Analysis and Testing of a Composite Fuselage Shield for Open Rotor Engine Blade-Out Protection

J. Michael Pereira[1], William Emmerling[2], Silvia Seng[3],
Charles Frankenberger[3], Charles R. Ruggeri[1], Duane M. Revilock[1]
Kelly S. Carney[1]

[1] NASA Glenn Research Center, Cleveland, Ohio
[2] FAA William J. Hughes Technical Center, Atlantic City, NJ
[3] Naval Air Warfare Center, Weapons Division, China Lake, CA

Outline

- Background
- Pre-test analysis
  - Test Configuration Design
  - Panel thickness design
- Blade-off Test
  - Test Setup
  - Instrumentation
  - Test Video
  - Test Results
  - Comparison with pretest predictions
- Conclusion

Background

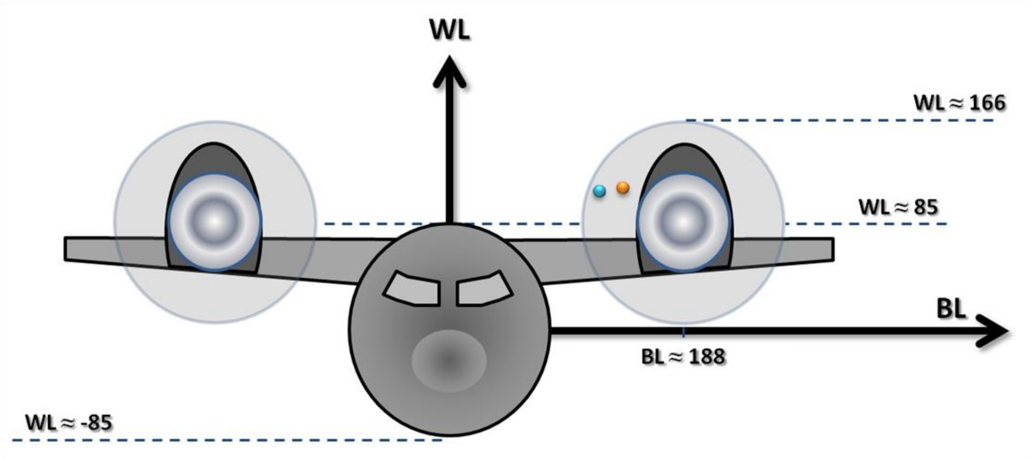
- In the 1980s open rotor engines were developed for improved fuel efficiency
- Technical challenges and lower fuel prices eventually reduced interest
- There has been recent renewed interest in these engines
- FAA goal is equivalent level of safety as ducted fan engines
- FAA investigating feasibility of fuselage shielding for open rotor engines

GE UDF

Pratt & Whitney/Hamilton Standard/Allison 578–DX

FAA Feasibility Study

- FAA selected a medium range aircraft configuration with a high wing and wing mounted open rotor engines

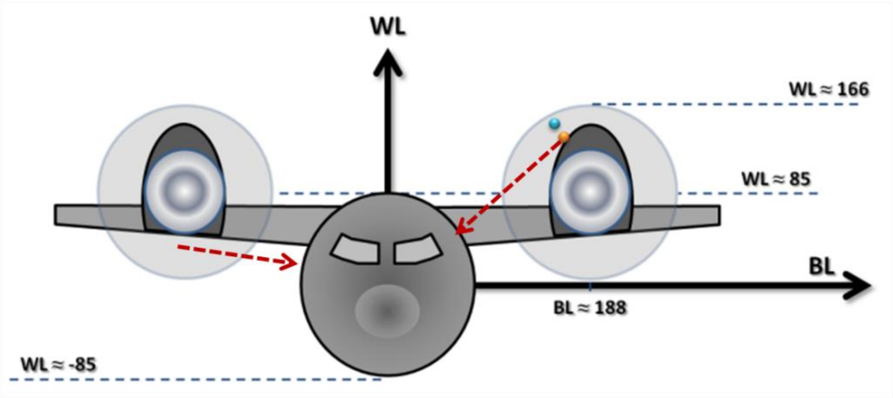


- Trajectory analyses conducted at NASA/GRC to predict the blade release angles for the worst case impact scenario
- Computational analyses conducted at NASA/GRC to predict required composite shield thickness
- LS-DYNA predictions based on model correlation with small scale ballistics testing
- Test configuration design – worst case scenario
- Full scale subcomponent test conducted at China Lake Naval Air Warfare Center

