# "Managing Damage Threats for Composite Structures: Unifying Durability and Damage Tolerance Perspective"

John Halpin (JCH Consultants) and
Hyonny Kim (UCSD)

- Damage Threat Assessment
  - –Technical & Policy AC20-107B
  - –Blunt Impact and Hidden Damage

June 4, 2009. FAA/EASA Meeting. JAL Headquarters, Tokyo

# AC20-107B(draft):

## 7. Proof of Structure-Static. and

## 8. Proof of Structure - Fatigue and Damage Tolerance.

- “--- When establishing details for the damage tolerance and fatigue attention shall be given to a through damage threat assessment, geometry, inspectability, good design, good design practice, and the types of damage/degradation of the structure under consideration. “ page 11
- a. Damage Tolerance Evaluation. Pages 12 & 13

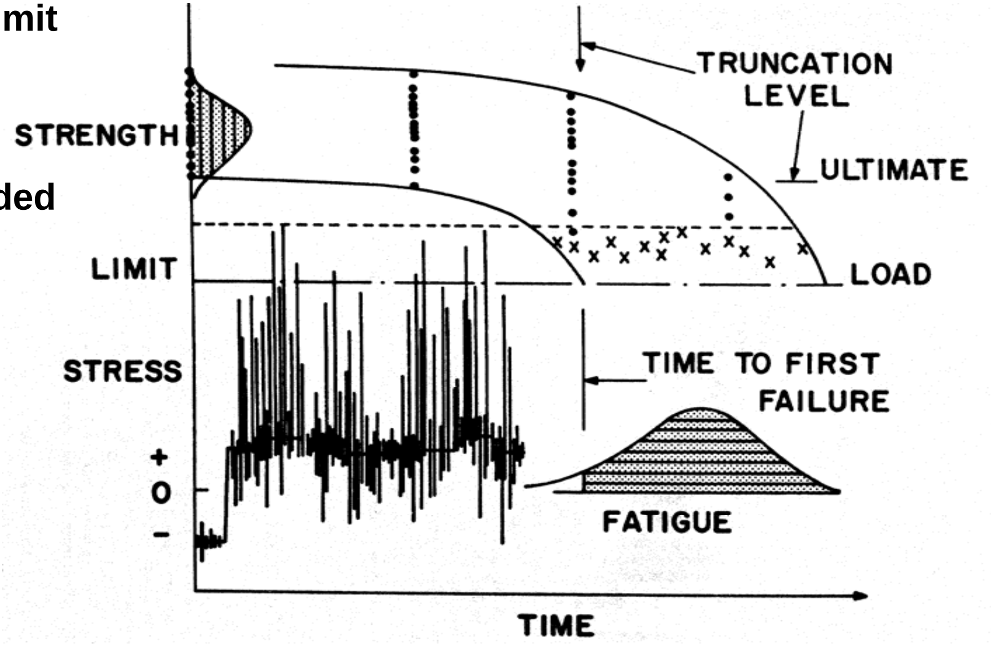
(1) A damage threat assessment must be performed

- (a) -- few industrial standards --
- (b) Foreign object damage ---
- (c) Damage classification ----

# The Rational for the Use of the B Basis Allowable

(Why can't we design to the mean, vs...... we need an A allowable. )

- Early 1970 concern;
  - Fighter load exceedances above limit load
  - Composite material scatter grater than metallics.
- Today's definitions of limit load included this aggressive usage
- Typical fighter load spectrum have a Weibull shape parameters $\alpha_P \sim 6$
  - (UL 1000 less likely LL)
  - Probability of exceeding UL of 0.001
- Typical Weibull material shape parameters;
  - $\alpha_R \sim 25$ Aluminum (5% COV)
  - $\alpha_R \sim 20$ Graphite High Strain Fiber composites (6.2% COV)
- Risk of failure (probability of large exceedances occurring with low strength item);
  - $1.5\text{x}10^{-3}$ for Graphite composites
  - $1.0\text{x}10^{-3}$ for Aluminum structure
- COMPARABLE RISKS



Transport aircraft have load spectra with less variability (fighter maneuver spectrum are sever)

# Status Matrix of Service Induced Impact Damage:

# Composite Structures: 3.2.24

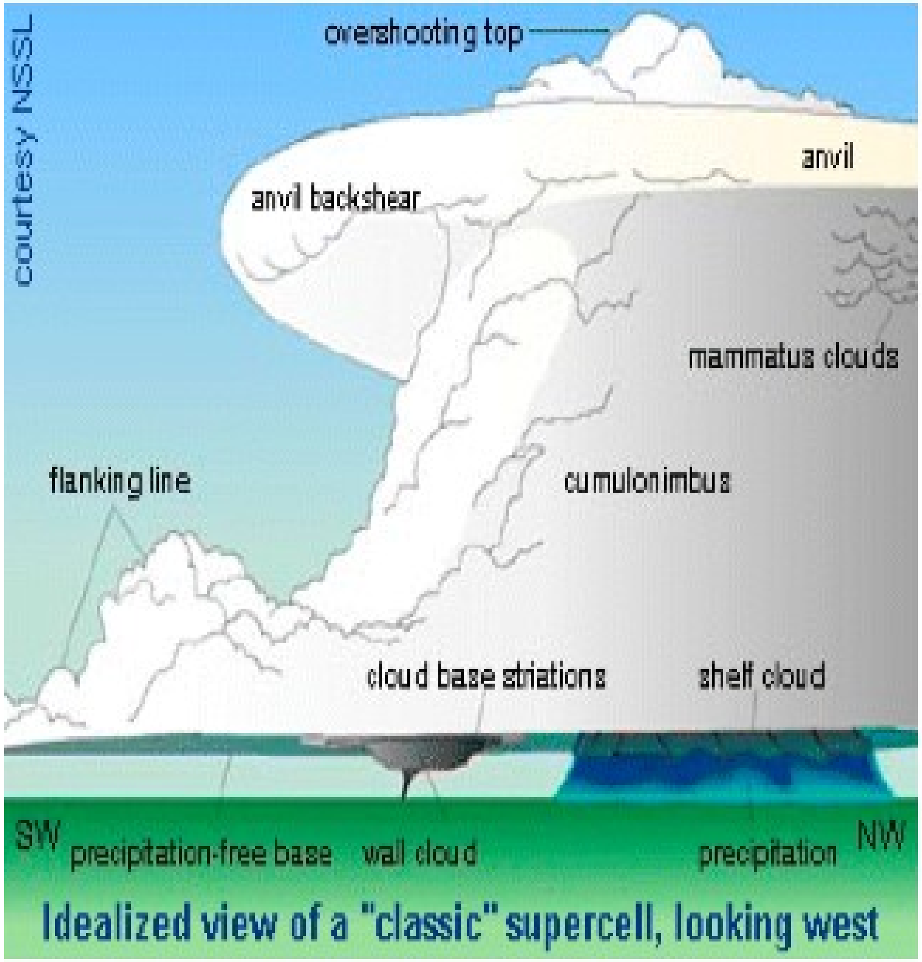
Should Damage Tolerance Threat Requirements be Defined by a “B or A Level Threat Allowable”?

| Threat | Test Protocol | Simulation Models | Threat Allowable | Self Evident Event | Impact Location(s); Zones 1 & 2 |
|---|---|---|---|---|---|
| Bird Strike | Gel-pack | Yes | “B”<br>FAR’s (Wt. & Vel.) | Yes | YES |
| Hail | Simulated Hail Ice, SHI? | Yes<br>Maturing | “B”<br>Up-date MIL HDBK 310 | Yes | YES |
| Runway Debris | Lead Ball ?<br>Drop-tower? | ? | “B”<br>Up-date<br>JSSG-2006 ? | Sometimes | Usually |
| Tire Rupture | Rubber Puck | ? | AC25.963-1 | Yes | YES |
| Panels Lost In-flight | ? | ? | ? | Yes | Sometimes |
| Tool-drop | Steel or Aluminum Hemisphere<br>Drop-tower | ? | JSSG-2006 Structures | Sometimes | Yes |
| Incidental Contact With Ground Vehicles | TBD | TBD | TBD | Sometimes<br>? | Yes |
| Others?<br>Lighting Strike | ---- | ----- | ----- | ----- | ----- |

**Hail Stone Growth Is Enhanced in Strong Storm Systems, Vertical Wind Gusts Carrying Small Hail Upward Becoming Large Stones. These Storms Generate Lightning, & Tornados. Extreme Sizes Are Typically Associated With Weather Dangerous for Aviation**

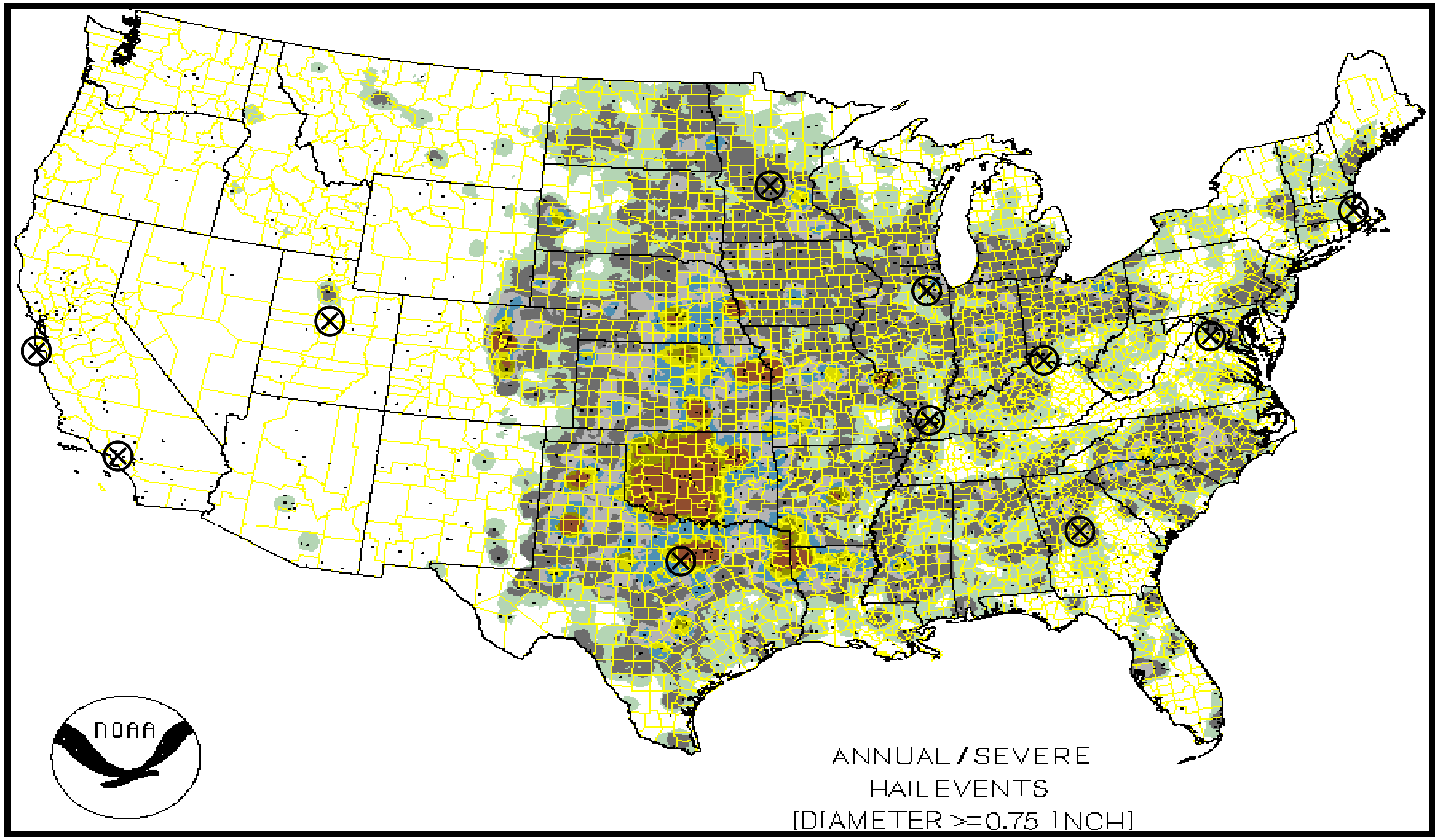
**Aggregates of Smaller Ice Particles.**

