# DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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# FAA Sponsored Project Information

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- **Graduate Student Researchers:**
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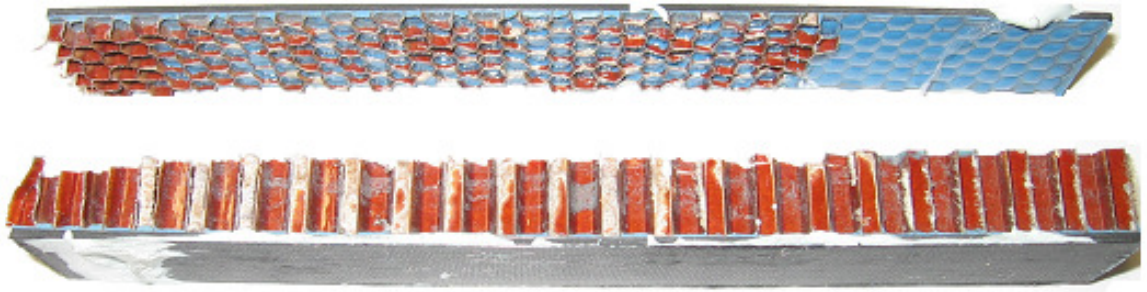
  - **Chris Weaver**
  - **Andy Gill**
- **FAA Technical Monitor**
  - **Curt Davies**

# BACKGROUND:
## FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

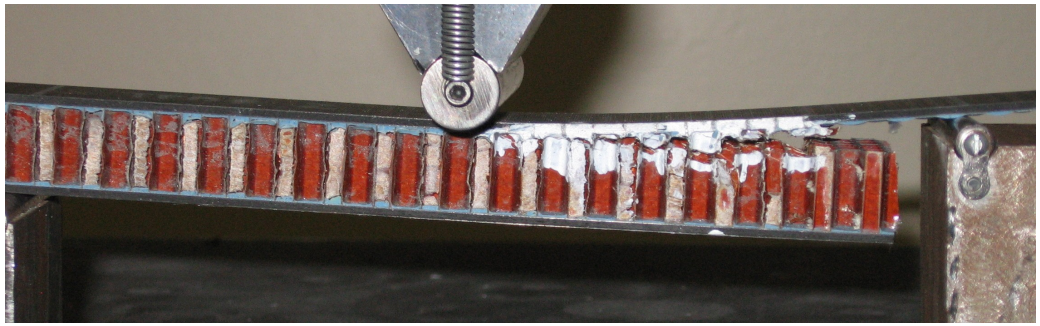
- **Fracture mechanics test methods for composites have reached a high level of maturity**
- **Less attention to sandwich composites**
  - **Focus on particular sandwich materials**
  - **Focus on environmental effects**
  - **No consensus on a suitable test configuration or specimen geometry for Mode I or Mode II fracture toughness testing**

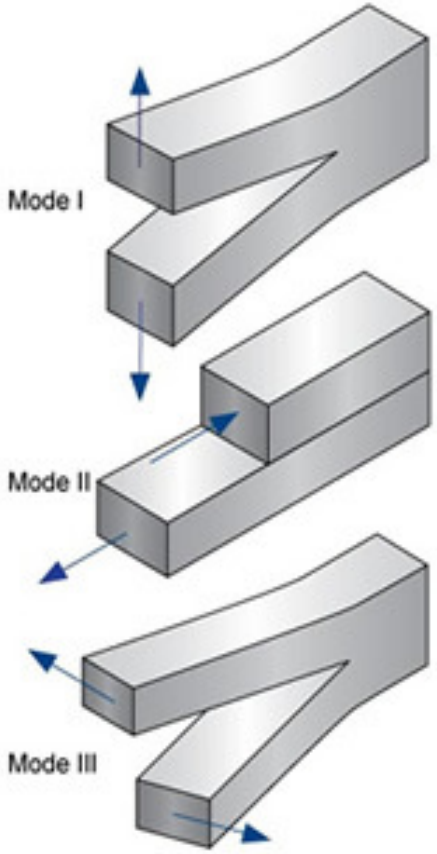


# RESEARCH OBJECTIVE

## Develop fracture mechanics test methods for sandwich composites

- Focus on facesheet core delamination
- Both Mode I and Mode II
- Suitable for ASTM standardization



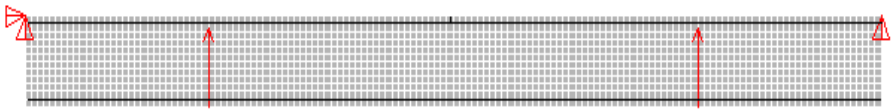


# RESEARCH APPROACH:
## THREE PHASE PROGRAM

- **PHASE I: Identification and initial assessment of candidate test methodologies**
- **PHASE II: Selection and optimization of best suited Mode I and Mode II test methods**
- **PHASE III: Development of draft ASTM standards**

