

Session 1: Sandwich Disbond Assessment

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Sept 2015: FAA/Bombardier Composite Transport DT & Maintenance Workshop

CMH-17 Honeycomb Sandwich Disbond Growth Team Status Mid 2015



BOMBARDIER
l'évolution de la mobilité



Transport
Canada

Transports
Canada



Content

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Road Map for Research

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Key Message

Introduction

Subject

Damage growth in unvented honeycomb sandwich structures due to Ground-Air-Ground (GAG) pressurization and in-plane loading

- **Airbus** shared experience at F&DT Workshops in Amsterdam, Tokyo & CMH-17 Meetings
 - Degradation due to disbonding affects operational safety
 - Methods for assessing propensity of sandwich structures to disbonding not fully matured, accepted and documented
 - In 2011 Larry Ilcewicz, FAA, initiated the Honeycomb Sandwich Disbond Growth Team as part of the CMH-17 organization
- ➔ Recap of Airbus Experience & CMH-17 Honeycomb Sandwich Disbond Growth Team Activities, Road Map & current status

Introduction

Honeycomb Sandwich Disbond Growth due to GAG-Cycle Pressurization & in-plane loading

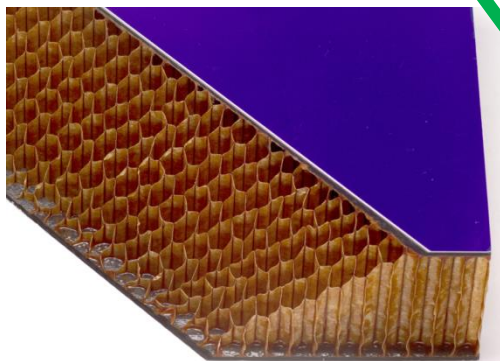
Flight Altitude

Assumption:

- Air volume enclosed in the structure
- Tight unvented structure



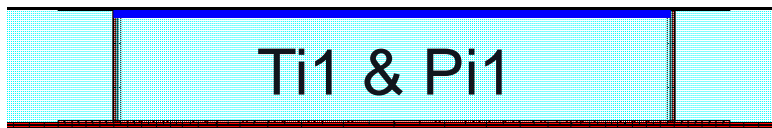
Ground Level



To1 & Po1



Ti1 & Pi1



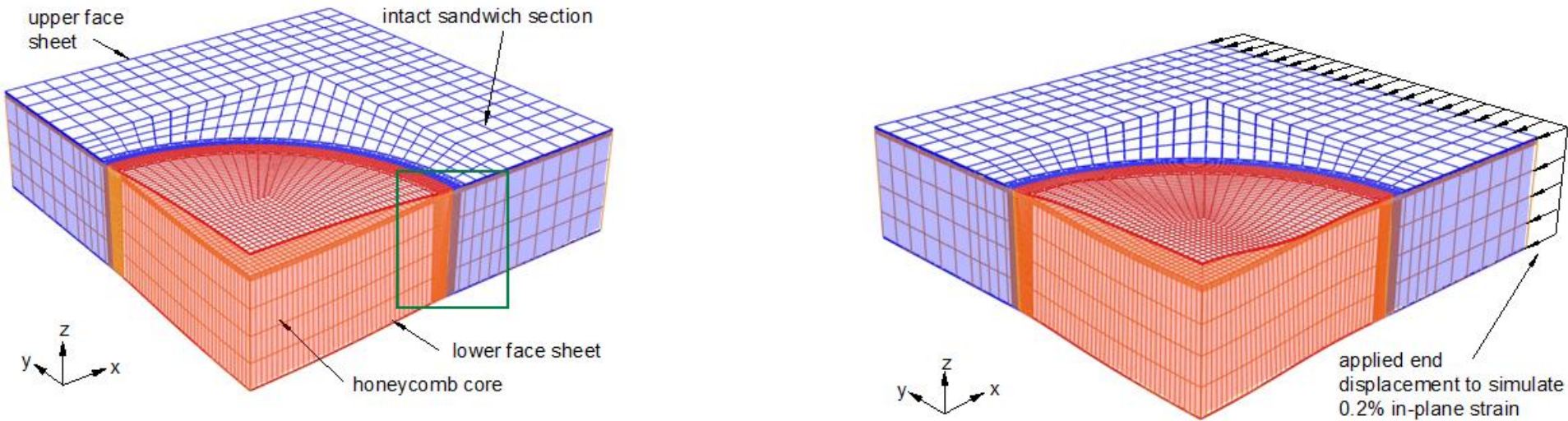
To2 & Po2

Ti2 & Pi2



Introduction

Honeycomb Sandwich Disbond Growth due to GAG-Cycle Pressurization & in-plane loading



GAG-Cycle pressurization

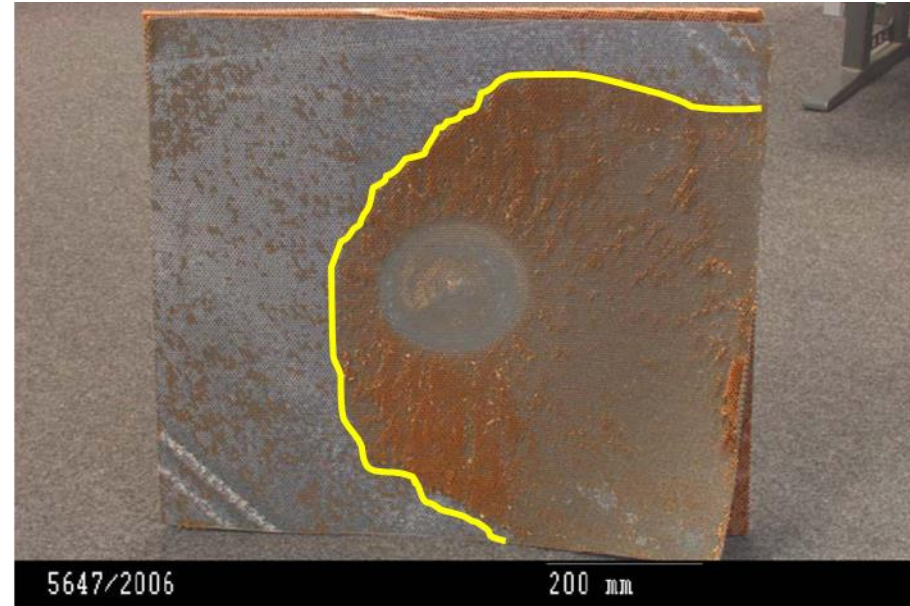
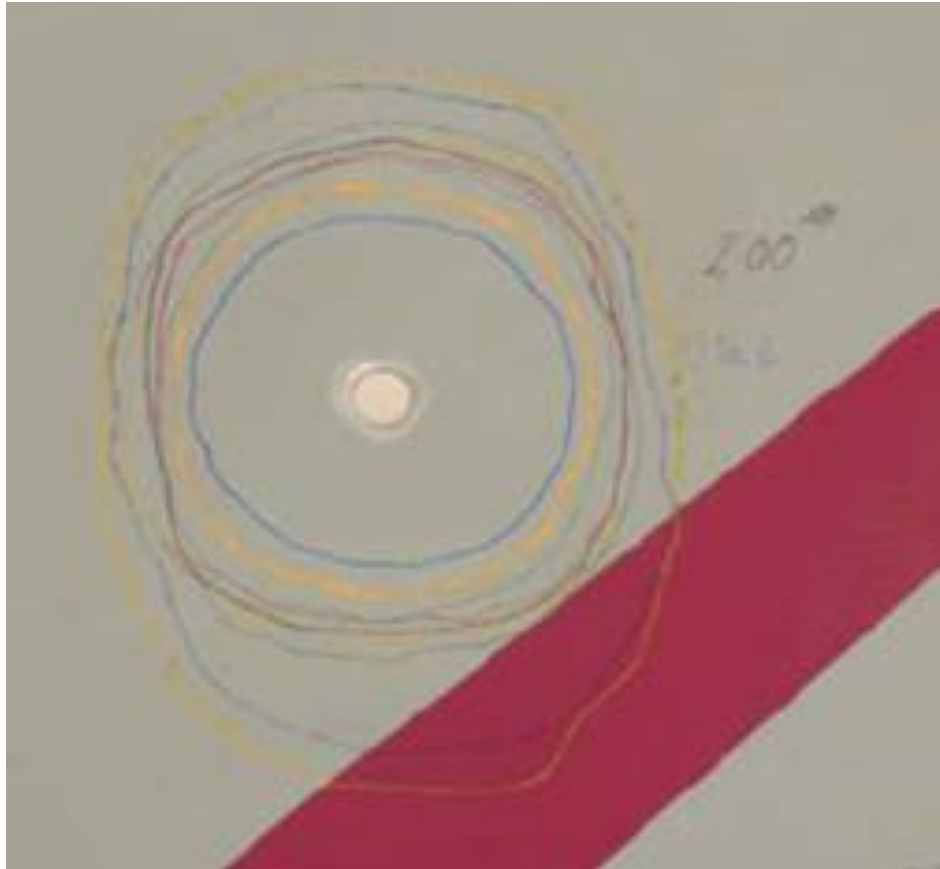
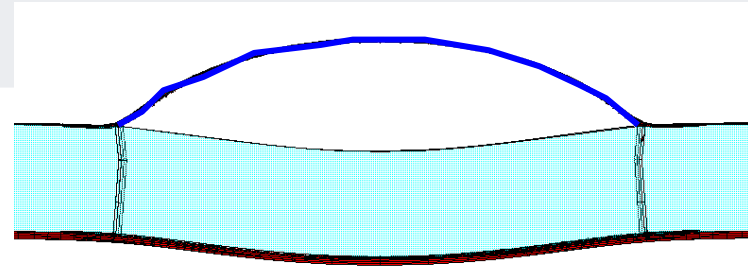
In-plane loading



