

CMH-17 Update

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EASA/FAA/ENAC European Bonded Structure Meeting
Cologne, Germany, June 13-14, 2013

Outline

- **Disbonding/Delamination Task Group: Purpose and Mission**
- **Existing Handbook Sections in CMH-17 Rev. G Vols. 1 and 3**
- **Main Goal for New Section in CMH-17 Rev. H: Chapter on Sandwich Facesheet/Core Disbonding**
 - **Background**
 - **Agenda Items and Actions Taken**
 - **Summary of Technical Meeting at NIA in Hampton, VA March 2011**
 - **Action Items Created**
 - **Activities in 2011 and 2012**
 - **Summary of Accomplishments and Unresolved Action Items**
 - **Path Forward**
- **Summary**

Disbonding/Delamination TG

Purpose and Mission

- Established in 2003 to write new sections and revise existing disbonding/delamination information in the handbook
- Task group co-chairs
 - Keith Kedward, UC-Santa Barbara
 - Hyonny Kim, UC-San Diego
 - Ronald Krueger, National Institute of Aerospace
- *The Disbonding and Delamination TG is a task group under Safety Management. The group will determine an overall strategy for the handbook to address disbonding and delamination. The task group will examine methodologies needed to assure through-thickness integrity of bonds and laminations in polymer matrix composites. The group will review the existing document to assure that the sections related to delamination and disbonding are up-to-date. The group will inherit maintenance responsibility for sections on bonded joints written by the Joints WG. Appropriate interfaces will be made with existing groups to address identified gaps, in particular a strong interface will be created with the Damage Tolerance TG. The creation of new sections may be recommended if the current outline does not meet the need of the strategic approach.*

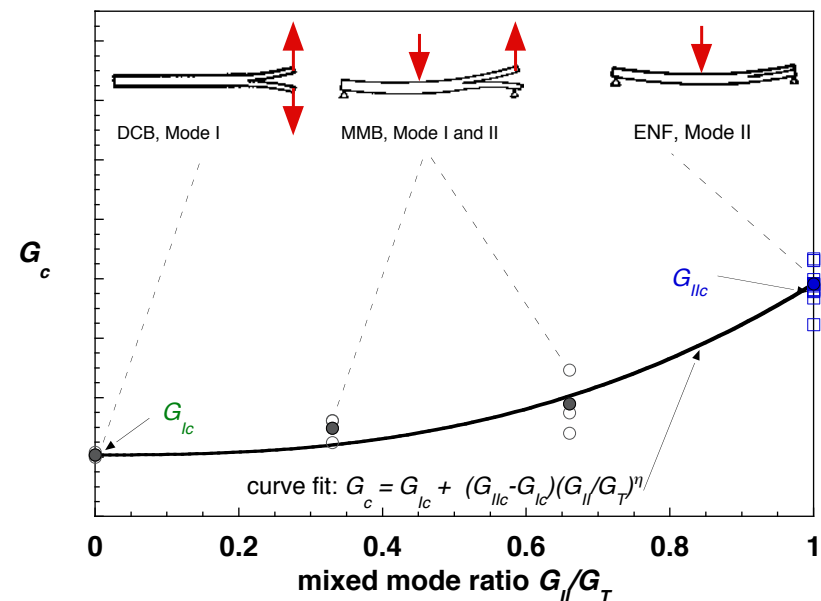
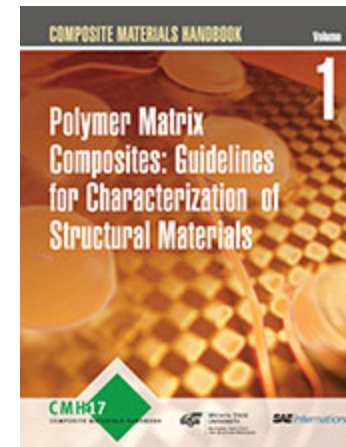
Handbook Sections in Rev. G

Volume 1

CMH-17

COMPOSITE MATERIALS HANDBOOK

- **Completely revised Volume 1 section 6.8.6 on Fracture Testing**
 - **6.8.6.1 Overview**
 - **6.8.6.2 Delamination fracture toughness**
 - *Mode I DCB test ASTM D 5528*
 - *Mode II 3ENF and 4ENF tests*
 - *Mixed-mode I/II MMB test ASTM D 6671*
 - *Mode III ECT test*
 - *other test methods*
 - **6.8.6.3 Through thickness fracture toughness**
 - **6.8.6.4 Intraply fracture toughness**
 - **6.8.6.5 Fracture toughness test for CMH-17 data submittal**