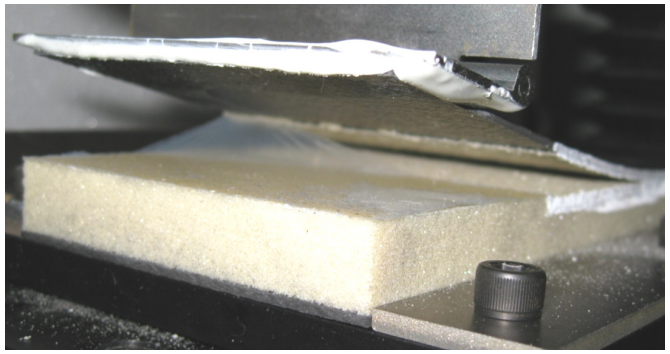
# INITIAL ASSESSMENT OF CANDIDATE TEST METHODOLOGIES

- **Identify candidate Mode I and Mode II test methodologies**
  - **Literature review**
  - **Modifications from adhesive and composite laminate tests**
  - **Original concepts**



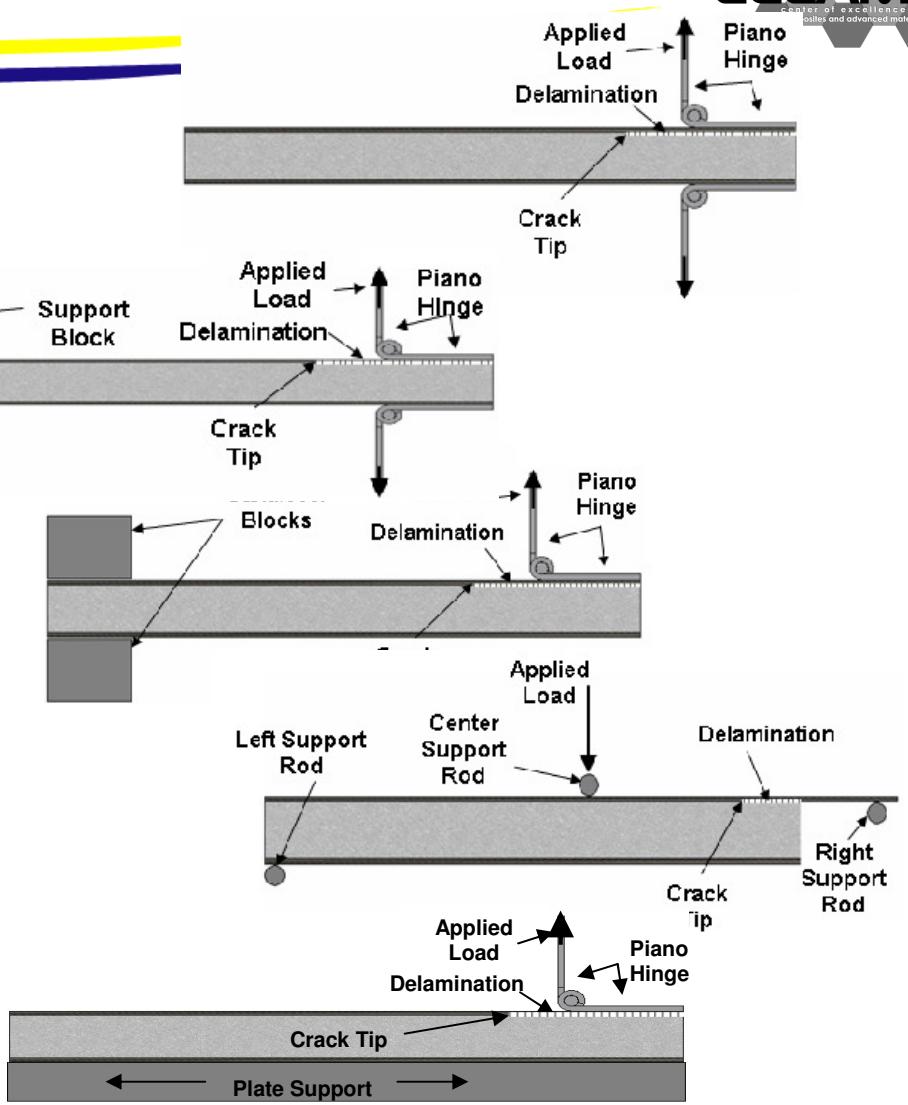
- **Assessment of candidate test configurations using finite element analysis**