Effect on disbond propagation & structural integrity

Introduction

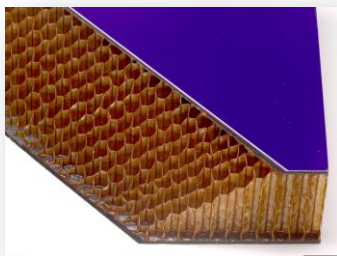
Airbus Vacuum Chamber GAG-Cycle Fatigue Tests



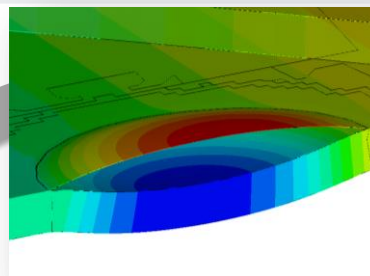
Tests in 2005 showed damage propagation & residual life capability

Airbus Experience

Sandwich Rudder Design



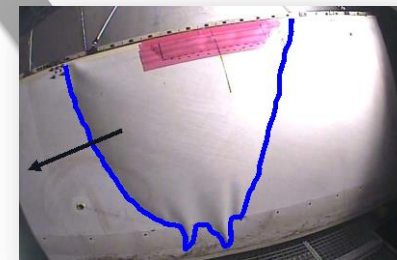
GAG-cycle analysis



March 2005 Sandwich rudder in service experience



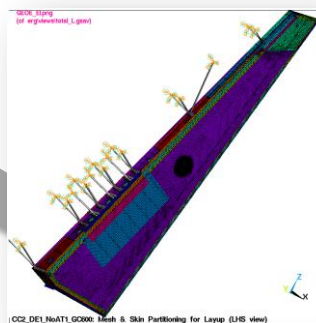
Airbus Circle of knowledge for sandwich disbond



GAG-cycle testing



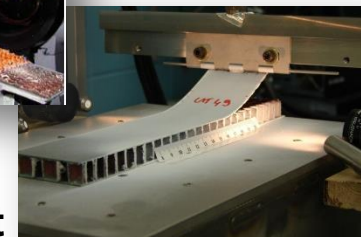
NDI inspection methods & capabilities



Disbond analysis on component level



Coupon Test Fracture Toughness



Airbus Experience

- Airbus shared the In-Service experience during Workshops
- Disbond growth due to GAG-Cycle pressurization & in-plane loading can affect operational safety
- Airbus expectations
 - International standard for honeycomb core fracture toughness testing → ASTM
 - Honeycomb core fracture mechanics approach
 - Matured & international accepted assessment of the phenomenon will help to keep honeycomb sandwich structures in business

CMH-17 – Honeycomb Sandwich Disbond Growth Team

CMH-17 Honeycomb Sandwich Disbond Growth Task Group

- International working group under the CMH-17 organisation
- Initiated by Larry Ilcewicz in 2011 & supported by Simon Waite EASA
- Chair: Ronald Krüger NIA, Hampton
- The Task Group activity is considered in the FAA AVS Composite Plan under Continued Operational Safety (COS) as high priority



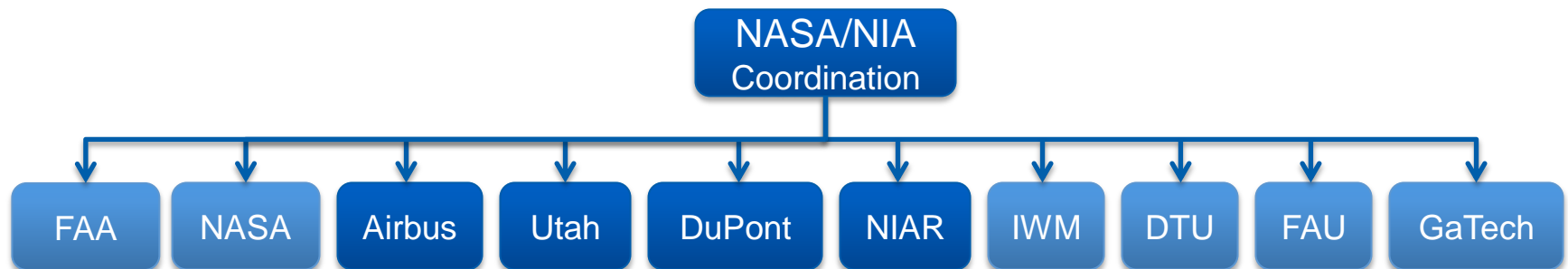
Honeycomb Sandwich Disbond Growth Team

CMH-17 – Honeycomb Sandwich Disbond Growth Team

Group Objective

Develop matured, accepted & documented methods for assessing propensity of sandwich structures to disbond growth under GAG-Cycle pressurization and in-plane loading

Active partners (September 2015)



CMH-17 Sandwich Disbond Growth Team Road Map

Road Map for Research (Status 2015)

Task 1: Coupon Test Standard Development

Task 2: Analysis Development

Task 3: Panel testing for analysis validation

Task 4: Sandwich Disbond Substantiation and Methodology Development

Task 5: Documentation of findings in CMH-17 Vol. 6

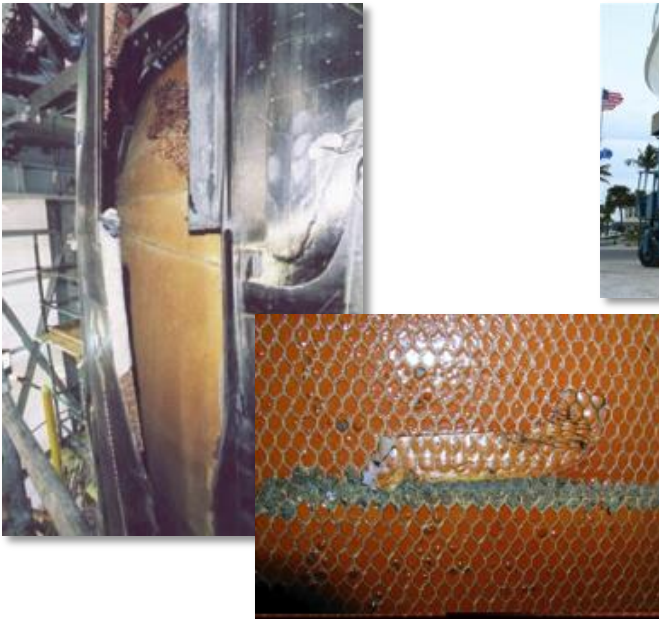
Data shown on the slides are provided & released by the individual partners

CMH-17 Sandwich Disbond Growth Team Road Map

Background

- Examples from Space, Marine & Aviation collected & discussed
- Occurrence of in-service component failures associated with disbonding in honeycomb core sandwich
- Structure integrity degradation due to disbonding affects continued operational safety

