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

Advanced Composites Consortium

Sandia National Laboratories

United Technologies

NASA ACC Technical Challenge Areas

1) Predictive Capabilities

- Robust analysis for smarter testing
- Better prelim design, fewer redesigns

2) Rapid Inspection

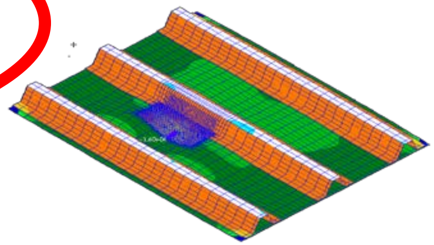
- Increase inspection throughput
- Quantitative characterization of defects
- Automated inspection

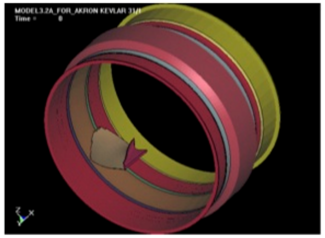
3) Manufacturing Process Simulation

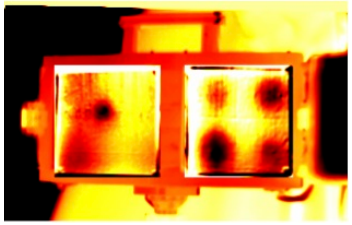
- Reduce manufacture development time
- Improve quality control
- Fiber placement and cure process models

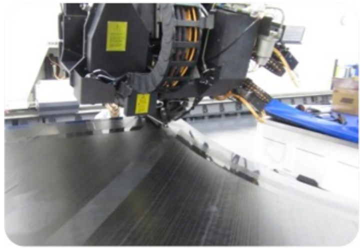
Verification & Validation

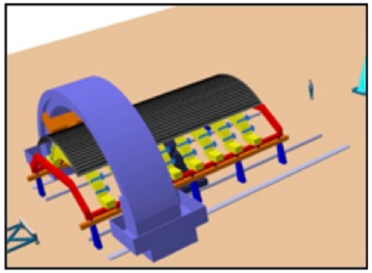
- Tie Technical Challenge work together
- Validate program benefits









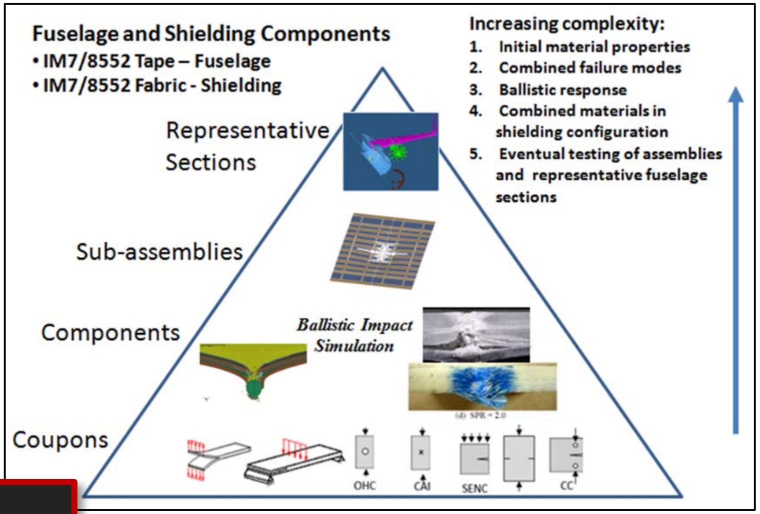


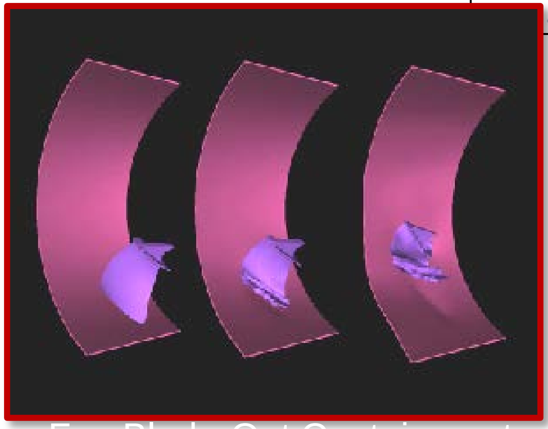
NASA ACC High Energy Dynamic Impact Overview

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





HEDI Technical Approach

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

Phase II:
Dynamic experiments on more representative structure

Validation Articles
Design, Manufacturing, and Testing

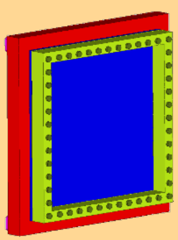
PDA Model Analysis
Evaluate ability of material models to simulate representative structure

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

Overview of NASA ACC HEDI Testing

Phase 1

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

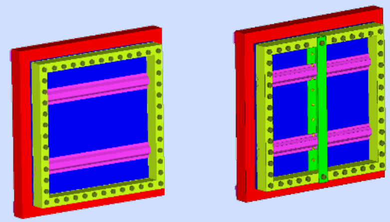


✓ *Completed*

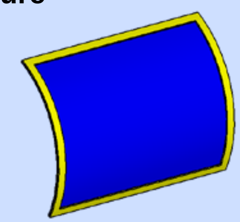
Phase 2

Build on Phase 1 testing adding:

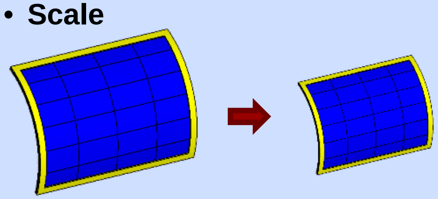
- **Configuration (fastener, stringer, frame)**