**Four Different Size Distributions Suggested by Data.**

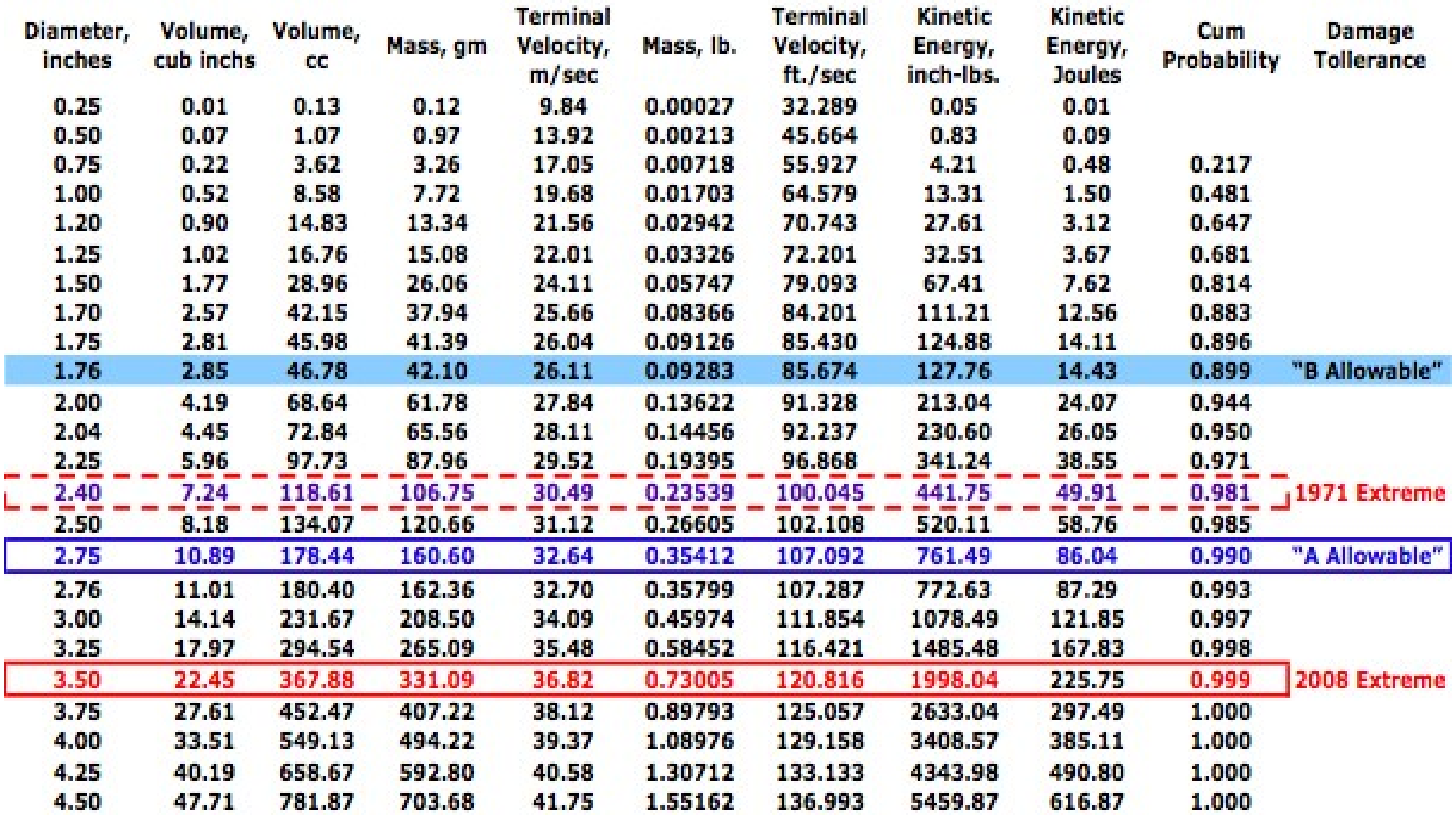


Idealized view of a "classic" supercell, looking west

# Composite US Hail Threat Data Base for 1955 to 2006 (2829 Reports), Has Been Developed and Is Summarized in the Table



# Insert Table Summary for the US Hail Distribution: 1955-2006 Data Base into 12.5.2.3 Ground Hail



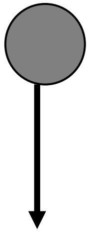
| Diameter, inches | Volume, cub inchs | Volume, cc | Mass, gm | Terminal Velocity, m/sec | Mass, lb. | Terminal Velocity, ft./sec | Kinetic Energy, inch-lbs. | Kinetic Energy, Joules | Cum Probability | Damage Tollerance |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.25 | 0.01 | 0.13 | 0.12 | 9.84 | 0.00027 | 32.289 | 0.05 | 0.01 | | |
| 0.50 | 0.07 | 1.07 | 0.97 | 13.92 | 0.00213 | 45.664 | 0.83 | 0.09 | | |
| 0.75 | 0.22 | 3.62 | 3.26 | 17.05 | 0.00718 | 55.927 | 4.21 | 0.48 | 0.217 | |
| 1.00 | 0.52 | 8.58 | 7.72 | 19.68 | 0.01703 | 64.579 | 13.31 | 1.50 | 0.481 | |
| 1.20 | 0.90 | 14.83 | 13.34 | 21.56 | 0.02942 | 70.743 | 27.61 | 3.12 | 0.647 | |
| 1.25 | 1.02 | 16.76 | 15.08 | 22.01 | 0.03326 | 72.201 | 32.51 | 3.67 | 0.681 | |
| 1.50 | 1.77 | 28.96 | 26.06 | 24.11 | 0.05747 | 79.093 | 67.41 | 7.62 | 0.814 | |
| 1.70 | 2.57 | 42.15 | 37.94 | 25.66 | 0.08366 | 84.201 | 111.21 | 12.56 | 0.883 | |
| 1.75 | 2.81 | 45.98 | 41.39 | 26.04 | 0.09126 | 85.430 | 124.88 | 14.11 | 0.896 | |
| 1.76 | 2.85 | 46.78 | 42.10 | 26.11 | 0.09283 | 85.674 | 127.76 | 14.43 | 0.899 | "B Allowable" |
| 2.00 | 4.19 | 68.64 | 61.78 | 27.84 | 0.13622 | 91.328 | 213.04 | 24.07 | 0.944 | |
| 2.04 | 4.45 | 72.84 | 65.56 | 28.11 | 0.14456 | 92.237 | 230.60 | 26.05 | 0.950 | |
| 2.25 | 5.96 | 97.73 | 87.96 | 29.52 | 0.19395 | 96.868 | 341.24 | 38.55 | 0.971 | |
| 2.40 | 7.24 | 118.61 | 106.75 | 30.49 | 0.23539 | 100.045 | 441.75 | 49.91 | 0.981 | 1971 Extreme |
| 2.50 | 8.18 | 134.07 | 120.66 | 31.12 | 0.26605 | 102.108 | 520.11 | 58.76 | 0.985 | |
| 2.75 | 10.89 | 178.44 | 160.60 | 32.64 | 0.35412 | 107.092 | 761.49 | 86.04 | 0.990 | "A Allowable" |
| 2.76 | 11.01 | 180.40 | 162.36 | 32.70 | 0.35799 | 107.287 | 772.63 | 87.29 | 0.993 | |
| 3.00 | 14.14 | 231.67 | 208.50 | 34.09 | 0.45974 | 111.854 | 1078.49 | 121.85 | 0.997 | |
| 3.25 | 17.97 | 294.54 | 265.09 | 35.48 | 0.58452 | 116.421 | 1485.48 | 167.83 | 0.998 | |
| 3.50 | 22.45 | 367.88 | 331.09 | 36.82 | 0.73005 | 120.816 | 1998.04 | 225.75 | 0.999 | 2008 Extreme |
| 3.75 | 27.61 | 452.47 | 407.22 | 38.12 | 0.89793 | 125.057 | 2633.04 | 297.49 | 1.000 | |
| 4.00 | 33.51 | 549.13 | 494.22 | 39.37 | 1.08976 | 129.158 | 3408.57 | 385.11 | 1.000 | |
| 4.25 | 40.19 | 658.67 | 592.80 | 40.58 | 1.30712 | 133.133 | 4343.98 | 490.80 | 1.000 | |
| 4.50 | 47.71 | 781.87 | 703.68 | 41.75 | 1.55162 | 136.993 | 5459.87 | 616.87 | 1.000 | |

**Note:Hailstone Extremes Defined by MBK-310 “GLOBAL CLIMATIC DATA FOR DEVELOPING MILITARY PRODUCTS” as 0.1 percent risk,** Gringorten, 1.1. (1972) Hailstone Extremes for Design, AFCRL-TR-72-0081, Air Force Surveys in Geophysics No. 238, AD743831.

# Example Problem: Hail impact

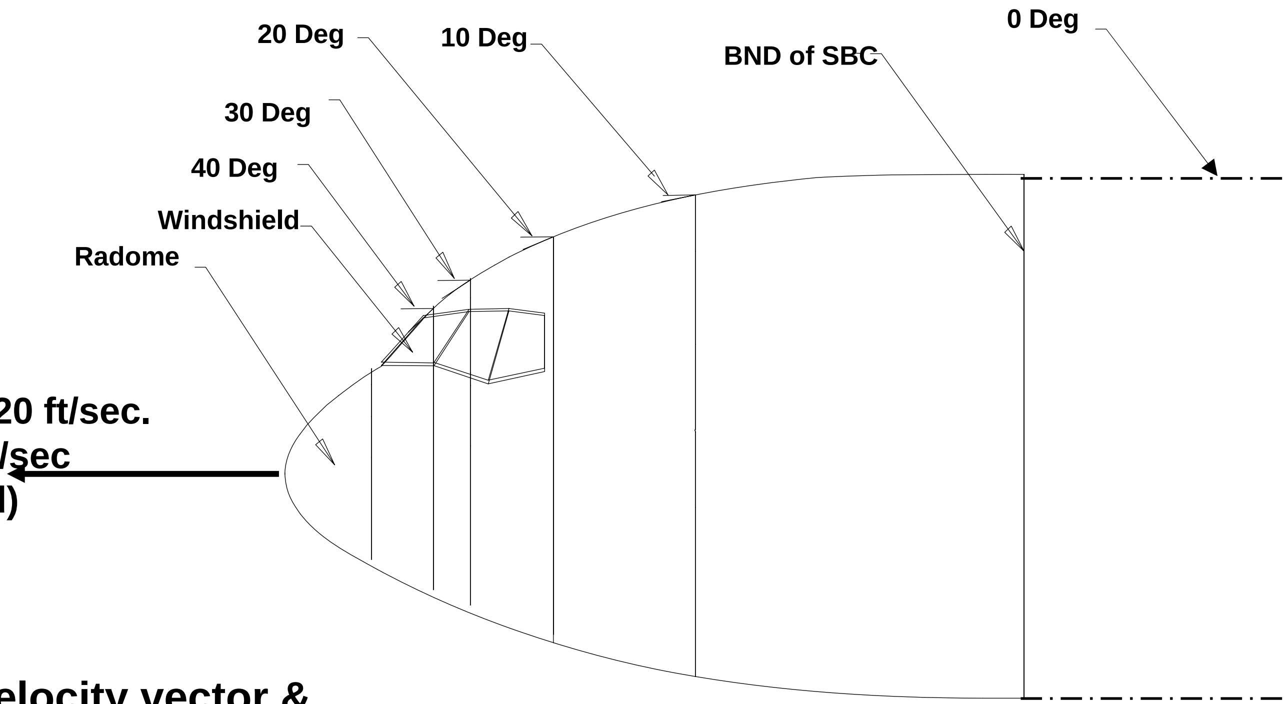
## In-flight and On-ground - 2.4 inch hail (98% Threat)

Weight~0.24 lbs



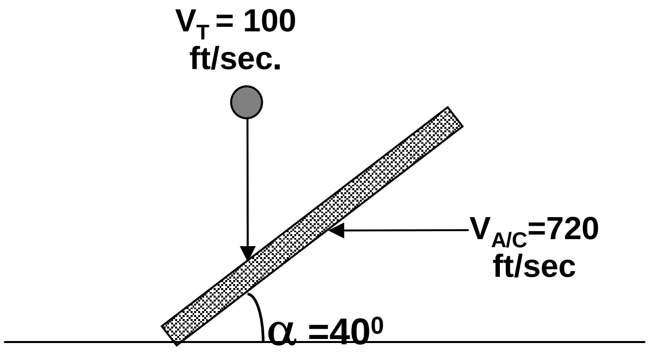
$V_T$ ~ 100 ft/sec.

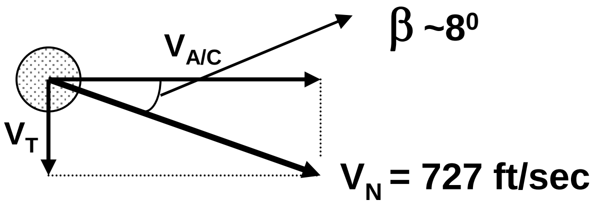
$V_{A/C}$ ~ 720 ft/sec. and 0 ft/sec (ground)



Determine normal velocity vector & Kinetic Energy components.

# Example Problem: Hail impact
# In-flight: Relative Closing Velocity Vector Approach





$V_N=\sqrt{[(-100)^2 + (724^2)]}$
= 727 ft/sec

Cos $\beta$ = -100/720 = 0.1389

$\beta$ = 98 - 90 = $8^0$

~ 8 degrees below flight path

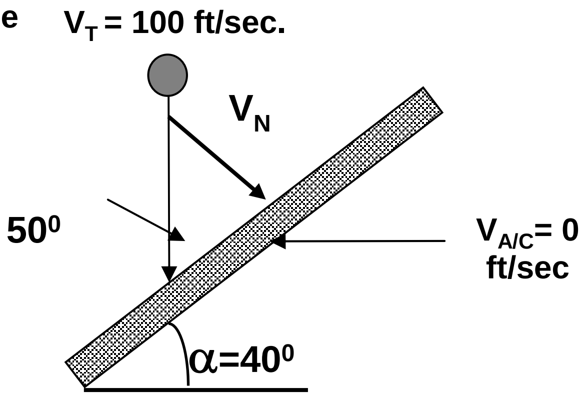
$V_{T\ (Normal)}$ is acting at
(90-40-8) = $42^0$

$V_{T\ (Normal)}$ = 727Cos $42^0$ = 540 ft/sec

KE(normal)~12,772 in-lbs

# Comparison:
# In-Flight and Ground Hail impact

**$KE_T$ = 438 in-lbs as ball of 0.235lbs collides with surface at $90^0$**



**$KE_N(TV)= KE_T Cos40^0$**

**= 335 in-lbs**

**Ground hail impact condition**

## Ground

- **$90^0$ impact**
  - **$KE_T$ = 438 in-lbs**
- **$40^0$ impact**
  - **$KE_T$ = 335 in-lbs**

## •In-Flight

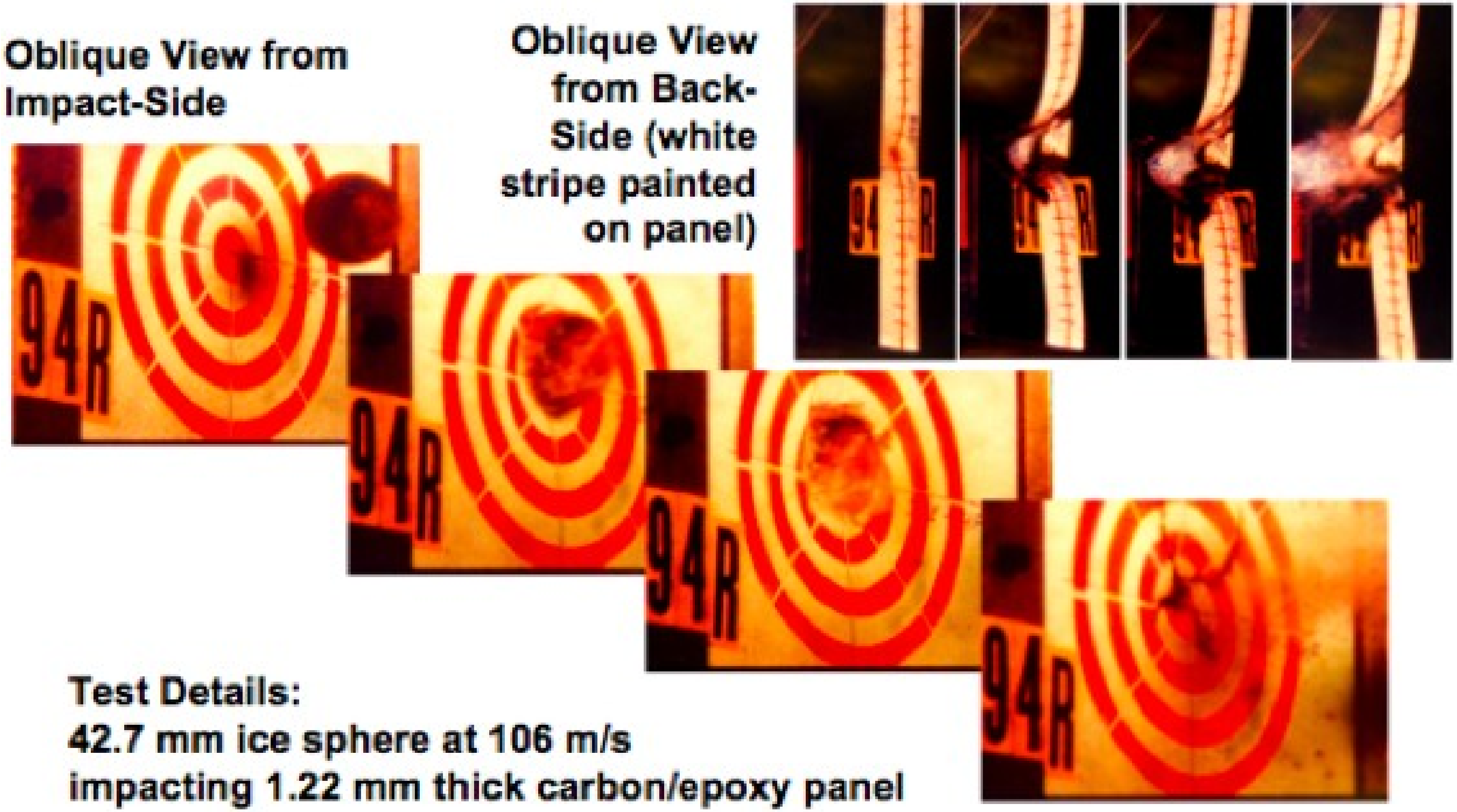
- **KE($40^0$)~12,772 in-lbs**

# Probabilistic Parameters for an In-flight Hail Requirement;  Primary Structure Elements

| Cumulative Probability of Occurrence, % | Air vehicle Velocity, KTAS | Hail Diameter, inches |
|---|---|---|
| 90 | 375 | 1.76 |
| 95 | 409 | 2.04 |
| 99 | 455 | 2.75 |

**NOTE: Kinetic Energy requirements would use these values and the relative velocity calculation for the individual subassemblies.**

# High velocity Simulated Hail Ice Ball Impacting a Toughened Graphite-Epoxy Panel (data by H. Kim)



Oblique View from Impact-Side

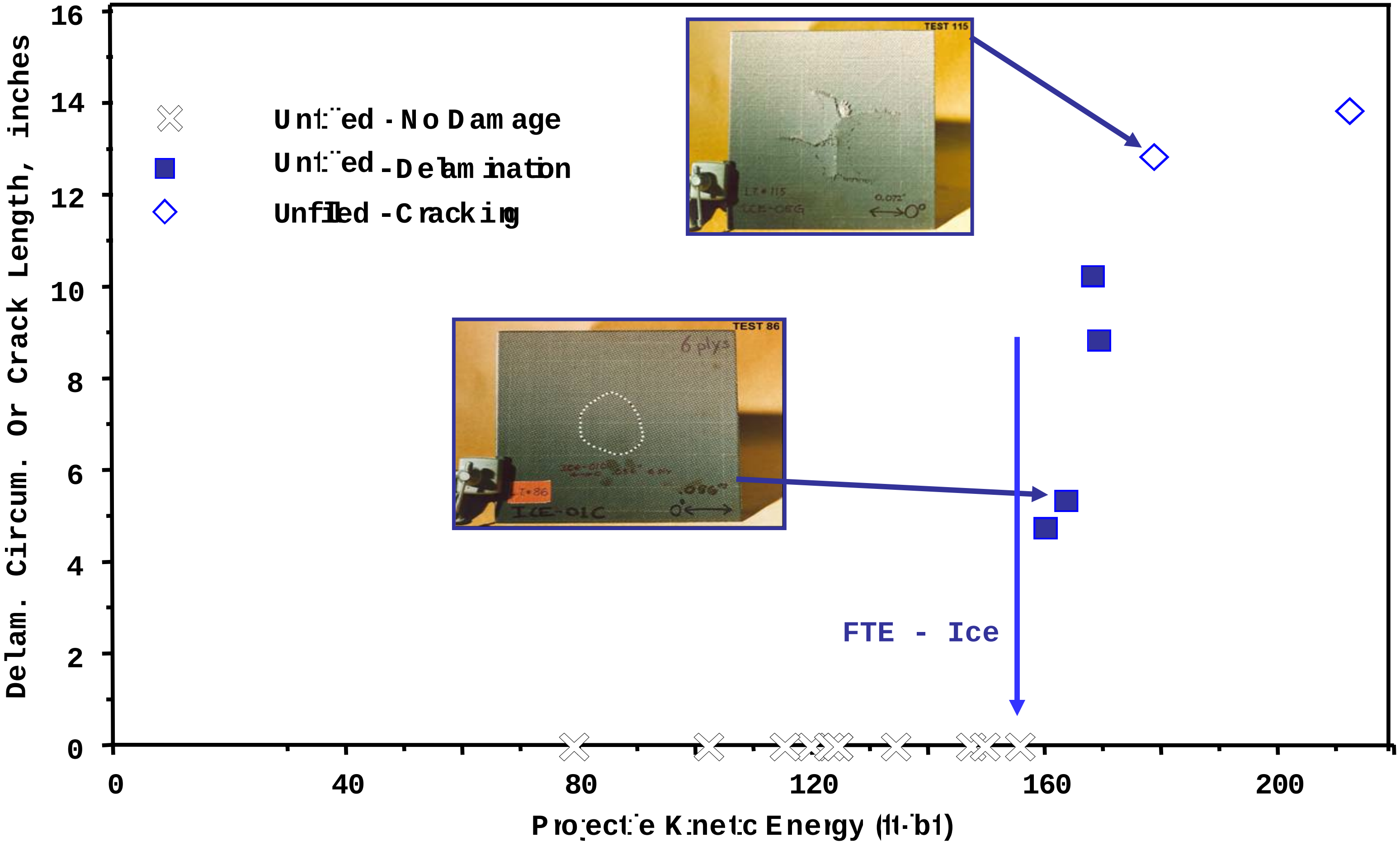
Oblique View from Back-Side (white stripe painted on panel)