Handbook Sections in Rev. G

Volume 1 - continued

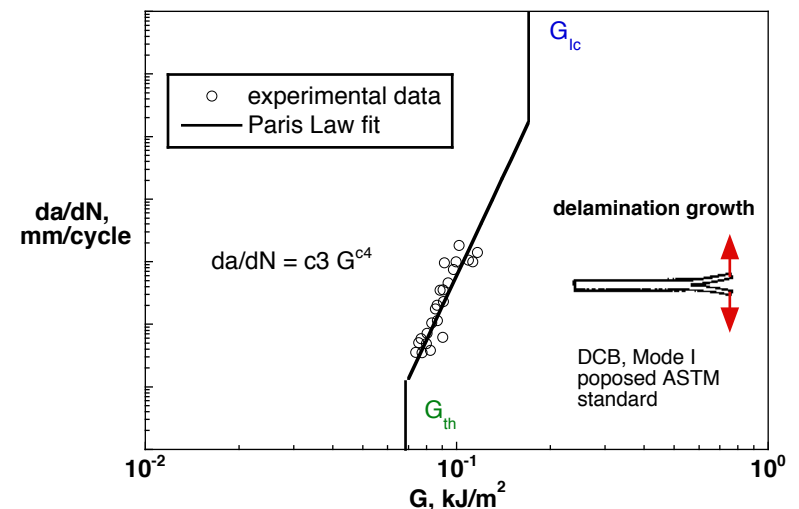
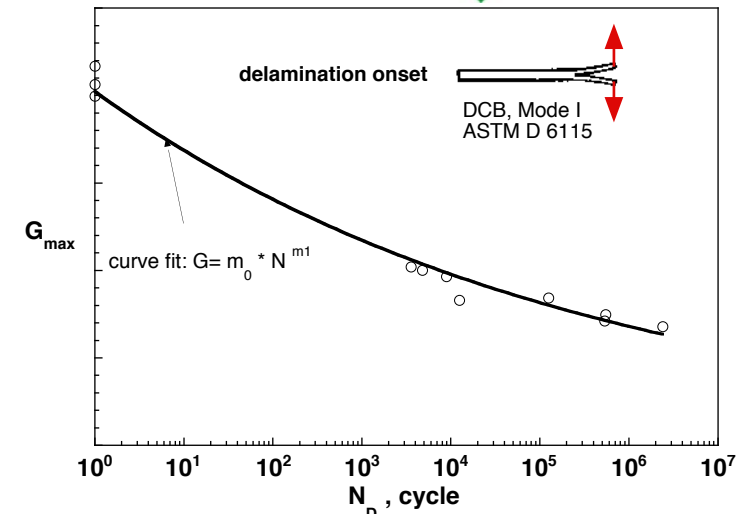
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COMPOSITE MATERIALS HANDBOOK

- Completely *new* Volume 1 section 6.9.4 on Fatigue Fracture Toughness

- 6.9.4.1 Overview
- 6.9.4.2 Effect of matrix toughness
- 6.9.4.3 Effect of mixed-mode ratio
- 6.9.4.4 Effect of R-ratio
- 6.9.4.5 Mode I test methods
- 6.9.4.6 Mode II test methods
- 6.9.4.7 Mixed-mode test methods

