DEVELOPMENT AND EVALUATION OF FRACTURE MECHANICS TEST METHODS FOR SANDWICH COMPOSITES

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FAA Sponsored Project Information

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- **FAA Technical Monitor**
  - Curt Davies

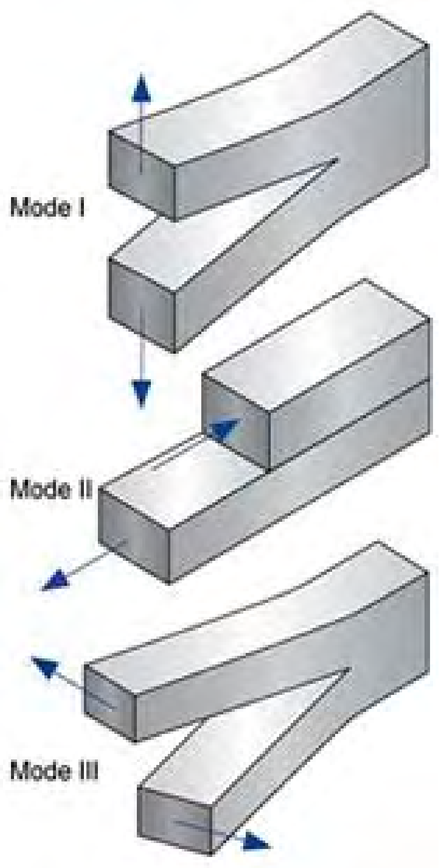
BACKGROUND:
FRACTURE MECHANICS TEST METHODS FOR SANDICH COMPOSITES

- **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

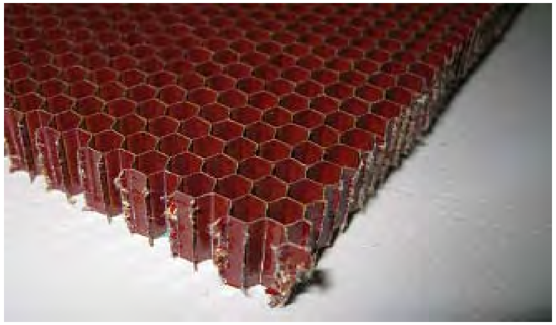
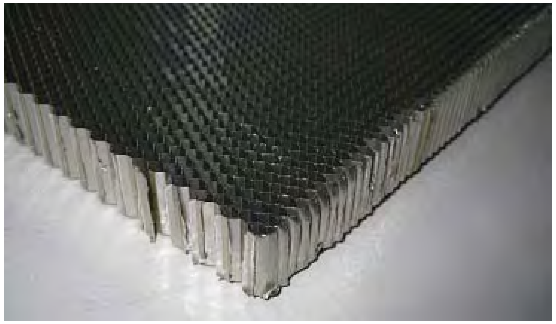
- **Identification and initial assessment of candidate test methodologies**
- **Selection and optimization of best suited Mode I and Mode II test methods**
- **Development of draft ASTM standards**

INITIAL FOCUS:
IDENTIFY AND ASSESS CANDIDATE TEST METHODOLOGIES

- Identification of candidate Mode I and Mode II test methodologies
  - Literature review
  - Modifications from adhesive tests
  - Original concepts
- Identification of materials and geometries currently in use for structural sandwich composites
- Assessment of candidate test configurations using finite element analysis
- Select promising configurations for mechanical testing

