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

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?

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

Design Criteria
- Decision Criteria for Inspection & Repair

When
- What
- Where
- Other

How
- Inspection for Cause?
Ground Equipment Adjacency

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 Approach B757

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)
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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

- Increasing Length Scale, Complexity, and Specificity
  - Phase III (Year 3)
  - Phase II (Year 2)
  - Phase I (Year 1)
- 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
- Scaling, B.C. Effects
  - Modeling Capability Development & Correlation with Test are Key Aspects at Each Level
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

Simply-supported + rotational stiffness

Free

Free

Simply-supported + rotational stiffness
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
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FEA of Frame Specimens

- 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)
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/](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
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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:

<table>
<thead>
<tr>
<th>Glass/Epoxy Panel Thk (mm)</th>
<th>Number of panels tested for tip radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.7mm</td>
</tr>
<tr>
<td>3.18</td>
<td>9</td>
</tr>
<tr>
<td>6.35</td>
<td>9</td>
</tr>
</tbody>
</table>
Peak Contact Force

Contact force not function of tip radius.

6.35 mm panel

3.18 mm panel

Contact Force vs Time
FTE1 for T 3.18mm

R 12.7mm No Dam
R 12.7mm FTE1+
R 50.8mm No Dam
R 50.8mm FTE1+
R 152.4mm No Dam
R 152.4mm FTE1+
Contact area strong function of tip radius.

Contact Pressure

Area Raw Data

- R 12.7mm No Dam
- R 12.7mm FTE1+
- R 50.8mm No Dam
- R 50.8mm FTE1+
- R 152.4mm No Dam
- R 152.4mm FTE1+
### Lab Scale Impact Tests Summary

#### Damage Initiation (Delam.) Threshold

<table>
<thead>
<tr>
<th>FTE1 for each panel thickness T, impactor tip radius R</th>
<th>R 12.7mm</th>
<th>R 50.8mm</th>
<th>R 152.4mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T 3.18mm</td>
<td>2.44J</td>
<td>4.44J</td>
<td>10.3J</td>
</tr>
<tr>
<td>T 6.35mm</td>
<td>6.47J</td>
<td>7.45J</td>
<td>10.8J</td>
</tr>
</tbody>
</table>

#### Cracking/Fiber Rupture Threshold

<table>
<thead>
<tr>
<th>FTE2 for each panel thickness T, impactor tip radius R</th>
<th>R 12.7mm</th>
<th>R 50.8mm</th>
<th>R 152.4mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T 3.18mm</td>
<td>7.04J</td>
<td>10.3J</td>
<td>N/A</td>
</tr>
<tr>
<td>T 6.35mm</td>
<td>17.0J</td>
<td>25.5J</td>
<td>N/A</td>
</tr>
</tbody>
</table>

> 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
• 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