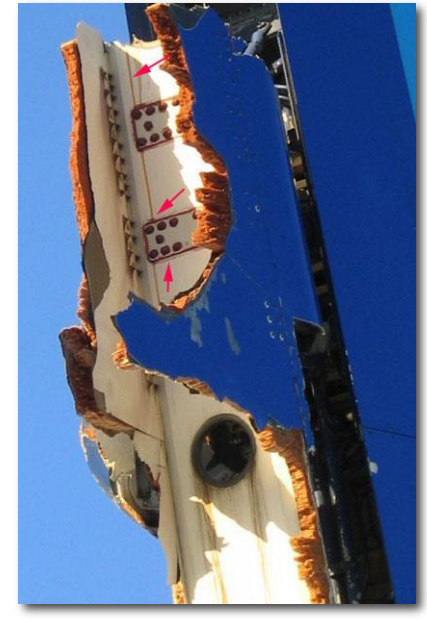
Space



Marine



Aviation



CMH-17 Group - Funding

• European Funding

- Airbus is funding a PhD at DTU – active since July 2015 (3 years)
- DTU has another PhD working on the subject
- EASA project proposal by Airbus, Airbus Helicopters, DTU, IWM, DuPont
→ EASA R&T final position pending → Project still expected for 2016

• US Funding

- Zhi Chen has accepted a position at the FAA Tech Center in Atlantic City (start date was June 29)
- NASA James Ratcliffe & Utah, Dan Adams – ASTM SCB Test Standard
- NIAR, Waruna, FAA & KART funding
- FAA funding likely to be available to support research
 - Discussion basis is the Road Map

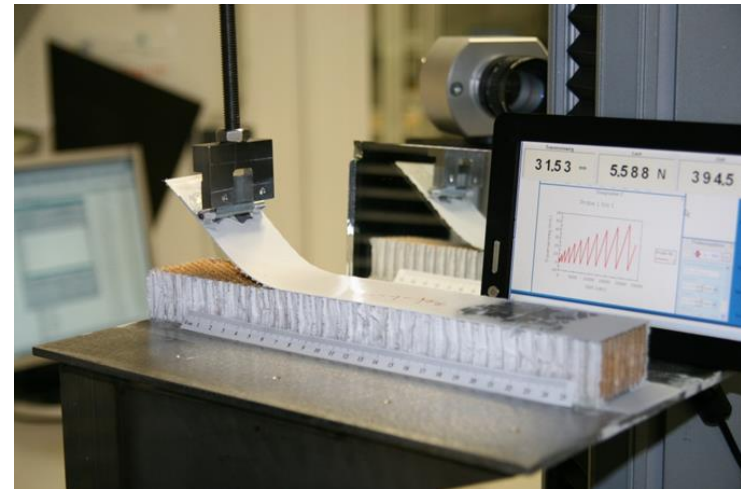
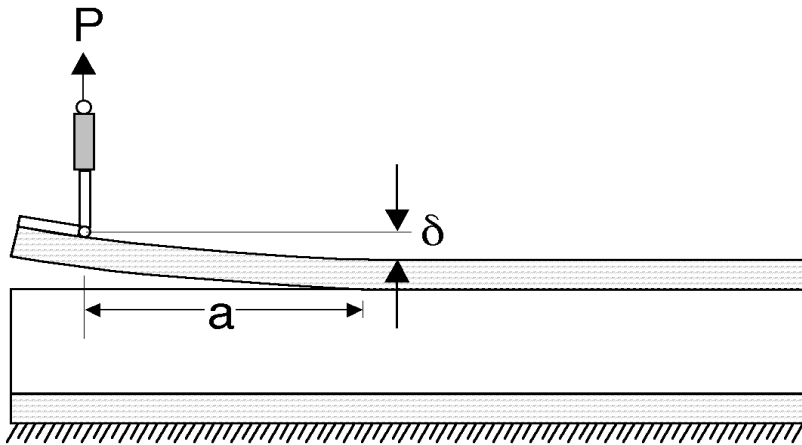
CMH-17 Sandwich Disbond Growth Team Road Map

Task 1: Coupon Test Standard Development

- Develop standard test methods for characterizing facesheet/core disbonding in sandwich components
- Covering static, damage tolerance (fatigue, damage growth) and environmental aspects (e.g. temperature knock down)

SCB Test

- SCB draft standard for mode I fracture toughness testing
- Collaboration with ASTM committee D30.09 (WK 47682)



Task 1: Coupon Test Standard Development



ASTM SCB (WK 47682)

- James Ratcliffe NASA Hampton & Dan Adams University of Utah

- **Specimen geometry**

- Length
- Width
- Initial crack length

- **Facesheet properties**

- Thickness
- Flexural stiffness
- Flexural strength

- **Core properties**

- Thickness
- Density
- Stiffness
- Strength

- **Mode mixity**

- Variations across specimen width
- Variations with crack length

- **Data reduction methods**

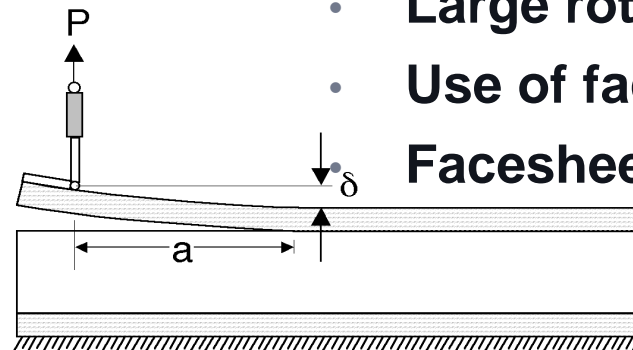
- **Thru-thickness crack placement**

- **Anticlastic curvature & curved crack front**

- **Large rotations of facesheet**

- **Use of facesheet doublers**

- **Facesheet curvature effects**



Task 1: Coupon Test Standard Development



SCB Round Robin Test

NIAR is providing SCB specimen

SCB Round Robin Test

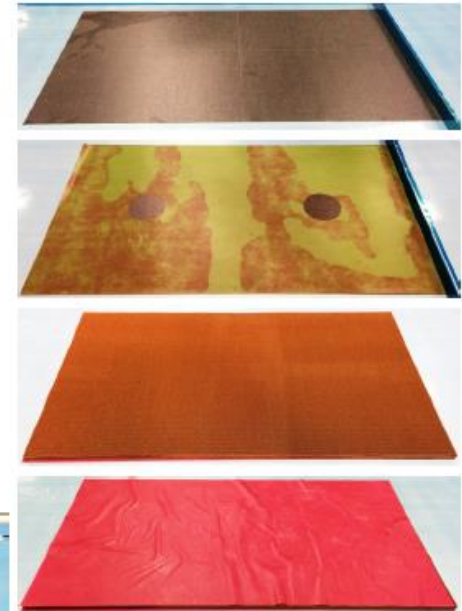
(7 Labs)

- NASA
- Utah
- NIAR
- DuPont
- DTU *)
- IWM
- Airbus

*) SCB & DCB-UBM

• Materials

- Facesheet
 - Cytec 5320-T650-3K plain weave
- Core
 - Hexcel HexWeb HRH-10
 - 0.125" cell size
 - 0.5" thickness
 - 3.0 pcf density
- Adhesive
 - FM300-2

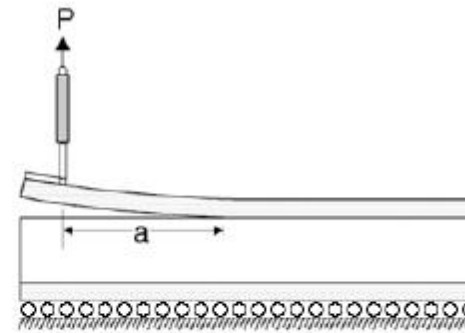
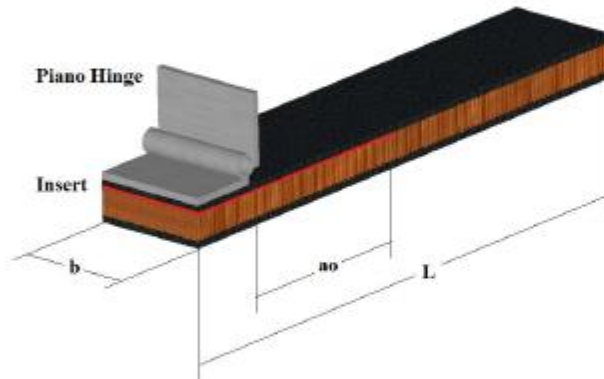