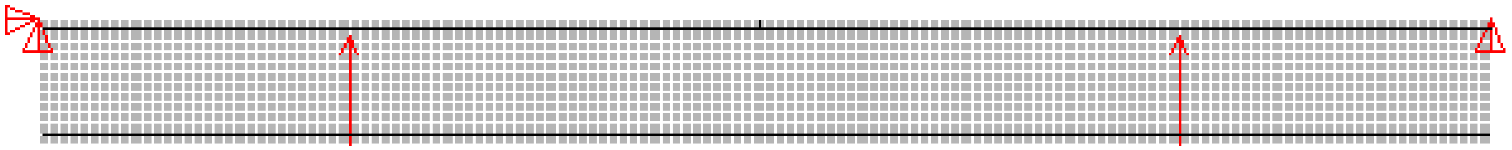
SANDWICH MATERIAL SELECTION FOR INITIAL ASSESSMENT

- Three 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
- Two facesheet materials (1.3-1.5 mm thickness each)
  - Woven carbon/epoxy, VARTM processed
  - Unidirectional carbon/epoxy, secondary bonding

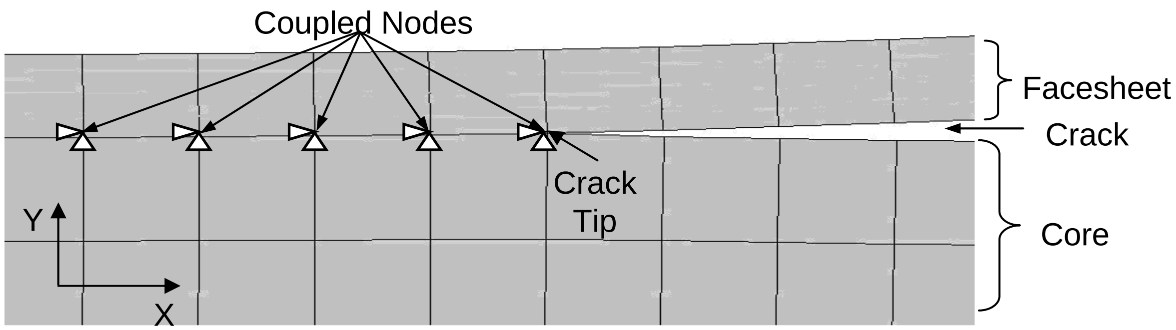
FINITE ELEMENT ANALYSIS OF INITIAL TEST CONFIGURATIONS

- **Evaluate fracture mode mixity (i.e. Mode I vs. Mode II)**
- **Analyze stress state within specimen**
- **Monitor crack opening after load application (Mode II)**
- **Determine suitable loading geometries**
- **Select promising Mode I and Mode II test configurations for mechanical testing**



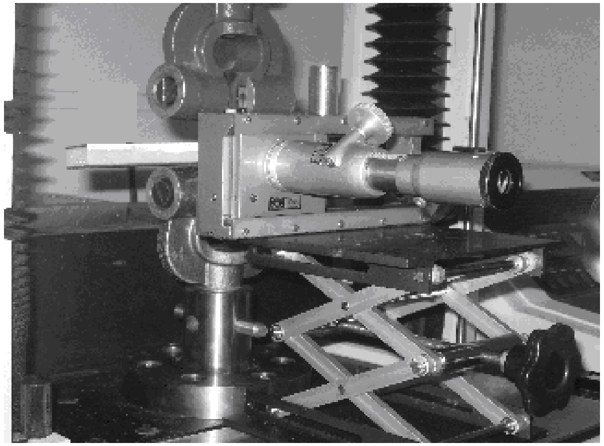
OVERVIEW:
FINITE ELEMENT MODELING

- **ANSYS 8.0 software**
- **Two-dimensional, plane strain, geometrically nonlinear analyses**
- **Crack path created with a row of overlapping nodes, coupled beyond crack tip**
- **Crack closure method used to calculate energy release rates, G_I and G_{II}**
  - **Constant applied load (45 Newtons)**
  - **Variable crack lengths (50 mm of crack growth)**