- **Curvature**

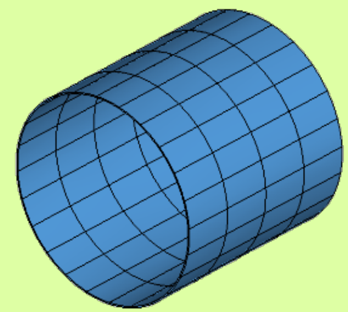


- **Scale**



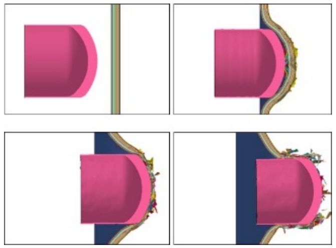
Planned

Aircraft Structure

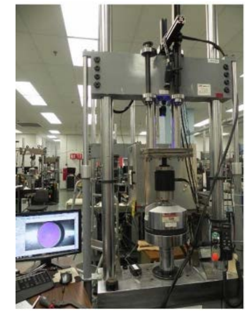


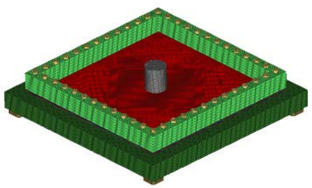
Projected Demo

Phase I Technical Development



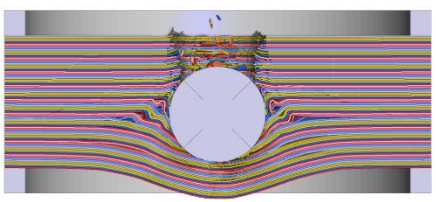
Model Evaluation with Case Studies





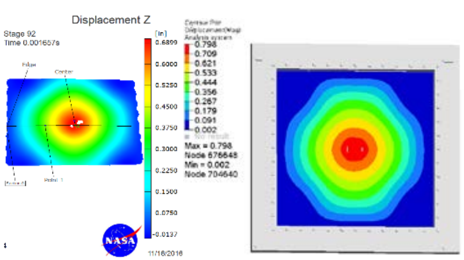
Blind Predictions

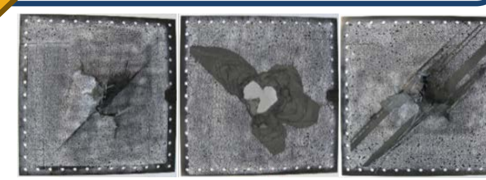
Material Characterization Testing



Material Model Calibration

Ballistic Impact Testing

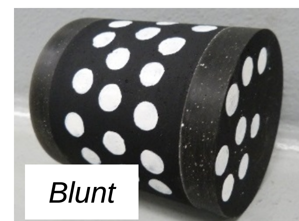


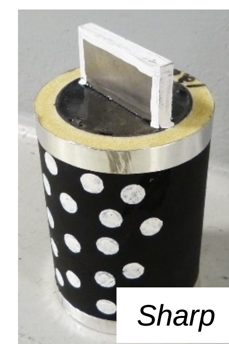


Test-Analysis Correlation

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

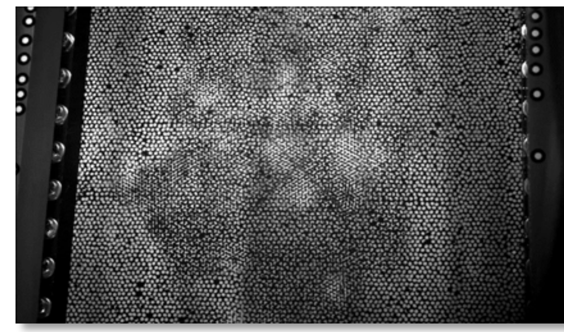


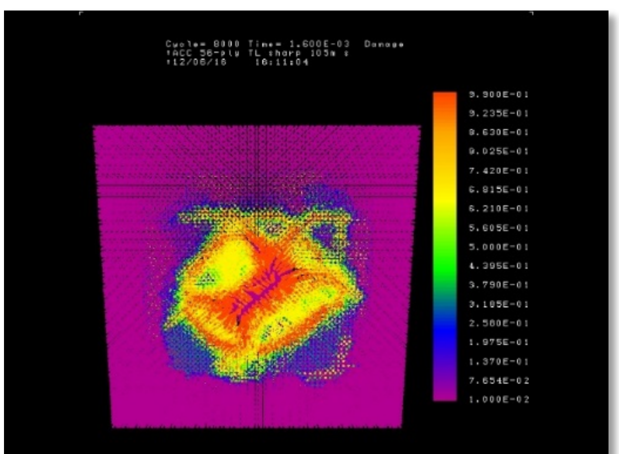


Capabilities and limitations of PDA models and significant test data for high energy dynamic impact