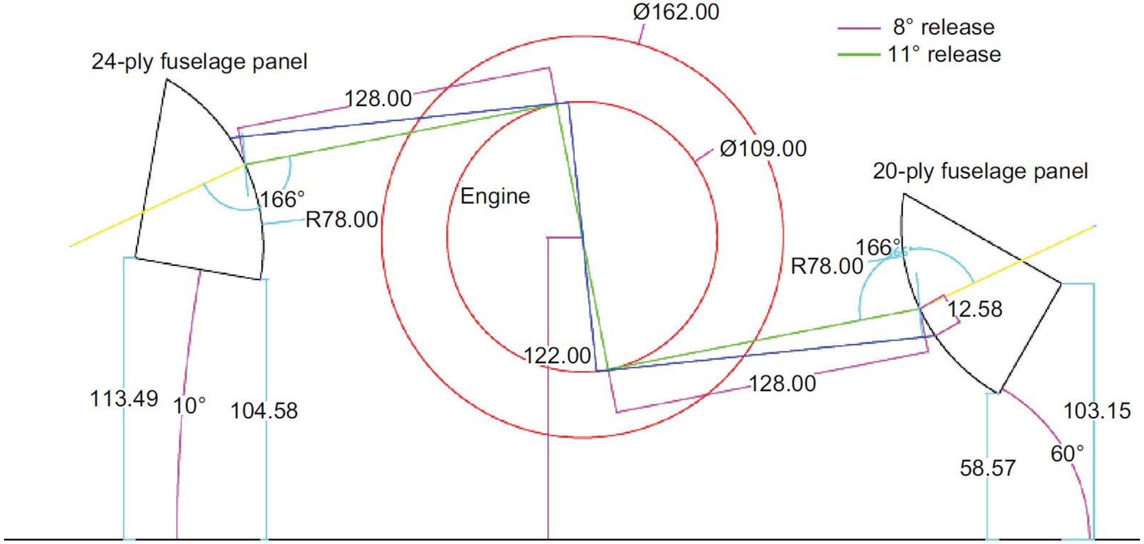
FAA Feasibility Study

- Trajectory analysis predicted blade release angles for the blade to impact the fuselage with a normal velocity vector aligned with the long axis of the blade.