- Collaboration with ASTM subcommittee D30.06 on Interlaminar Properties



Handbook Sections in Rev. G

Volume 3

CMH-17

COMPOSITE MATERIALS HANDBOOK

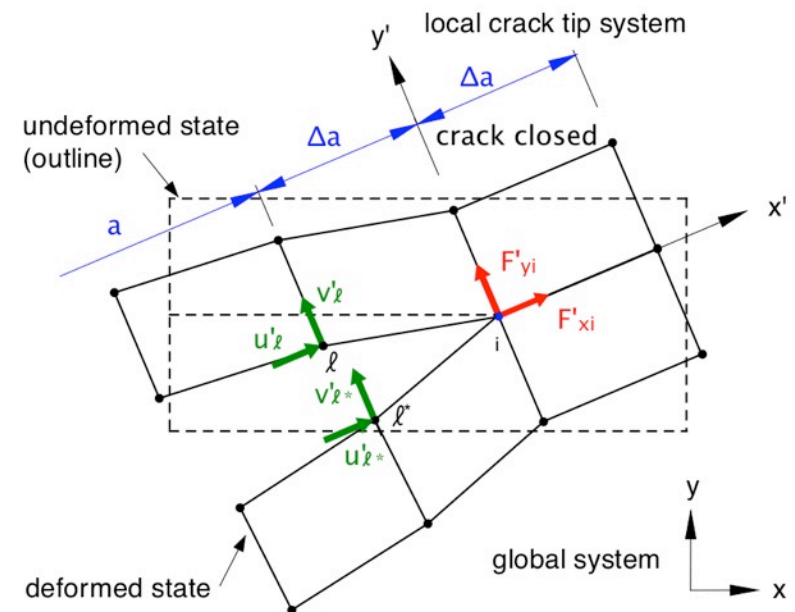
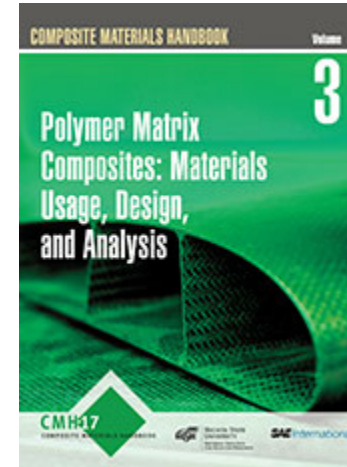
- **Completely *new* Volume 3 section 8.7.4 on Calculation of Strain Energy Release Rate**

- 8.7.4.1 Introduction
- 8.7.4.2 Major steps in determination of G
- 8.7.4.3 Calculation of G

$$G_I = \frac{1}{2\Delta ab} F'_{yi}(v'_{\ell} - v'_{\ell*})$$

$$G_{II} = \frac{1}{2\Delta ab} F'_{xi}(u'_{\ell} - u'_{\ell*})$$

- 8.7.4.4 Determination of mode mix
- 8.7.4.5 Practical 2-D and 3-D applications



Handbook Sections in Rev. G

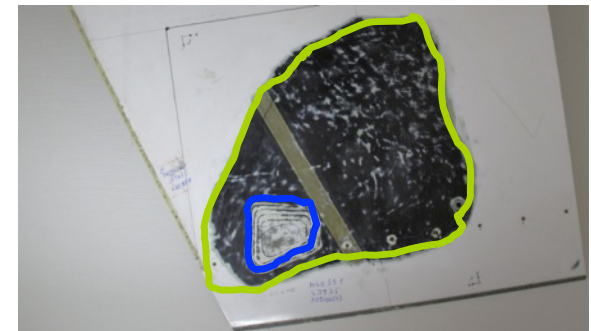
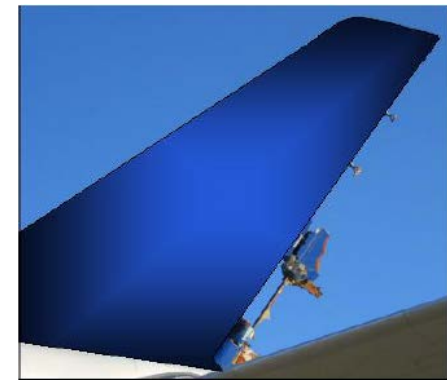
Volume 3 - continued

- **Completely *revised* Volume 3 section 10.4.5 on Finite Element Modeling of Bonded Joints**
- **Completely *new* Volume 3 section 12.6.4.1 Durability and damage onset analysis**
 - 12.6.4.1.2 Matrix cracking onset analysis
 - 12.6.4.1.2 Delamination onset analysis
- **Completely *new* Volume 3 section 12.6.4.3 Cumulative life prediction**
- **Completely *new* Volume 3 section 12.9.3.1 Durability and damage onset case studies**
 - 12.9.3.1.1 Skin/stringer disbonding strength and life
 - 12.9.3.1.1 Rotor hub flexbeam fatigue life

Main Goal for New Section in Rev. G Chapter on facesheet/core disbonding

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COMPOSITE MATERIALS HANDBOOK

- **Background**
 - **In-Service occurrences with Sandwich Structures triggered comprehensive studies**
 - Structural failure in flight
 - Disbond detected due to contamination.
 - Disbond detected due to failed repair
 - **The cause: Sandwich Damage Growth under GAG-cycle (Ground-Air-Ground)**
 - **Airworthiness importance of the subject for primary structures**
 - **Issue of adequate inspection methods and program to detect sandwich disbond and contamination**



Figures from: Ralf Hilgers, *Substantiation of Damage Growth within Sandwich Structures*, presented at CMH-17 meeting, Costa Mesa, 2010.