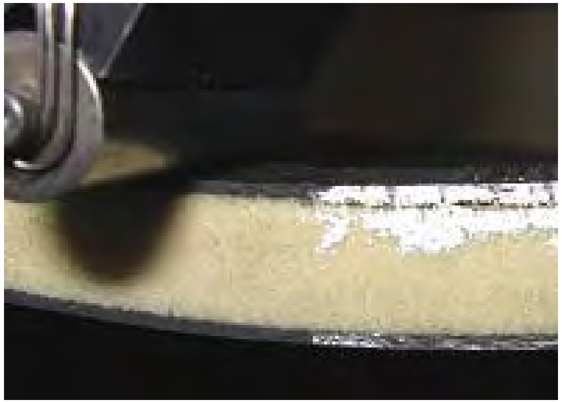
OVERVIEW:
INITIAL MECHANICAL TESTING

- 5 kip Instron load frame
- Traveling microscope
- White paint used to enhance visibility of crack growth
- Three replicates per test condition
- Use of finite element analysis to calculate energy release rates



SANDWICH CONFIGURATIONS FOR INITIAL ASSESSMENT

- **Carbon-Epoxy/Polyurethane Foam (CE/PF)**
  - 12.7 mm thick polyurethane foam core
  - 1.3 mm thick quasi-isotropic carbon fabric/epoxy facesheets
  - VARTM processed



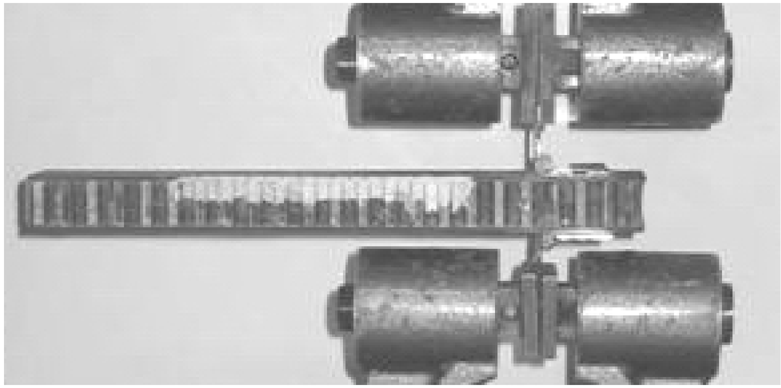
- **Carbon-Epoxy/Nomex Honeycomb (CE/NH)**
  - 14 mm thick Nomex honeycomb
  - 1.5 mm thick quasi-isotropic prepreg carbon/epoxy facesheets
  - Secondary bonding using film adhesive

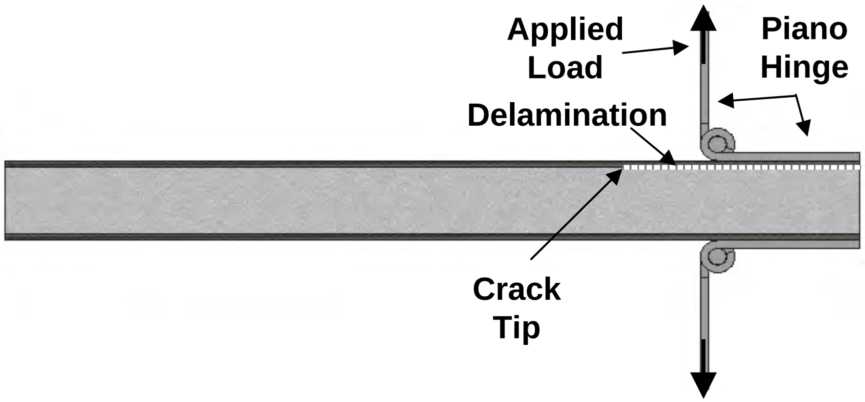
IDENTIFICATION OF MODE I TEST CONFIGURATIONS

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

CANDIDATE MODE I CONFIGURATION:
DOUBLE CANTILEVER BEAM (DCB)