**Test Details:**
42.7 mm ice sphere at 106 m/s
impacting 1.22 mm thick carbon/epoxy panel

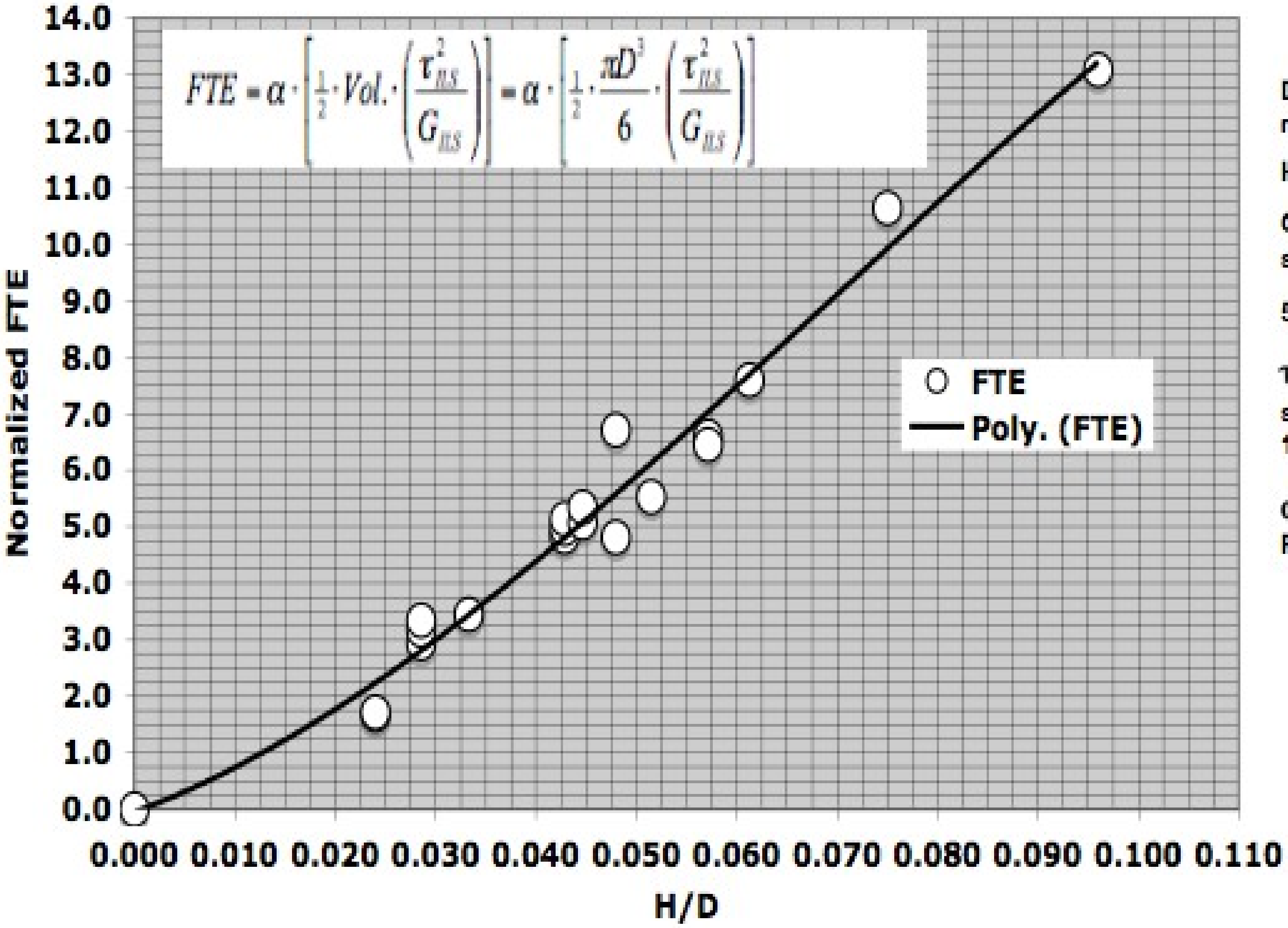
# Hail Impact Damage Size is Dependent on Kinetic Energy

## Demonstration Failure Threshold Energy

**0.072 in. thick panel Woven Carbon/Epoxy Panels impacted by 1.68 in. Dia. Simulated Hail Ice, (data by H Kim)**



# Parametric Correlation For SHI Impact Data by H. Kim



$$FTE = \alpha \cdot \left[ \frac{1}{2} \cdot Vol. \cdot \left( \frac{\tau_{ILS}^2}{G_{ILS}} \right) \right] = \alpha \cdot \left[ \frac{1}{2} \cdot \frac{\pi D^3}{6} \cdot \left( \frac{\tau_{ILS}^2}{G_{ILS}} \right) \right]$$

D = Hail diameter, meters

H = thickness

$G_{ILS}$ = Transverse shear Modulus, ~

517 GPa

$\tau$ = Interlaminar shear strength ~ 100 MPa

$\alpha$ ="Normalized FTE"

# Withstanding Thickness Estimates for Ground Hail Exposure Impacting at 90 degrees to Surface

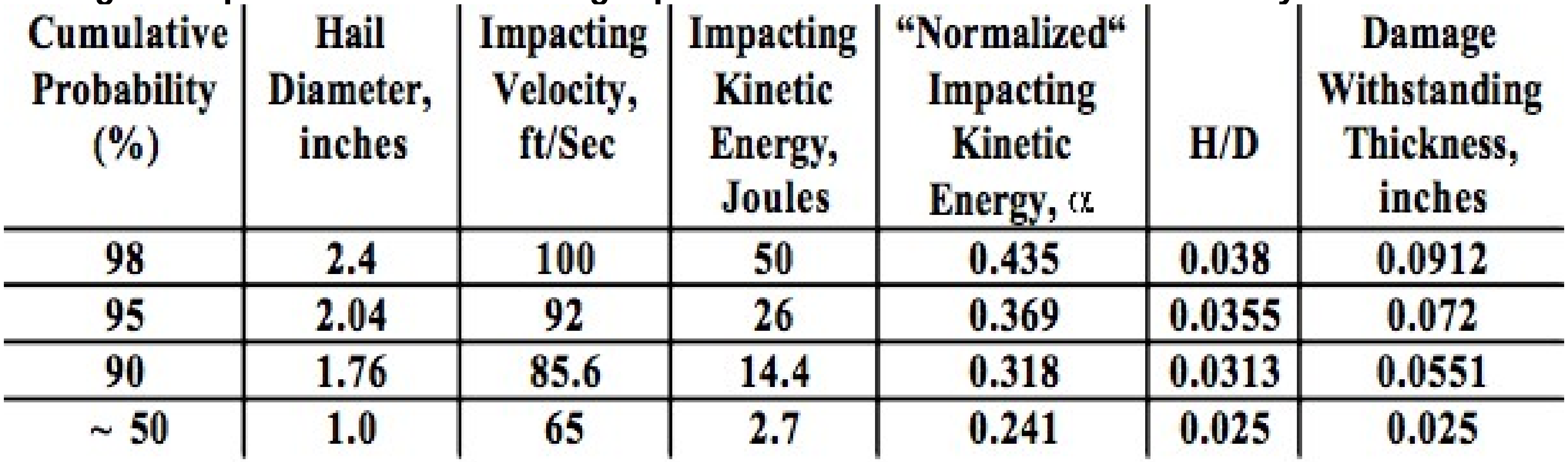
Ground hail impact occurs at Terminal Velocities, TV, and Kinetic Energies, J,

$$KE\ (TV,\ J) \rightarrow FTE = \alpha\ (\ 506382\ )\ D^3$$

Rearranging the equation;

$$\alpha = KE\ (TV,\ J)\ /\{506382\ D^3\}$$

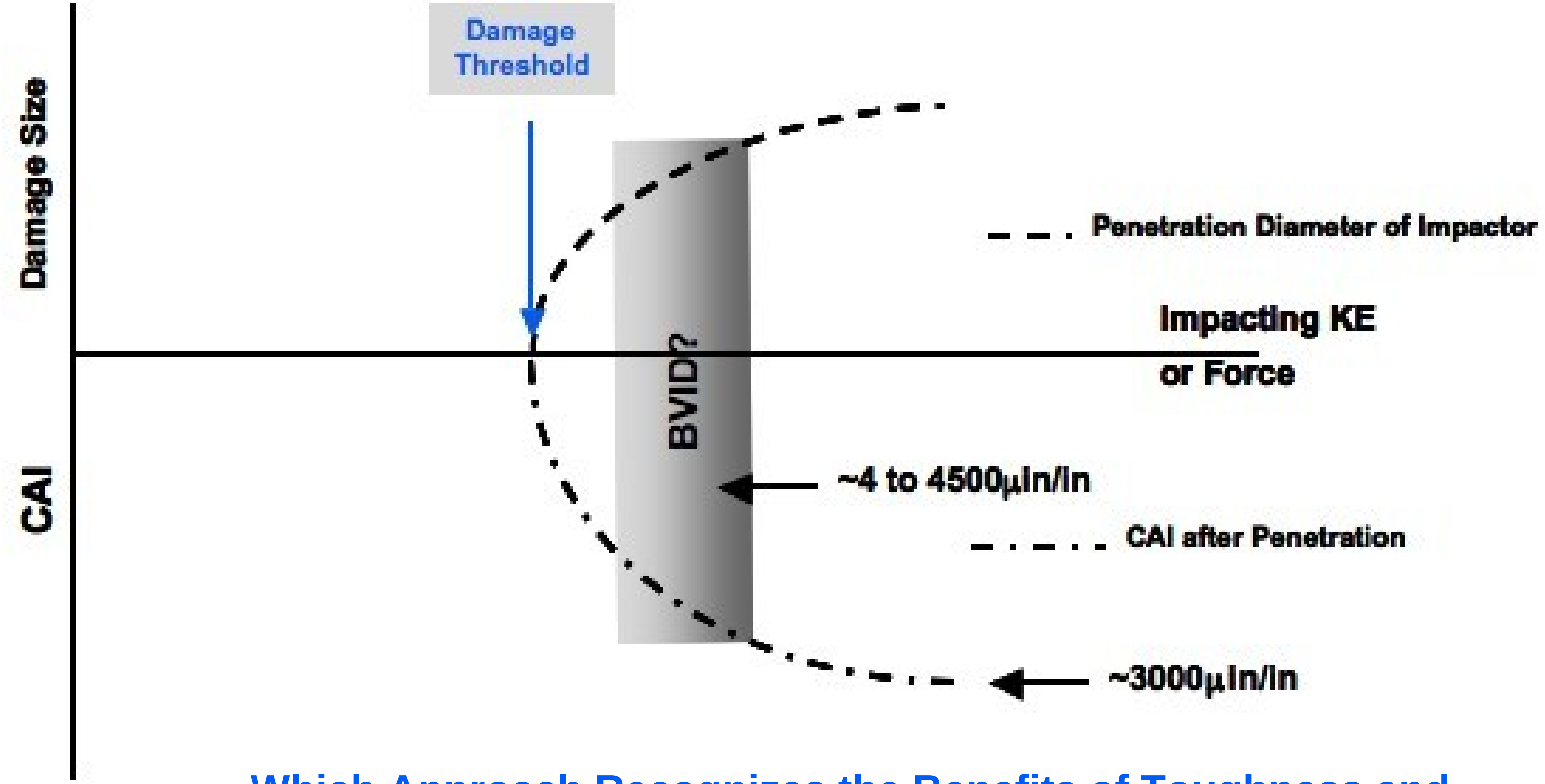
Using the previous table & graph the H/D ratio is defined by $\alpha$



| Cumulative Probability (%) | Hail Diameter, inches | Impacting Velocity, ft/Sec | Impacting Kinetic Energy, Joules | "Normalized" Impacting Kinetic Energy, $\alpha$ | H/D | Damage Withstanding Thickness, inches |
|---|---|---|---|---|---|---|
| 98 | 2.4 | 100 | 50 | 0.435 | 0.038 | 0.0912 |
| 95 | 2.04 | 92 | 26 | 0.369 | 0.0355 | 0.072 |
| 90 | 1.76 | 85.6 | 14.4 | 0.318 | 0.0313 | 0.0551 |
| ~ 50 | 1.0 | 65 | 2.7 | 0.241 | 0.025 | 0.025 |

**Current dual aisle fuselage skins ~ ECONOMIC LIMIT ~ 0.070 to 0.090 inches thick**

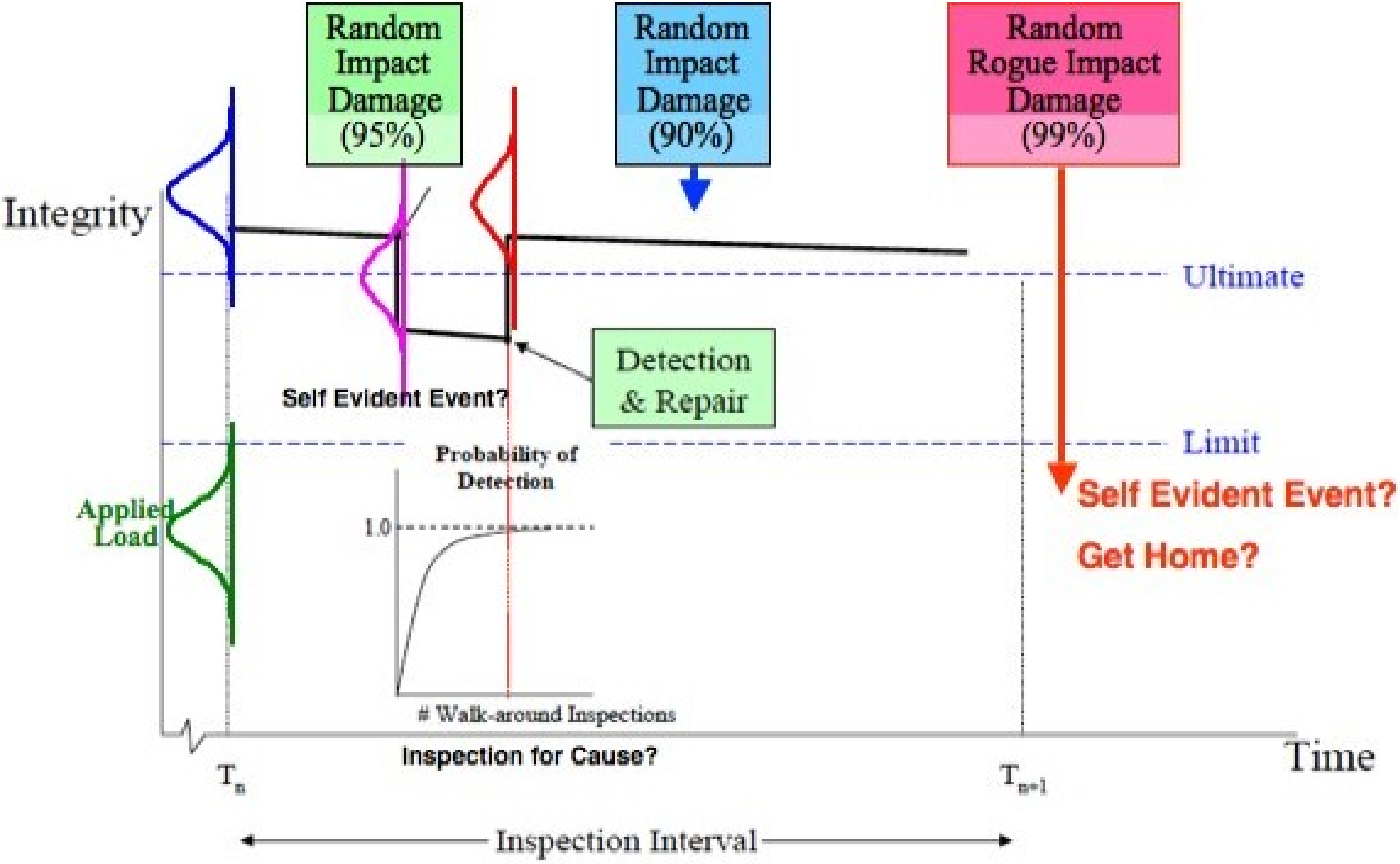
# What Metric Should the Designer Use?
# Is BVID a Design Parameter?
# What Makes Physical Sense, Damage Threshold or the Bottom of the CAI Curve?



