FACE SHEET/CORE DISBOND GROWTH IN HONEYCOMB SANDWICH PANELS SUBJECTED TO GROUND-AIR-GROUND PRESSURIZATION AND IN-PLANE LOADING

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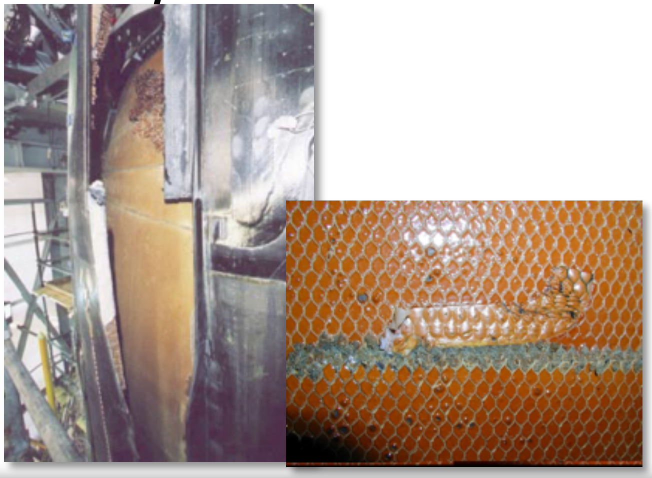
OVERVIEW

- **Background**
- **Objective**
- **Detailed Problem Description**
- **Analysis Methodology**
  - Fracture Mechanics Approach
  - Finite Element Modelling
- **Initial Model Verification and Validation**
- **Analysis Results**
  - Analysis of a Flat Panel Under Internal Pressure, In-Plane and Combined Loading
  - Analysis of a Curved Panel
- **Summary**
- **Concluding Remarks**

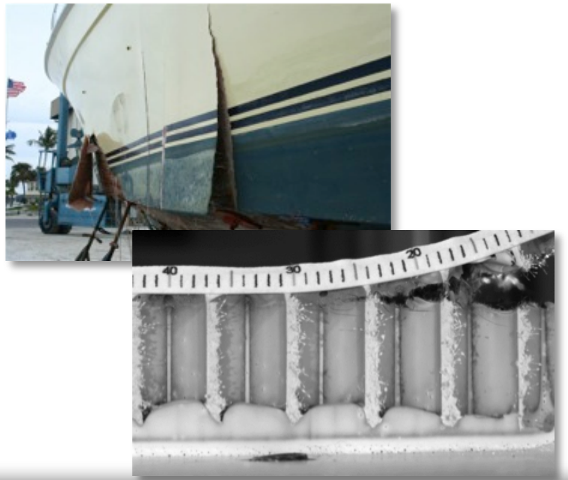
BACKGROUND

- **Problem**
  - **In-service component failures associated with disbonding in unvented honeycomb core sandwich**
  - **Degradation due to disbonding affects operational safety**
  - **Failures may discourage use of composites in 'future' vehicles**
  - **Methods for assessing propensity of sandwich structures to disbonding not fully matured, accepted and documented**
  - **Methods development is currently being discussed within the Disbond/ Delamination Task Group in CMH-17**

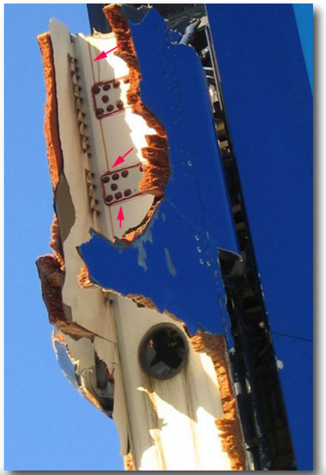
Space



Marine



Aviation



OBJECTIVE

- Identify, describe and address the phenomenon associated with face sheet/core disbonding
- Increase the knowledge on the subject and the awareness of consequences
- Develop a methodology to assess face sheet/core disbonding in honeycomb sandwich components similar to delamination in composite laminates
  - Develop standard test methods for characterizing face sheet/core disbonding in sandwich components
  - Develop a fracture mechanics based methodology to assess face sheet/core disbonding in sandwich components
  - Develop models and analysis tools for face sheet/core disbonding in sandwich components subjected to ground-air-ground cycles and/or in-plane loading
  - Evaluate the developed test methods and analysis tools using honeycomb sandwich panel tests

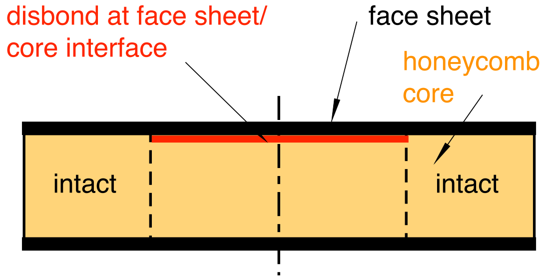
DETAILED PROBLEM DESCRIPTION

- **Pressure difference between the in- and outside of unvented sandwich structures**
  - Caused by alternating ambient pressure and temperature
  - Results in significant deformations and core volume increase
  - Volume increase results in pressure decrease based on the ideal gas law

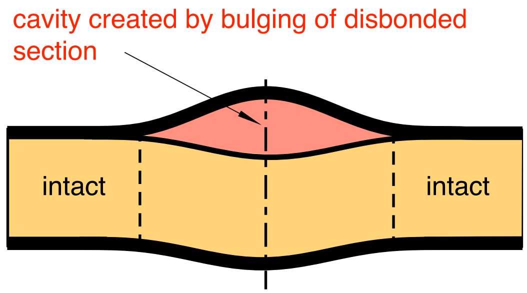
$$p\,V = n\,R\,T$$

- **Initial disbonds between face sheets and core**
  - increase the peeling effect and
  - decrease the structural reliability significantly
- **For an accurate structural analysis, a coupled pressure-deformation problem needs to be solved**