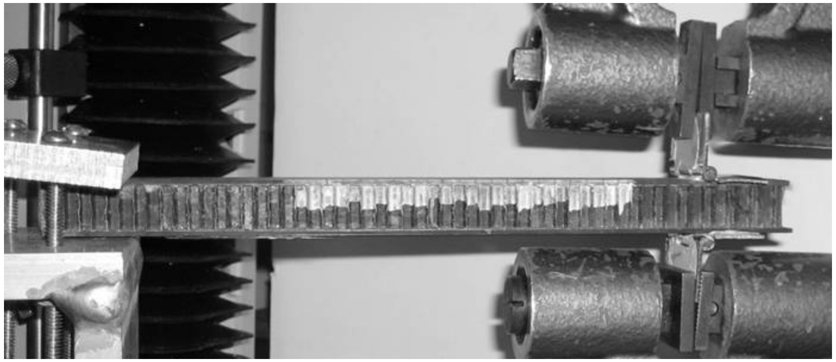
- **Based on ASTM D 5528 for monolithic composite laminates**
- **For sandwich composites:**
  - **Significant Mode II component**
  - **Significant bending stresses in core**
  - **Crack “kinking” for Nomex honeycomb core**
- ***Determined to be unsuitable for a standard test method***

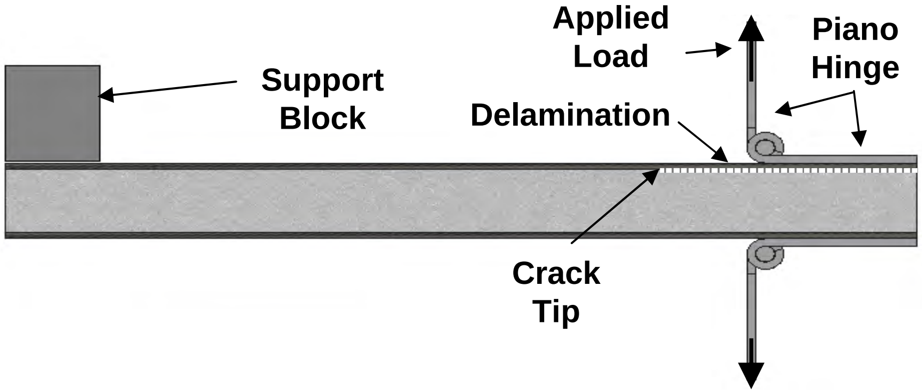




CANDIDATE MODE I CONFIGURATION:
MODIFIED DCB

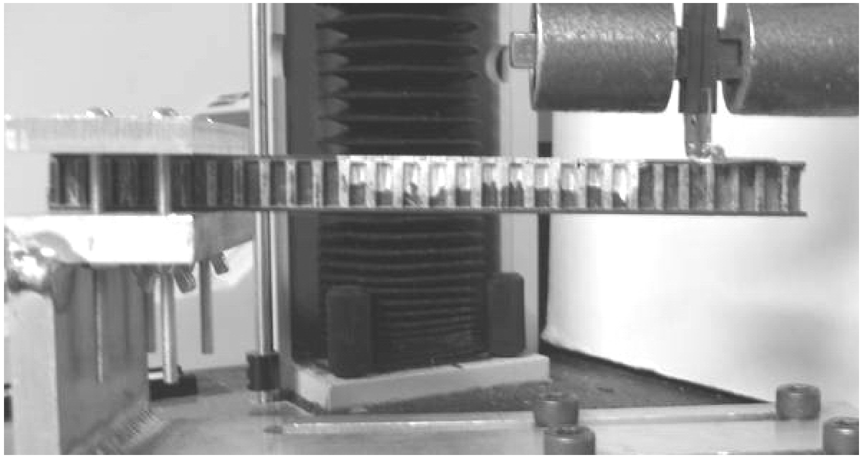
- **Support block prevents specimen rotation**
- **No significant improvement over DCB configuration:**
  - **Significant Mode II component**
  - **Crack "kinking" for Nomex honeycomb core**
- ***Determined to be unsuitable for a standard test method***