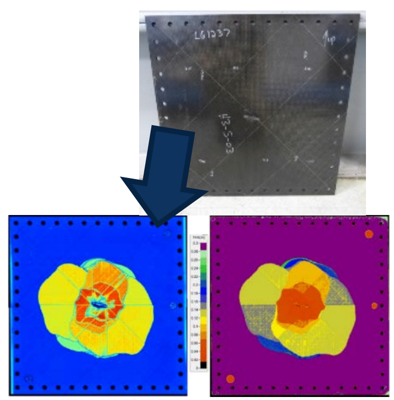
Detailed Phase I Accomplishments

- **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**

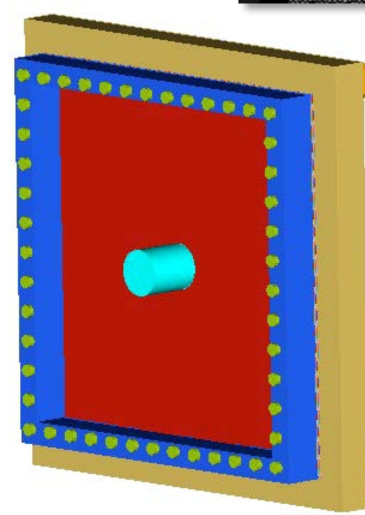


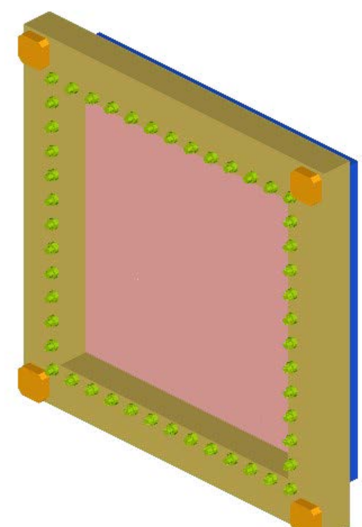


Damage state prediction from Peridynamics

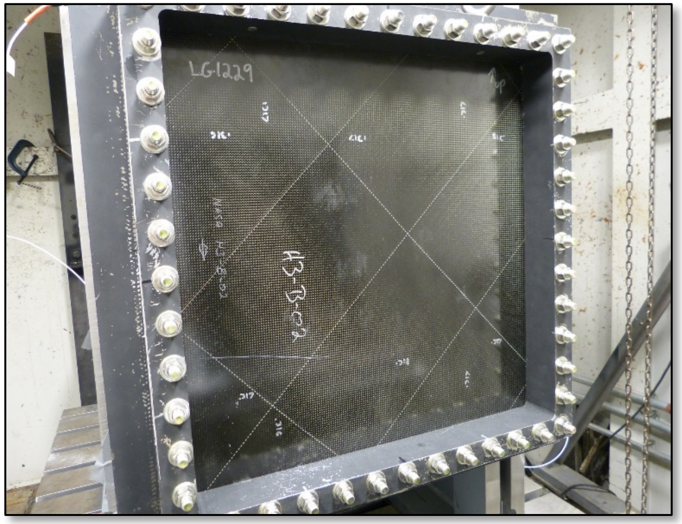


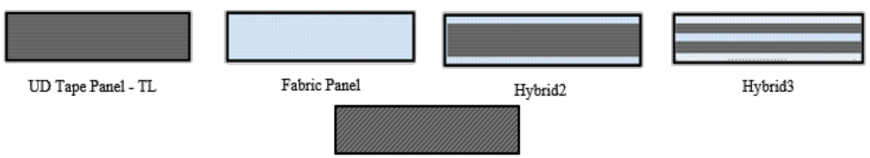
Example NDE of impact panel





Ballistic Impact Testing Overview





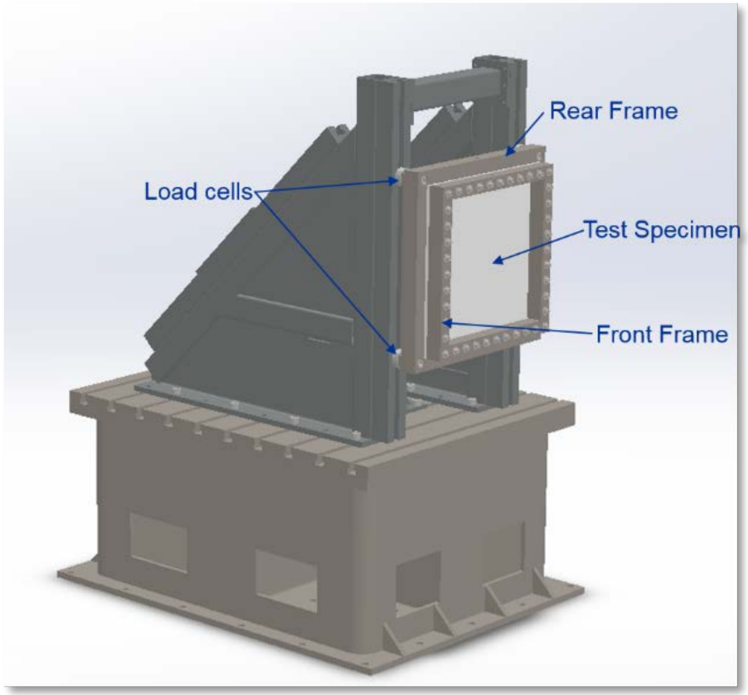
Forty-two (42) ballistic impact tests on flat panels

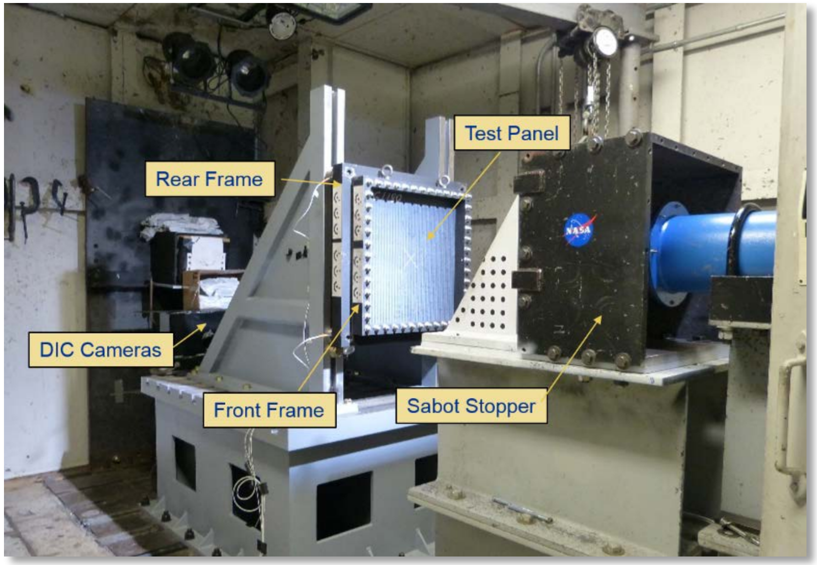
- Two (2) material systems
  - IM7/8552 UD tape & PW fabric
- Five (5) unique laminate types
- Two (2) projectiles

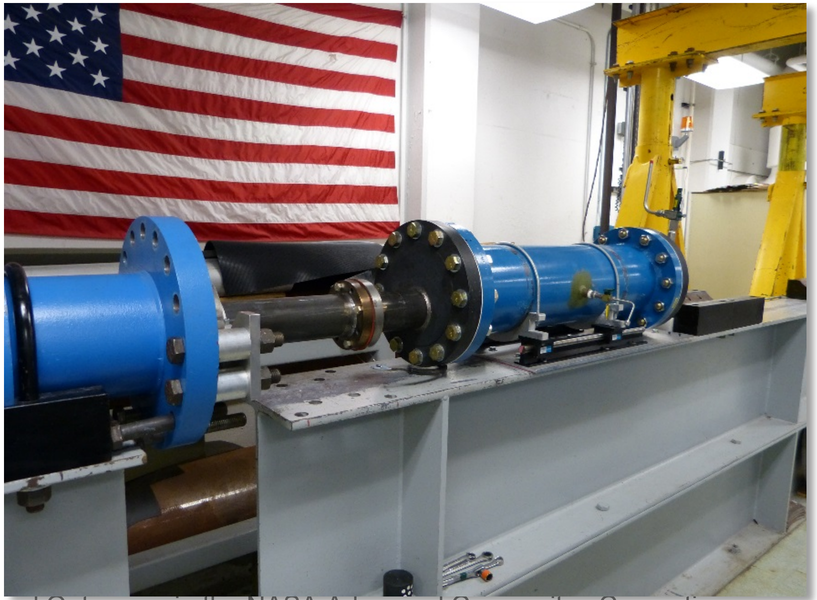
Blunt Projectile – 0.93lbs
Flexane® 94– 3” diameter

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

Ballistic Impact Testing Overview

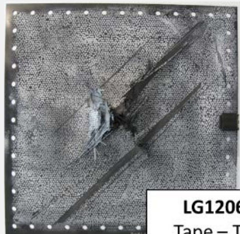




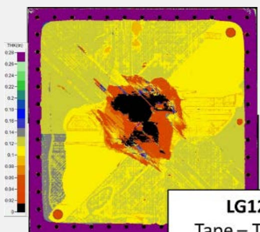


- Single stage gas gun
- 3" inner diameter
- 23' length
- 1900 in^3 pressure vessel volume

Ballistic Impact Testing

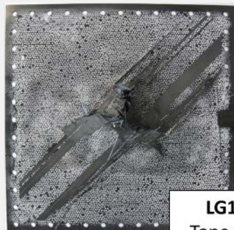


LG1206 Back
Tape – TL (40p)
667 ft/s
204 ft/s (Penetrate)