KART

Task 1: Coupon Test Standard Development

NIAR - Activities

- Large Test matrix
- Environmental tests (temperature, fluid)
- Results released in two FAA Reports



Task 1: Coupon Test Standard Development

IWM Activities Test Rig & Test Procedure Improvement

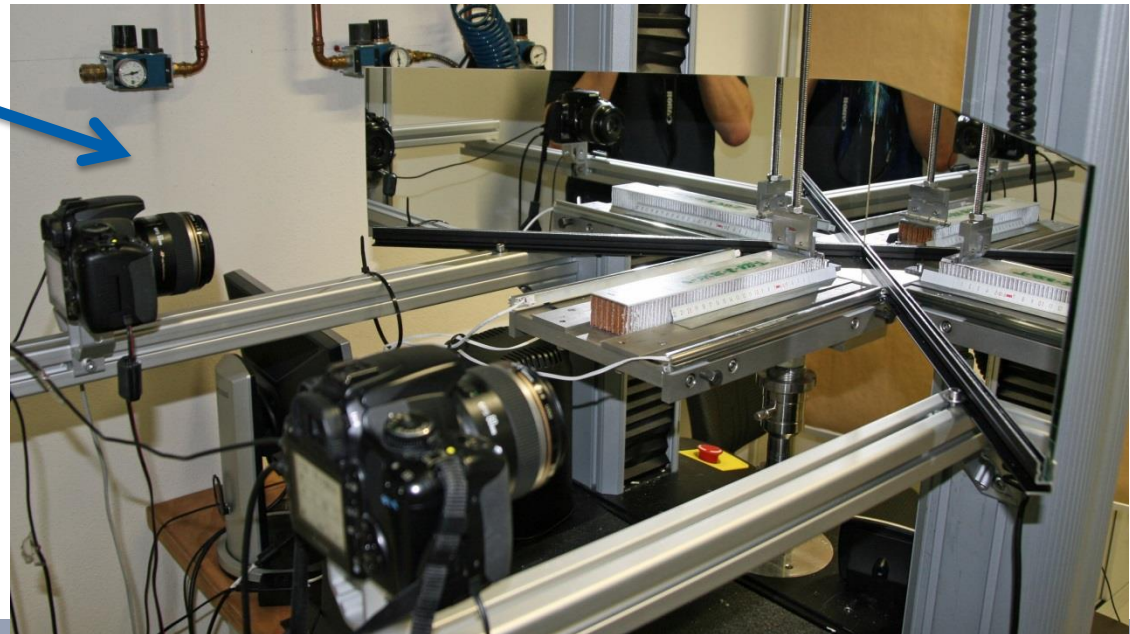


Enhancements:

- Robust clamping jaws
- In plane view via mirror
- Enhanced illumination
- Automated crack tip recognition (ongoing)

Standard:

- Specimen adhesively bonded on a rigid fixture
- Visual crack length measurement
- Experimental and numerical case studies

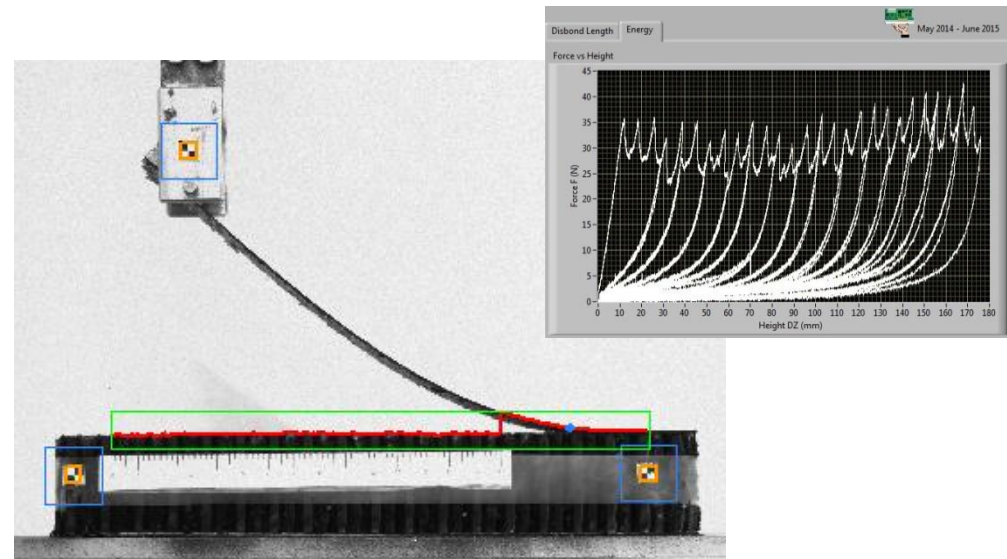
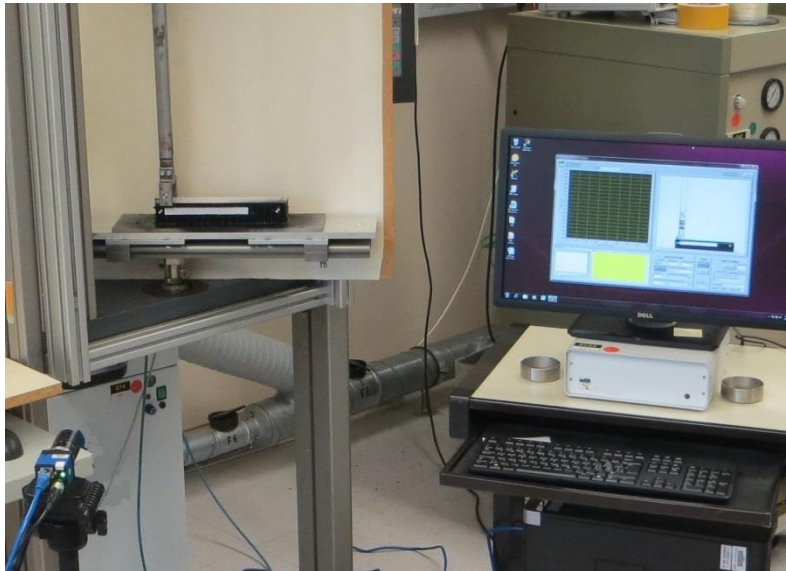


Task 1: Coupon Test Standard Development



DuPont Activities

- As DuPont is the supplier of the honeycomb core Aramid paper to understand its role within the fracture toughness measurement
- Objective to develop out of the ASTM procedure an industry applicable coupon test workbench
- Automatic data acquisition & Optical Extensometer (marker & pixel tracking)

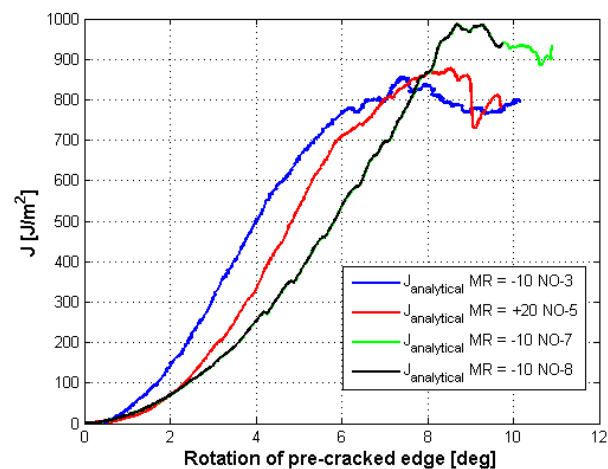
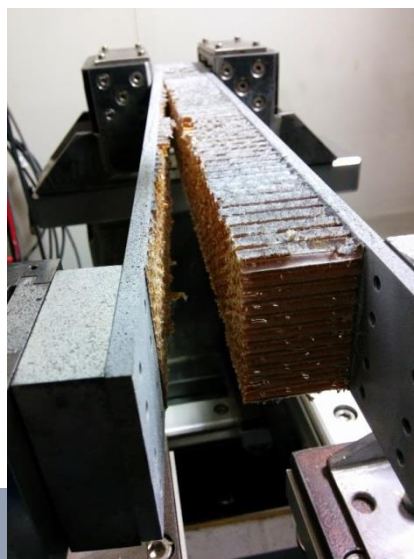
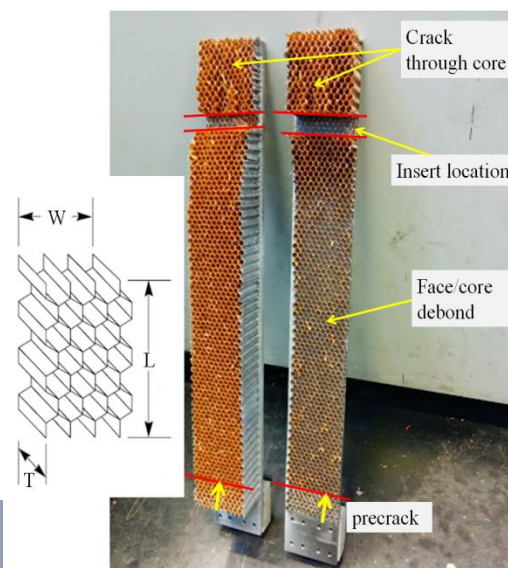
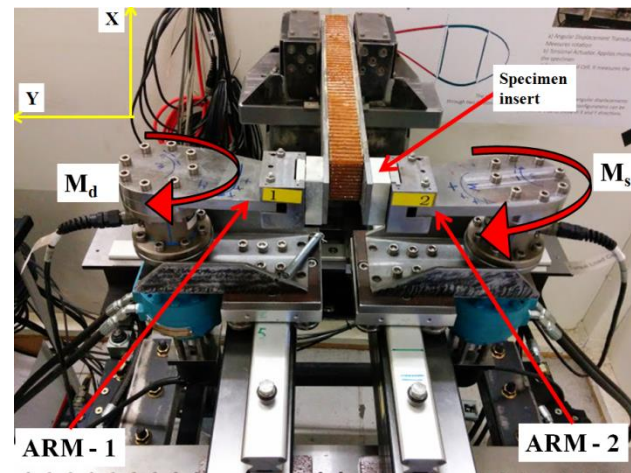