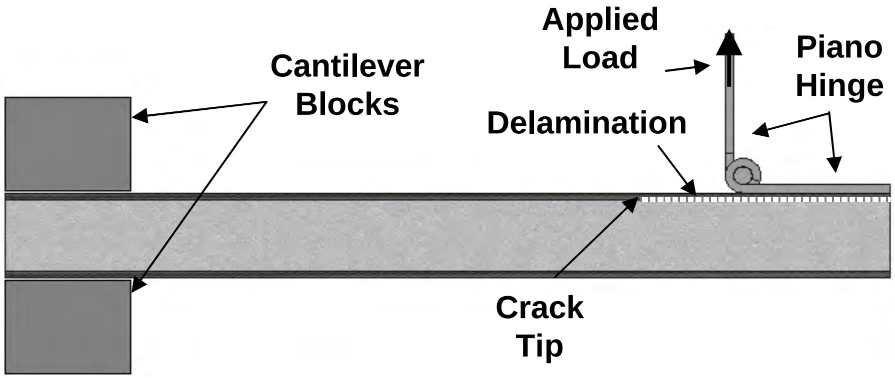




CANDIDATE MODE I CONFIGURATION: SINGLE CANTILEVER BEAM (SCB) WITH CANTILEVER SUPPORT

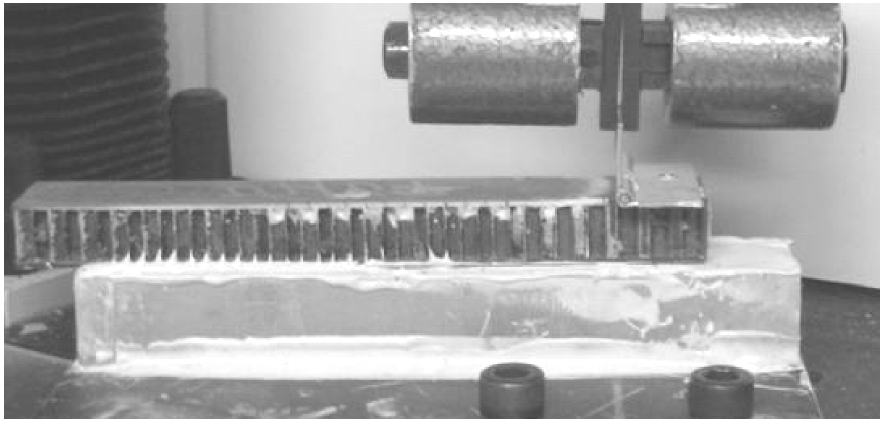
- **Reduction in bending of sandwich specimen**
  - **Minimal Mode II component (less than 5%)**
  - **Reduced bending stresses in core**
- **Crack "kinking" for Nomex honeycomb core**
- ***Not well suited for a standard test method***

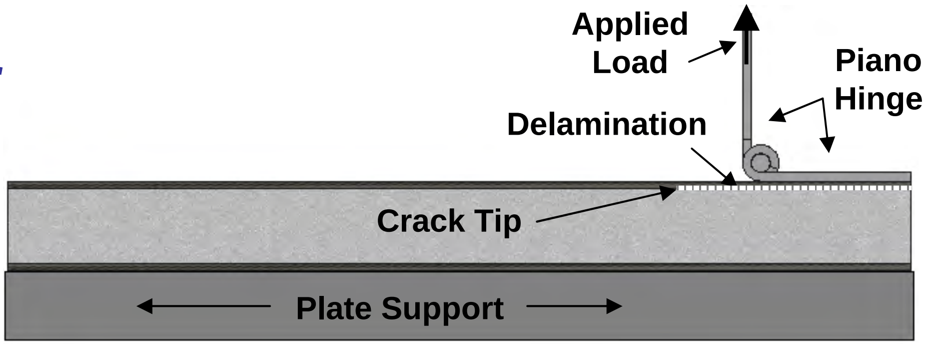




CANDIDATE MODE I CONFIGURATION:
PLATE-SUPPORTED SINGLE CANTILEVER BEAM (SCB)