CMH-17 55th meeting in Atlanta

November 2009

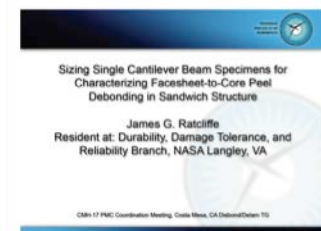


- **Agenda items created by Larry Ilcewicz for Disbonding/Delamination TG**
 - **AI-09-11: Review details in Airbus presentations at FAA/CACRC Composite Damage Tolerance Workshop (Tokyo, 6/09)**
 - **AI-09-12: Contact Airbus engineers and develop engineering (analysis, test methods) and guidelines added as Rev. H content to properly manage the problem for existing and future sandwich considerations**
- **Actions following the meeting**
 - **contacted Ralf Hilgers (Airbus Hamburg) and Roland Thevenin (Airbus Toulouse)**
 - **received their presentations from the FAA Workshop for Composite Damage Tolerance & Maintenance in Tokyo 2009**
 - Ralf Hilgers: *Substantiation of Damage Growth within Sandwich Structures*
 - Roland Thevenin: *Flight Control Sandwich Structures & Inspections*
 - **invited them to participate in future CMH-17 sandwich facesheet disbond activities**

CMH-17 56th meeting in Costa Mesa July 2010

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **Presentations at the Disbonding/Delamination TG meeting**
 - **Ralf Hilgers: *Substantiation of Damage Growth within Sandwich Structures***
 - **Roland Thevenin: *Flight Control Sandwich Structures & Inspections***
 - **James Ratcliffe (NIA): *Sizing Single Cantilever Beam Specimens for Characterizing Facesheet-Core Peel Debonding in Sandwich Panels***
- **Presentation at the CMH-17 Forum**
 - **Ralf Hilgers: *Summary - Substantiation of Damage Growth within Sandwich Structures***



Actions taken after the Costa Mesa Meeting



- **Teleconference/ Web Meeting November 30, 2010**
 - **Plan technical meeting**
 - **Objective**
 - Focus on technical content
 - Presentations of research conducted by Airbus including detailed results
 - Detailed discussion of results, identification of gaps
 - Presentations by other collaborators
 - Detailed discussion
 - Identify and prioritize research topics
 - Identify potential sources of funding
 - Identify collaboration
 - Identify clear goals, create milestones
- **Overview presentation at the Forum in Kansas City in conjunction with the 57th CMH-17 PMC meeting in March 2011**
- **Technical Meeting at NIA in Hampton, VA March 23 – 24, 2011**
 - **33 participants from**
 - **industry (OEMs, suppliers)**
 - **government (FAA, NASA and contractors)**
 - **Academia**

Technical Meeting at NIA in Hampton March 23-24, 2011

- ***Composite Safety and Certification Initiatives*** (Ilcewicz, Davies - FAA)
- ***Airbus Presentation I – Introduction (2h)***
(Hilgers (Airbus Hamburg) and Thevenin (Airbus Toulouse))
 - Sandwich damage growth due to GAG-cycle (phenomenon description; in-service experience, possible known root causes;
 - Airbus approach to define the in-service Inspection bulletins (static & fatigue G_{IC} , damage size and interval estimation)
 - Inspection methods & capabilities
- ***Airbus Presentation II – Design (15 min)***
- ***Airbus Presentation III - Test Methods/Data Reduction (1h)***
 - Airbus tests performed to understand the damage growth under GAG-cycle on subcomponent test panel level
 - Sandwich DCB testing (static & fatigue)
- ***Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites*** (Adams – U. of Utah, Ratcliffe - NIA)
- ***Fracture Mechanics Analysis of Face/Core Debonds*** (Carlsson – FAU)

Technical Meeting at NIA in Hampton March 23-24, 2011 - continued

- ***Airbus Presentation IV - Analysis Methods/Protocol (1h)***
(Ralf Hilgers (Airbus Hamburg) and Roland Thevenin (Airbus Toulouse))
 - ANSYS Analysis procedure flow chart
 - DCB Specimen
 - Subcomponent test panels analysis
 - Rudder Analysis
- ***Investigation of face sheet/core disbonding in CFRP/foam core sandwich structures under quasi-static and fatigue loading using the Single Cantilever Beam test*** (Rinker - Fraunhofer Institute, Germany)
- ***Long-term Environmental Degradation of Composites Sandwich Aircraft Structures - Research Activities at NRC Canada*** (Li - National Research Council Canada)
- ***Improving Impact Resistance and Damage Tolerance of Aramid-Cored Sandwich Structures*** (Richardson – DuPont, USA)
- ***Fatigue Damage Growth of Fluid-Ingressed Sandwich Structures*** (Seneviratne - NIAR/Wichita State University)
- ***Disbond stoppers in nacelle inlet structures*** (Liou – Goodrich)