- **Initial configuration at ground elevation**



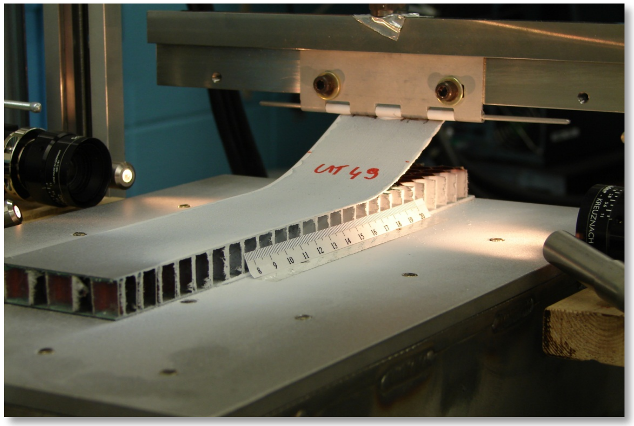
- **Deformed configuration at cruising altitude**

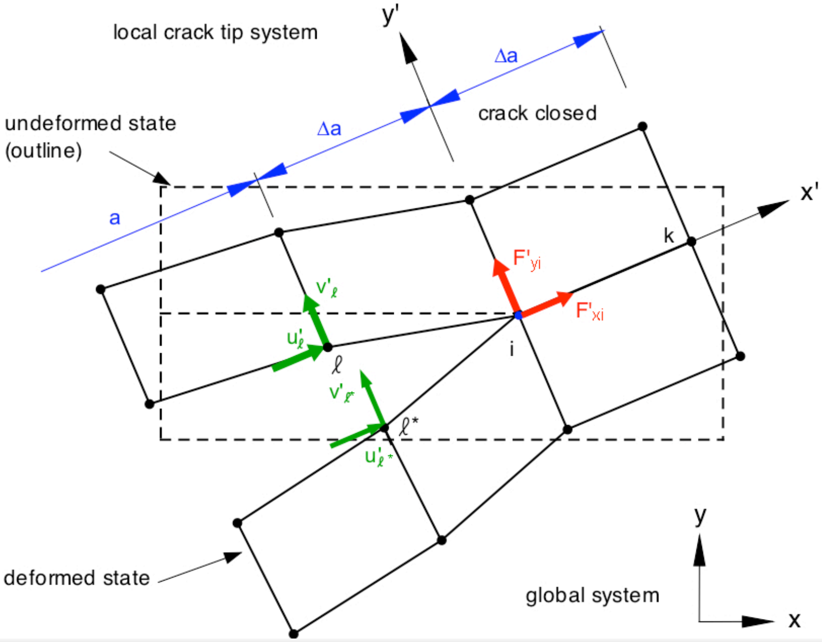


ANALYSIS METHODOLOGY

Fracture Mechanics Approach

- **Two steps are required to identify, describe and address face sheet/ core disbonding**
  - **Test standard development in ASTM committee D30 (WK 47682)**
    - Characterize the properties of the face sheet/core interface[14]
    - Measure fracture toughness G_c
  - **Analysis Development**
    - Compute the energy release rate along the disbond front
    - Use the Virtual Crack Closure Technique (VCCT) based on the results obtained from a finite element analysis
- **Propagation is predicted to occur once the computed value exceeds the measured fracture toughness**



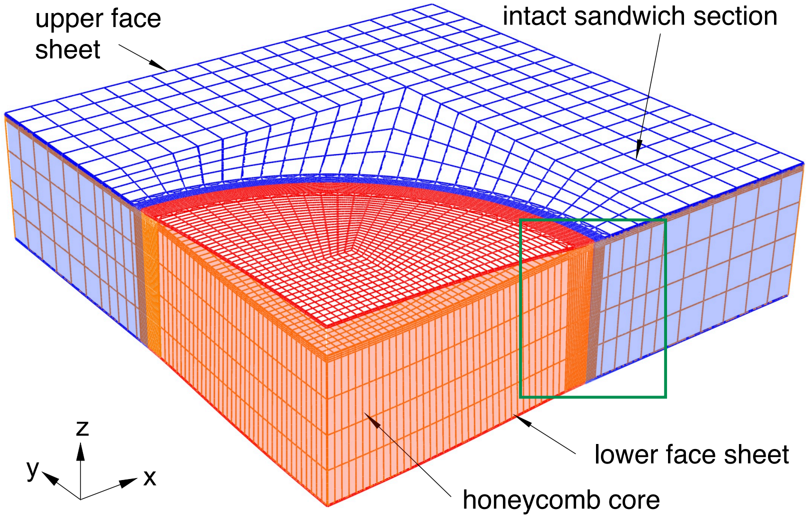


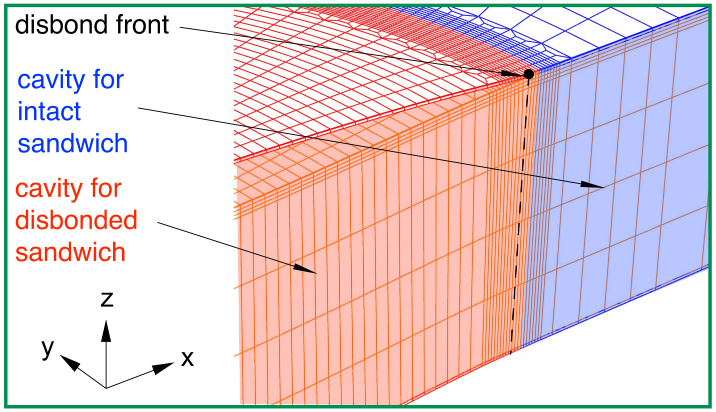
[14] reference to publication cited in conference proceedings