Task 1: Coupon Test Standard Development

Mixed-mode screening of honeycomb sandwich specimens (pilots) : DCB-UBM

- G-controlled testing (static & fatigue)
- Control of mode-mixity and energy release rate
- Analytical J-integral expressions derived used to obtain energy release rate



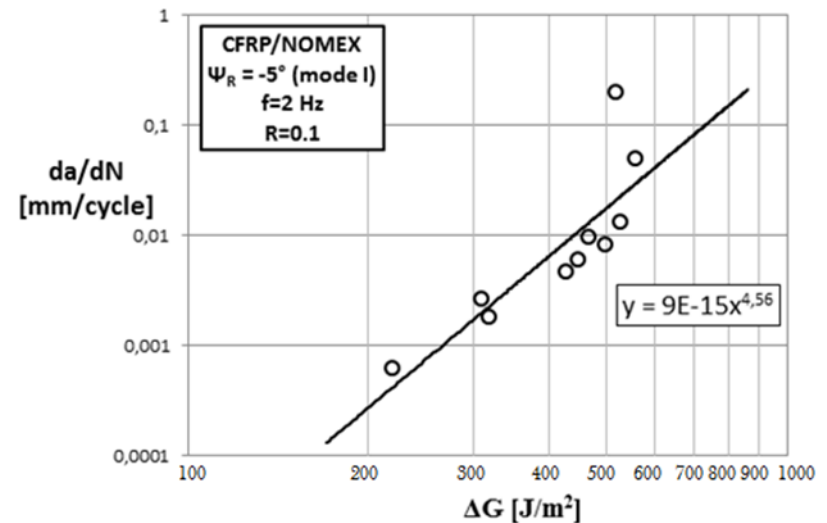
Task 1: Coupon Test Standard Development

G-controlled Static and Fatigue MMB Tests

- Constant crack growth rate
- More accurate material characterization compared to load or displacement controlled tests
- Possibility of using the same specimen for several tests



Crack Speed (da/dN) vs Cyclic Energy Release Rate (ΔG) for fatigue tests

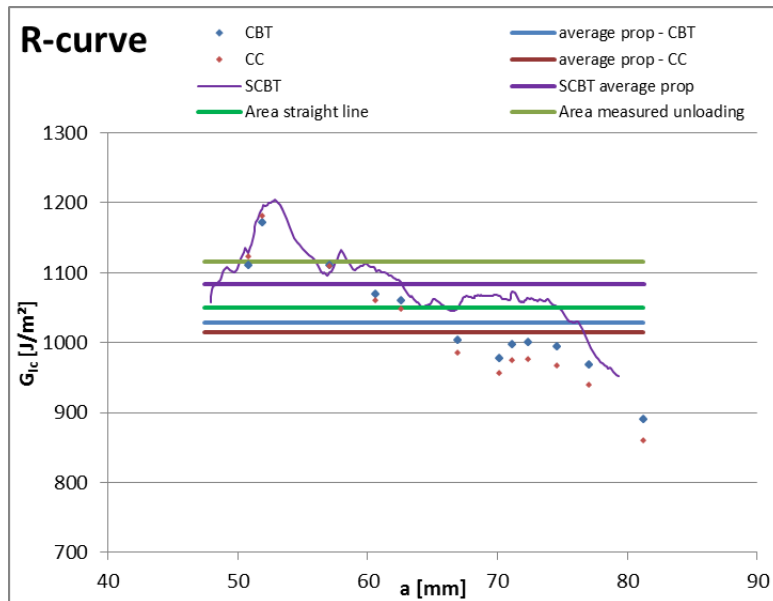


Task 1: Coupon Test Standard Development



Airbus Activities

- Supports from OEM coupon test in-field experience to achieve a test procedure which is industry applicable
- Comparison and refinement of different Data Reduction methods in order to
 - Identify the most robust and correct data reduction method
 - Simplify the test method (avoid crack length observation, simple data reduction)



Task 1: Coupon Test Standard Development

Open items

- Detailed discussion about the test procedure in monthly WebEx meetings
- Round Robin Test Program (7 Labs)
 - SCB & DCB-UBM specimen manufactured
 - Detailed discussion about the test procedure
 - Testing → soon

Achievements (status September 2015)

- November 2014 Hampton US SCB Testing Workshop
- SCB draft standard for mode I fracture toughness testing
- Collaboration with ASTM committee D30.09 (WK 47682)

CMH-17 Sandwich Disbond Growth Team Road Map

Task 2: Analysis Development

- Develop a fracture mechanics based methodology to assess facesheet/core disbonding in sandwich components
- Develop models and analysis tools for facesheet/core disbonding in sandwich components subjected to ground-air-ground cycles and/or in-plane loading
- Goal is to develop a model & analysis tools which can be implemented in component structure finite element models and not only on sub-scale models

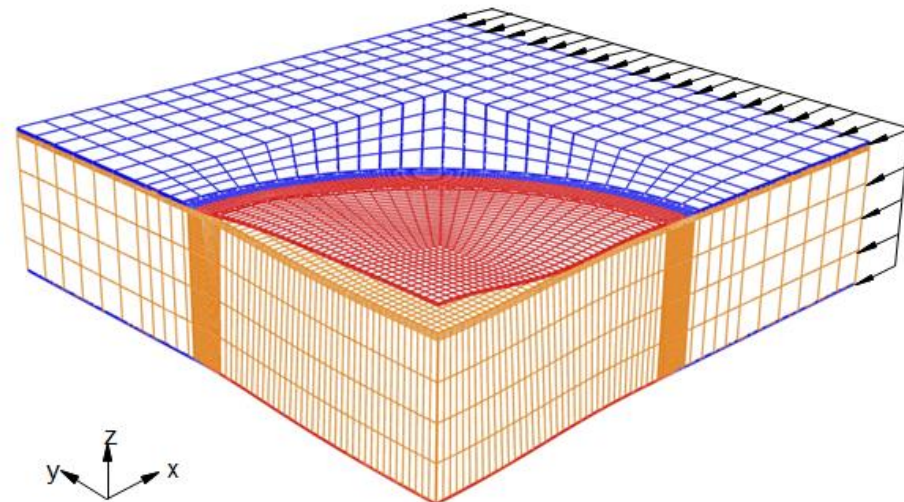
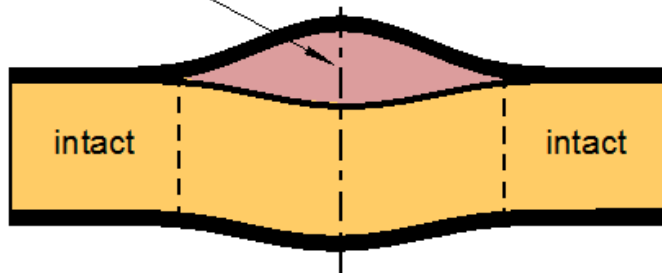
Task 2: Analysis Development



