb structure shown here but did no damage to the CFRP main torque box





777 In-Service Experience-Details

Skin/Spar Damage—Ground Handling Equipment Impact



Conventional Bolted Repair

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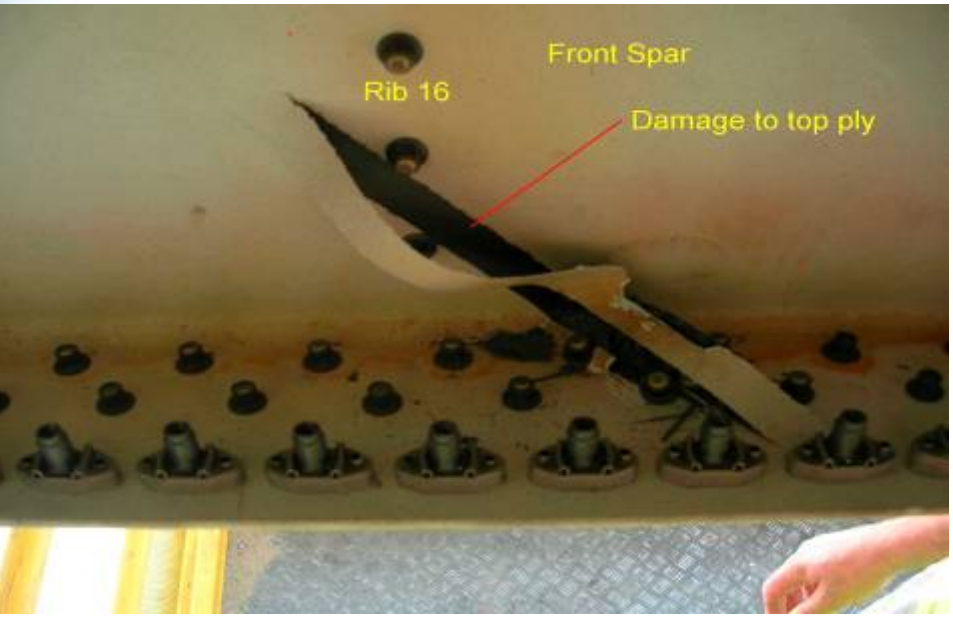
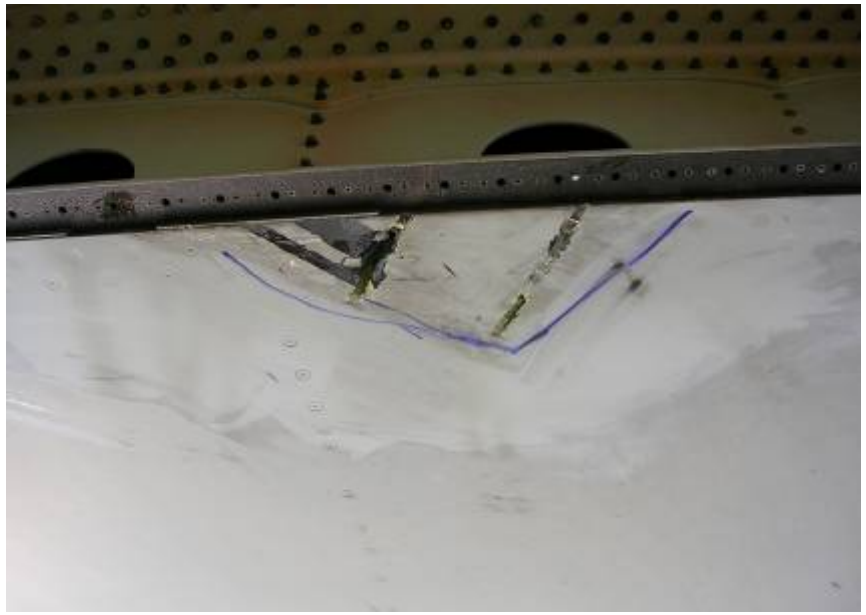
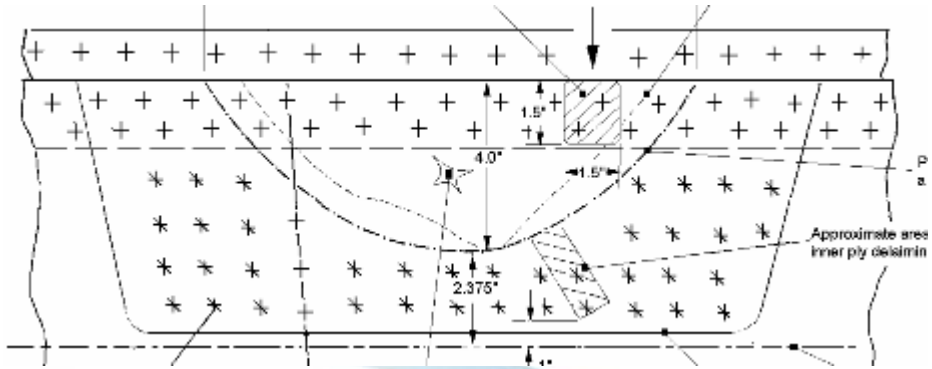
- **Ground Equipment Impact**







777 In-Service Experience-Details

- **Runway Debris**

Proper Maintenance Reporting in the Field

- **Accidental events happen and the aircraft design must account for these.**
- **CFRP structure needs to designed robust to account for those events which are not known at the time of design.**
- **Most high energy damage events are easily seen and reported but some high energy but low speed blunt events may require reporting at the time of incidence.**
- **Training for ground handling personnel working around composite and aluminum airframes is an important part of damage detection.**