- **Preliminary testing of promising configurations**



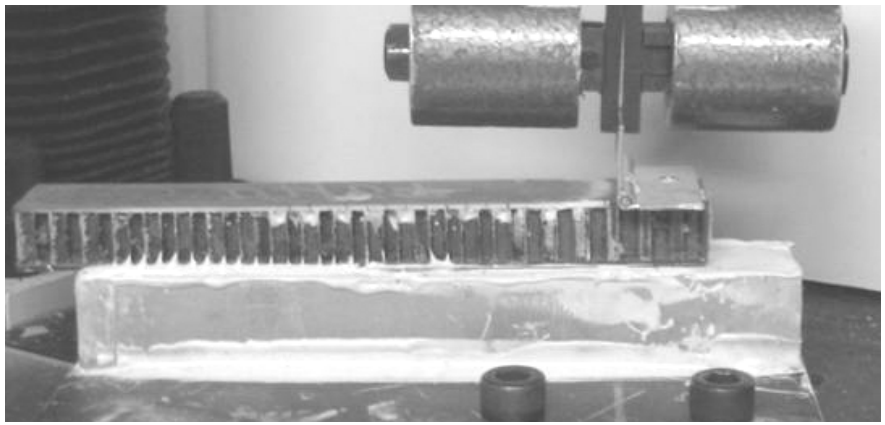
# EVALUATION OF CANDIDATE MODE I TEST CONFIGURATIONS

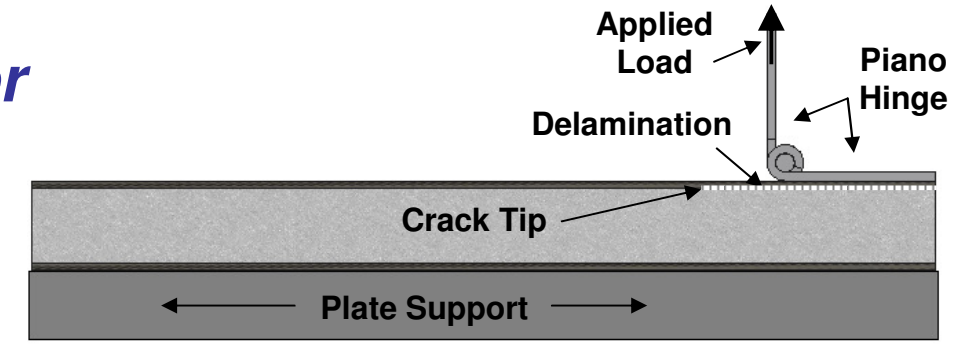
- Double Cantilever Beam (DCB)
- Modified DCB (MDCB)
- Single Cantilever Beam (SCB) with cantilever beam support
- Three Point Flexure (TPF)
- Plate-Supported Single Cantilever Beam SCB



# SELECTED MODE I CONFIGURATION: PLATE-SUPPORTED SINGLE CANTILEVER BEAM (SCB)

- **Elimination of bending of sandwich specimen**
  - **Minimal Mode II component (less than 5%)**
  - **No significant bending stresses in core**
- **No crack "kinking" observed**
- ***Appears to be suitable for a standard test method***



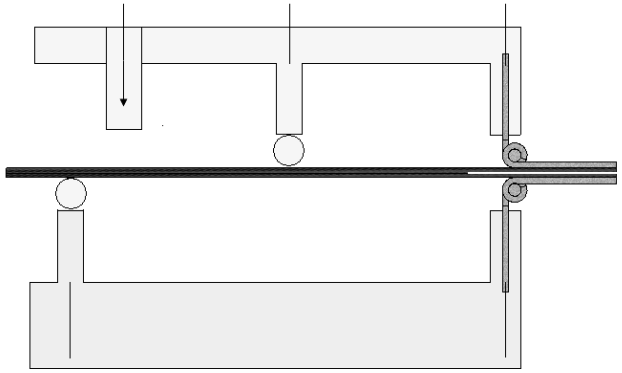


# EVALUATION OF MODE II SANDWICH COMPOSITE TEST CONFIGURATIONS

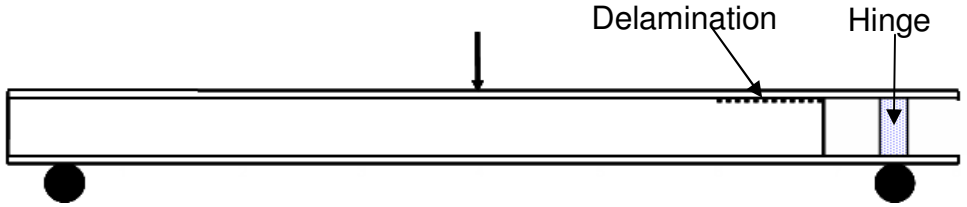
- Three-point End Notch Flexure (3ENF)
- Mixed Mode Bending (MMB)
- End Load Split (ELS)
- Four-point delamination test
- Cracked Sandwich Beam (CSB) with hinge
- Modified CSB with hinge
- Facesheet delamination test
- DCB with uneven bending moments
- Three-point cantilever
- Double sandwich test

# CHALLENGES IN DEVELOPING A SUITABLE MODE II TEST

- **Maintaining Mode II dominated crack growth with increasing crack lengths**
- **Obtaining crack opening during loading**
- **Obtaining stable crack growth along facesheet/core interface**