ANALYSIS METHODOLOGY

Finite Element Modelling – 1/4

- **A quarter section of a flat panel was modelled**
  - Circular disbond radius: 152.4 mm (6”)
  - Square section modelled: 304.8 mm (12”)
  - Abaqus/Standard® was used (C3D20)
    - Boundary conditions applied at symmetry planes
    - Surface contact used between top face sheet and core in the disbonded section
- **Sandwich properties based on previous results**
  - Thin face sheet: 0.772 mm (0.03”)
    - CYCOM 5320PW plain weave fabric
    - [45/0/90/-45] quasi-isotropic layup
  - Thick core: 76.5 mm (3.0”)
    - Hexcel HRH-10® honeycomb
    - NOMEX® paper with 48 kg/m^3 (3.0 lb/ft^3) density and 3.175 mm (1/8”) cell size
    - Modelled as an orthotropic, homogeneous continuum





ANALYSIS METHODOLOGY

Finite Element Modelling – 2/4

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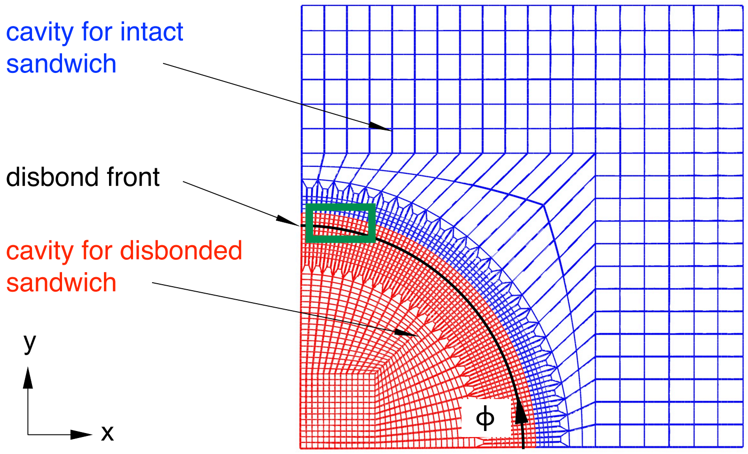
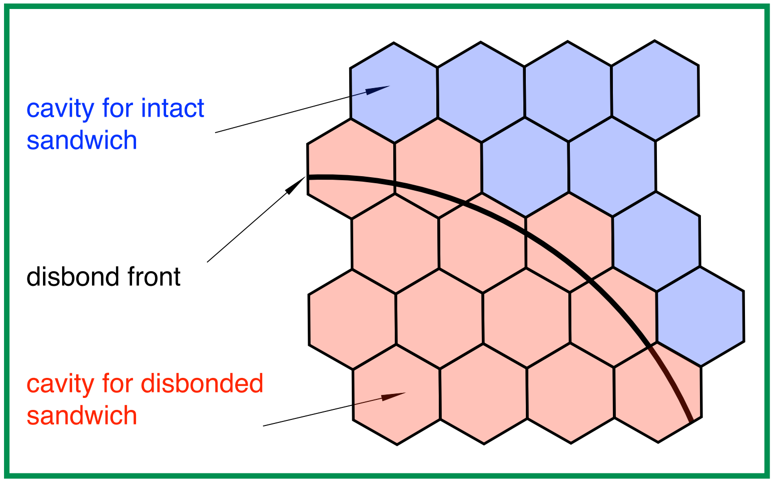
- **Pressure deformation coupling was simulated using fluid filled cavities**
  - Abaqus/Standard® feature enabled the definition of fluid-filled cavities enclosed by structural elements
  - The ideal gas law is solved within each increment until equilibrium is found
  - The volume of the fluid cavities was assumed to be equal to that of the entire sandwich core
  - Two separate cavities were defined
    - One cavity was used to simulate the intact part
    - The other cavity included only the disbonded section
    - The disbonded cavity extended by one cell size, 3.175 mm (1/8”), ahead of the disbond front