Worst case

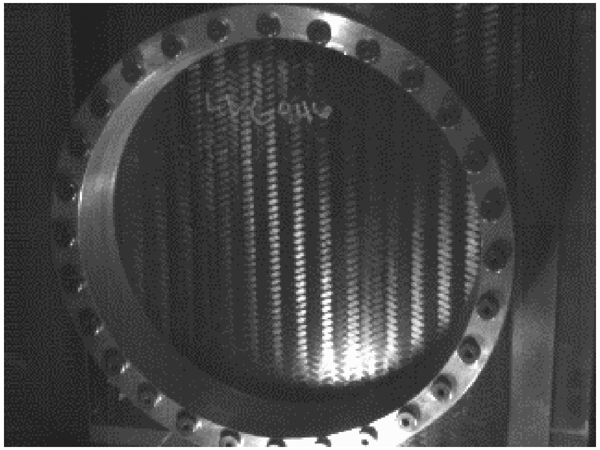


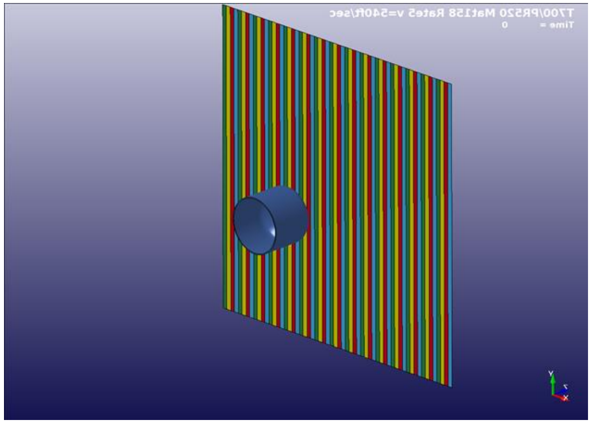
Test Configuration

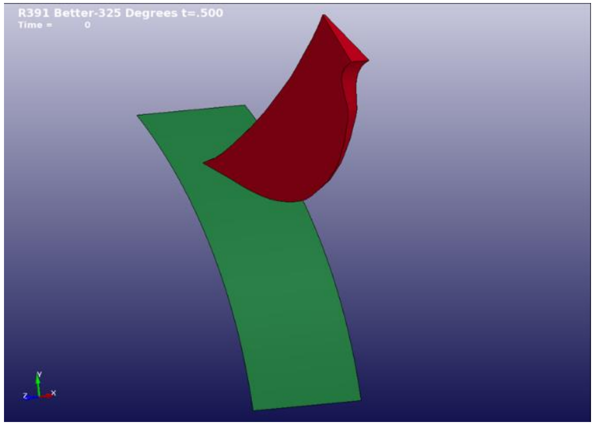


Pre-test Predictions

- Computational analyses used material properties and impact test data for resin transfer molded T700S/PR520 triaxially braided composite
- Composite shields for the full scale test utilized the same fiber and architecture and a similar resin (Cytec MTM45-1), hand laid up.
- Shields were curved panels with a radius of 6.5 ft, an axial length of 4 ft and an arc length of 8 ft.







Pre-test Predictions

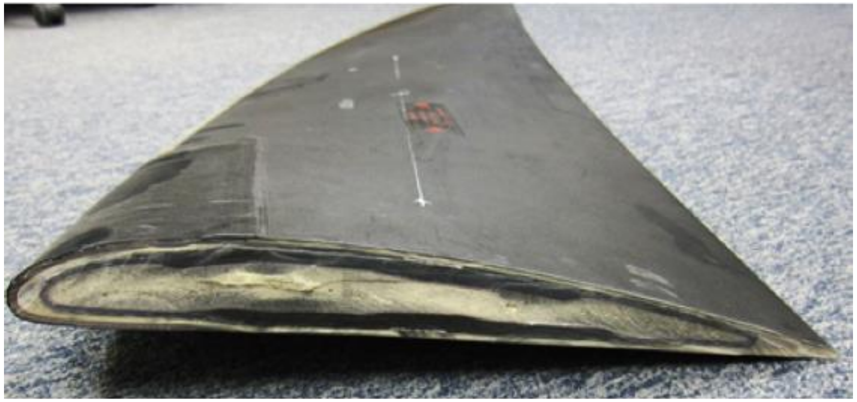
- Pre-test simulations predicted that a 20 ply composite panel would allow the blade to penetrate and a 24 ply panel would prevent penetration
- Predictions for additional weight assumed a nominal fuselage thickness, shield thickness varying on circumferential position
- For counter-rotating blades (2 rotors) shielding weight added estimated to be less than 250 lb.