Mixed Mode Bend (MMB) Configuration

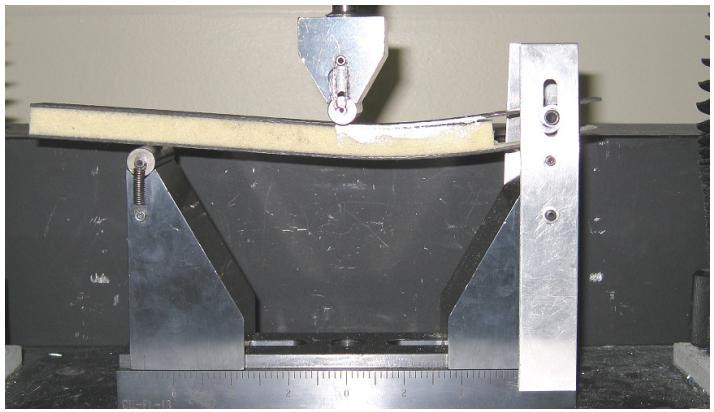


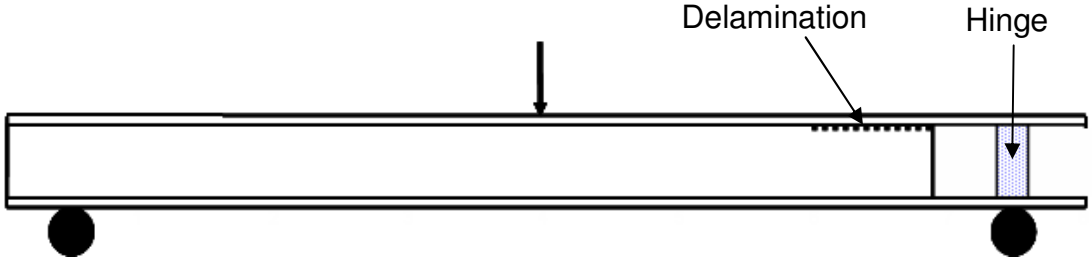

Modified Cracked Sandwich Beam (CSB) with Hinge

***Only two test methods appeared suitable…***

# SELECTED MODE II CONFIGURATION: MODIFIED CRACKED SANDWICH BEAM (CSB) WITH HINGE

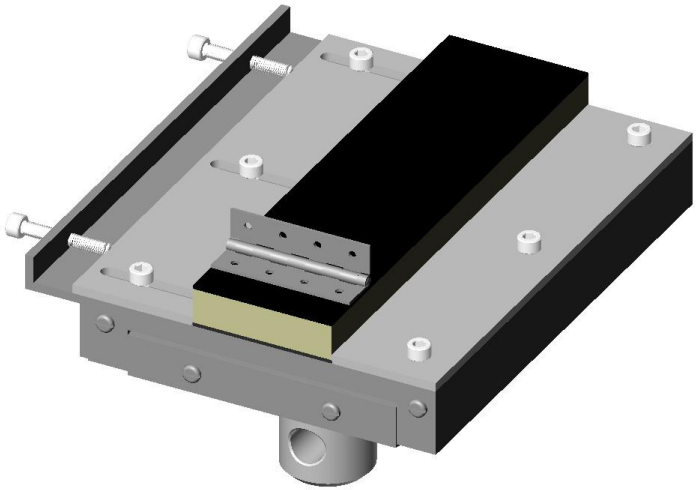
- Crack opening as delamination propagates
- High percentage Mode II (>80%) for all materials investigated
- Semi-stable crack growth along facesheet/core interface
- ***Appears to be suitable for a standard Mode II test method***