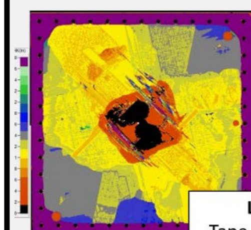


LG1206
Tape – TL (40p)
667 ft/s
204 ft/s (Penetrate)

UD Tape only
Quasi-isotropic

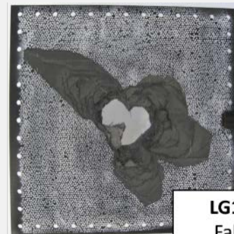


LG1242 Back
Tape – NTL (40p)
660 ft/s
240 ft/s (Penetrate)

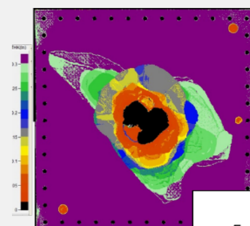


LG1242
Tape – NTL (40p)
660 ft/s
240 ft/s (Penetrate)

UD Tape only
Non-Traditional

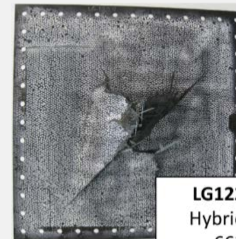


LG1214 Back
Fabric (40p)
663 ft/s
397 ft/s (Penetrate)

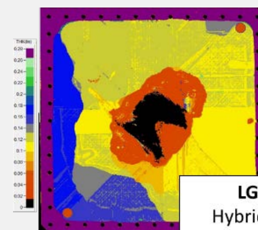


LG1214
Fabric (40p)
663 ft/s
397 ft/s (Penetrate)

PW Tape only



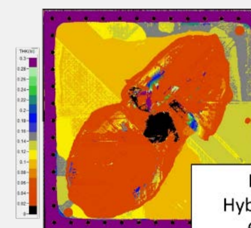
LG1224 Back
Hybrid2 (40p)
663 ft/s
223 ft/s (Penetrate)



LG1224
Hybrid2 (40p)
663 ft/s
223 ft/s (Penetrate)

UD Tape /
PW Fabric (2)

LG1229 Back
Hybrid3 (40p)
670 ft/s
140 ft/s (Penetrate)

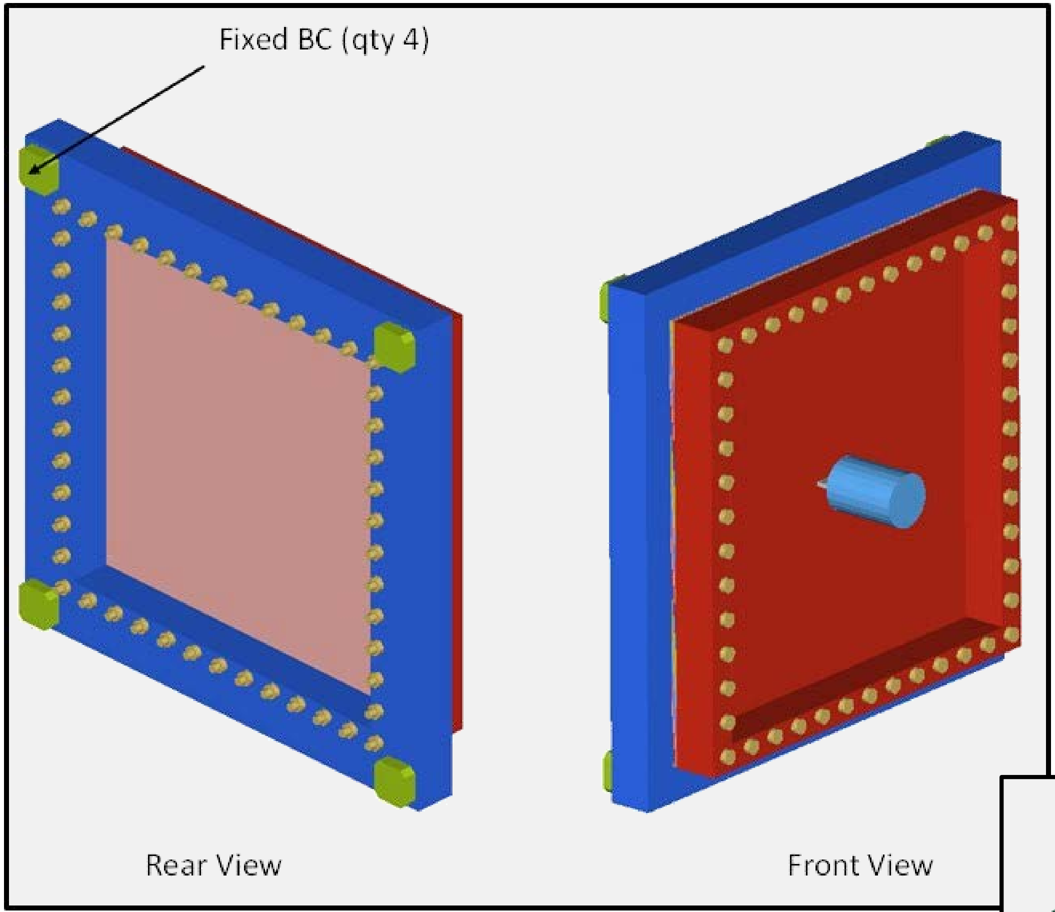


LG1229
Hybrid3 (40p)
670 ft/s
140 ft/s (Penetrate)

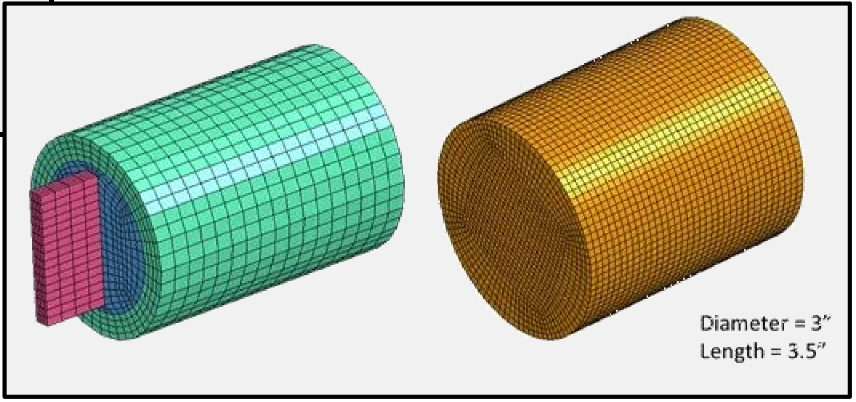
UD Tape /
PW Fabric (3)