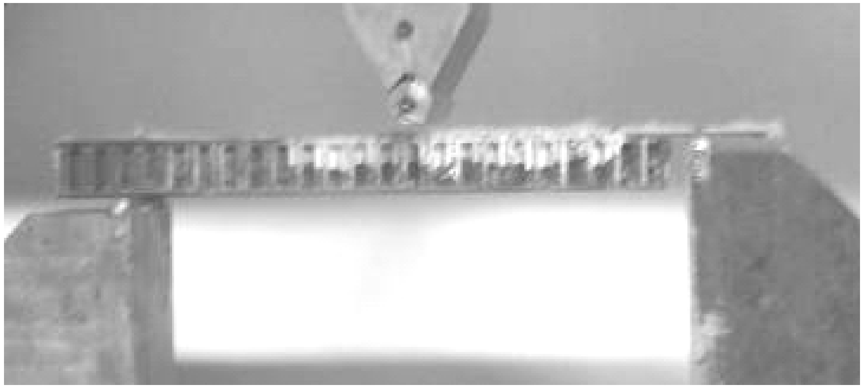
- **Elimination of bending of sandwich specimen**
  - **Minimal Mode II component (less than 5%)**
  - **No significant bending stresses in core**
- **No crack "kinking" observed**
- ***Appears to be suitable for a standard test method***

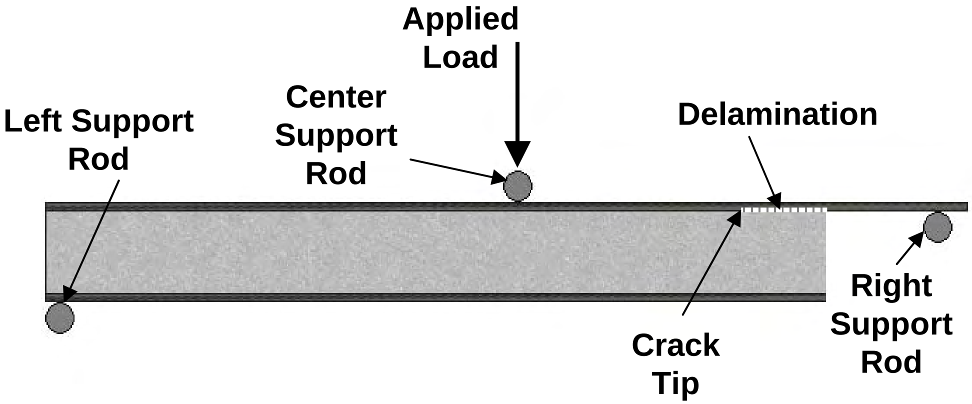




CANDIDATE MODE I CONFIGURATION:
THREE-POINT FLEXURE (TPF)

- **No crack "kinking" observed**
- **Significant bending of sandwich specimen**
  - **Significant bending stresses in core**
  - **Minimal Mode II component (less than 5%)**
- **Extra machining operations required for specimen**
- ***Not well suited for a standard test method***