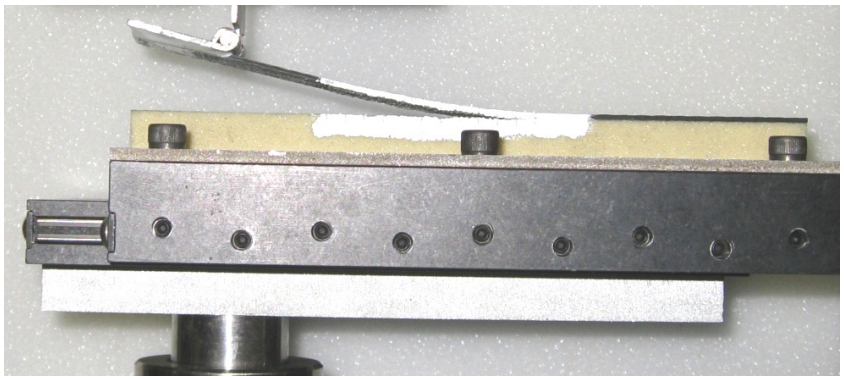


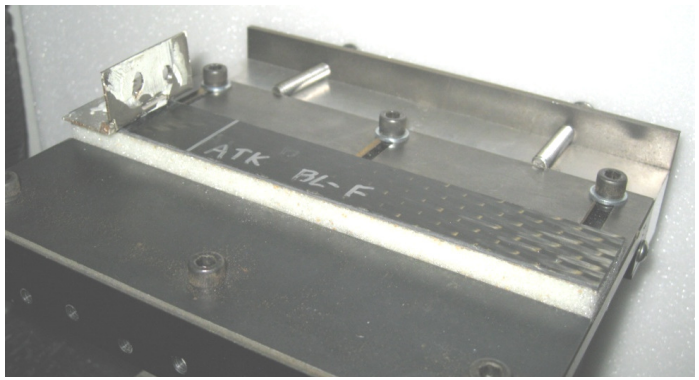
# DEVELOPMENT OF TEST FIXTURING:
# MODE I TESTING

## Plate-Supported Single Cantilever Beam (SCB)



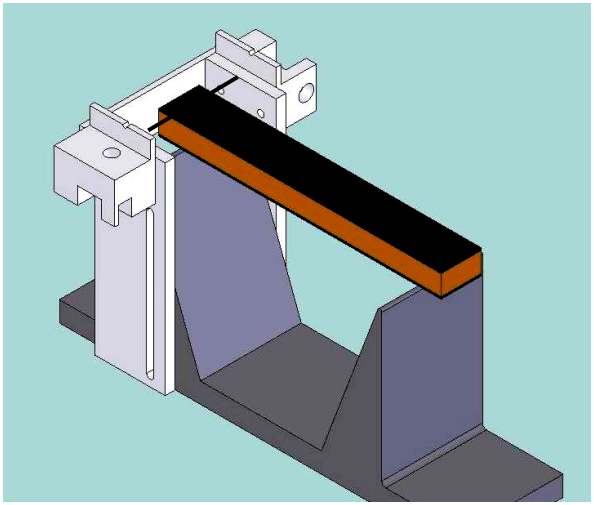
- Ability to test 1 in. to 3 in. wide sandwich specimens
- Edge clamp restraints at base eliminates adhesive bonding
- Translating fixture base maintains vertical loading



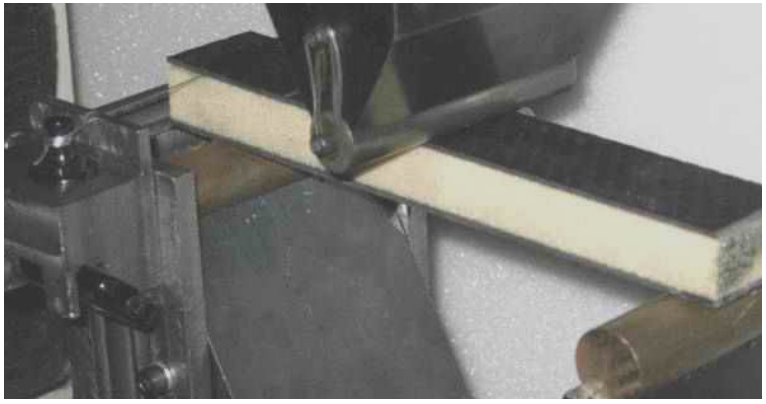


# DEVELOPMENT OF TEST FIXTURING: MODE II TESTING

## Cracked Sandwich Beam (CSB)

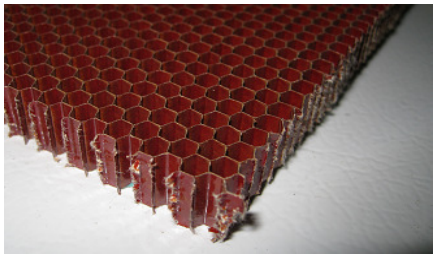
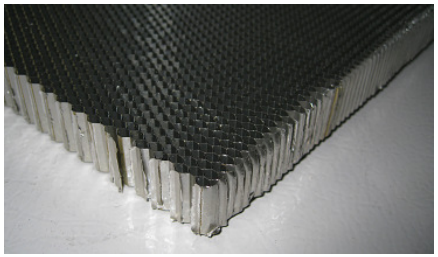


- Modified three-point flexure fixture
- Support top facesheet without need of core removal
- Elimination of bonded aluminum block



# CURRECT FOCUS:
# TEST METHOD ASSESSMENT

- **Determination of Acceptable Ranges of Specimen Parameters**
  - **Facesheet parameters**
    - **Thickness, flexural stiffness, flexural strength**
  - **Core parameters**
    - **Thickness, density, stiffness, strength**
  - **Specimen and delamination geometry**
- **Use of three different core materials (12-14 mm thickness)**
  - **Polyurethane foam core with density of 160 kg/m$^3$ (10 lb/ft$^3$)**
  - **Nomex honeycomb core**
  - **Aluminum honeycomb core**
- **Carbon/epoxy facesheets (1.3-1.5 mm thickness each)**