Blunt Projectile

Progressive Damage Analysis (PDA)

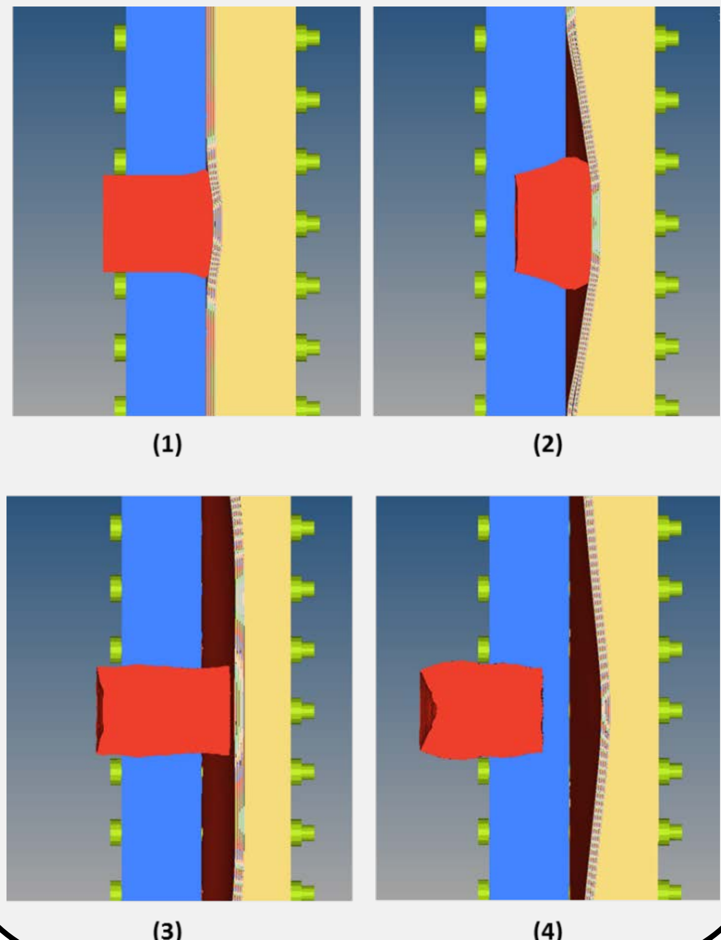


- LS-DYNA MAT 162/261
- Smoothed Particle Galerkin
- EMU Peridynamics

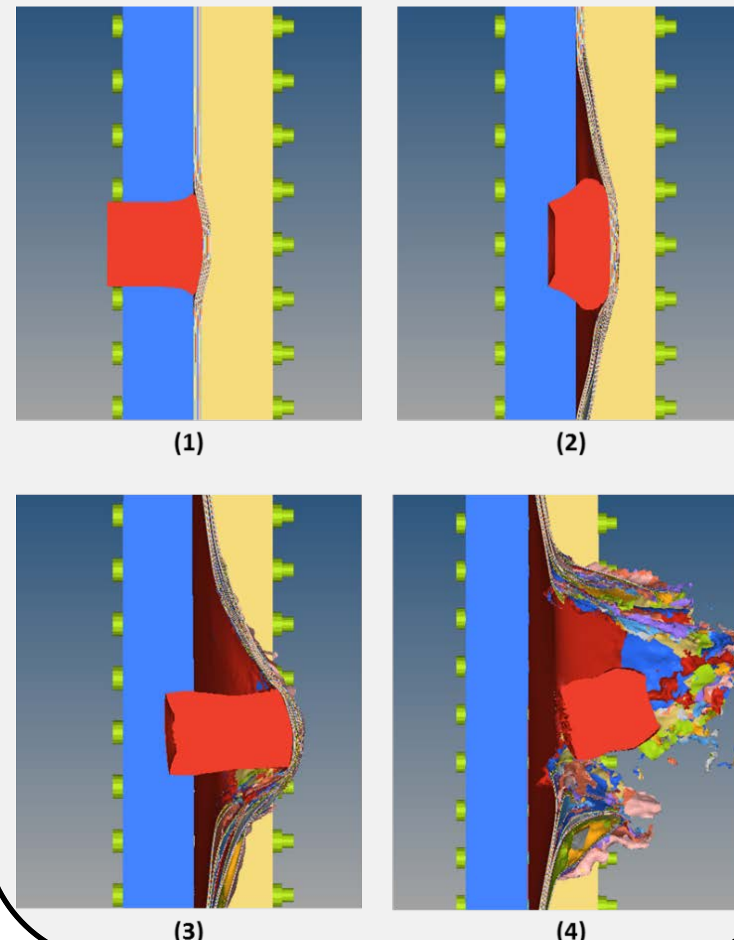


Progressive Damage Analysis (PDA)