ANALYSIS METHODOLOGY

Finite Element Modelling – 3/4

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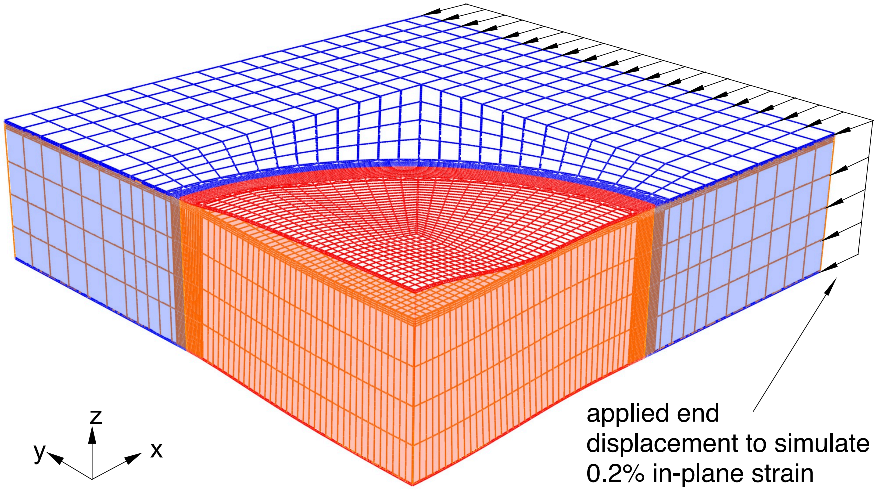
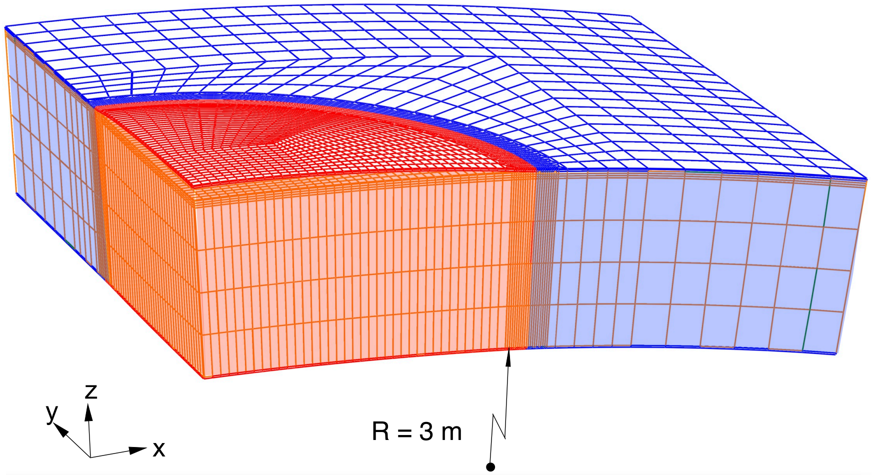
- **Model of a flat panel with in-plane loading**
  - Study the effect of in-plane service load on a flat control surface
  - In-plane displacement applied to the model to simulate a 0.2% (2000 με) strain condition during a flight maneuver
  - A compressive strain condition was chosen since it was believed that it would aggravate the condition
- **Model of a curved panel**
  - Honeycomb sandwich constructions may be used for cylindrical fuselage structures
  - A 3 m radius (wide body airliner) was chosen for this study



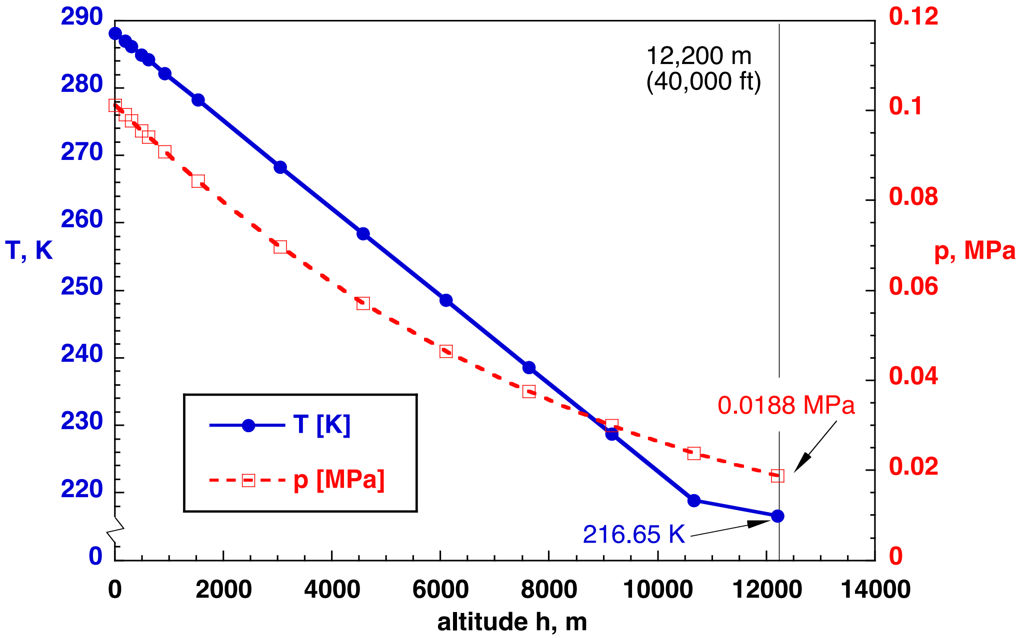


ANALYSIS METHODOLOGY

Finite Element Modelling – 4/4

- **Internal pressurization of the disbond**
  - Commercial jetliner ascent scenario was considered from 0 to 12192 m (0 to 40000 ft).
  - The pressure and temperature values were taken from the International Standard Atmosphere ISO 2533
  - The temperature in the core was defined to be equal to the ambient temperature
  - Pressure and volume inside the cavities were calculated during the analysis
- **Additional load conditions**
  - 0.2% (2000 με) strain condition only
  - Combination of GAG and 0.2% (2000 με) strain