Parametric ABAQUS Models for Flat & Curved Sandwich Panel was created

- Based on guidance from Airbus, Martin Rinker (IWM) developed a finite element model during his stay at NASA/NIA in 2012
- Goal was to simulate and study the GAG cycle using a 3D solid model in Abaqus/Standard
- Model includes pressure-deformation coupling following the ideal gas law
- Crack Front assessed using VCCT

cavity created by bulging of disbonded section

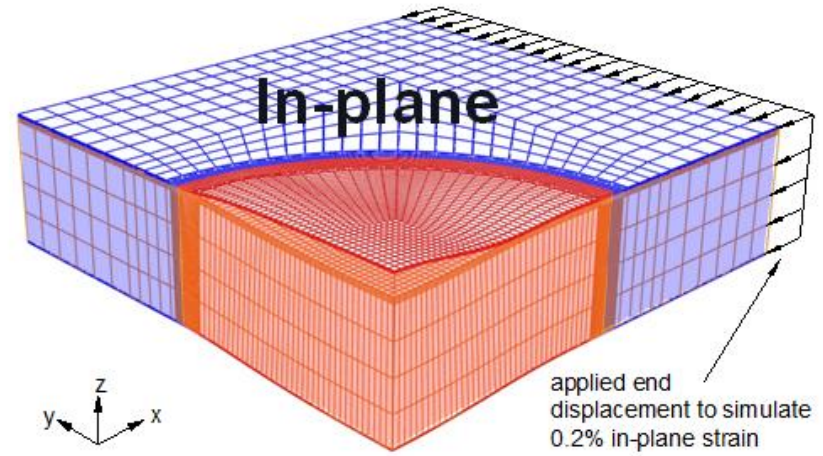
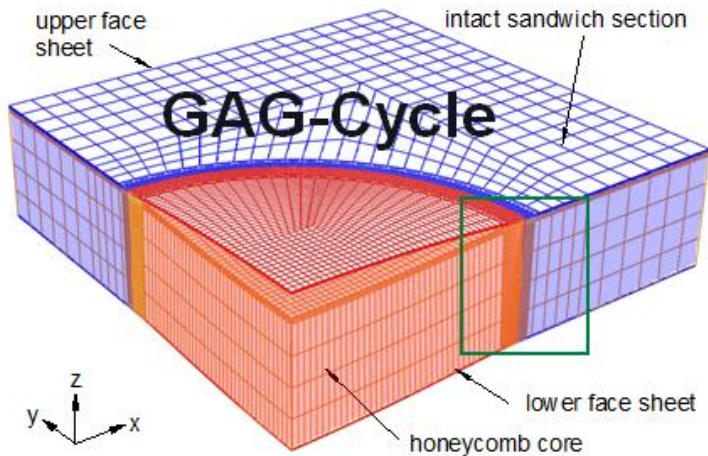


Task 2: Analysis Development

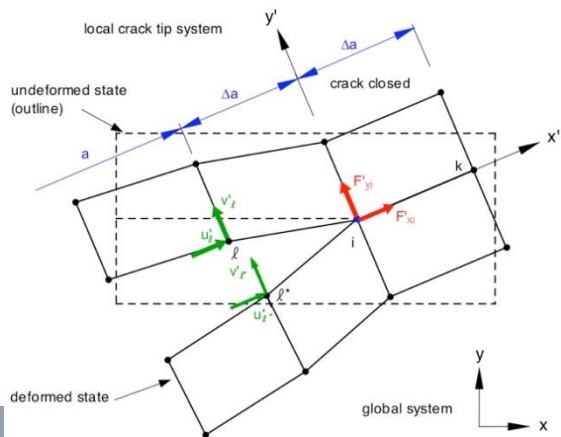


ABAQUS model evolution

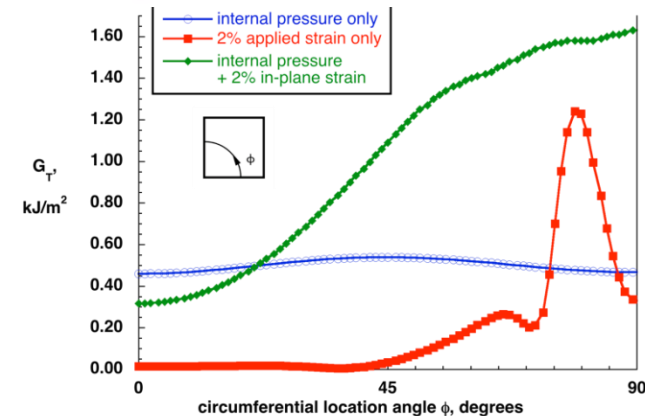
Zhi Chen at NASA (2014) and now at the FAA Tech Center extended the model to include in-plane loading and also simulated curved panels



VCCT Crack growth



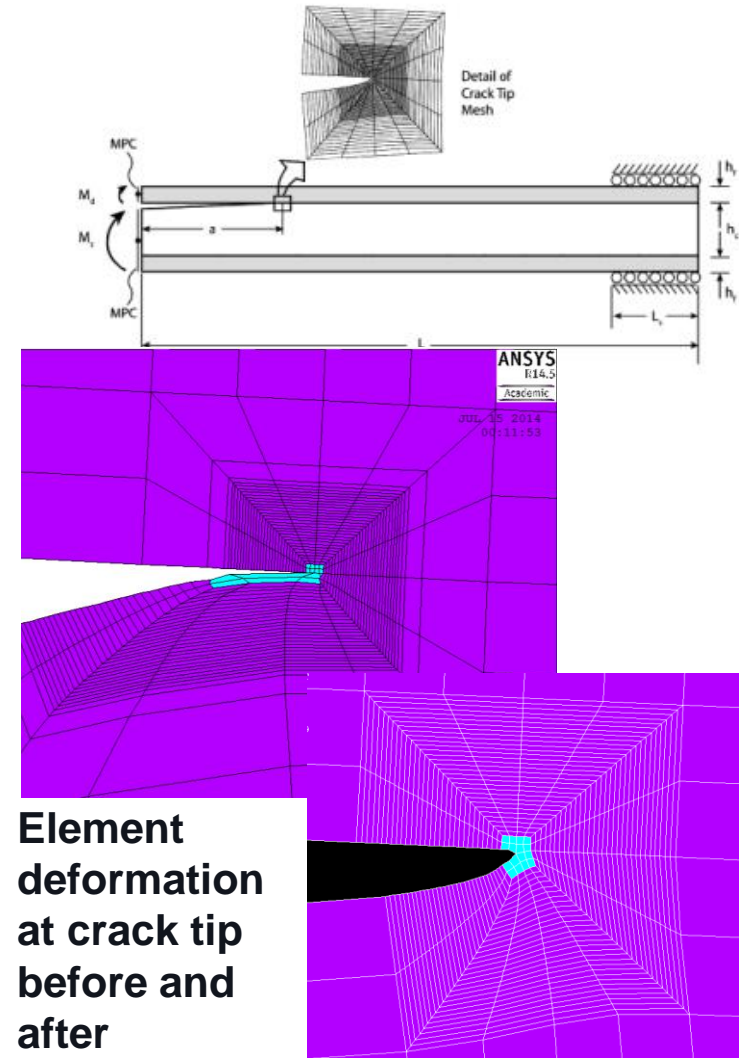
Energy release rate along disbond front



Task 2: Analysis Development

Honeycomb Core In-plane moduli

- Subject: Discussion of the large in-plane stiffness change at the honeycomb core to face sheet interface (crack location)
- Fracture mechanics analysis by VCCT and CSDE showed
- In-plane elastic properties using *Gibson-Ashby* relations – CSDE implementation provide more realistic results
- Group discussion on subject necessary