Rebound



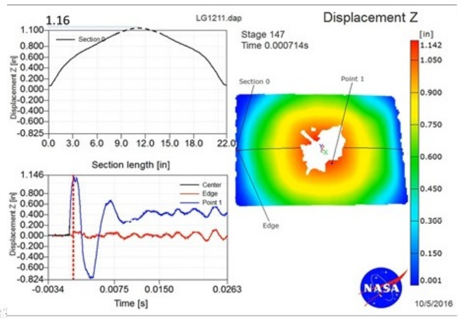
Penetration



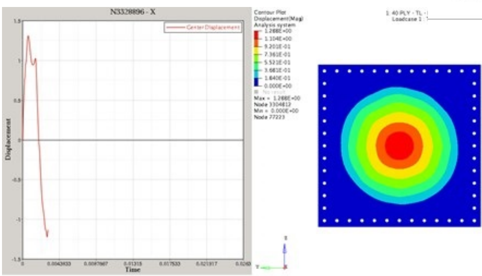
Blunt Projectile – Typical Response

Test-Analysis Comparison

Displacement

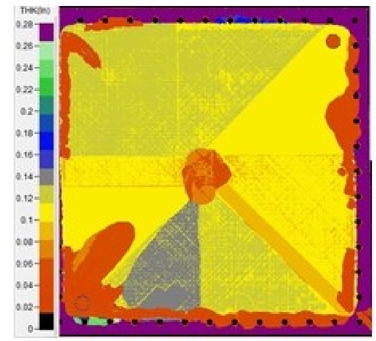


Test

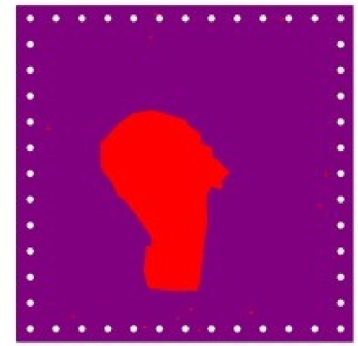


MAT 162 Simulation

Delamination

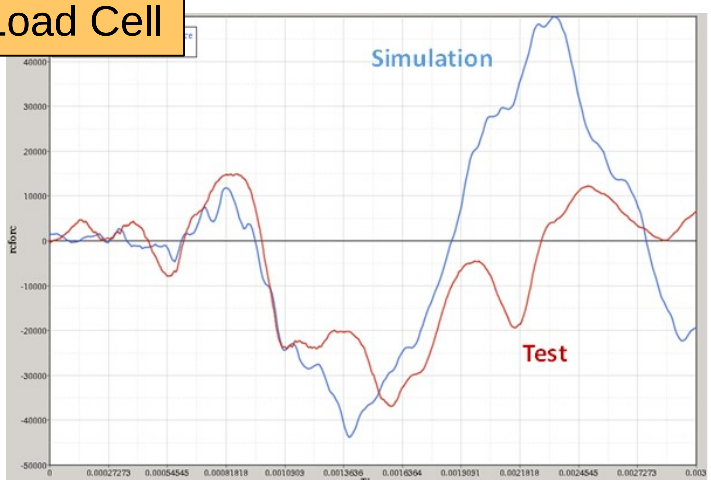


Panel NDE

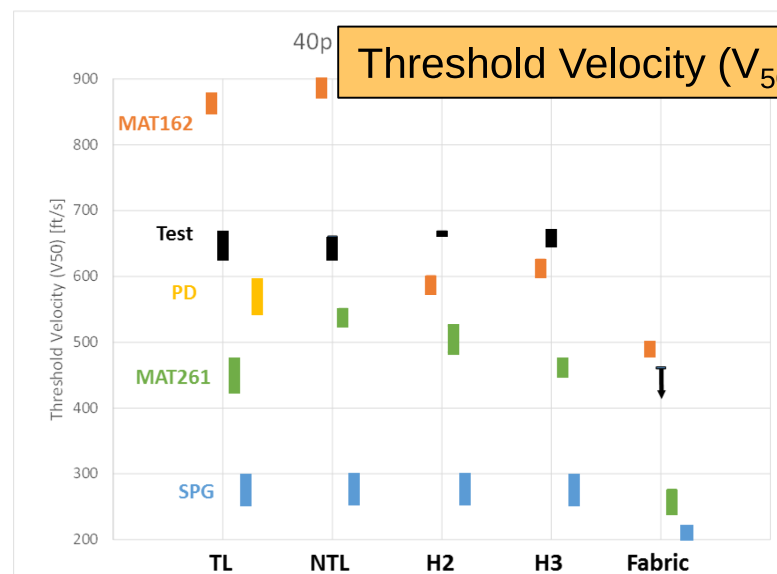


Simulation

Load Cell



Threshold Velocity (V_{50})



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

Acknowledgements

- This effort was performed under the support of the NASA Advanced Composites Project and Consortium
  - 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.

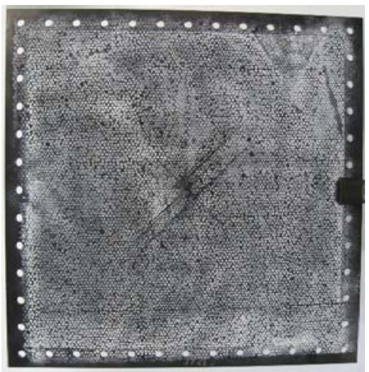
Questions?