Open Rotor
Dynamic Blade Release Test

Naval Air Warfare Center-WD
FAA Technical Center
NASA Glenn Research Center


270
JLG
CAPACITY 500 LBS
2 PERSONS
EXT. CAP 250 LBS
GRVW 2750 LBS
www.jlg.com
JLG 1930ES

Blade



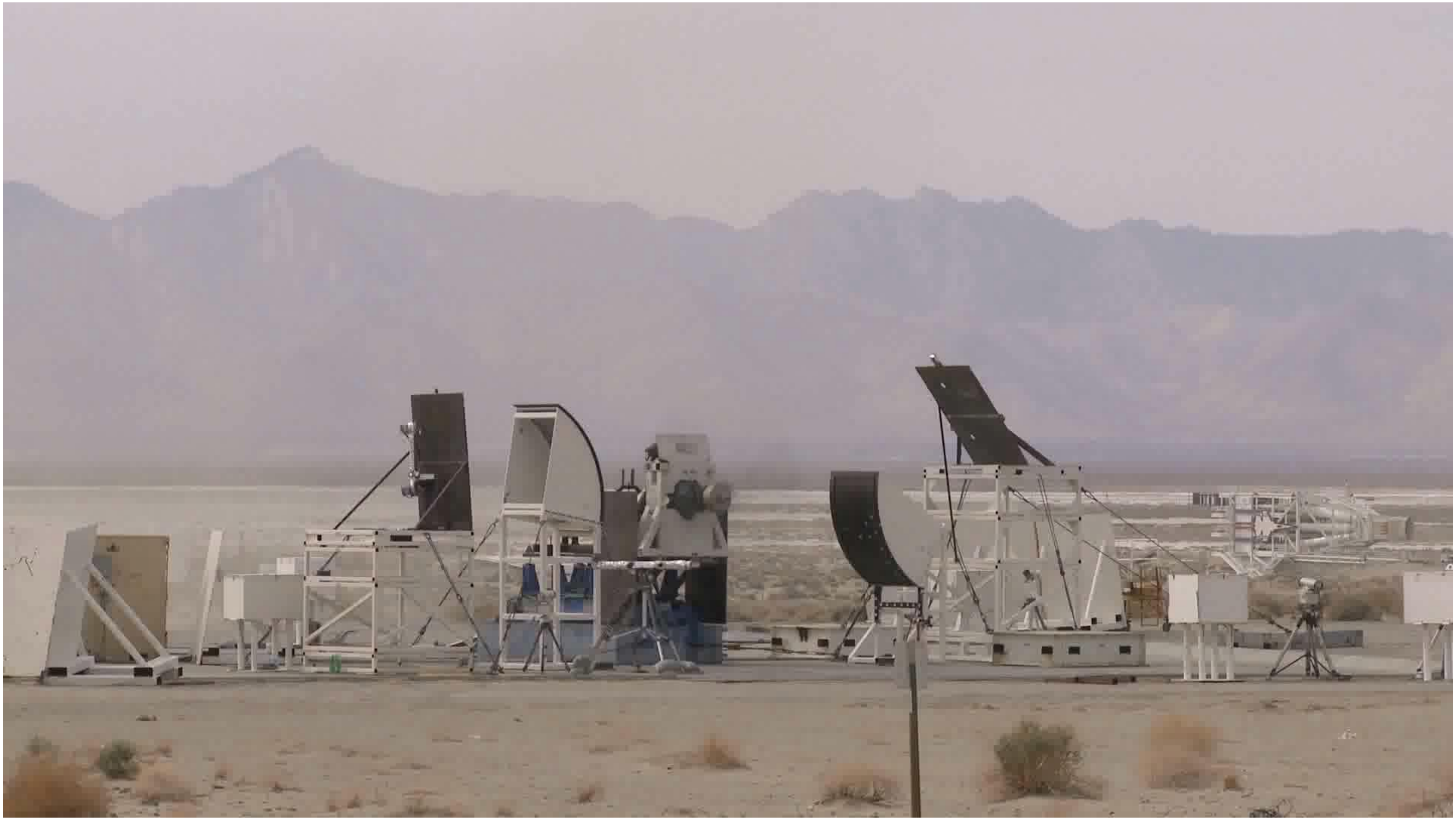
Overall length: 41.25”
Weight: 15.11 lb

Instrumentation

- High speed cameras for qualitative assessment
- Three pairs of cameras for photogrammetric measurements
- Six accelerometers on each test frame
- Assorted instrumentation for monitoring engine conditions