**Which Approach Recognizes the Benefits of Toughness and Provides the Basis for Continuing Airworthiness?**

# Self Evident Rogue Events

# Impact Damage Tolerance-Management:
# Example of Random Discrete Threat Events



# Damage Tolerance Awareness Criteria?

(Durability and Continuing Airworthiness)

- **Self Evident Damage?;**
  - Cracking and corrosion
  - Fail-safety; Readily detectable means that a local failure or partial failure would be apparent from in- flight or post-flight visual observations, or they would be obvious during a scheduled visual inspection conducted within the predicted safe period of unrepaired usage.
- **Self Evident Damaging Events;**
  - Bird strike, tire rupture, hail, --
  - Damage Threats EXTERNAL TO AIRFRAME
    - Threat Characterization?
    - B-Allowable and/or enveloping?
    - Performance based criteria (FAA Tire rupture example)
    - Typically impact threats
  - Maintenance for Cause option?
- **Ground Operations Concerns**
  - Blunt Impact with GSE & Buildings
  - Hot GSE engine exhaust impinging airframe surface
    - exceeding composite in-service $T_G$

# The FAA Has Proposes 5 Damage Detection Categories.

## *Historical (FAR & JSSG) Implied Risk for Quantified Damage Threats*

- **Category 1 They are damages that may go undetected by field inspection methods (or allowable defects). Ultimate loads capability must be retained anytime (birdstrike, MIL ground-hail, tool drop & FOD). A fatigue substantiation allowing for these damages is a sort of flaw tolerant safe life demonstration including completion of ultimate loads capability**

***Category 1 90% KE Level (Damage Threshold?)***

- **Category 2 : Damage detected by field inspection at specified intervals. They are the so-called Visible Impact Damage (VID). A reliable inspection interval must be demonstrated and Limit Load capability retained.**

***Category 2 90% or 95%KE Level (Self Evident Event?)***

**(Minimum Period of Unrepaired Service Usage?)**

- **Category 3 : Obvious damage detectable within a few flights. They are damages obvious to operations in a "Walk Around" inspection or due to a loss of form/fit/function. Quick detection must be demonstrated and Limit Loads capability retained.**

***Category 3 95% KE Level (Self Evident Event?)***

- **Category 4 : Discrete source damage known by pilot to limit flight maneuvers. They are damage in flight from events that are obvious to pilot (rotor burst, birdstrike, lightning, in-flight hail). "Get home" capability must be retained as defined for discrete source events.**

***Category 4 99% KE Level (Self Evident Event?)***

- **Category 5 : Severe damage created by anomalous ground or flight events. They are damages due to RARE SERVICE EVENTS or to an extent beyond what is considered in design. Collision with a vehicle on ground, or severe ground hail exposure, are typical of such events. Immediate reporting is required with new substantiation.**

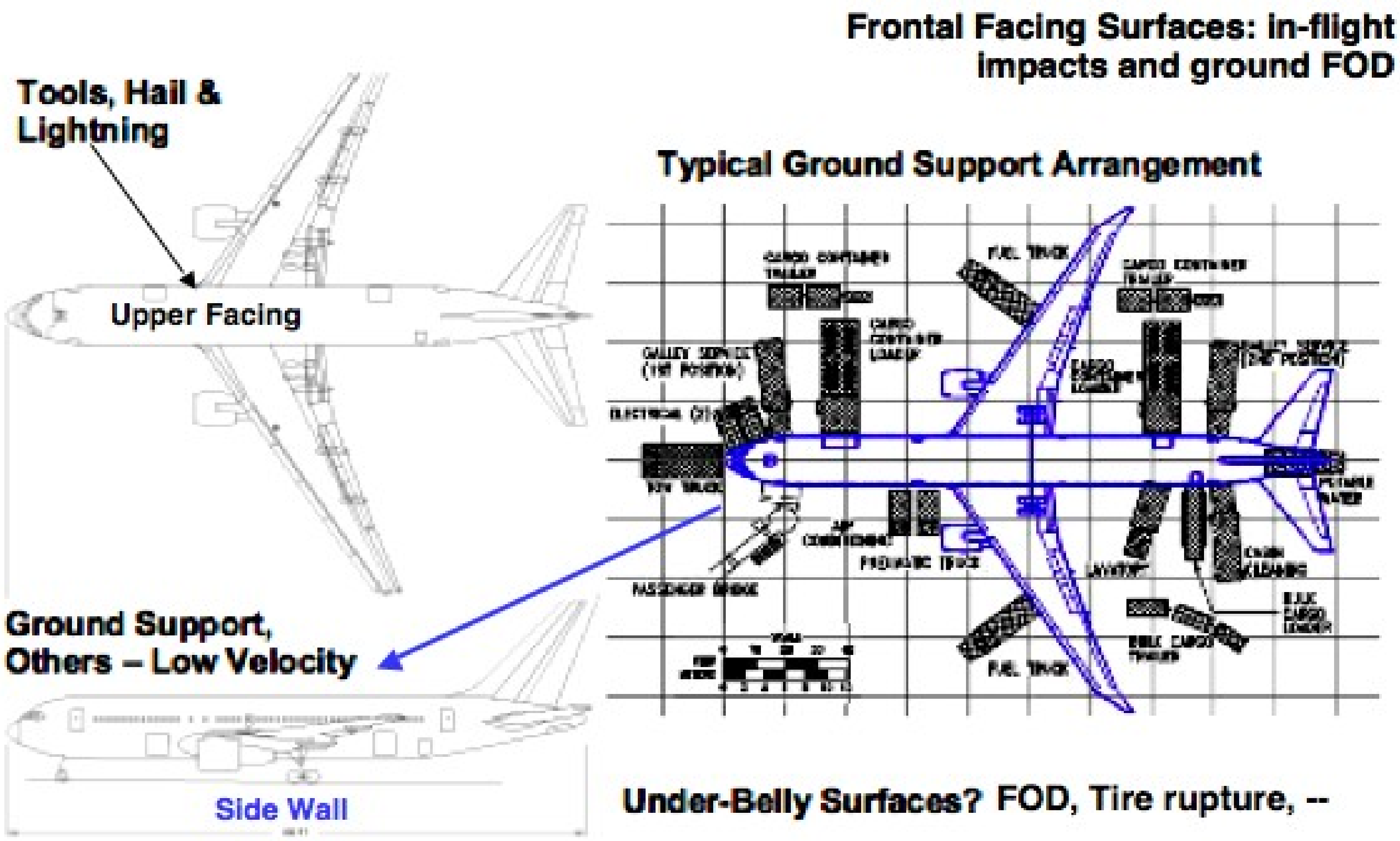
# Lightning Damage?

- **Rogue Event**
- **Inspection and maintenance for cause?**
  - **Structural integrity; Damage Tolerance**
    - **Damage threshold?**
    - **Punch through criteria?**
  - **Electo-magnetic integrity**
  - **Equivalent to local thermal spike or local impact?**

# Overlapping AIR WORTHINESS MANAGEMENT:

- **Preventive design**
- **Maintenance for Cause (discrete source damage, JSSG) when possible:**
  - **Bird strike, FOD, Hail Ice (in-flight & on-ground), Tire rupture (on-ground, in-flight), Lightning, & --- (Threats characterized, structures zoned, cause and effect --)**
  - **Individual aircraft focus**
    - **Self evident damaging event**
    - **Visually self evident damage?**
    - **Inspections & maintenance (What, When, Where, How?) provides a focused and timely process**
- **Operations Focused Inspection, management of other damage classes:**
  - **Other Potential Failure modes:**
    - **Load induced delamination (maybe heavy landings, --)**
    - **Thermal induced delamination (GSE exhaust, --)**
    - **Corrosion & Other**
  - **Anomalous events (Blunt Impacts, --- )**
  - **Individual aircraft focus**
  - **Damage Categories**
- **General inspection at heavy maintenance (all aircraft)**
  - **Defined usage or age interval (maybe 10 years)**
  - **Protection from hidden damage, unknown events, ---**
  - **Provides data for updating individual aircraft air worthiness management.**
- **Balancing Risk**

# Typical A/C plan form:
# Different Exposed Areas and Impact Threats



Frontal Facing Surfaces: in-flight impacts and ground FOD

Tools, Hail & Lightning

Upper Facing

Typical Ground Support Arrangement

Ground Support, Others – Low Velocity

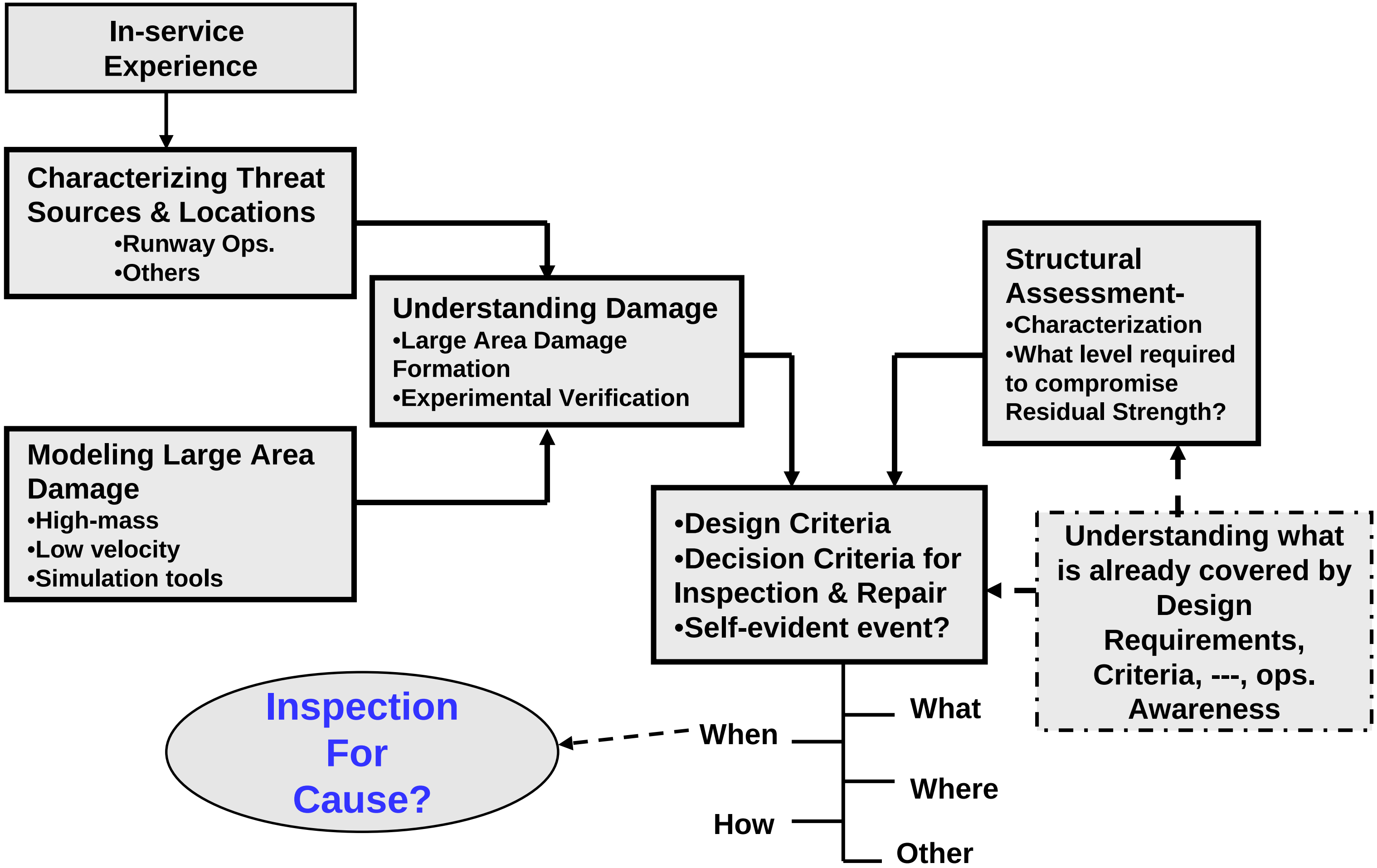
Side Wall

Under-Belly Surfaces? FOD, Tire rupture, --

# Blunt Impact

- **Low velocity, high mass large contact area event, i.e., “Blunt impact” (e.g., ground vehicle impact, GSE) where significant damage may not be clearly visible:**
  - **representing 30-40% plus of aircraft damage**
  - **IATA statistics suggest 767 class aircraft experiencing about 1.5 ground impact events per aircraft per year.**
  - **ground impact frequency is an OPERATIONAL ISSUE independent of airframe construction**
  - **typical GSE impact could involve a vehicle of about 6,000 lbs traveling at 3 to 5 miles per hour (4.8 to 8 kilometers per hour) distributed across an area of 1 to 4 square feet (0.1 to 0.37) square meters.**

# Logic for Low Velocity High-mass Large Area,"Blunt," Impact



In-service Experience

Characterizing Threat Sources & Locations
- Runway Ops.
- Others

Understanding Damage
- Large Area Damage Formation
- Experimental Verification

Modeling Large Area Damage
- High-mass
- Low velocity
- Simulation tools

Structural Assessment-
- Characterization
- What level required to compromise Residual Strength?

- Design Criteria
- Decision Criteria for Inspection & Repair
- Self-evident event?

Understanding what is already covered by Design Requirements, Criteria, ---, ops. Awareness

What

When

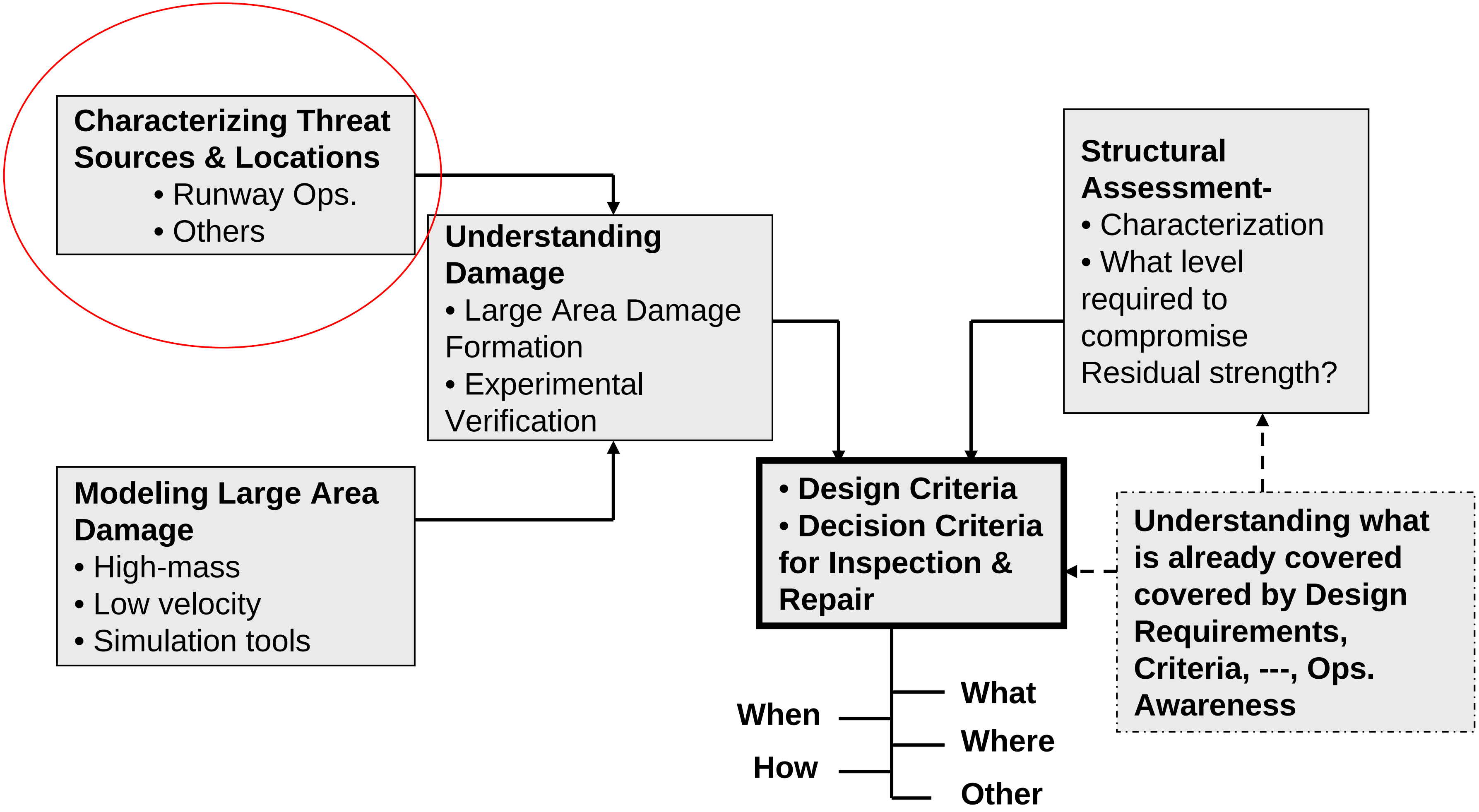
Where

How

Other

Inspection For Cause?