Test-Analysis Comparison

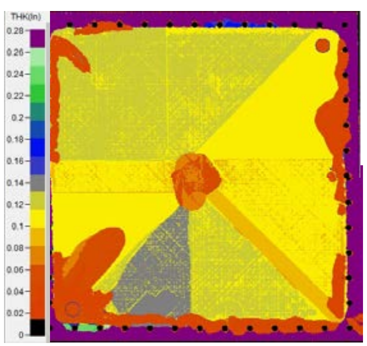
Delam

Disp

Test



Panel Rear-View

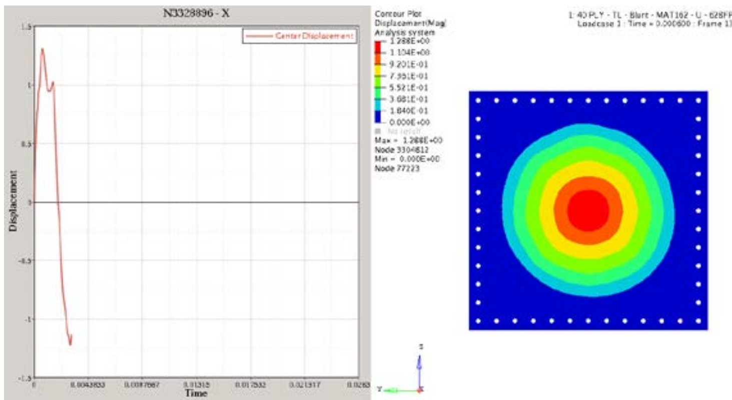


Panel NDE – Time of Flight

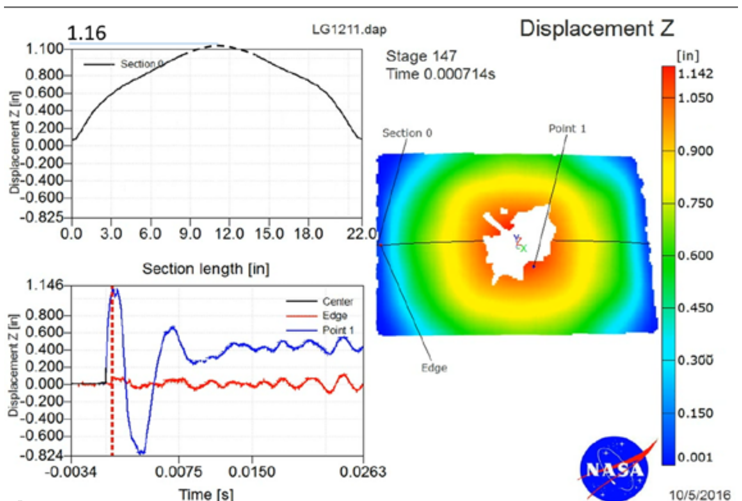
Simulation

Panel Rear-View

Delamination



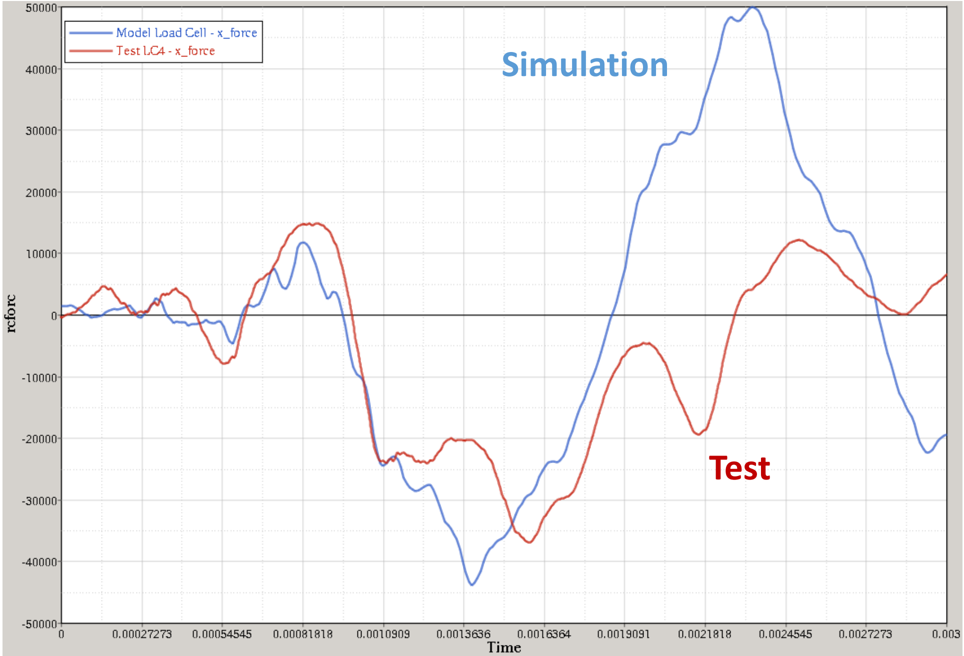
MAT 162 Simulation



Test

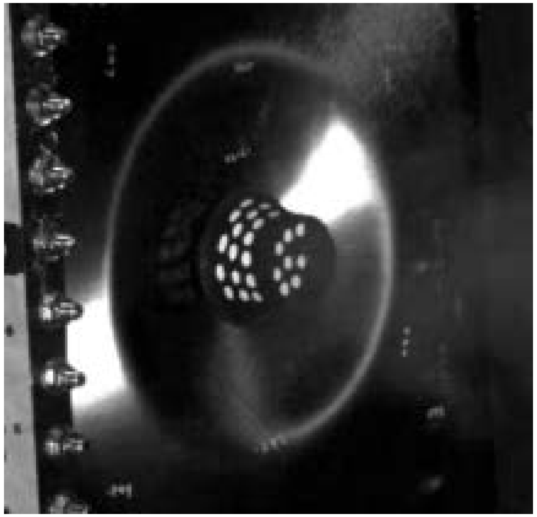
.29" Quasi-isotropic UD tape – Blunt projectile