Photogrammetry Setup

Dynamic Open Rotor Composite Shield Test

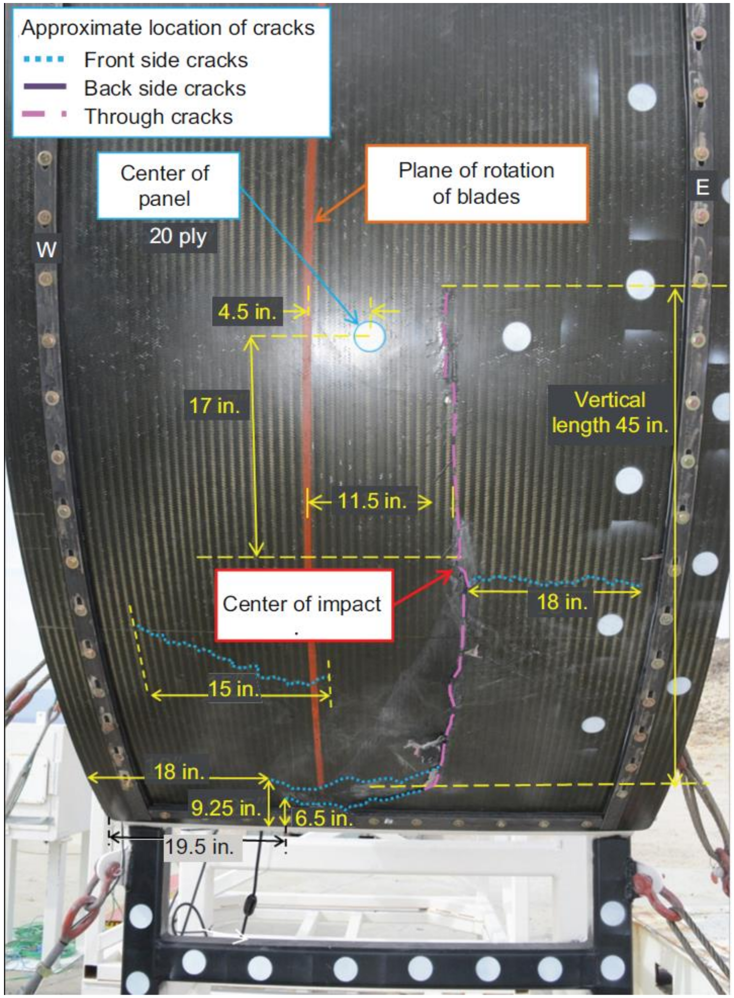


Test Observations

- Blade separation occurred at desired clock position
- Blades separated cleanly from root section
- Blades traveled to target panels impacting end on (~90 degree impact)
- Both blades impacted the target panels
- Impact
  - 24 ply panel - Deflected blade with no through crack
  - 20 ply panel – Blade penetrated panel

