NASA ACC High Energy Dynamic Impact: Methodology and Outcomes

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Outline

- NASA ACC High Energy Dynamic Impact Overview
- Ballistic Impact Testing
  - Test Set-up
  - Test Results
- Test Analysis Comparison
  - LS-DYNA MAT162
  - LS-DYNA MAT261
  - Smoothed Particle Galerkin (SPG)
  - EMU Peridynamics
Team

NASA

Boeing

GE Aviation

Sandia National Laboratories

United Technologies
1) Predictive Capabilities
   • Robust analysis for smarter testing
   • Better prelim design, fewer redesigns

2) Rapid Inspection
   • Increase inspection throughput
   • Quantitative characterization of defects
   • Automated inspection

3) Manufacturing Process Simulation
   • Reduce manufacture development time
   • Improve quality control
   • Fiber placement and cure process models

Verification & Validation
   • Tie Technical Challenge work together
   • Validate program benefits
The NASA ACC High Energy Dynamic Impact (HEDI) activity aims to reduce the number of analysis and testing iterations by developing analytical models that accurately predict:

- Physical response
- Damage
- Failure modes

for large scale composite structures.
**GOAL:** Develop analytical models that accurately predict physical response, damage, and failure modes of large composite structures. *Limitations and “best practices” documented*

**Validation Articles**
Design, Manufacturing, and Testing

**PDA Model Analysis**
Evaluate ability of material models to simulate representative structure

**Phase I:**
- Capabilities and limitations of material models
- Coupon characterization and flat panel ballistic impact tests

**Phase II:**
Dynamic experiments on more representative structure
Overview of NASA ACC HEDI Testing

Phase 1
- Sub-element ballistic panel impact testing
- Non-configured flat panels

✓ Completed

Phase 2
Build on Phase 1 testing adding:
- Configuration (fastener, stringer, frame)
- Curvature
- Scale

Projected Demo

Aircraft Structure
Phase I Technical Development

Model Evaluation with Case Studies

Blind Predictions

Material Model Calibration

Test-Analysis Correlation

Material Characterization Testing

Ballistic Impact Testing
Phase I Accomplishments

• Assessed and developed Progressive Damage Analysis (PDA) models
  • Conducted coupon-level characterization testing
  • Updated stiffness, damage, and strength parameters

• Conducted extensive ballistic impact testing

• Evaluated model performance in predicting damage and panel behavior
  • Promising results
  • Improved upon past performance
  • Areas of improvement to target in Phase II

Capabilities and limitations of PDA models and significant test data for high energy dynamic impact
Detailed Phase I Accomplishments

- Four (4) analysis approaches: LS-Dyna MAT162, MAT261, and SPG; EMU Peridynamics
- Forty-two (42) ballistic impact tests on sub-element panels
  - Two (2) material systems with tape & fabric
  - Five (5) unique laminate configurations
  - Two (2) projectiles
- Collaboration with GE, P&W, and Sandia NL

Damage state prediction from Peridynamics

Example NDE of impact panel
Ballistic Impact Testing Overview

Forty-two (42) ballistic impact tests on flat panels
- Two (2) material systems
  - IM7/8552 UD tape & PW fabric
- Five (5) unique laminate types
- Two (2) projectiles

Blunt Projectile – 0.93lbs
Flexane® 94– 3” diameter

Sharp Projectile – 0.75lbs
2” x 2” x 0.25” Titanium Plate
Flexane® 94 – 3” diameter
Ballistic Impact Testing Overview

- Single stage gas gun
- 3” inner diameter
- 23’ length
- 1900 in³ pressure vessel volume
Ballistic Impact Testing

- UD Tape only
  - Quasi-isotropic
- UD Tape only
  - Non-Traditional
- PW Tape only
- UD Tape / PW Fabric (2)
- UD Tape / PW Fabric (3)

**Blunt Projectile**
Progressive Damage Analysis (PDA)

- LS-DYNA MAT 162/261
- Smoothed Particle Galerkin
- EMU Peridynamics

Fixed BC (qty 4)

Rear View

Front View

Diameter = 3"
Length = 3.5"
Progressive Damage Analysis (PDA)

Blunt Projectile – Typical Response

Rebound

Penetration
Test-Analysis Comparison

- **Displacement**
- **Load Cell**
- **Delamination**
- **Panel NDE**
- **Simulation**

**Threshold Velocity ($V_{50}$)**

- **Disc Test**
- **PD**
- **MAT162**
- **MAT261**
- **SPG**

**Test** vs. **Simulation**

**MAT 162 Simulation**

**Test**

**Load Cell**

**MAT 162 Simulation**

**Displacement**

**Panel NDE**

**Simulation**
Summary

- **Phase I**
  - Material models developed
    - Characterization coupon testing – complete
    - Promising results from MAT162, MAT261, and peridynamics
  - Ballistic impact test: flat panels – complete
  - Identification of tech gaps

- **Phase II**
  - Testing of more complex structures
  - Validation of PDA models

Significant strides have been made towards the goal of using simulation of composites in impact applications
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• Industry wide effort to reduce composite aircraft certification timeline by 30% by improving technology in manufacturing, testing, analysis, etc.
• Study was a product of the research involving development of PDFA tools for high energy dynamic impact

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.
Questions?
Test-Analysis Comparison

Delam

Test

Panel Rear-View

Simulation

Panel Rear-View

Panel NDE – Time of Flight

Delamination

.29” Quasi-isotropic UD tape – Blunt projectile

Disp

MAT 162 Simulation

Displacement Z

Test
Test-Analysis Comparison

Load Cell
Ballistic Impact Testing Overview
Ballistic Impact Testing

Amplitude data is on the left, time of flight (TOF) data is on the right
Ballistic Impact Testing

LGE1210 Back
Tape - TL (40p)
290 ft/s
62 ft/s (Penetrate)

LGE1215 Front
Fabric (40p)
292 ft/s
49 ft/s (Penetrate)

LGE1241 Back
Tape - NTL (40p)
264 ft/s
-71 ft/s (Rebound)

LGE1221 Front
Hybrid2 (40p)
293 ft/s
150 ft/s (Penetrate)

LGE1230 Front
Hybrid3 (40p)
286 ft/s
62 ft/s (Penetrate)

Spare Panel
Tape - NTL (40p)
281 ft/s
156 ft/s (Penetrate)

LGE1210 Front
Tape - TL (40p)
290 ft/s
62 ft/s (Penetrate)

LGE1215 Front
Fabric (40p)
292 ft/s
49 ft/s (Penetrate)

LGE1241 Front
Tape - NTL (40p)
264 ft/s
-71 ft/s (Rebound)

LGE1221 Front
Hybrid2 (40p)
293 ft/s
150 ft/s (Penetrate)

LGE1230 Front
Hybrid3 (40p)
286 ft/s
62 ft/s (Penetrate)
Test-Analysis Comparison

Rear View

Front View

Fixed BC (qty 4)

Sharp Projectile
Material Model Characterization