# Roadmap for Low Velocity High-Mass Wide-Area “Blunt” Impact Project



**Characterizing Threat Sources & Locations**
- Runway Ops.
- Others

**Understanding Damage**
- Large Area Damage Formation
- Experimental Verification

**Modeling Large Area Damage**
- High-mass
- Low velocity
- Simulation tools

**Structural Assessment-**
- Characterization
- What level required to compromise Residual strength?

- **Design Criteria**
- **Decision Criteria for Inspection & Repair**

**Understanding what is already covered covered by Design Requirements, Criteria, ---, Ops. Awareness**

**When**

**How**

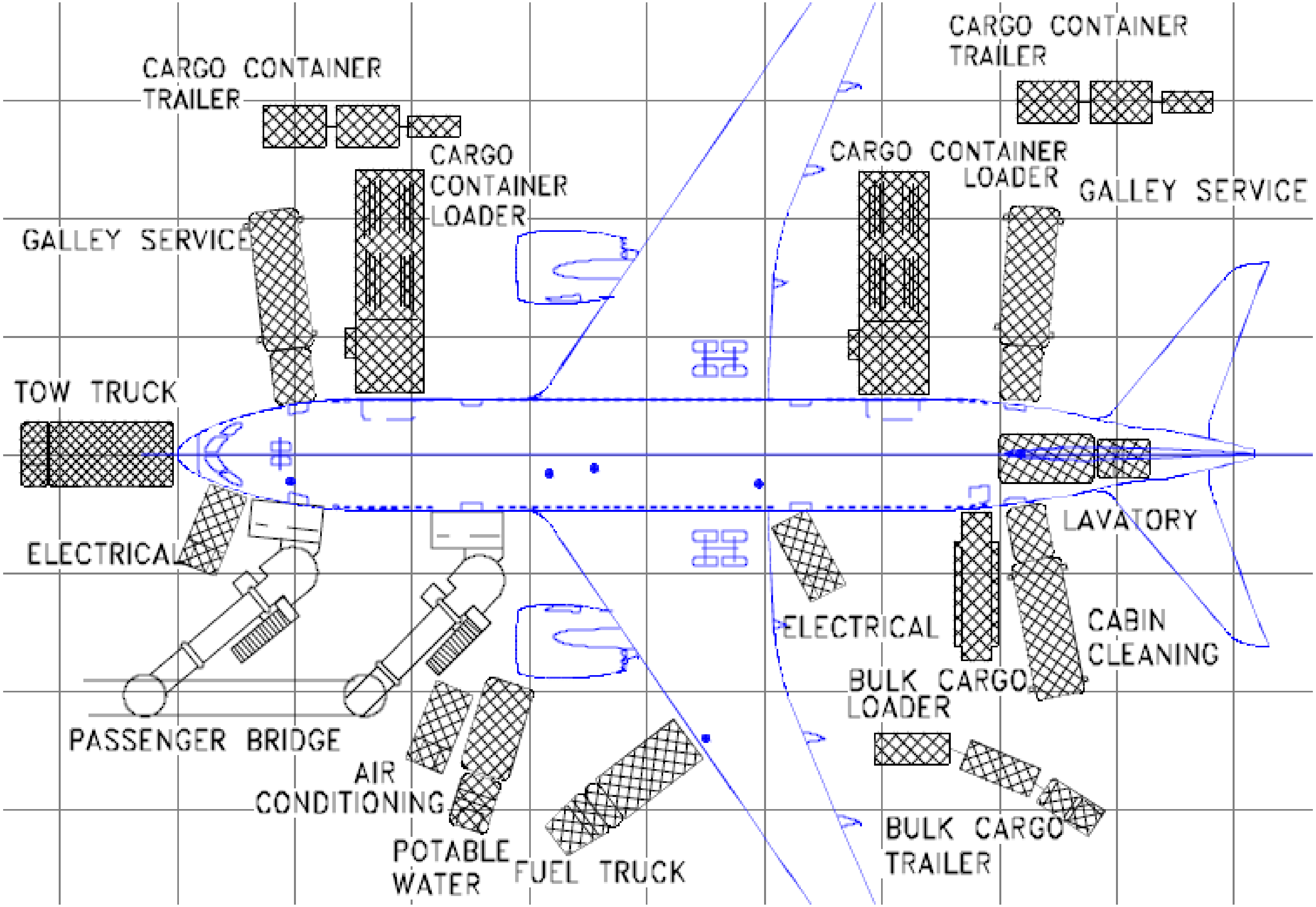
**What**

**Where**

**Other**

**Inspection for Cause?**

# Ground Equipment Adjacency



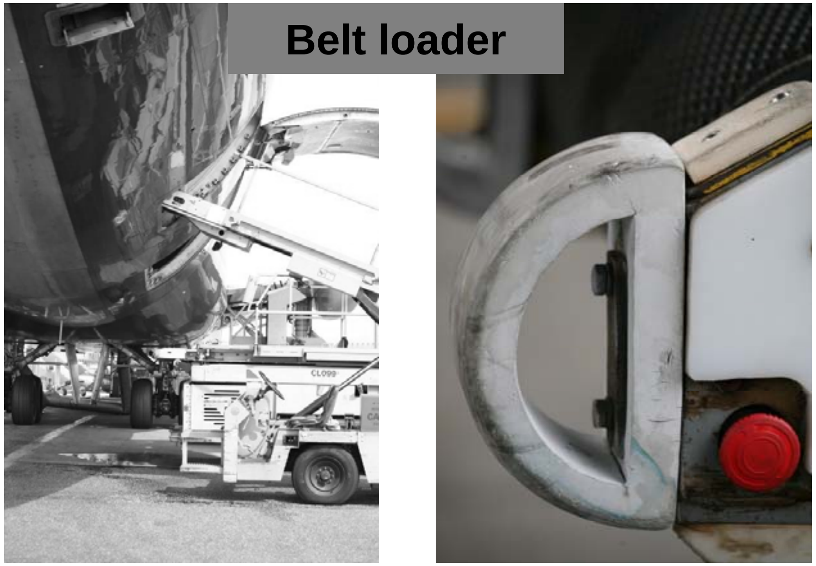
Source: 787 Airplane Characteristics for Airport Planning, D6-58333, Rev. A 2007.

- 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

# LAX Observation

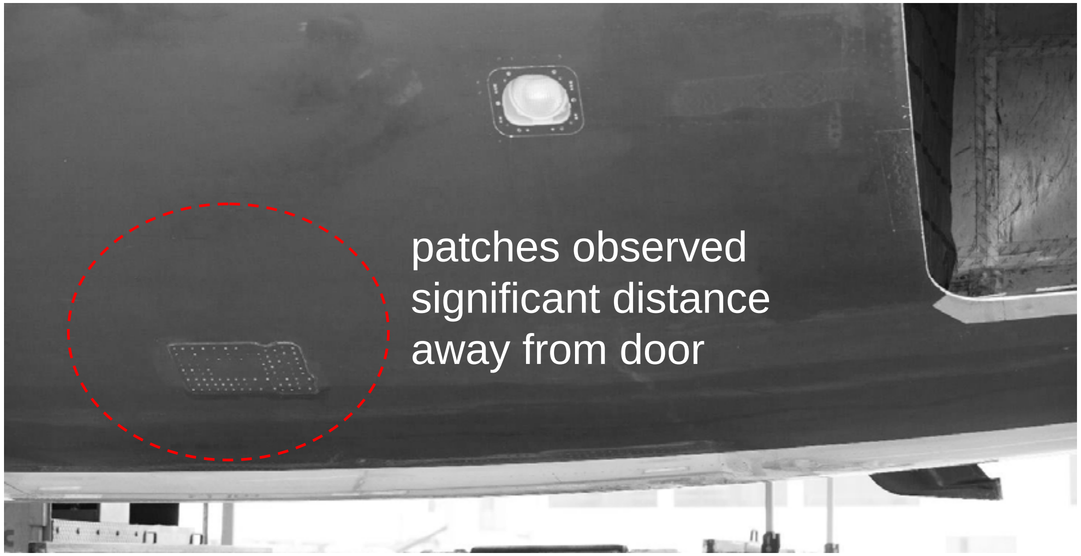
- Focus on Ground Service Equipment (GSE)
    - major source of damage
    - damage anticipated near doors and access panels
    - also observed further away in un-reinforced areas
- Other events possible, such as:
    - maintenance equipment or unattended GSE blown into the aircraft
    - aircraft settling onto equipment during the fueling and passenger loading
    - luggage cart can impact a belt loader, forcing contact between the belt loader and aircraft
- Different aircraft size/geometry influences impact sources
    - small aircraft
        - » at risk of contact with lower GSE
        - » more crowded at gate
    - larger aircraft have difficult docking angles (e.g., at aft door); risk for scraping body fairing

GSE bumpers and walkway bumper

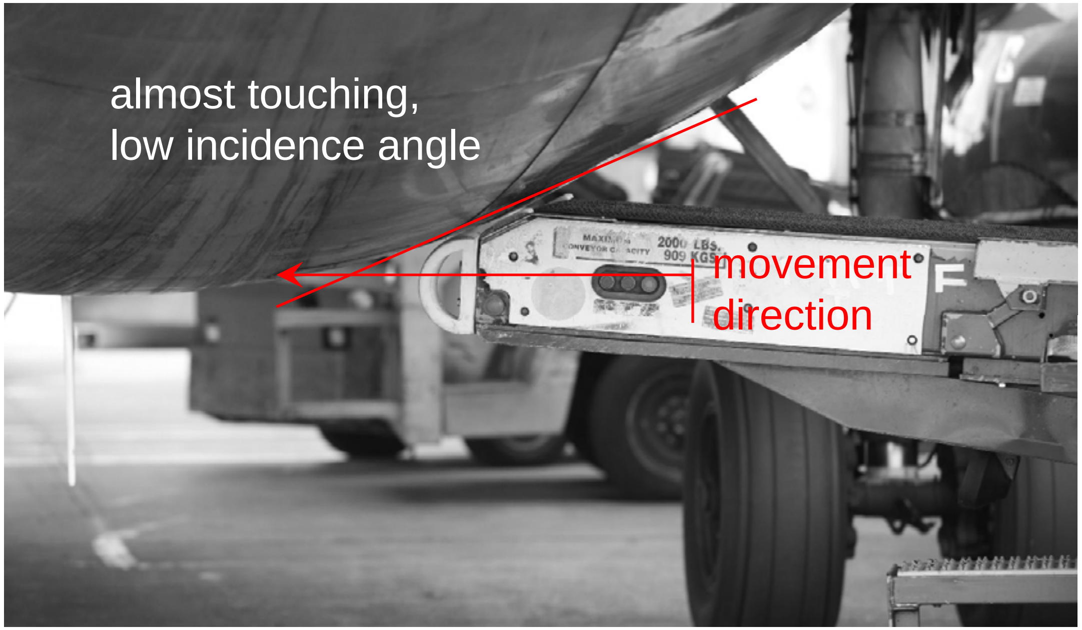


Belt loader

# Additional Observations

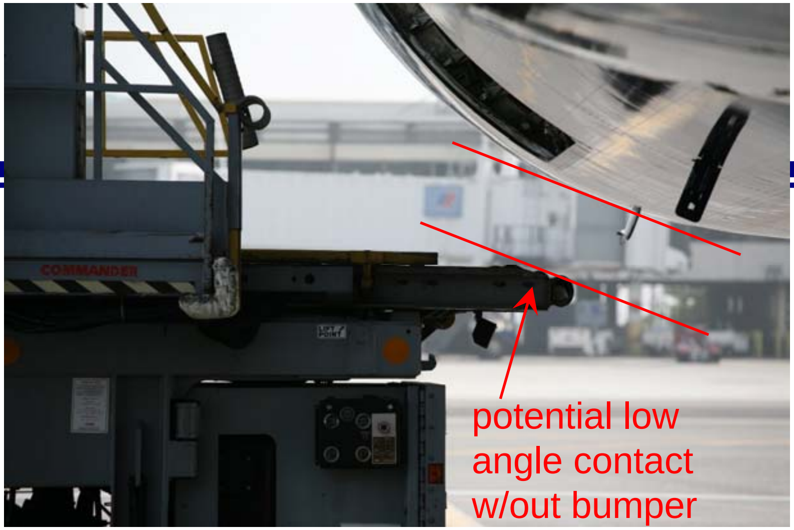


patches observed significant distance away from door

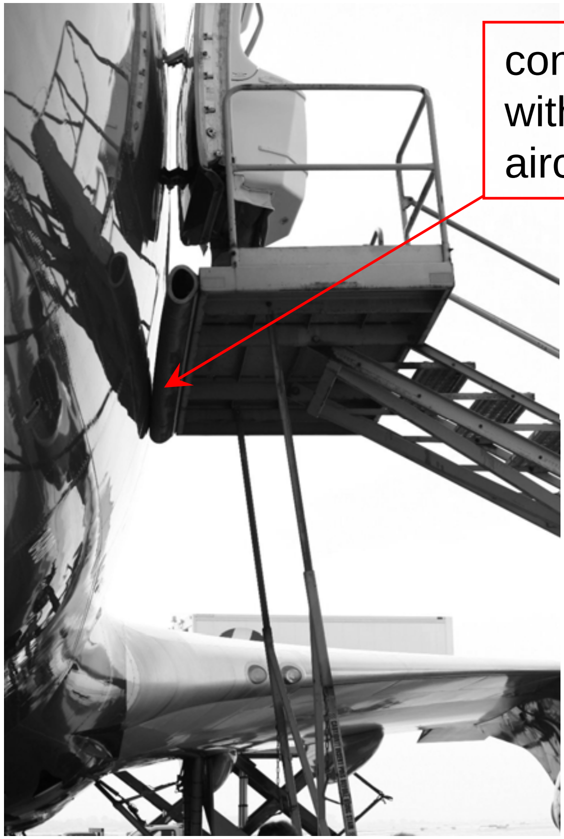


almost touching, low incidence angle

movement direction

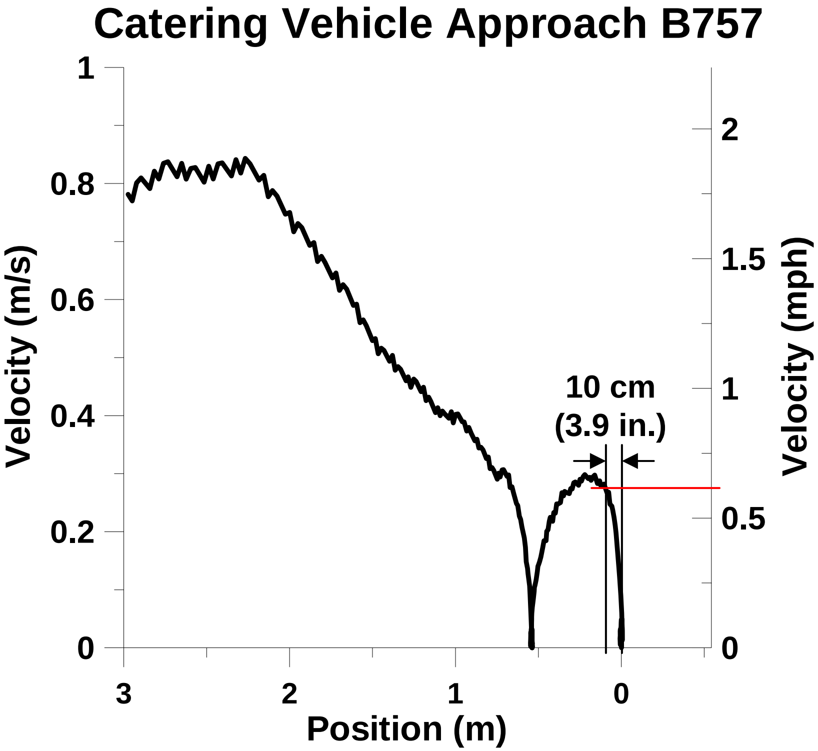


potential low angle contact w/out bumper



contact with aircraft

# Video Analysis:
# Catering Truck Approach



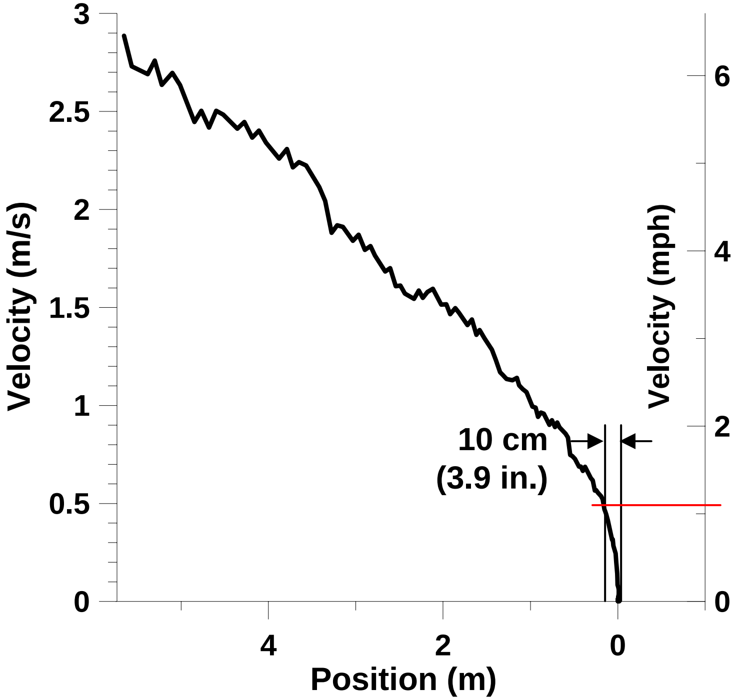
**Catering Vehicle Weight: 5000 lb (2270 kg)**

**Velocity of ~0.25 m/s within 10 cm of stopping**

**Kinetic Energy:**

- **284 J at 0.5 m/s (209 ft-lbf at 1.12 mph)**
- **71 J at 0.25 m/s (52 ft-lbf at 0.56 mph)**