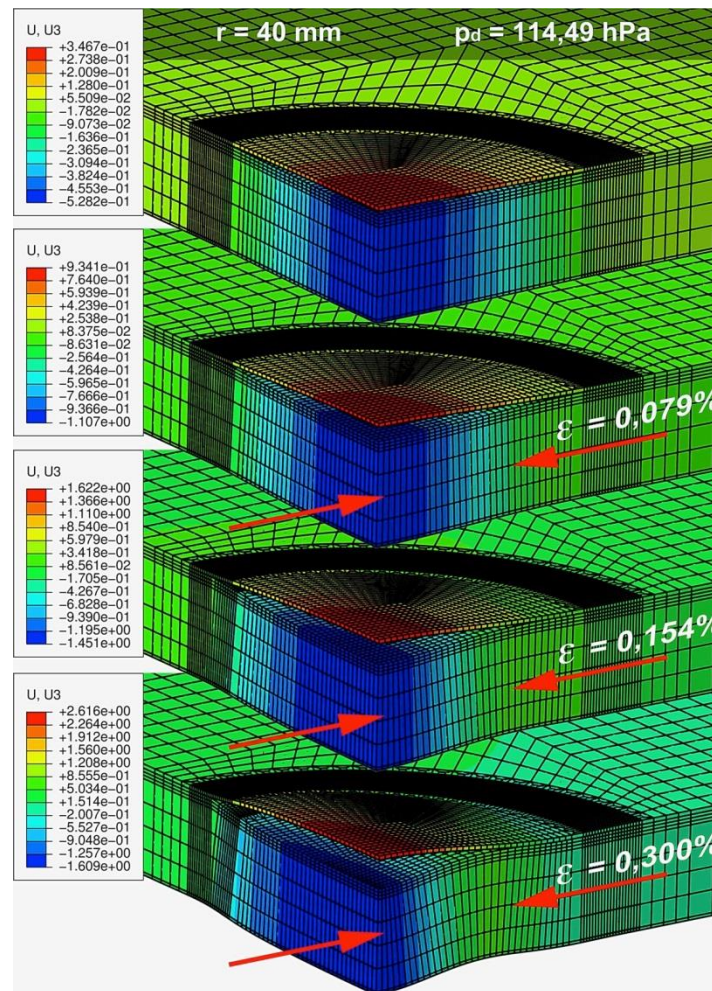
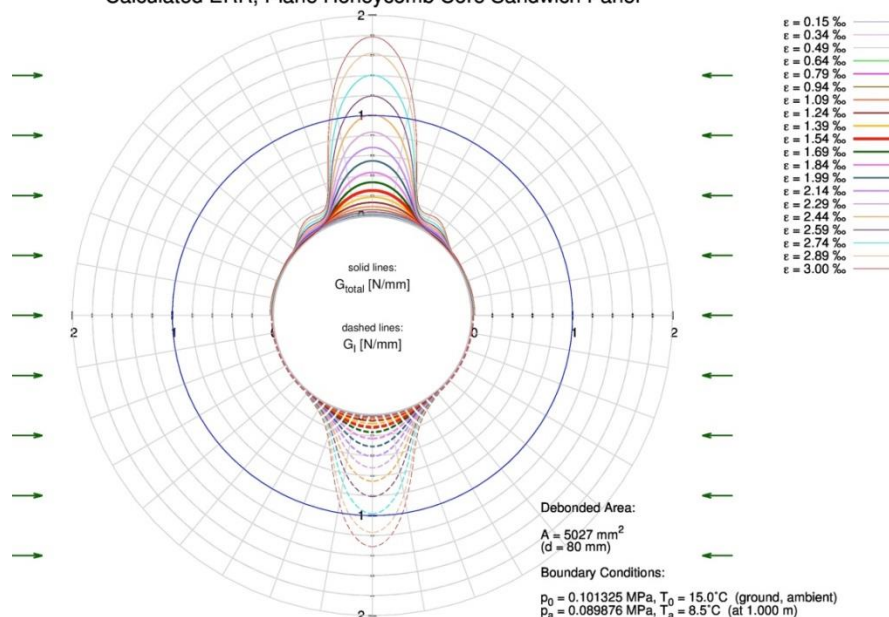


Task 2: Analysis Development

Flat Panel Disbond Study under mainly in-plane loads

- Gain experience how the model is working
- Fracture mechanics and buckling/postbuckling sensitivity analysis

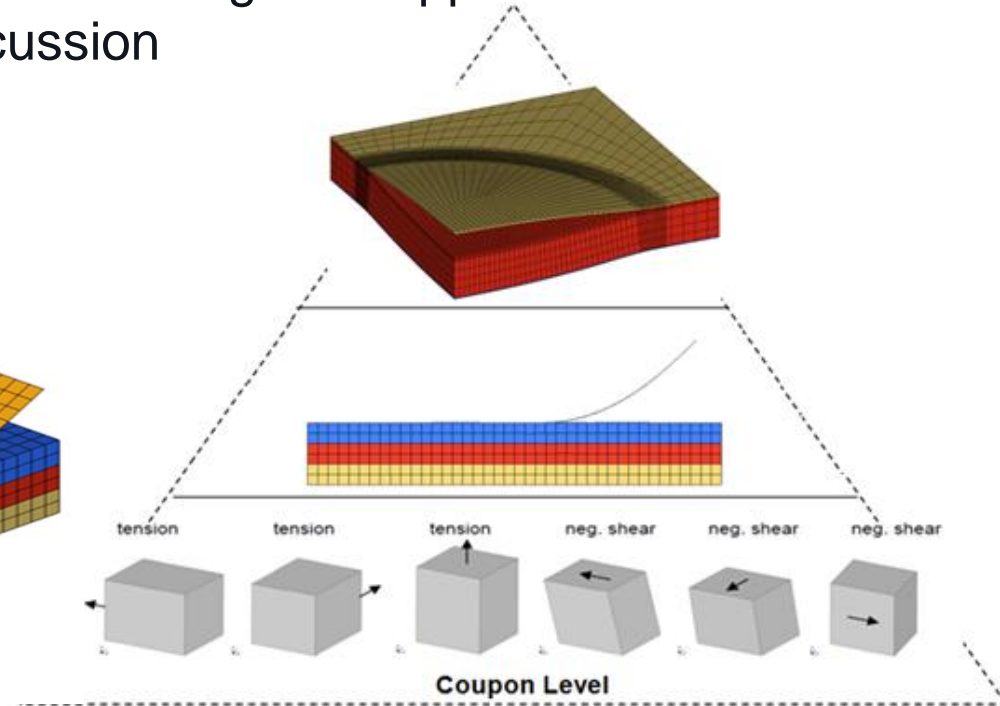
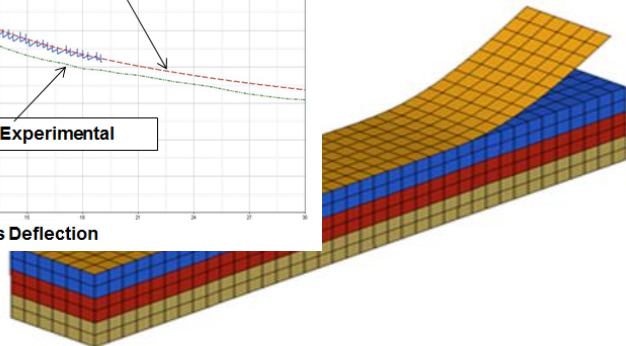
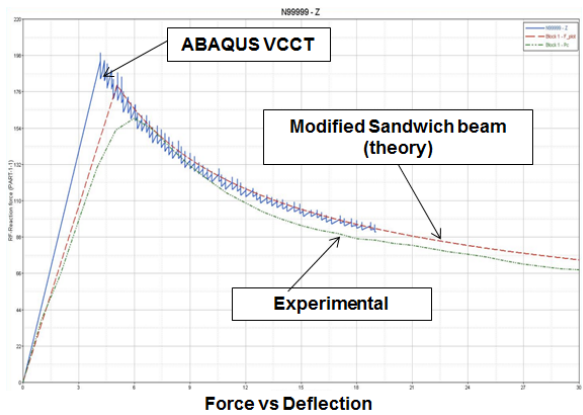
Calculated ERR, Plane Honeycomb Core Sandwich Panel



Task 2: Analysis Development

Coupon Test & Panel Analysis

- Study damage growth under in-plane loading (more relevant for Helicopters)
- Use of ABAQUS & RADIOSS
- Use of detailed honeycomb core knowledge to support fracture mechanics approach group discussion



Task 2: Analysis Development

Open items

- Analysis Workshop scheduled for October 2015, Wichita
 - Analysis coordination between partners necessary to avoid duplication of work
 - Honeycomb Core Fracture Mechanics Approach to be discussed

Achievements (status September 2015)