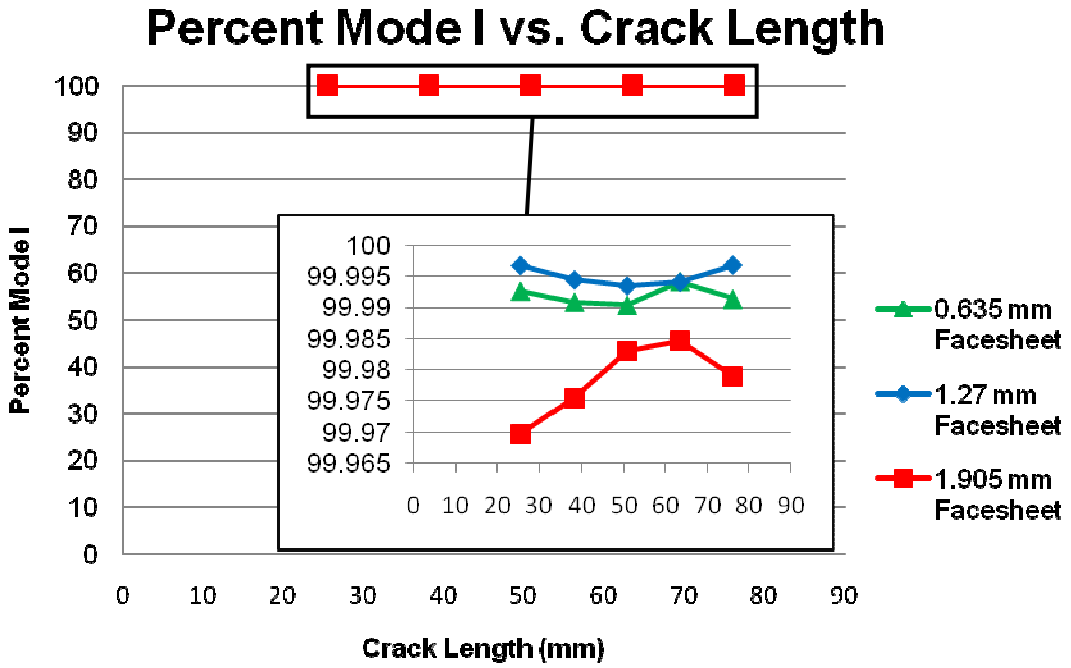




# MODE I SENSITIVITY STUDY: FACESHEET THICKNESS EFFECTS

*Woven carbon/epoxy facesheets, polyurethane foam core*

- **Mode I dominant over range of facesheet thicknesses and crack lengths considered**

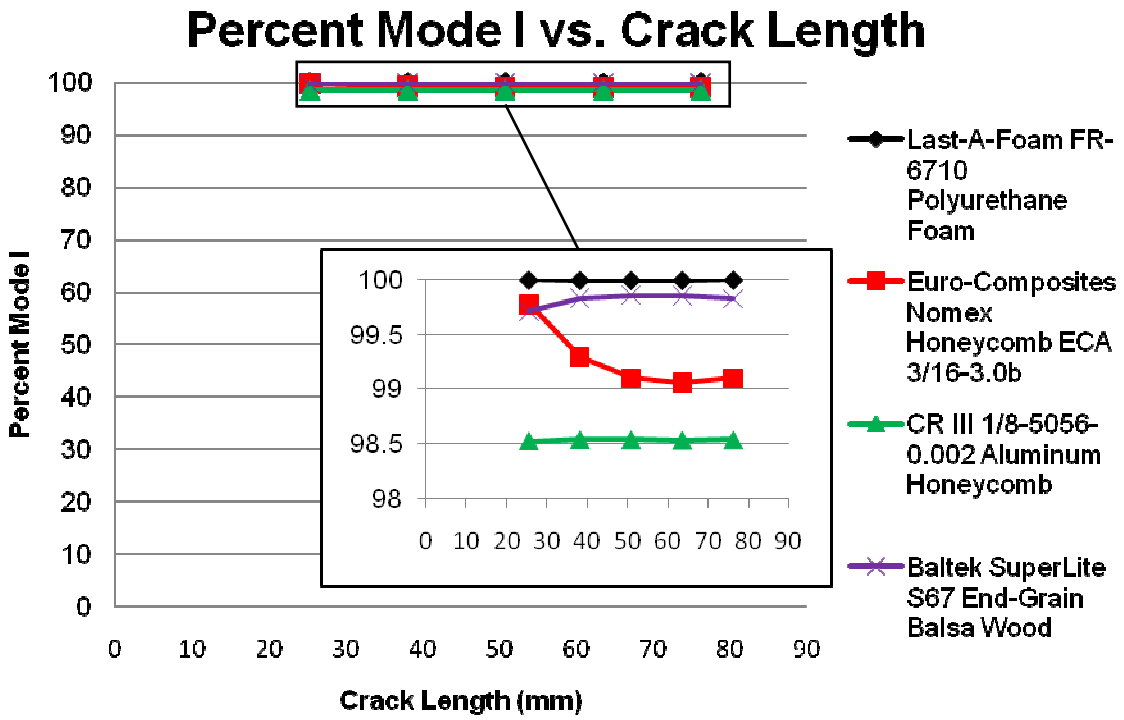
Plate-Supported Single Cantilever Beam (SCB)