# Video Analysis:
# TUG Belt Loader Approach



## TUG Belt Loader Approaching B757

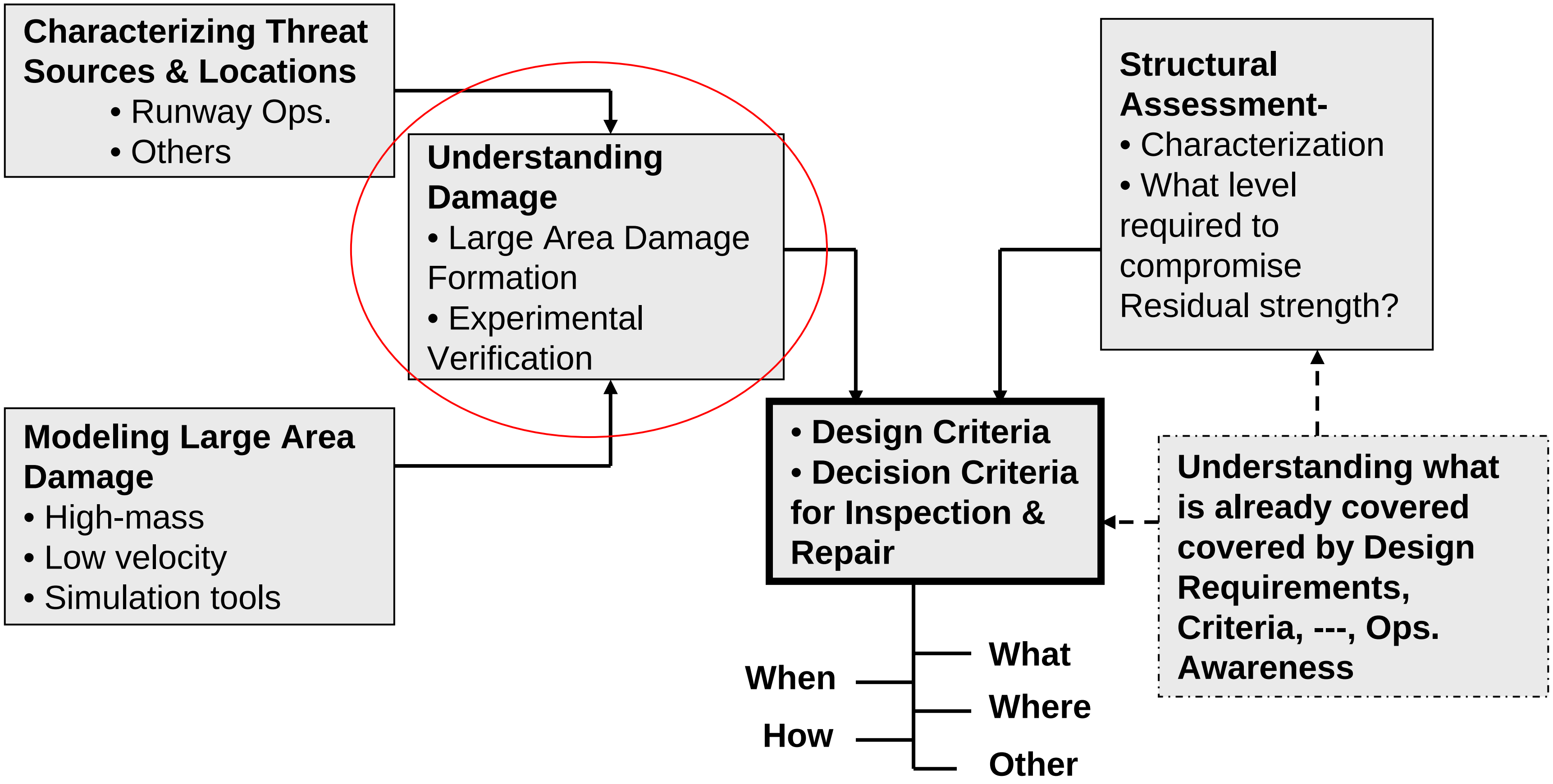
**TUG Vehicle Weight: 6680 lb (3030 kg)**

**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)**

# Roadmap for Low Velocity High-Mass Wide-Area “Blunt” Impact Project



**Characterizing Threat Sources & Locations**
- Runway Ops.
- Others

**Understanding Damage**
- Large Area Damage Formation
- Experimental Verification

**Modeling Large Area Damage**
- High-mass
- Low velocity
- Simulation tools

**Structural Assessment-**
- Characterization
- What level required to compromise Residual strength?

- **Design Criteria**
- **Decision Criteria for Inspection & Repair**

**Understanding what is already covered covered by Design Requirements, Criteria, ---, Ops. Awareness**

**When**
**How**
**What**
**Where**
**Other**

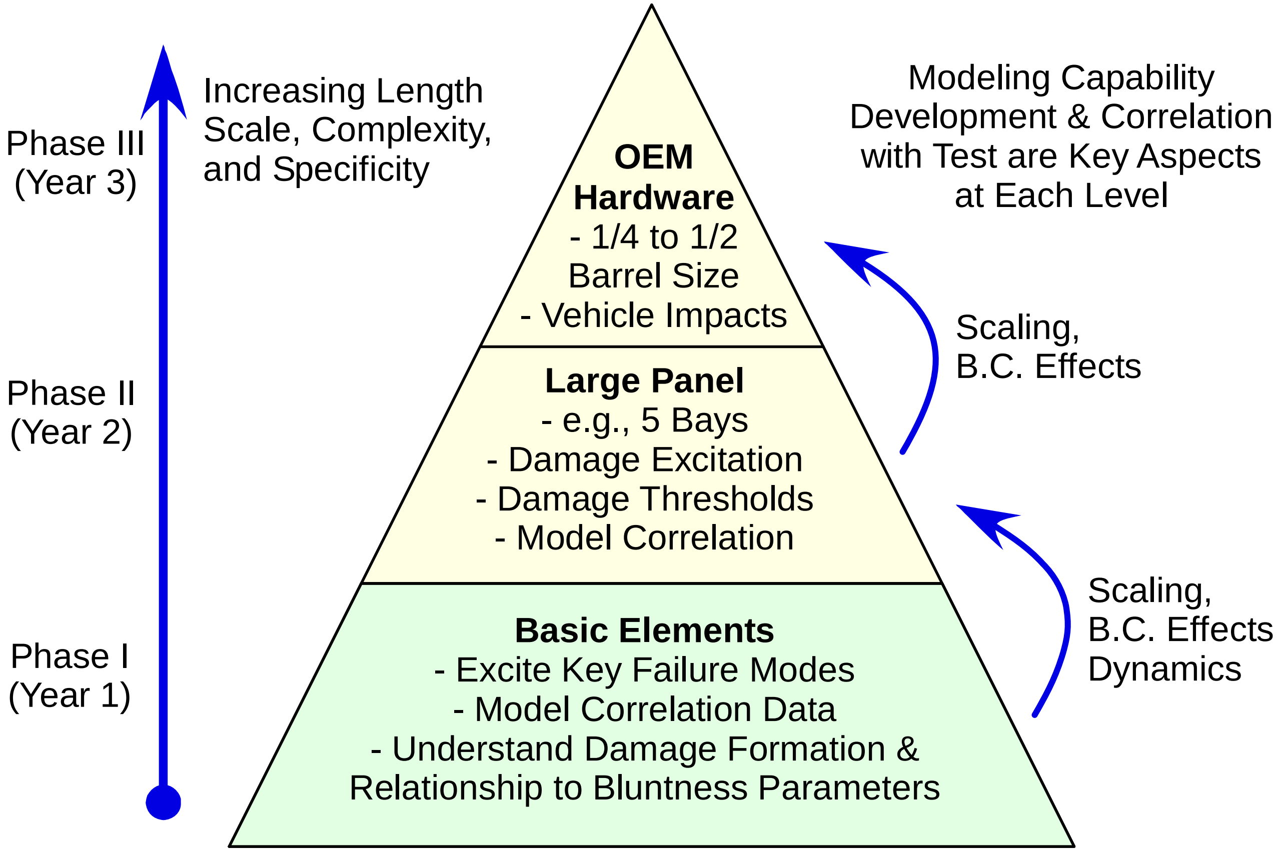
**Inspection for Cause?**

# Blunt Impact Damage Experiments

## Full-Scale Test Specimens

- **Two different specimen types defined during Jan09 Workshop at UCSD**
  - **Frame Specimen**
  - **Stringer Specimen**
- **Specimens intended to be representative of large commercial aircraft fuselage**
  - **geometry**
  - **failure modes produced**

## Full-Scale Blunt Impact Test Phases



Phase III
(Year 3)

Phase II
(Year 2)

Phase I
(Year 1)

Increasing Length Scale, Complexity, and Specificity

**OEM Hardware**
- 1/4 to 1/2 Barrel Size
- Vehicle Impacts

**Large Panel**
- e.g., 5 Bays
- Damage Excitation
- Damage Thresholds
- Model Correlation

**Basic Elements**
- Excite Key Failure Modes
- Model Correlation Data
- Understand Damage Formation & Relationship to Bluntness Parameters

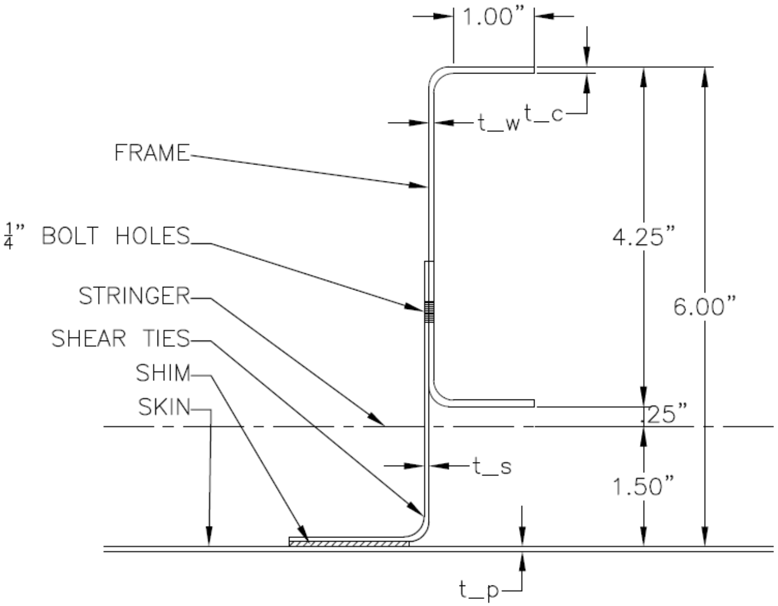
Modeling Capability Development & Correlation with Test are Key Aspects at Each Level

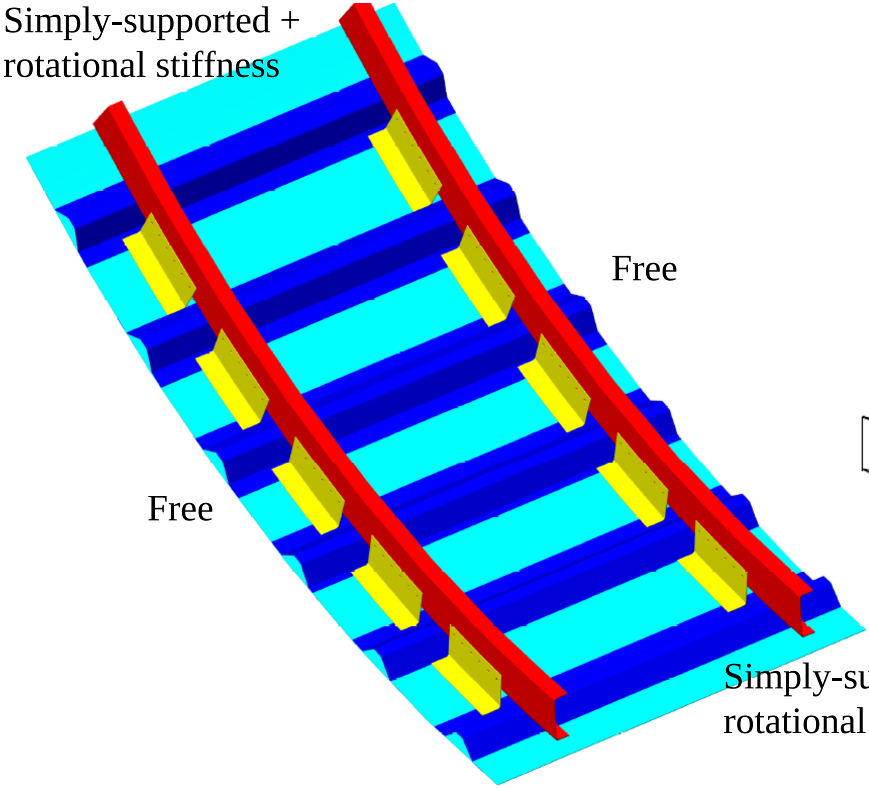
Scaling,
B.C. Effects

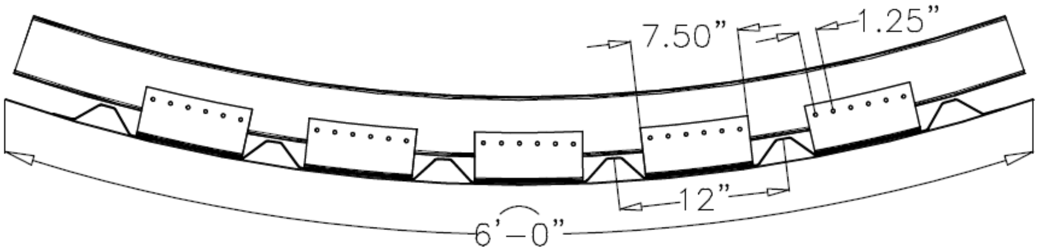
Scaling,
B.C. Effects
Dynamics

# Frame Specimens

- Specimens primarily focused on damage development to circumferential frame members and their connection to the skins
- Quasi-isotropic layups
- Frame bolted to shear ties which are bonded to panel skin