- **Decrease of temperature and pressure with increasing altitude**



ANALYSIS RESULTS

Flat panel under internal pressure loading – 1/3

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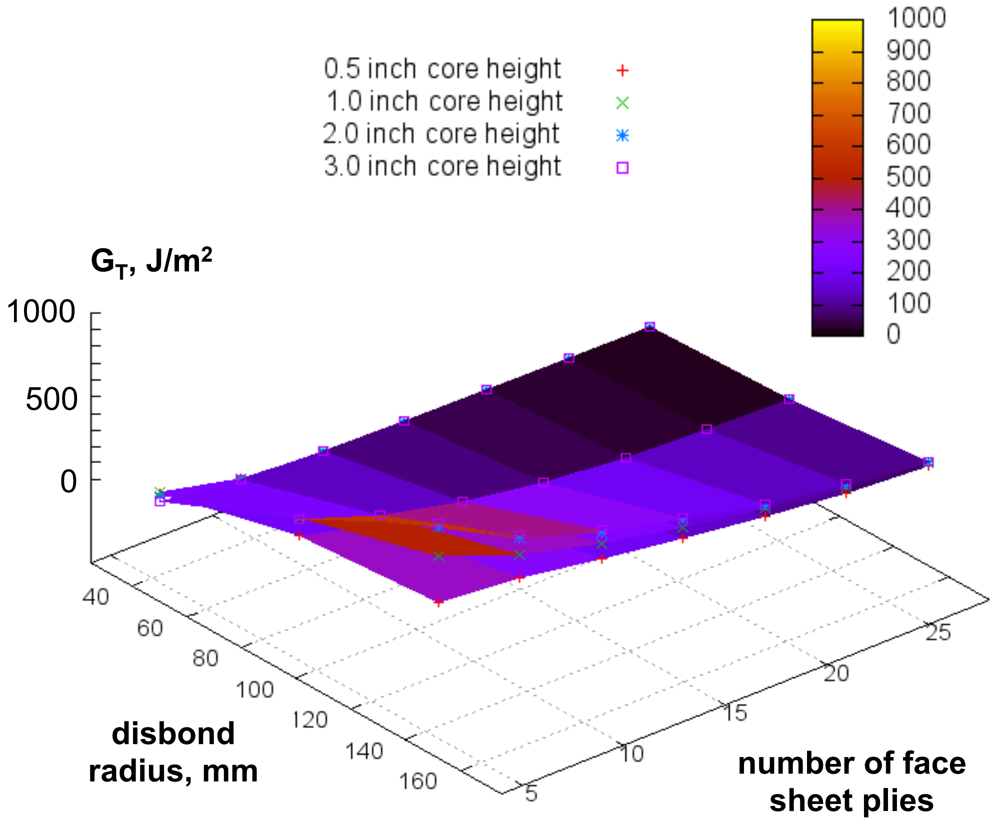
- **Initial study[6]**
  - Variation of
    - Face sheet thickness, number of plies
    - Disbond radius
    - Core density: 29 kg/m^3, 48 kg/m^3, 80 kg/m^3 (1.8 lb/ft^3, 3.0 lb/ft^3, 5.0 lb/ft^3)
    - Core thickness: 12.5 mm, 25.4 mm, 50.8 mm, 76.5 mm (0.5" – 3.0")
  - Results
    - Variation of core density does not have a significant effect on computed G_T
    - Large disbond radius and thin face sheets result in maximum G_T
- **Current study**
  - Dimensions based on results from initial study

- **Averaged G_T along crack front**

3.275 mm (1/8") cell size, 48 kg/m^3 (3.0 lb/ft^3) core density



ANALYSIS RESULTS

Flat panel under internal pressure loading – 2/3

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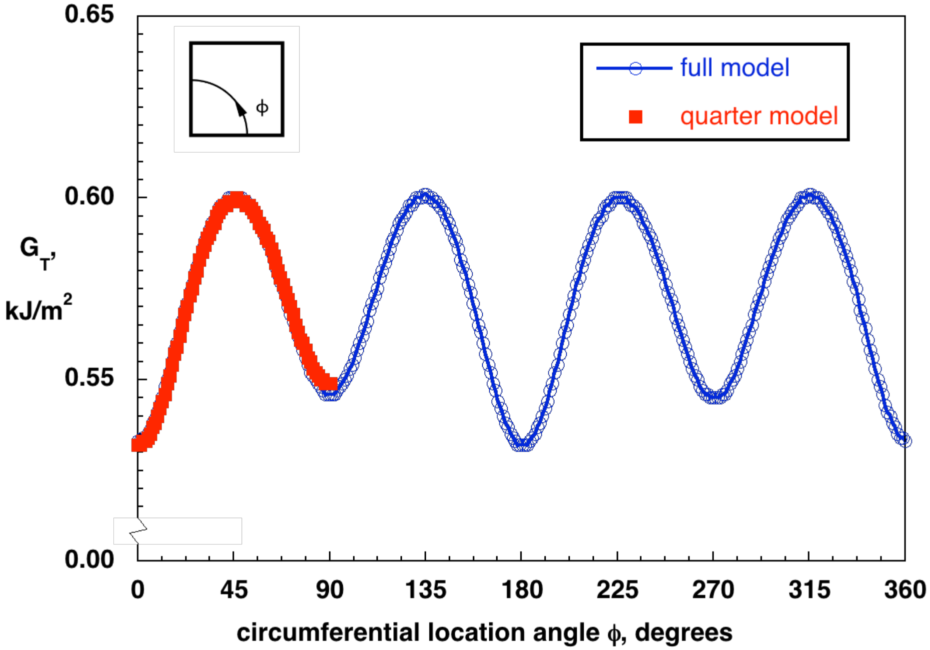
- **Conditions**
  - 12,192 m altitude (40,000 ft)
    - External pressure p=0.0188 MPa
    - External temperature T= 216.65 K
- **Verification for using a FE model of a quarter section of the panel**
  - Analysis using a full model of the panel with circular disbond
  - Analysis using a model of a quarter panel with boundary conditions
  - Excellent agreement of computed G_T along the front for the currently used quasi-isotropic layup
  - *Deviation, however, for other layups that violate the symmetry conditions of the model*