# MODE I SENSITIVITY STUDY: CORE MATERIAL EFFECTS

- Mode I dominant over range of cores considered
- Minimal variability among materials and crack lengths
- Test appears suitable for a wide range of common core materials

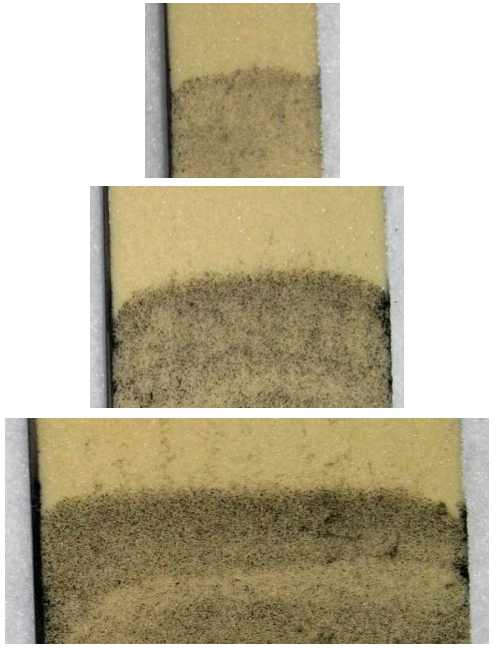
Plate-Supported Single Cantilever Beam

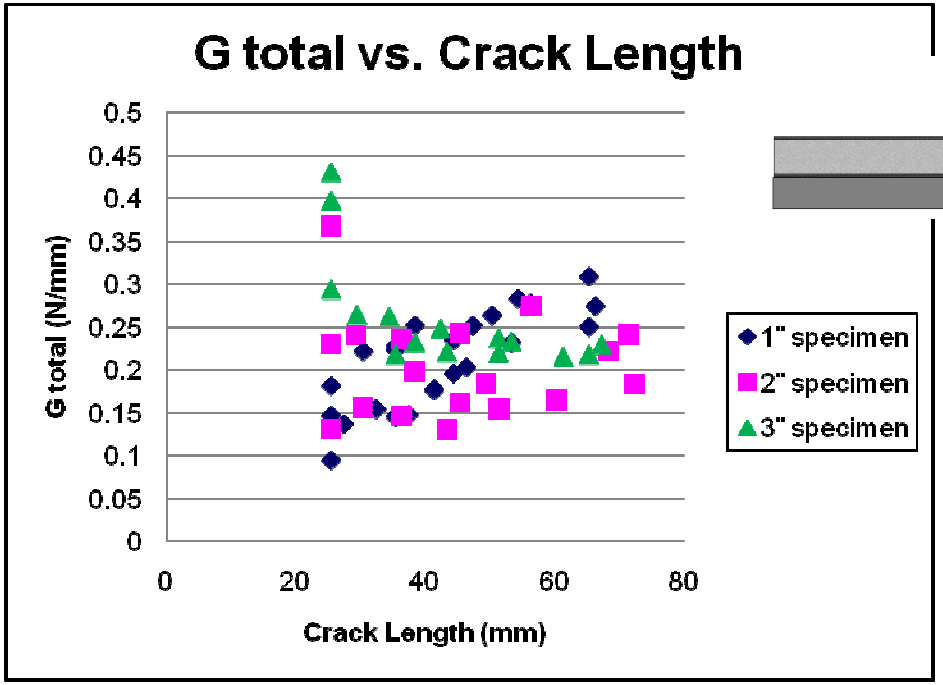


# MODE I SENSITIVITY STUDY: SPECIMEN WIDTH EFFECTS

*Woven carbon facesheets, polyurethane foam core*

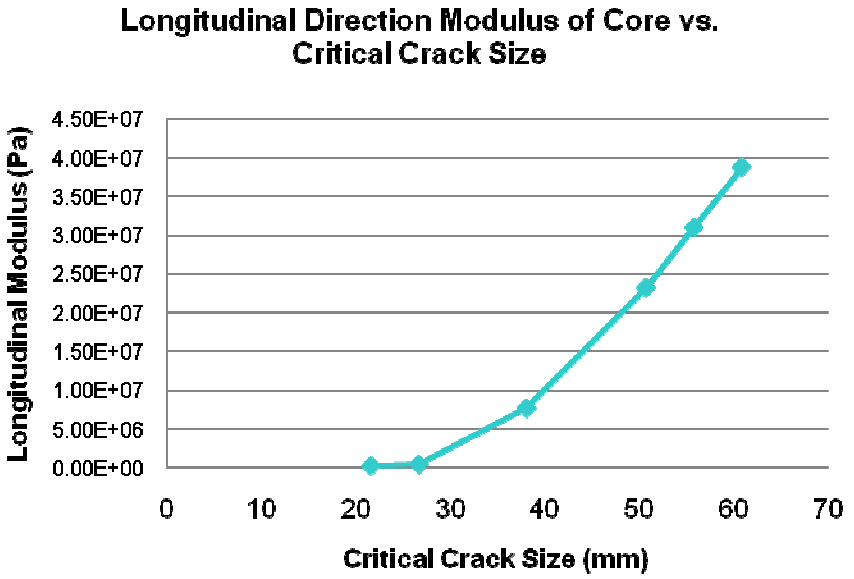
- 1 in., 2 in., and 3 in. wide specimens investigated
- Crack front during crack growth established using dye penetrant

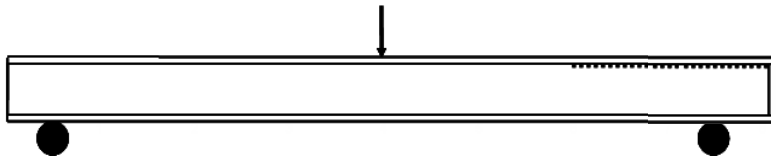




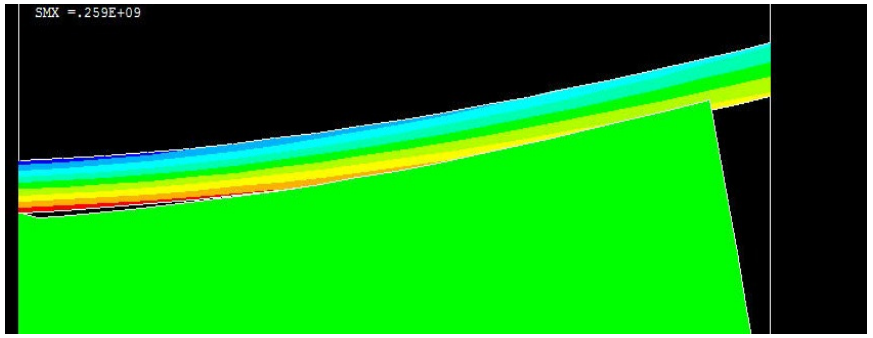

# MODE II SENSITIVITY STUDY: CORE MATERIAL EFFECTS

- **Core in-plane modulus has little effect on % Mode II**
  - **Foam, Nomex, and aluminum honeycomb all remained above 90%**