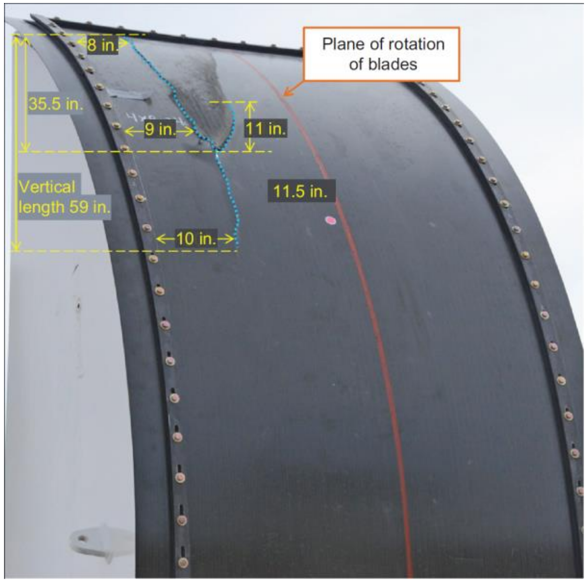
Test Results – 20 Ply Panel

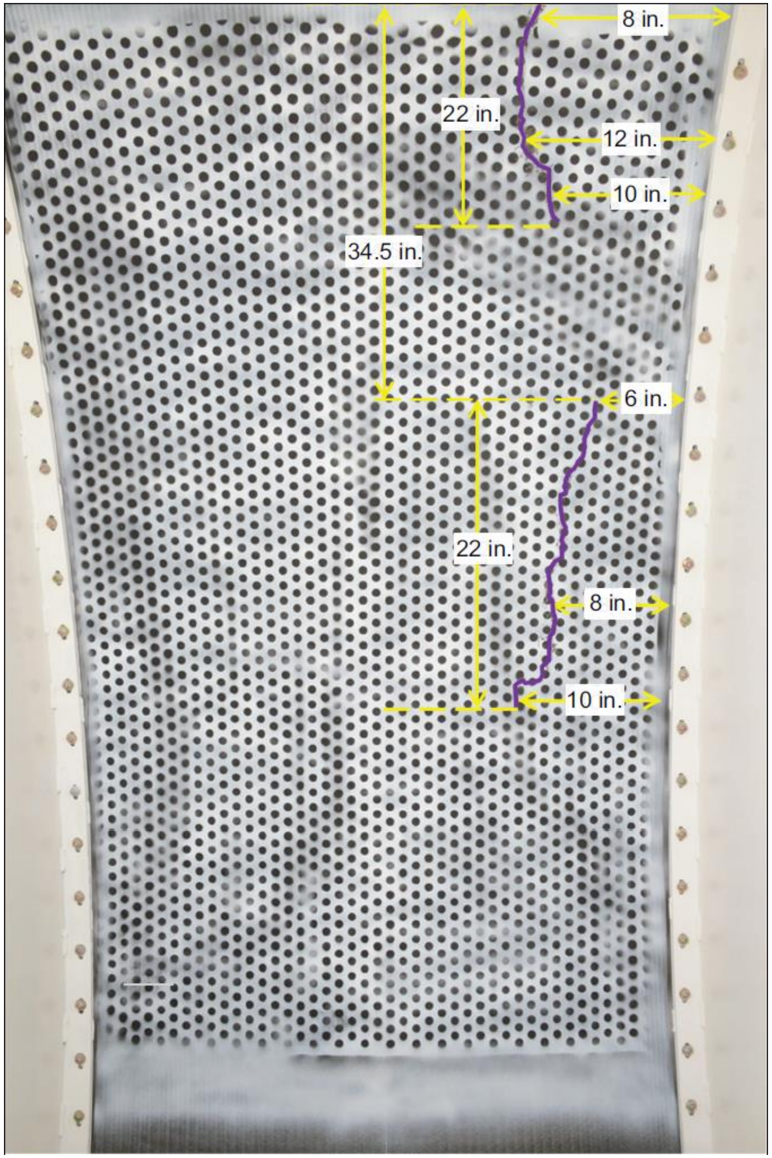
- Blade release angle: 188 degrees
- Trajectory of blade cg: 4 degrees above horizontal
- Blade impacted tip first, with long axis aligned with velocity vector
- Blade caused one long longitudinal tear and four front side cracks that did not extend to backside
- Blade completely penetrated the panel