- **Distribution of energy release rate along the disbond front**

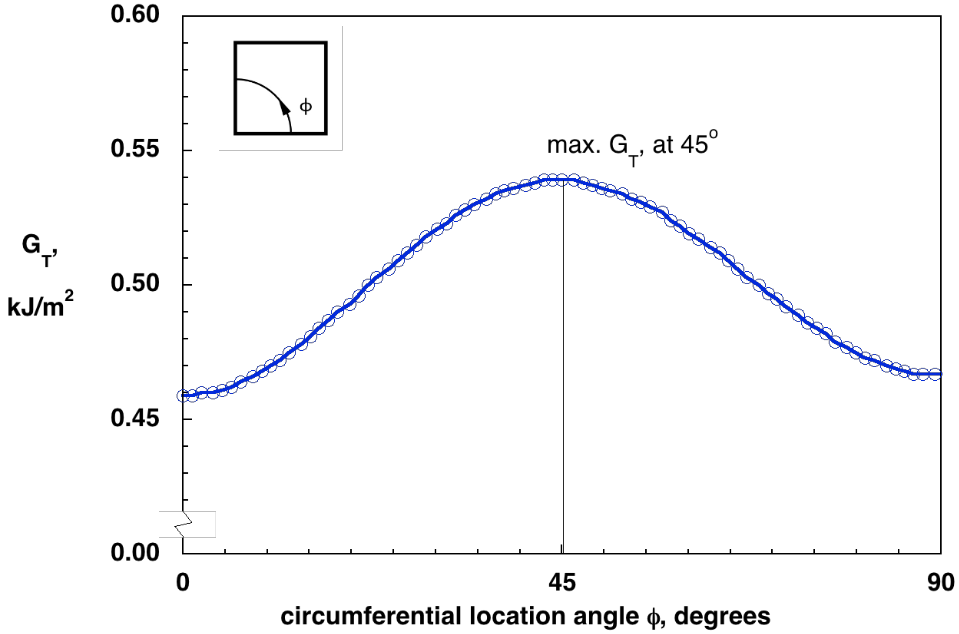


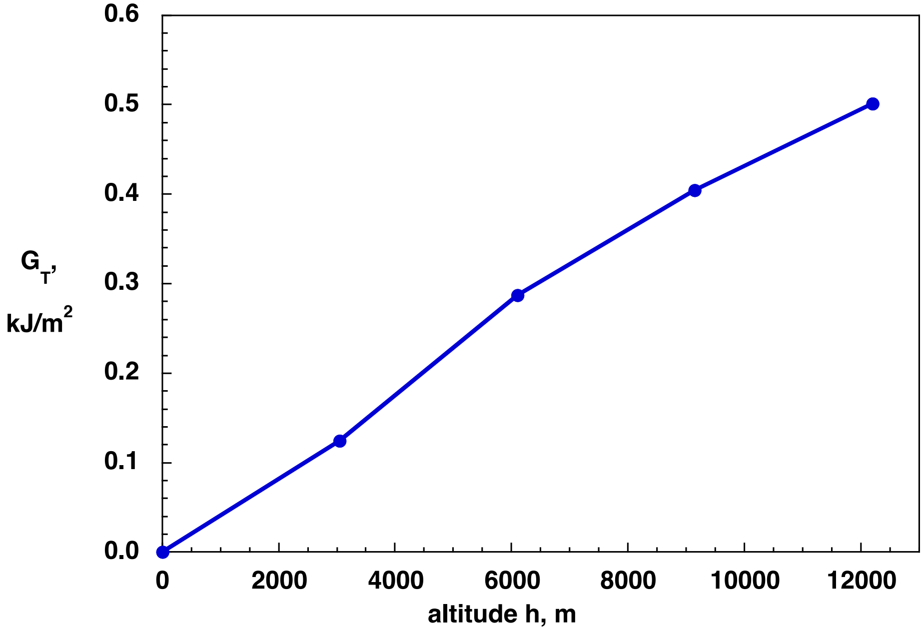
ANALYSIS RESULTS

Flat panel under internal pressure loading – 3/3

- **Conditions**
  - 12,192 m altitude (40,000 ft)
    - External pressure p=0.0188 MPa
    - External temperature T= 216.65 K
- **Result**
  - Max G_T observed at ϕ=45°

- **Conditions**
  - 0 m - 12,192 m altitude
  - Sea level to cruising altitude
- **Results for max G_T at ϕ=45°**
  - G_T increases monotonically with increasing altitude