- **Core in-plane modulus affects crack length at which interaction begins**



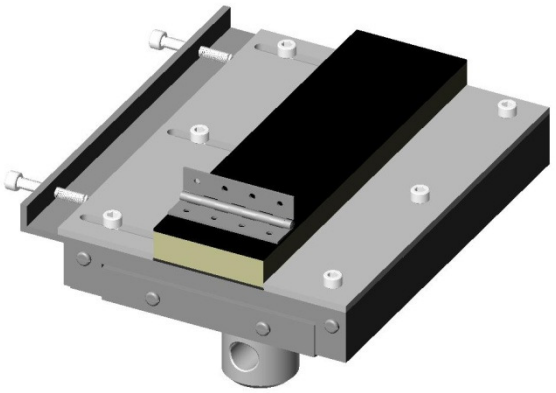



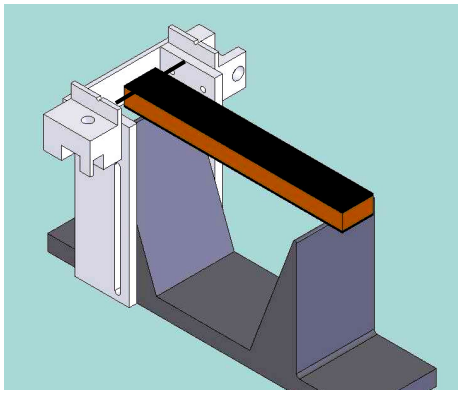
Cracked Sandwich Beam (SCB)



# CURRENT ACTIVITIES:
## Further Development of Mode I and Mode II Test Methods

- Evaluation of Improved Mode I and Mode II Test and Analysis Methodologies
- Selection of Test and Analysis Methodologies for Standardization
- Validation of Selected Mode I and Mode II Test and Analysis Methodologies
- Preparation of Draft ASTM Standards





# A LOOK FORWARD

- **Benefit to Aviation**
  - Standardized fracture mechanics test methods for sandwich composites
    - Mode I fracture toughness, $G_{IC}$
    - Mode II fracture toughness, $G_{IIC}$
  - Ability to predict delamination growth in composite sandwich structures