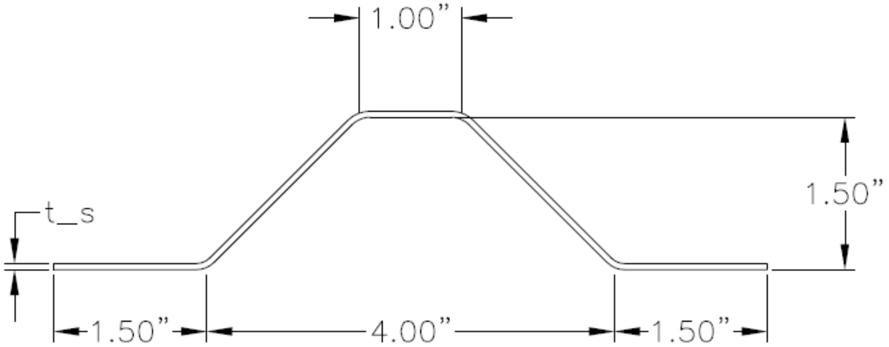


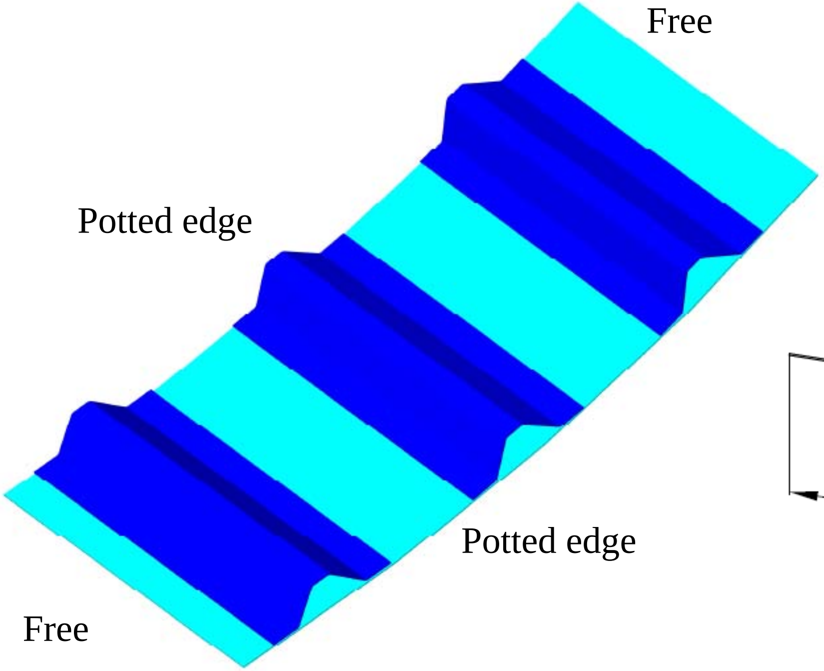


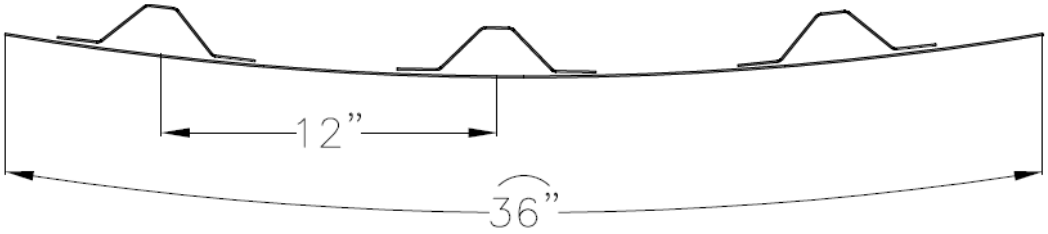


# Stringer Specimens

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

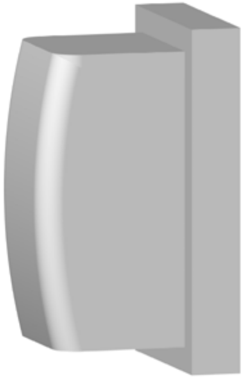






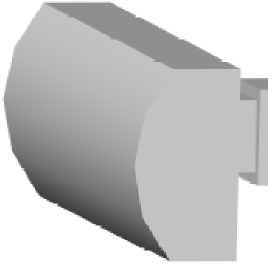
# Impactor Geometries

**Rigid 3.5” radius impactor**

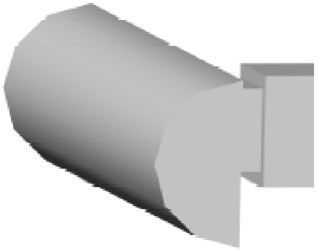


**Rigid 12” radius impactor**

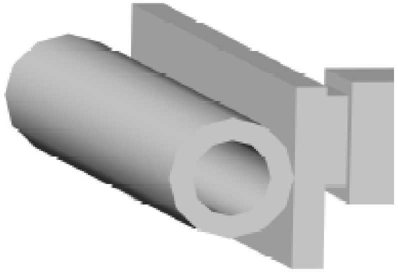
**Soft Bumper (actual product)**



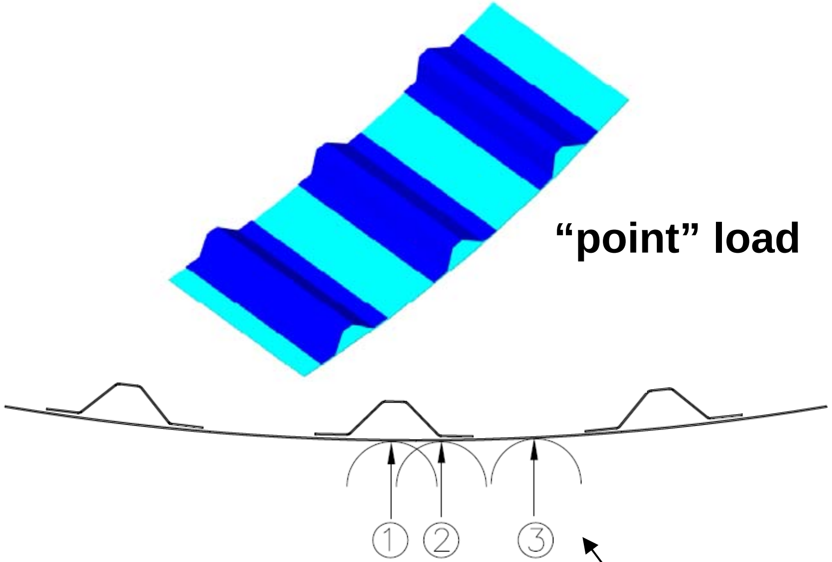
**Rigid 12” radius line loading impactor**



**Rigid 3.25” radius line loading impactor**

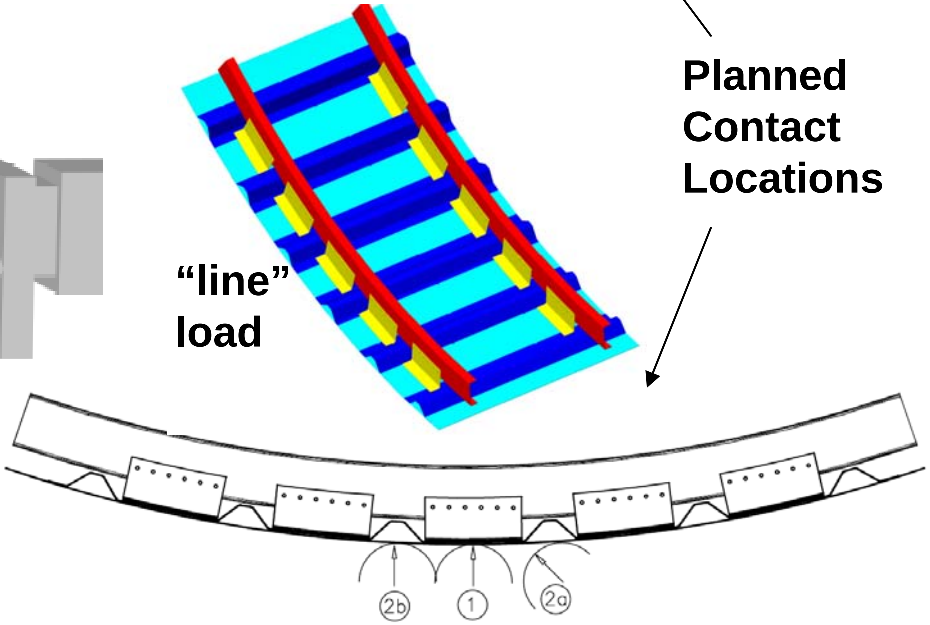


**Bumper line loading impactor**



**“point” load**

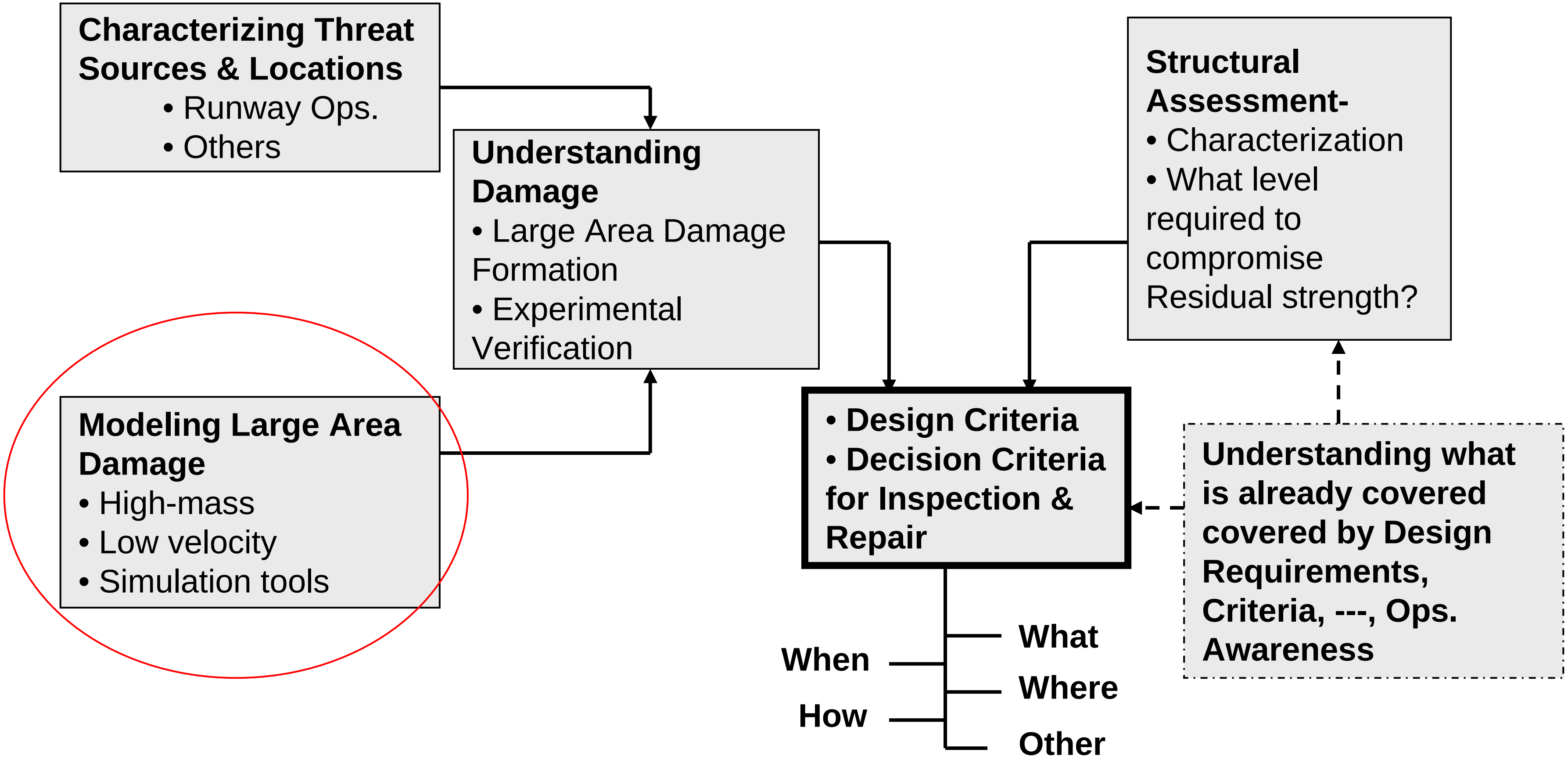
**Planned Contact Locations**



**“line” load**

# Roadmap for Low Velocity High-Mass Wide-Area “Blunt” Impact Project

UCSD
Department of Structural Engineering



**Characterizing Threat Sources & Locations**
- Runway Ops.
- Others

**Understanding Damage**
- Large Area Damage Formation
- Experimental Verification

**Modeling Large Area Damage**
- High-mass
- Low velocity
- Simulation tools

**Structural Assessment-**
- Characterization
- What level required to compromise Residual strength?

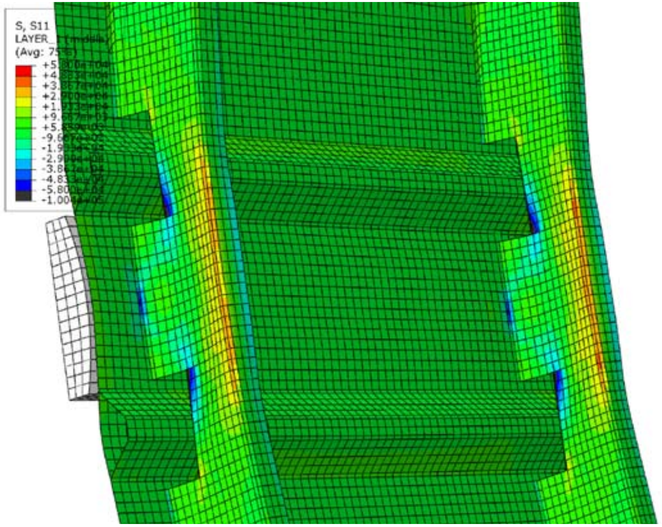
- **Design Criteria**
- **Decision Criteria for Inspection & Repair**

**Understanding what is already covered covered by Design Requirements, Criteria, ---, Ops. Awareness**

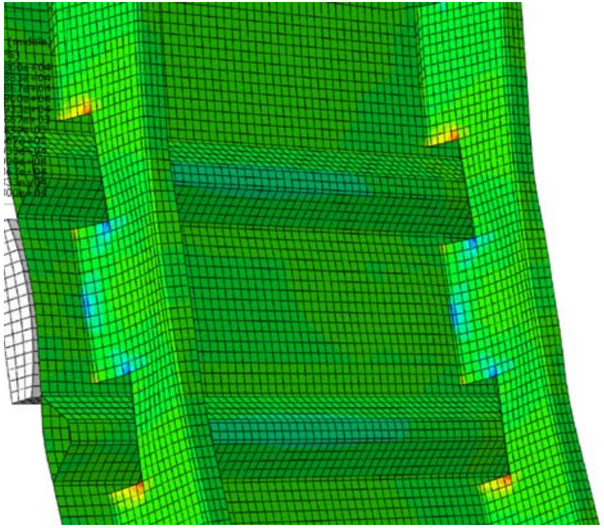
**Inspection for Cause?**

# FEA of Frame Specimens

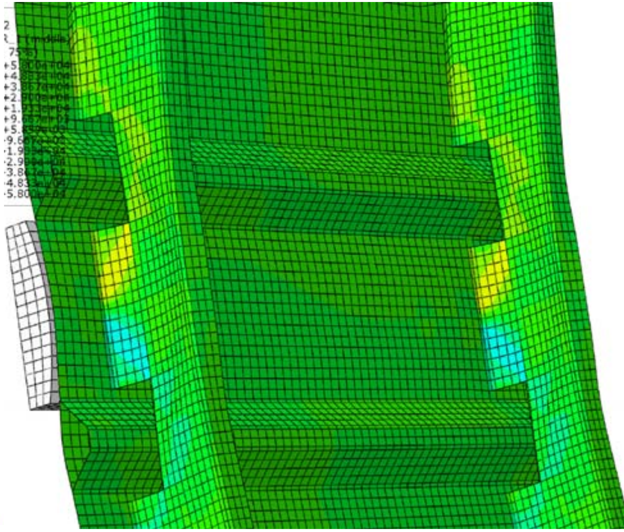
UCSD
Department of Structural Engineering



**S11 stress in the frame direction**

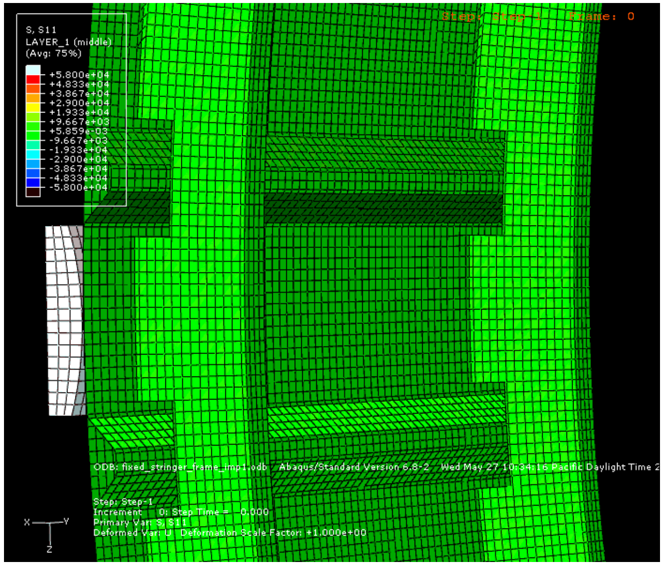


**S22 stress in stringer direction**



**S12 shear stress**

- **12” radius rigid line loading at 0.5” indentation depth**
- **Stresses plotted at the midplane**
- **Peak bending stress in frame (S11)**
- **Large tensile stresses (S22) exists in shear ties located *away* from impact location – pull-off loading**
- **Warpage/rotation of frames (open section)**



ODB: fixed_stringer_frame_imp1.odb Abaqus/Standard Version 6.8-2 Wed May 27 10:34:16 Pacific Daylight Time 2

Step: Step-1
Increment 0: Step Time = 0.000
Primary Var: S, S11
Deformed Var: U Deformation Scale Factor: +1.000e+00

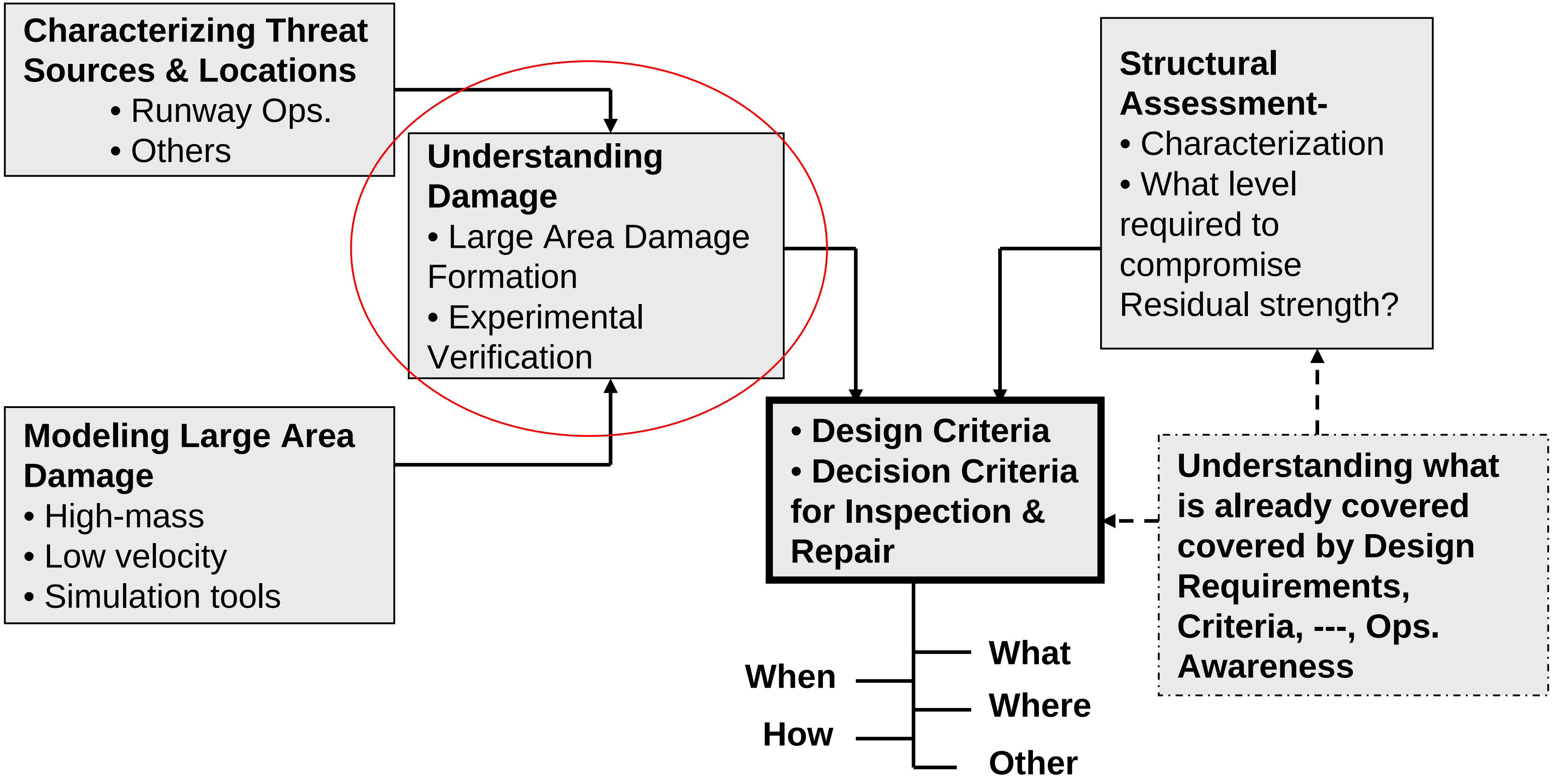
# Summary of Activities

- Blunt Impact Workshop at UCSD in La Jolla, CA – held on Jan. 23, 2009
  - 40 participants from OEM, airlines, agency, industry, academia
  - summary document posted to website: http://csrl.ucsd.edu/UCSDbluntimpact/
    - » major source of damage (30-40%) is from ground service equipment, during pushback
    - » frequency of occurrence for composite a/c expected to be same as for metal
    - » need exists for basic experiments and modeling methods
- LAX observation – March 19, 2009
  - direct observation of ground operations at UAL ramps
    - » quantitative information extracted from photos, video documentation
  - much thanks to Eric Chesmar and United Airlines for hosting activity