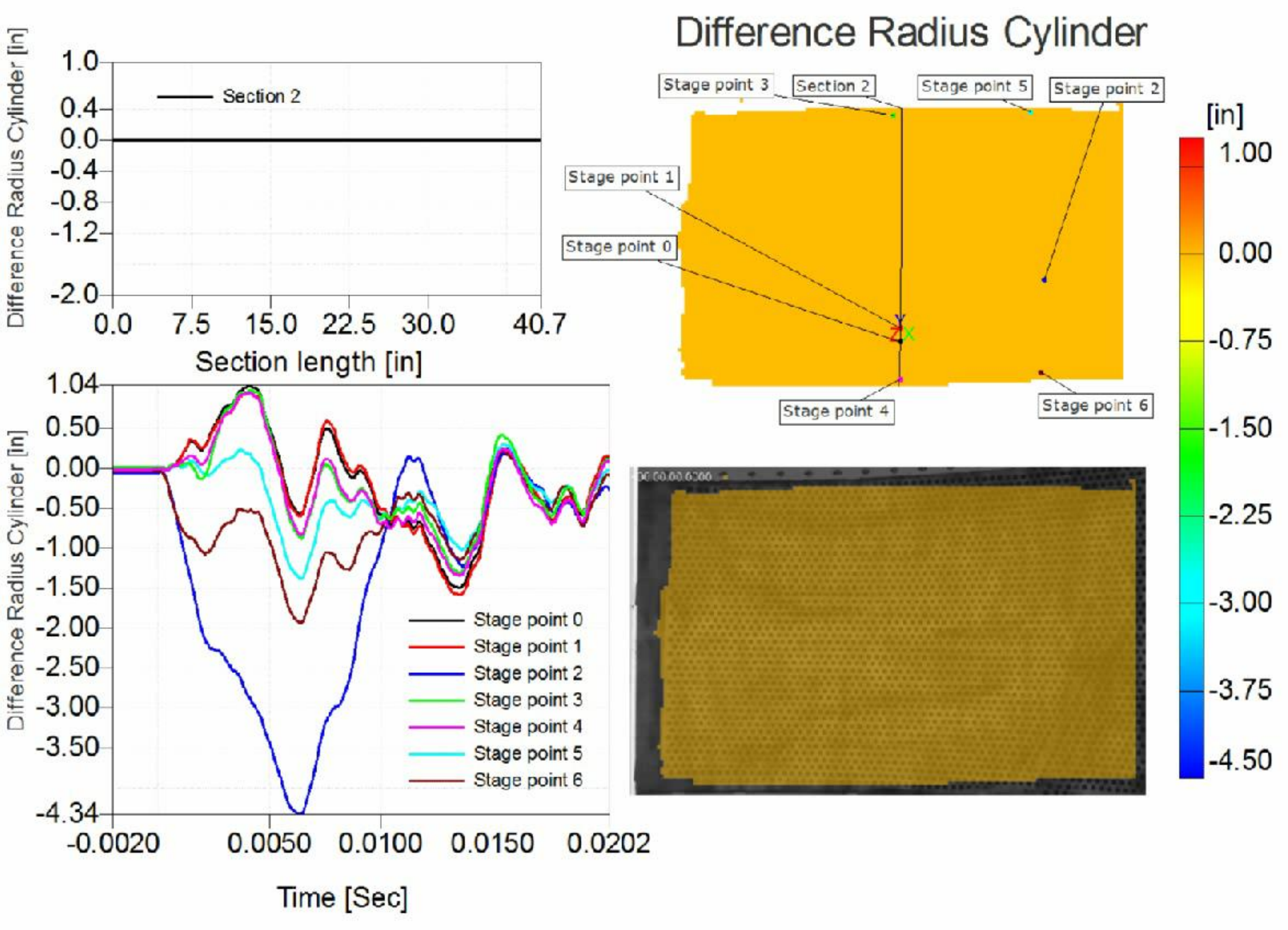
Test Results – 24 Ply Panel

- Blade release angle: 8 degrees
- Trajectory of blade cg: 4 degrees below horizontal
- Blade impacted tip first, with long axis aligned with velocity vector
- Blade did not penetrate panel
- Tears on both front side and back side
- Front and back tears not aligned – no through penetration of cracks