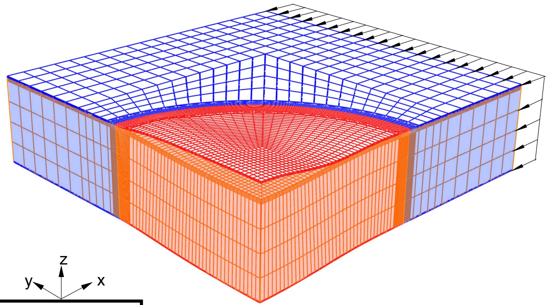


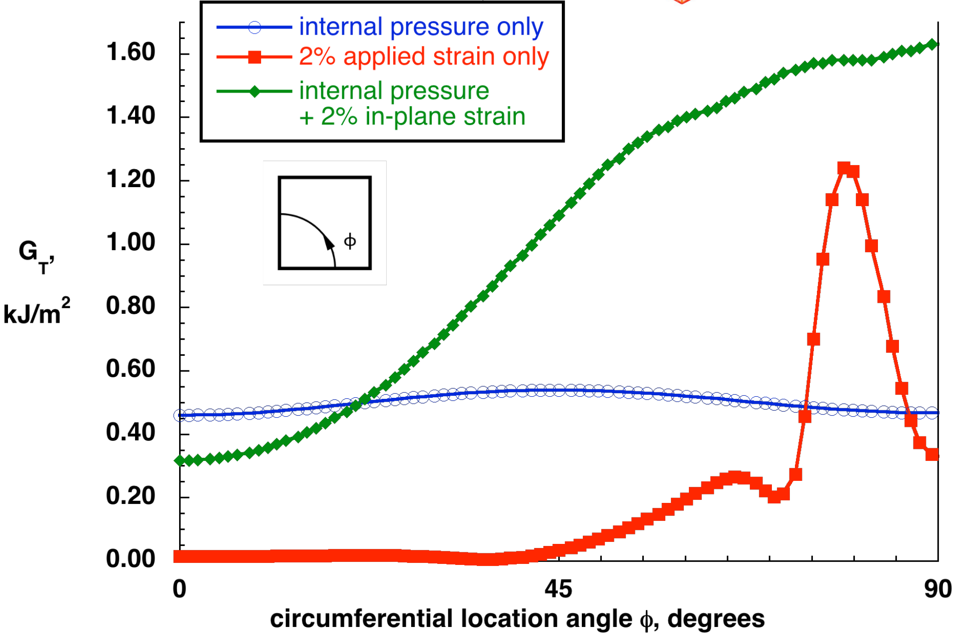
ANALYSIS RESULTS

Flat panel under in-plane and combined loading

- **Conditions**
  - 12,192 m altitude (40,000 ft)
    - External pressure p=0.0188 MPa
    - External temperature T= 216.65 K
  - 0.2% (2000 με) applied in-plane strain to simulate service loads on a flat control surface
  - Combined internal pressure + 0.2% (2000 με) in-plane strain
- **Results**
  - Out of plane deformation of the disbonded section changes
  - Leads to a change in the G_T distribution
  - In-plane strain aggravates the condition
  - Due to non-linearity superposition of the results is not possible

- **Distribution of energy release rate along the disbond front**



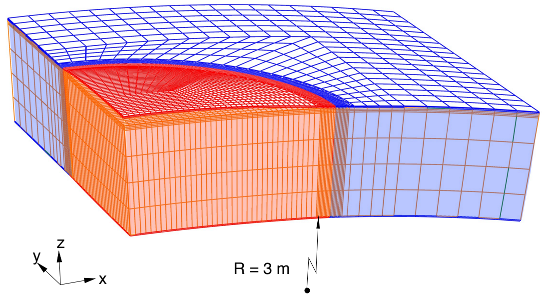


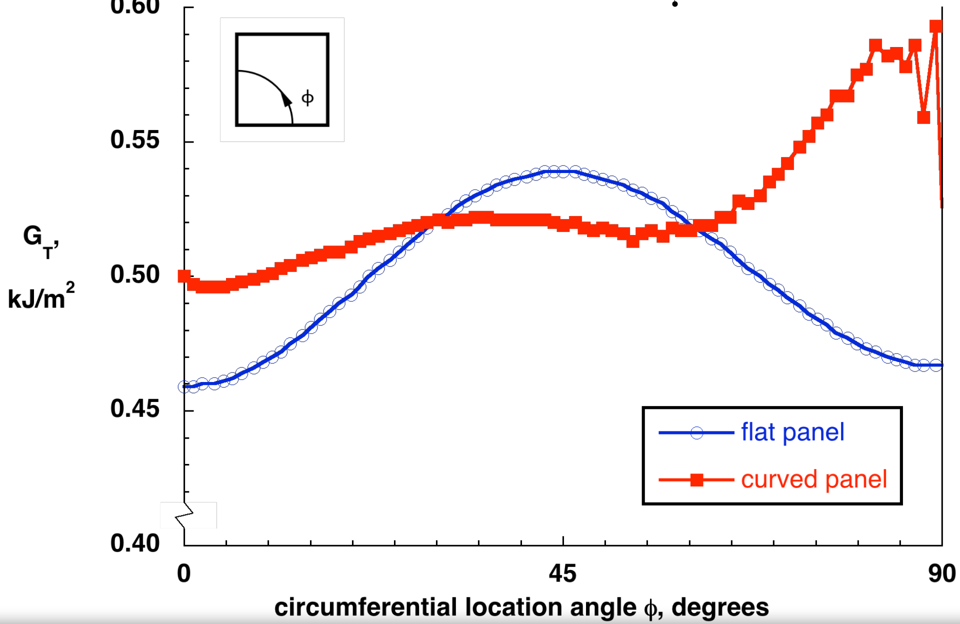
ANALYSIS RESULTS

Analysis of a curved panel

- **Conditions**
  - 12,192 m altitude (40,000 ft)
    - External pressure p=0.0188 MPa
    - External temperature T= 216.65 K
  - Flat panel
  - Curved panel with 3 m radius
- **Results**
  - Symmetry of the G_T distribution is lost for the curved panel
  - Locally and on average the computed G_T is higher than the result obtained from the flat panel
  - Result is unexpected
  - In-plane strain may further aggravate the condition
  - Additional analyses with different radii and more refined mesh should be preformed before a definite statement is made

- **Distribution of energy release rate along the disbond front**





SUMMARY

- A sandwich panel containing a circular disbond at the face sheet/core interface was studied.
- A fracture mechanics approach was used.
- The pressure-deformation coupling was a focus of the analysis.
- Special fluid-filled cavities were used to model the entrapped air.
- Sandwich panels with large disbonds, thin face sheets, and thick cores are most critical.
- Computed averaged energy release rate values increased almost linearly with increasing altitude.
- The presence of the in-plane compressive strain aggravated the condition along the crack front.
- Due to the non-linearity of the problem, the results for combined load cases cannot simply be obtained by superposition of the individual load cases.
- For a curved panel with 3 m radius, the computed energy release rate values were higher than the values computed for a flat panel.