Test-Analysis Comparison

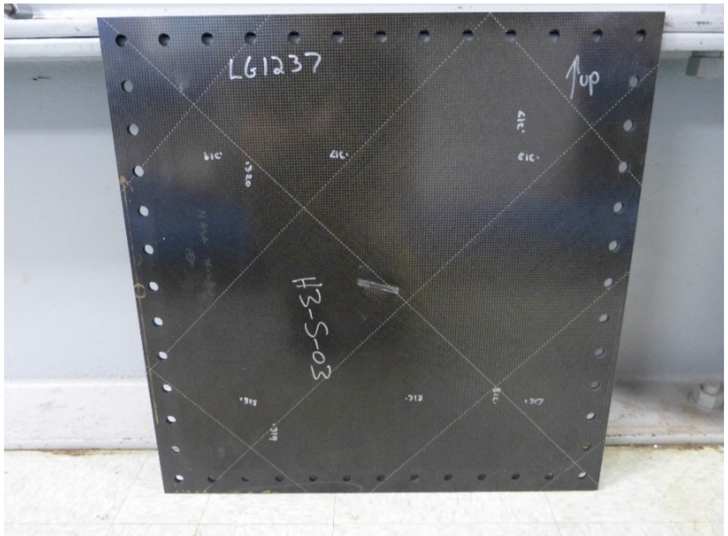


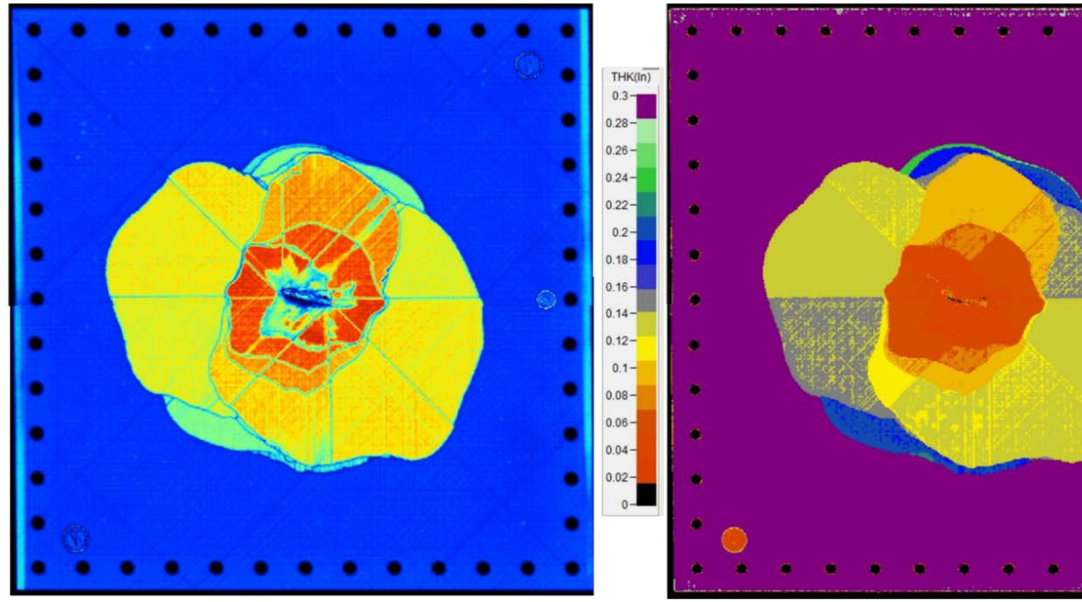
Load Cell

Ballistic Impact Testing Overview



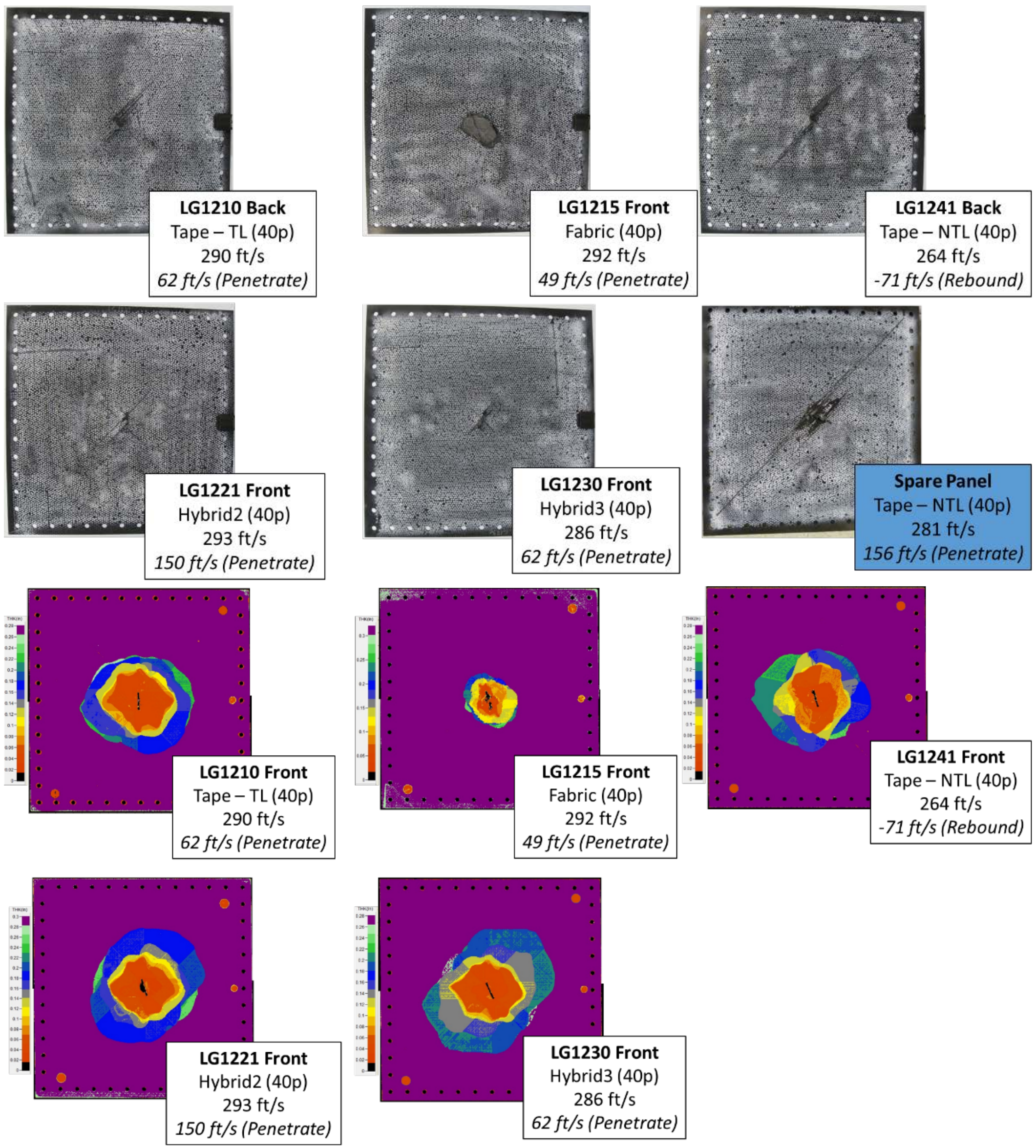
Ballistic Impact Testing



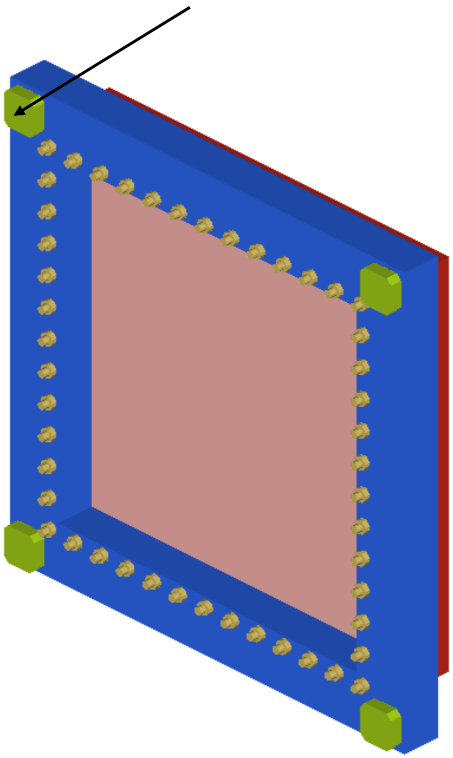


Amplitude data is on the left, time of flight (TOF) data is on the right

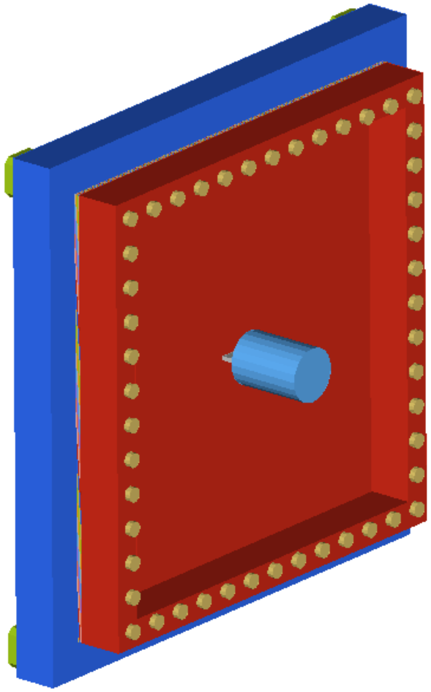
Ballistic Impact Testing



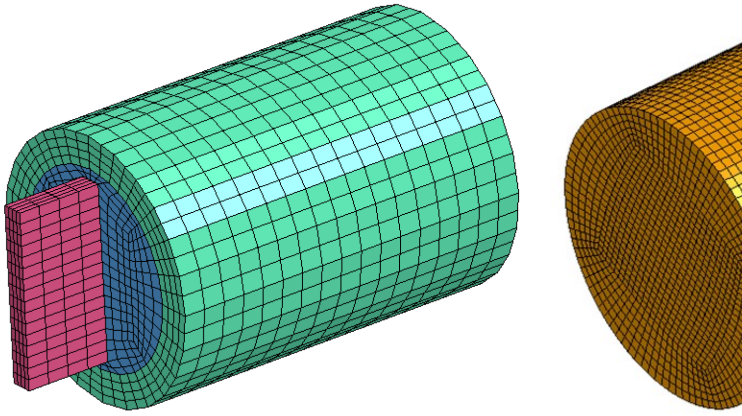
Test-Analysis Comparison



Rear View



Front View



Sharp Projectile

Material Model Characterization