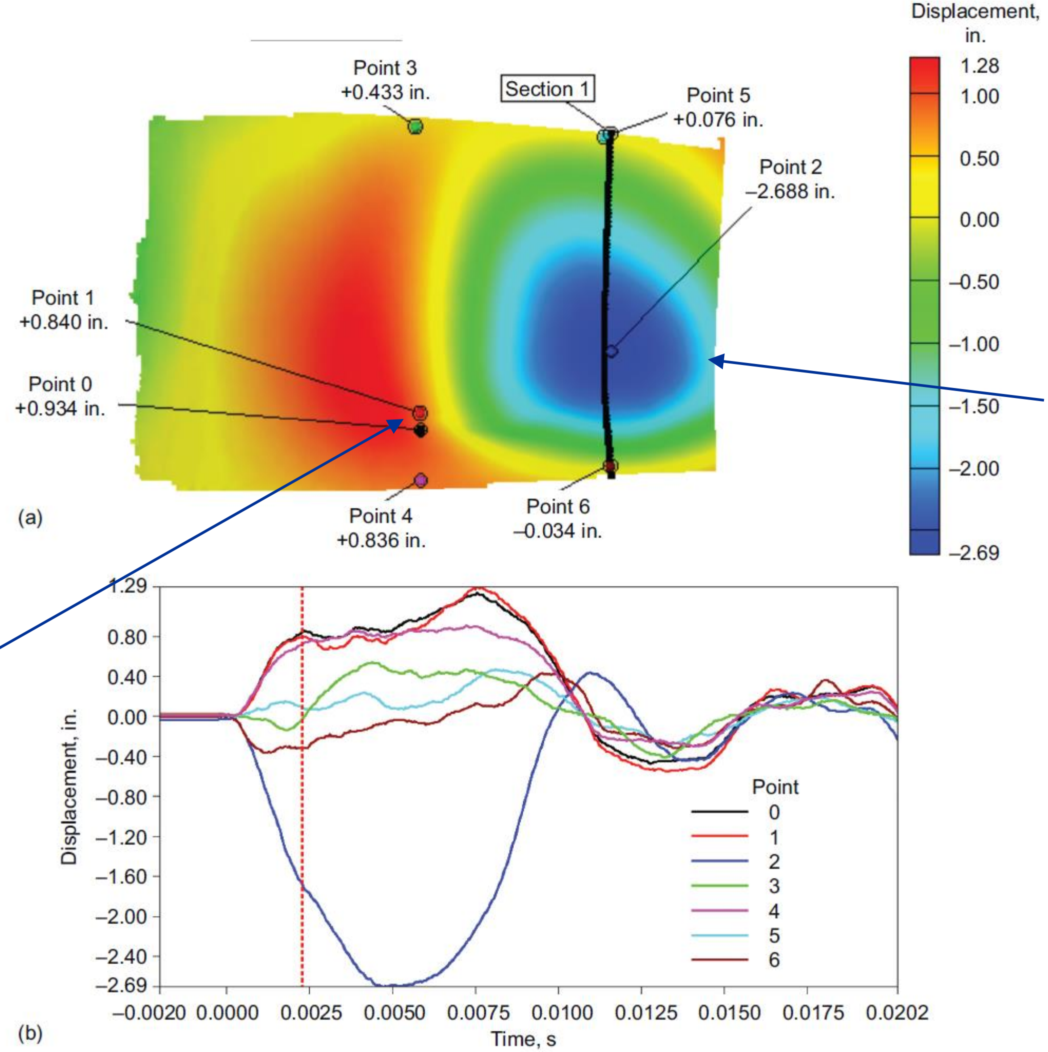




24 Ply Panel Backside Displacement



24 Ply Panel – Movement Correction



Second crack initiated at boundary

Compressive failure between points 0 and 1

Test Conclusions

- Good correlation with pretest predictions
- 24 Ply panel deflected the blade and did not have a thru failure
  - Good agreement with analysis
- 20 Ply panel was cracked completely through
  - Blade penetrated panel
  - Crack was longer than pretest prediction.

Conclusions

- Composite shielding may be a feasible solution to fuselage shielding for open rotor engines
- Advances in composite impact models needed to predict accurate failure modes and to be predictive rather than correlative

Future Work

- Material properties of actual composite shield material are being measured
- Open Rotor Shield Test will be used as a validation case for improved composite impact models