CONCLUDING REMARKS

- Overall, the finite element analysis with fluid cavities appears to perform well and is capable of capturing the pressure-deformation coupling in the disbonded section of the panel.
- Based on the current preliminary results, however, it is recommended that additional validation studies be performed to compare.
  - The computed local deformation field of the disbonded face sheet with far field measurements
  - The computed pressure inside the cavity with measured values.
- Additionally, analyses of curved panels with different radii should be performed before a definite statement about the effect of panel curvature on the crack tip loading is made.
- Methods development will continue within the Disbond/Delamination Task Group in CMH-17

ACKNOWLEDGEMENTS

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BACKUP SLIDES

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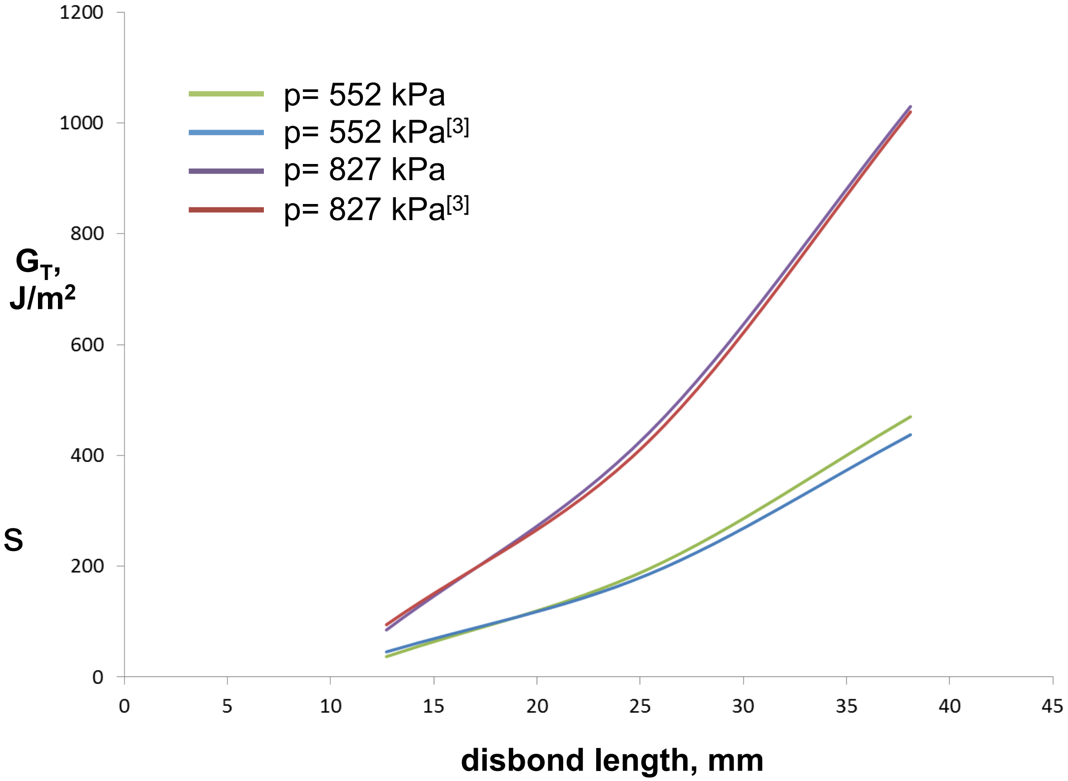
INITIAL MODEL VERIFICATION AND VALIDATION – 1/2

- **X-33 cryogenic fuel tank**
  - NASA sandwich disbond investigation[3]
    - Square delamination
    - Panel pressurized by a compressor
    - Defined load, no pressure-deformation coupling
    - Calculations were performed using surface loads
  - Current analysis approach[6]
    - Same dimensions as NASA publication
    - Pressure application with Abaqus fluid elements
    - VCCT calculation using post-processing routine
  - Result comparison
    - Good correlation between G_T values calculated using different models



INITIAL MODEL VERIFICATION AND VALIDATION – 2/2

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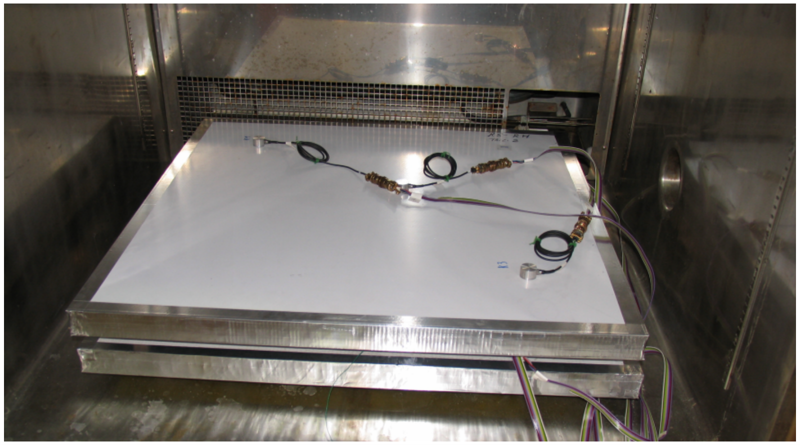
- **Sandwich panel with disbond**
  - Airbus test in vacuum chamber[4]
    - Panel with 350 mm disbond
    - Pressure-deformation coupling needs to be considered
    - Pressure in disbonded core section was measured during test
    - FE analysis was performed calculating pressure-deformation coupling iteratively



  - Current analysis approach
    - Same dimensions as Airbus panel
    - Pressure pressure-deformation coupling solved with Abaqus fluid elements
  - Result comparison
    - Pressure-deformation coupling is correctly solved via Abaqus Fluid Cavity Simulation
    - Pressure in core:
      - Airbus test: 0.0582 MPa
      - Airbus analysis: 0.0577 MPa
      - Current analysis: 0.0571 Mpa
- **Additional validation studies should be performed to compare test results and analysis**
  - Compare deformation field
  - Compare pressure inside the cavity