- Parametric Abaqus/Standard finite element model ready to simulate flat or curved panels under GAG-Cycle pressurization & in-plane loading
- Fracture Mechanics VCCT & CSDE

CMH-17 Sandwich Disbond Growth Team Road Map

Task 3: Panel testing for analysis validation

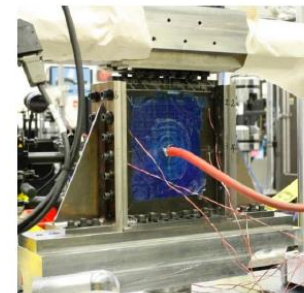
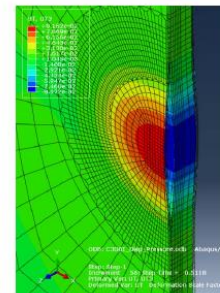
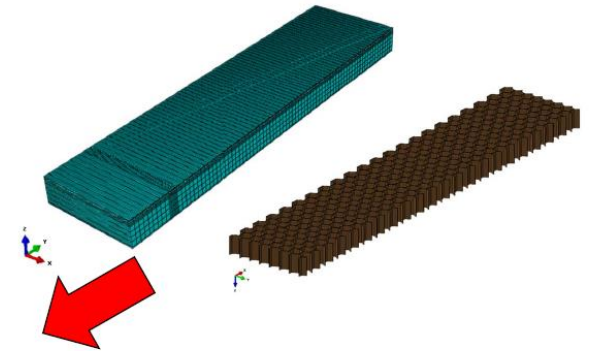
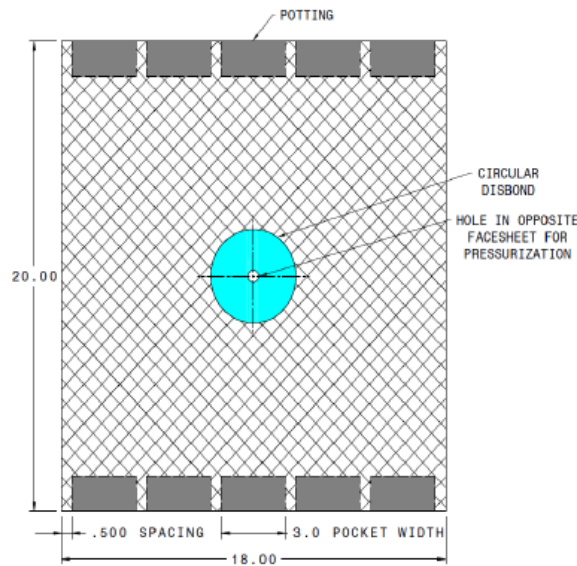
- Evaluate the developed test methods and analysis tools using honeycomb sandwich panel tests
- **Validation Panel Testing**
 - **Tests performed at NIAR**
 - Internal core pressure, panel in-plane compression loading, combined loads
 - Static and fatigue
 - **Tests performed at DTU**
 - Upgrading of existing test rigs are ongoing

Task 3: Panel testing for analysis validation



Edgewise Compression Disbond Test (Matrix Static & Fatigue)

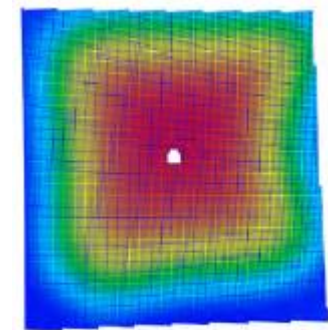
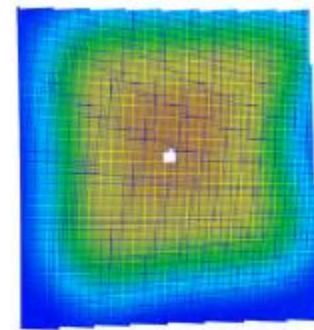
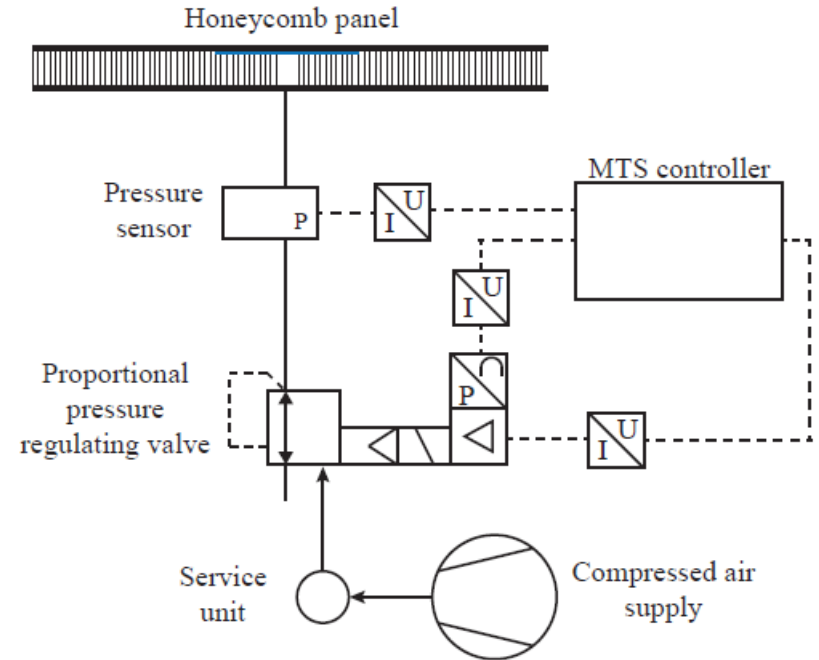
- GAG cycle pressurization
- In-plane loads
- Combination
- Test done in 2015



Task 3: Panel testing for analysis validation

Sandwich Panel Testing under preparation

- GAG-Cyclic loading is applied on honey comb sandwich panel by regulating the compressed air at disbonded zone.
- Disbond propagation is monitored using digital image correlation (DIC)



CMH-17 Sandwich Disbond Growth Team Road Map

Task 4: Sandwich Disbond Substantiation and Methodology Development

Airbus Nondestructive Inspection (NDI)

- Ultrasonic Impulse Echo and Elasticity Laminate Checker (ELCH) were developed to detect disbanded or cracked core of the far side of the sandwich structure under maintenance conditions with the required level of inspection sensitivity.
- **Recent Airbus NDT & GE development on phased array roller probe**



Elasticity Laminate Checker (ELCH)



Ultrasonic Impulse Echo Inspection



GE- Roller Probe

- 60 elements, linear array
- 0.5 MHz
- Active array 120mmx20mm

CMH-17 Sandwich Disbond Growth Team Road Map

Task 5: CMH-17 Vol. 6 implementation

- Gather and study relevant case studies (Aviation, Space, Marine, etc.)
- Identify, describe and address the phenomenon associated with facesheet/core disbonding and core fracture
- Document findings in new chapters of CMH-17 Vol. 6
 - Develop chapter on mode I fracture toughness testing based on ASTM SCB standard
 - Develop chapters on mixed- mode fracture toughness testing, fatigue and environmental effects
 - Develop chapter on analysis methods
 - Develop chapter on fracture mechanics based methodology for sandwich face-sheet/core disbonding

Linked Research

Mark Tuttle University of Washington

- Moisture Diffusion in Sandwich Composites
- FAA funded project (Start Sep. 2015)

- Overall objective: Determine if condense-freeze-thaw-evaporate cycle within core region cycle is detrimental:
 - Change in bending stiffness, E_{eff} (measure using 4-pt bend)
 - Change in GI and GII (measure using methods being developed by Adams et al @ Univ of Utah)
 - Produce “large number” (suggest 32) of instrumented panel specimens (16 with autoclave, 16 with hot press)

Summary

- **Damage growth in unvented honeycomb sandwich structures due to Ground-Air-Ground (GAG) pressurization and in-plane loading**
 - ➔ **Degradation due to disbonding affects operational safety**
- **CMH-17 group – objective - Develop matured, accepted & documented methods for assessing propensity of sandwich structures**
 - ➔ **Fracture Toughness SCB ASTM Test Standard**
 - ➔ **Analysis Tool Box validated by test to assess disbonds**
 - ➔ **To achieve the goal of the CMH-17 working group the FAA / EASA funding is essential and/or wider involvement of industry**
 - ➔ **Airbus is already key sponsor of the group activity**

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Q&A