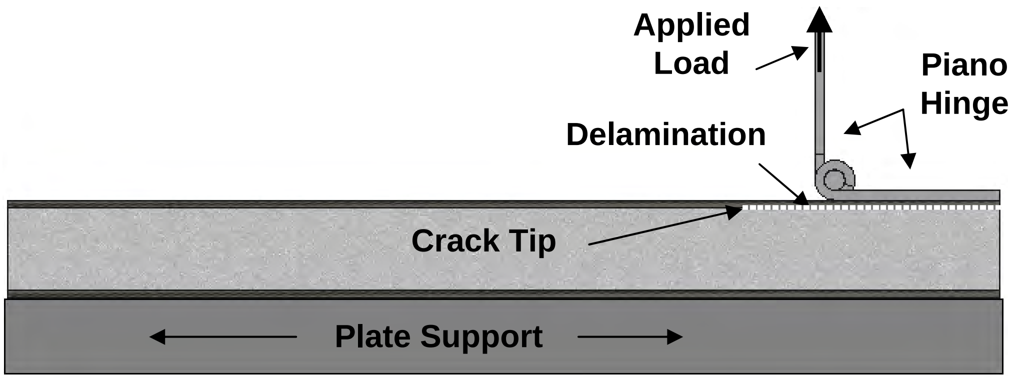




SUMMARY:
MODE I TEST CONFIGURATIONS

Plate-Supported Single Cantilever Beam (SCB) test configuration recommended for further investigation

- Identification of suitable specimen geometries
- Development of suitable test fixture

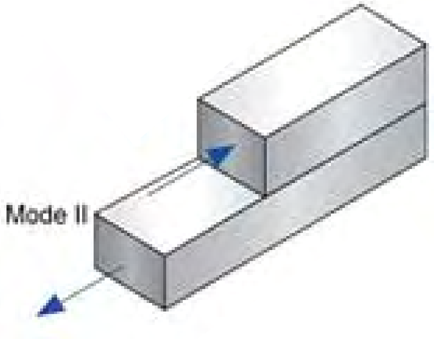


IDENTIFICATION OF MODE II SANDWICH COMPOSITE TEST CONFIGURATIONS

- 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**

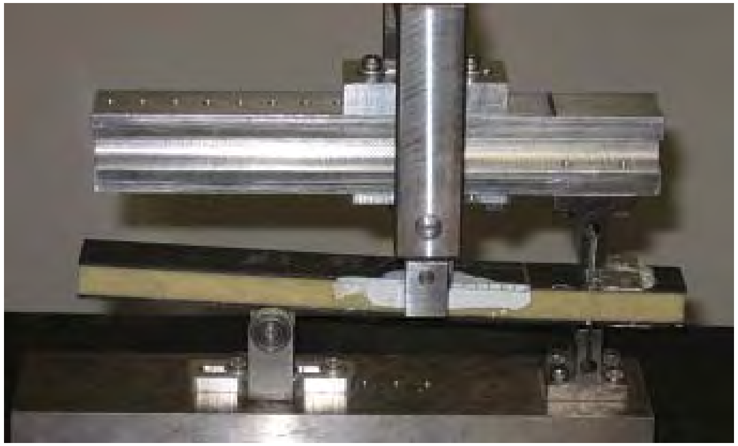


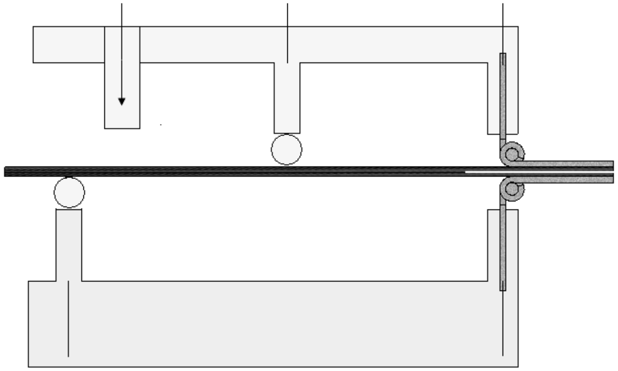
Only two test methods appeared suitable…

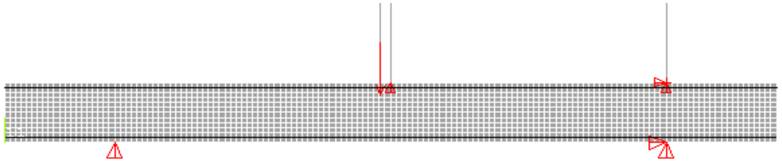
CANDIDATE MODE II CONFIGURATION:

MIXED-MODE BEND (MMB) TEST

- **Crack opening as delamination propagates**
- **Possible to achieve high percentage Mode II (>90%) using short lever arm lengths**
- **Semi-stable crack growth**
- **Crack “kinking” for Nomex honeycomb core**
- **Core crushing for aluminum honeycomb core**
- ***Not well suited for a standard Mode II test method***

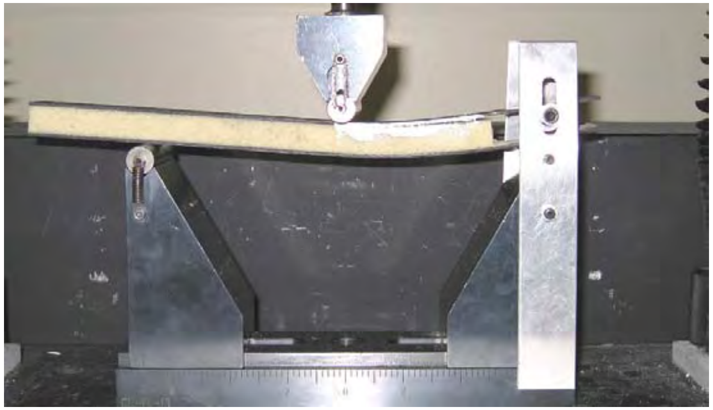


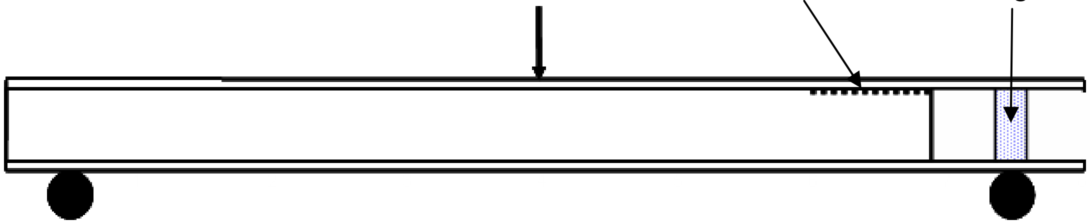




CANDIDATE MODE II CONFIGURATION: MODIFIED CRACKED SANDWICH BEAM (CSB) WITH HINGE

- **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***

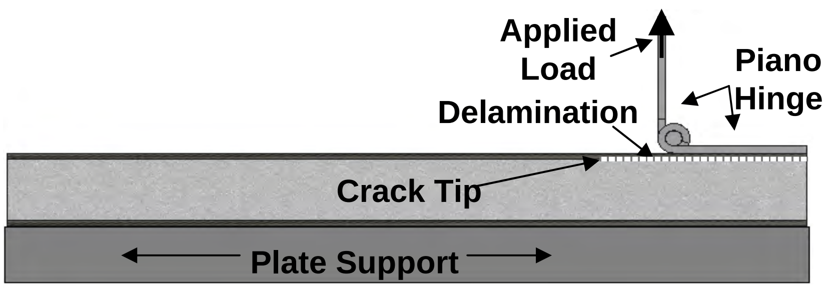




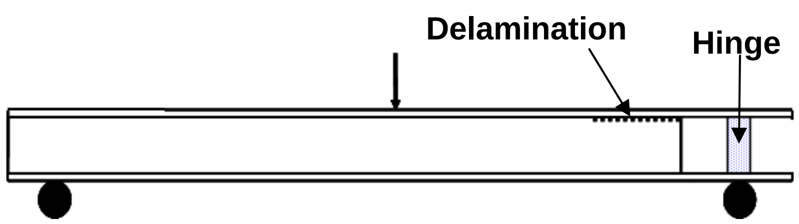
CURRENT STATUS

Further evaluation of selected test methods:

- Parametric study to investigate range of applicability
  - Sandwich composite materials
  - Sandwich composite geometries
- Development of improved test fixturing



Mode I:
Plate-Supported Single Cantilever Beam (SCB)



Mode II:
Cracked Sandwich Beam (SCB) with hinge

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