- Specimen design and test definition
  - Test plan (1st ver) issued April 23, 2009 – posted on blunt impact website
  - Working Meeting planned for June 29-July 1, 2009 at UCSD

- Lab scale impact experiments
  - basic investigation of effects of impactor radius on localized damage development

# Roadmap for Low Velocity High-Mass Wide-Area “Blunt” Impact Project



**Characterizing Threat Sources & Locations**
- Runway Ops.
- Others

**Understanding Damage**
- Large Area Damage Formation
- Experimental Verification

**Modeling Large Area Damage**
- High-mass
- Low velocity
- Simulation tools

**Structural Assessment-**
- Characterization
- What level required to compromise Residual strength?

- **Design Criteria**
- **Decision Criteria for Inspection & Repair**

**Understanding what is already covered covered by Design Requirements, Criteria, ---, Ops. Awareness**

**When**

**How**

**What**

**Where**

**Other**

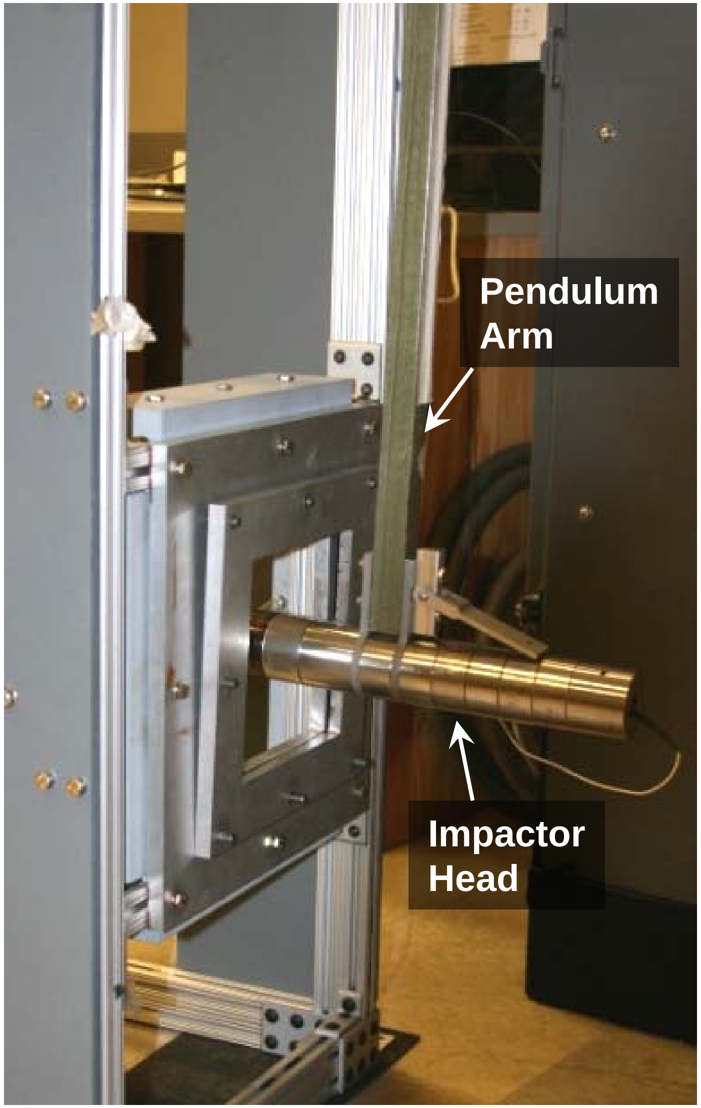
**Inspection for Cause?**

# 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:**

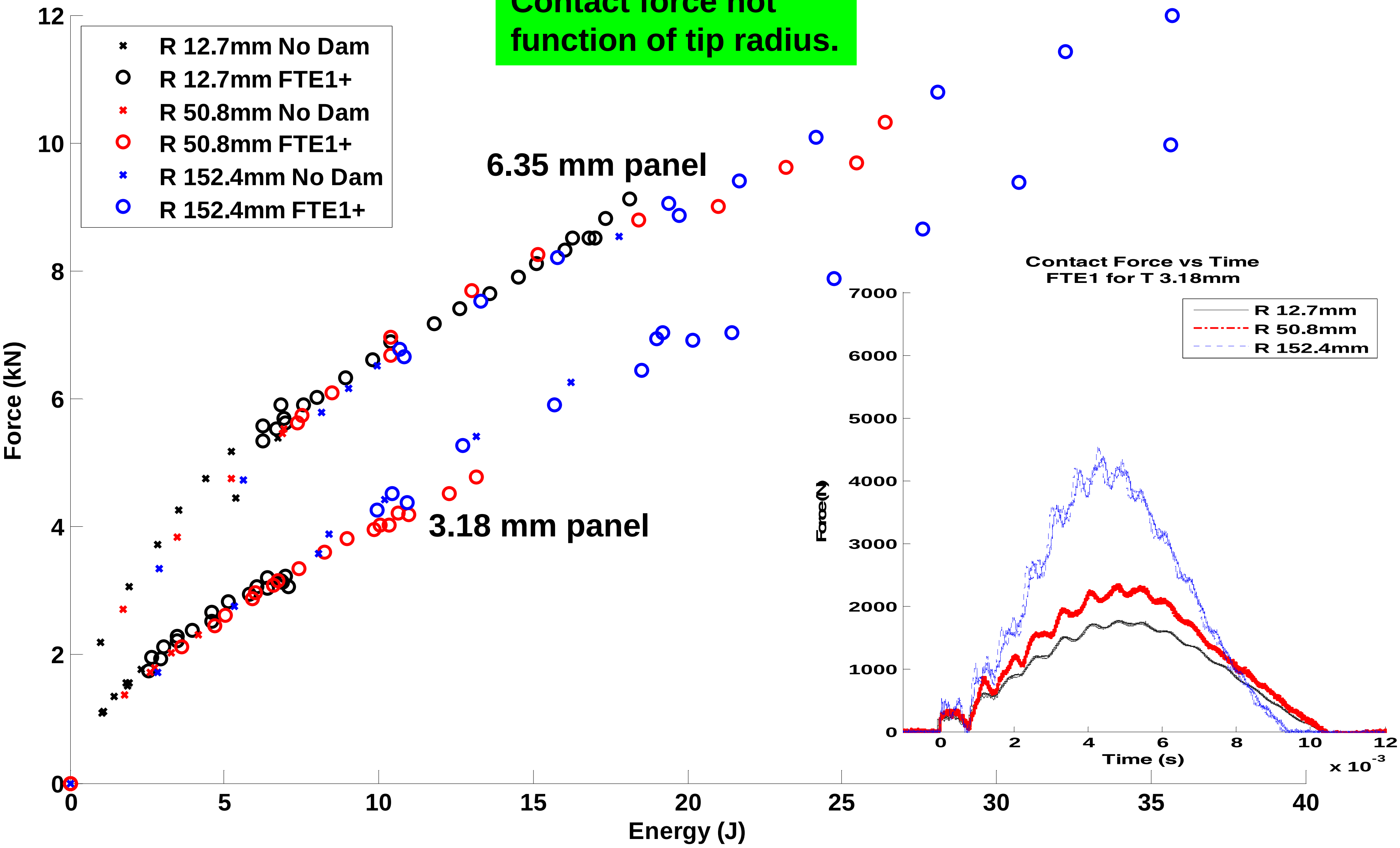
| Glass/Epoxy Panel Thk (mm) | Number of panels tested for tip radius | | |
|---|---|---|---|
| | 12.7mm | 50.8mm | 152.4mm |
| 3.18 | 9 | 10 | 8 |
| 6.35 | 9 | 7 | 7 |



# Peak Contact Force

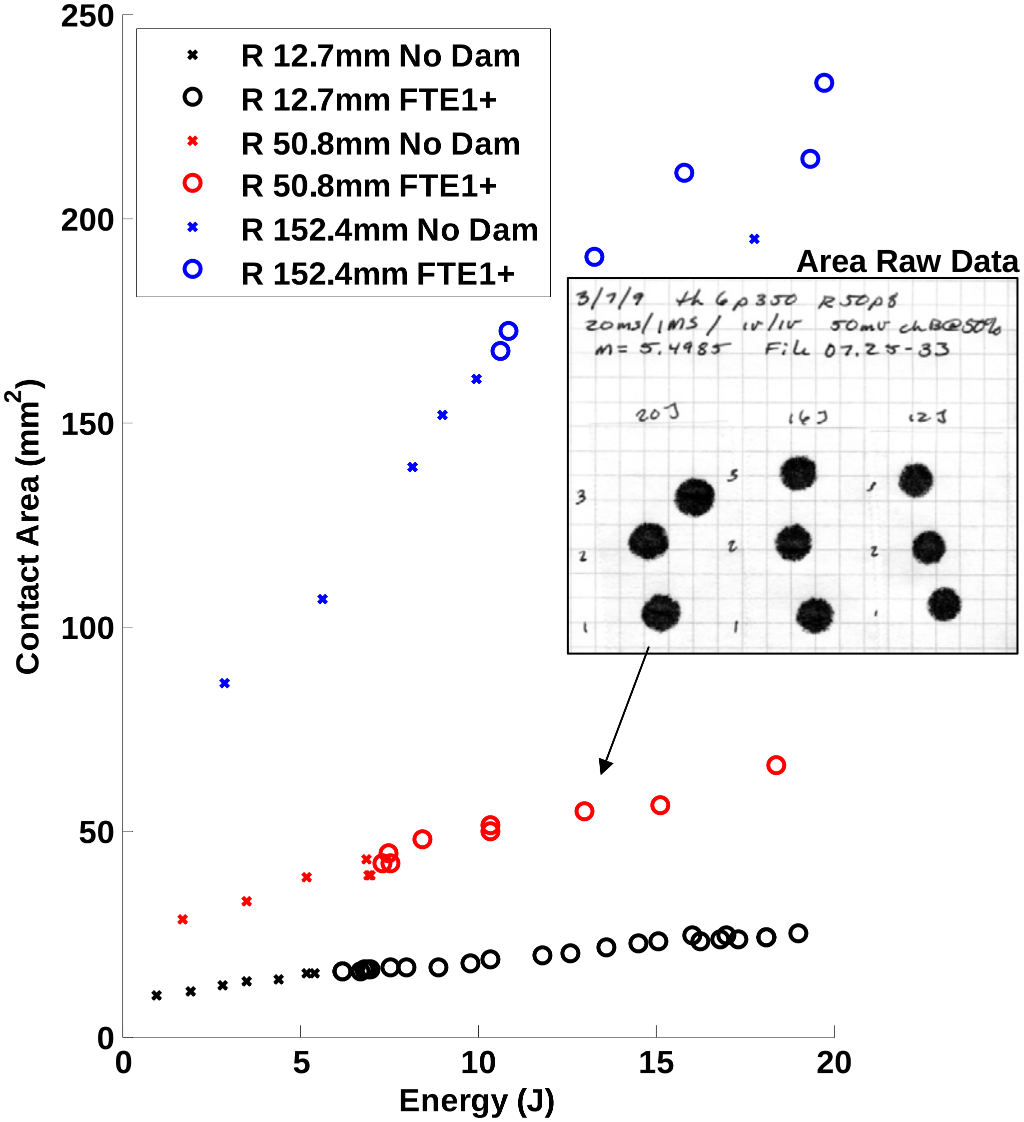
Department of Structural Engineering

**Contact force not function of tip radius.**

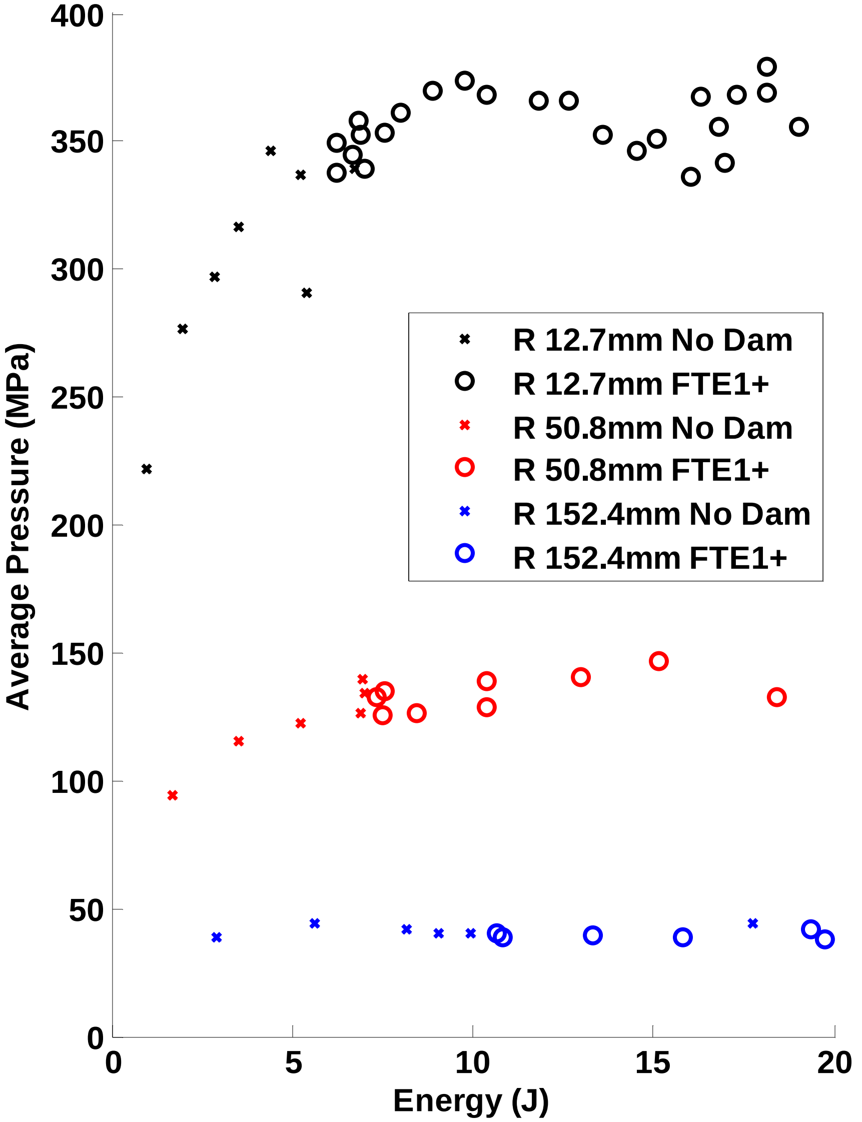


# Contact Area & Pressure

## Contact area strong function of tip radius.



## Contact Pressure



# Lab Scale Impact Tests Summary

## 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

# Overall Conclusions

- **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?**

- **FEA of blunt impact test specimens shows**
  - **large internal stress develops for small indentation (0.25 to 0.5 in.)**
  - **high stresses in frame, shear ties**
    - » **pull-off loading in shear ties *away* from impact location**

# UCSD Project on Blunt Impact

- Project funding from FAA with cost-share from team members
  - part of JAMS COE – technical monitor is Curt Davies
  - teaming: JC Halpin, Bombardier, Cytec, San Diego Composites, Sandia, Jack Bish
  - ice and other high velocity impacts are also part of this program

- 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
    - » 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 visual detectability?
  - 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

# Project Timeline (Year 1)

- **January 23, 2009 – Blunt Impact Workshop**
- **February to May – design test specimen (including stress predictions)**
- **June 29 to July 1, 2009 Working Meeting**
  - **review UCSD test specimen design**
  - **detailed test plan development**
  - **feedback from industry & agencies on direction of project**
  - **more info at: http://csrl.ucsd.edu/UCSDbluntimpact/**
- **June & July – test fixtures and manuf. tooling design, material acquisition**
  - **Cytec will provide prepreg and adhesive**
- **July & August – fabrication**
- **late August – conduct stringer panel tests**
- **September & October – conduct frame panel tests**

**For more information, contact Hyonny Kim at hyonny@ucsd.edu**