Technical Meeting at NIA in Hampton

March 23-24, 2011 - continued

- **Action Items**
 - **Develop charter for our group** (Ilcewicz, Thevenin, Krueger)
 - **Seek out additional lessons learned**
 - NASA e.g. X-33 (Rick Young, James Reeder)
 - Canadian (Lucy Li)
 - DoD (Curtis Davies)
 - GA (Curtis Davies)
 - European (Simon Waite)
 - **Future Research Topics**
 - **Standardized Test Methods** (Ratcliffe, Adams, Carlsson, Berggreen)
 - Identify methods required and missing
 - White paper
 - Identify collaborators, contributors
 - **Component Tests for GaG Cycle Testing** (Joe Fila, Ralf Hilgers)
 - **Develop Design Space for Sandwich** (Boucher, Czabaj, Hilgers)
 - Define approach, testing and analysis required
 - Loading scenarios other than GaG
 - Identify collaborators, contributors
 - **Analytical Methods** (Krueger, Ratcliffe, Czabaj, Davila, Rose)

Actions taken after Hampton meeting

- **Presentation by Hyonny Kim at the FAA/EASA/Industry Composite Transport Workshop in Atlanta, May 17-19, 2011.**
- **Teleconference/ Web Meeting July 11, 2011**
 - reviewed action items
- **Martin Rinker of FhG arrived in Hampton to work with NIA/NASA researchers for one year**
- **Teleconference/ Web Meeting November 4, 2011**
 - reviewed action items
- **Monthly Teleconferences/ Web Meetings of a small core team**
 - **Martin Rinker (FhG), James Ratcliffe & Ronald Krueger (NIA/NASA)**
 - **Isabelle Paris, Claude Boucher, Rushabh Kothari (Bombardier/Lear)**
 - **Ley Richardson (DuPont)**
 - **Barry Millward (EuroComposites)**
 - **Dan Adams (University of Utah)**
 - **Waruna Seneviratne (NIAR/Wichita State University)**

Actions taken after Hampton meeting - continued

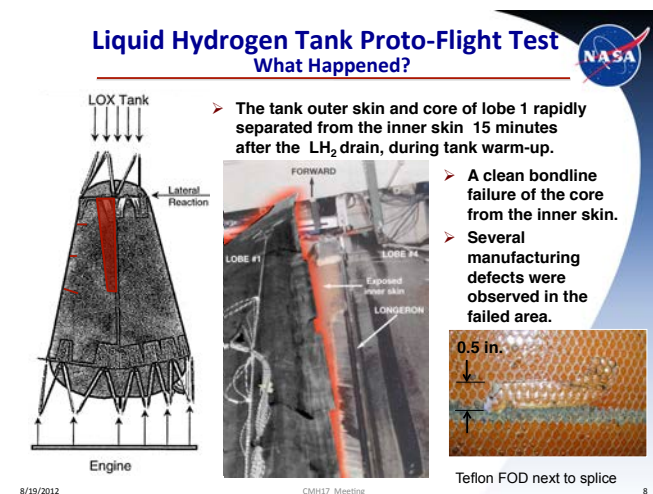
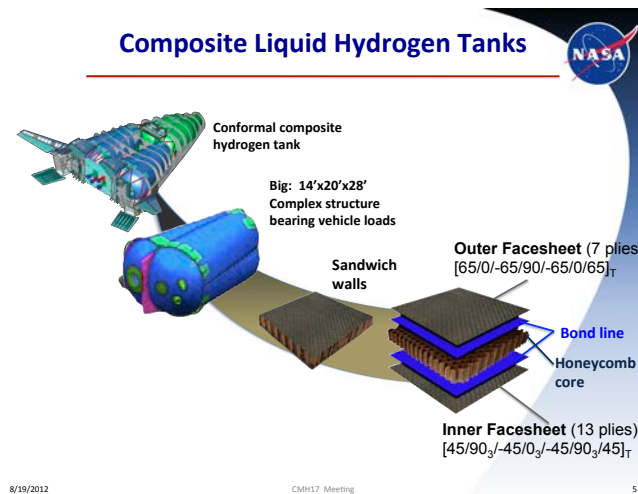
- **CMH-17 58th PMC meeting in Wichita, KS, November 16, 2011**
 - presented overview
- **CMH-17 59th PMC meeting in Cambridge, MA, August 22, 2012**
 - presented overview and results
 - Started first discussion about a European meeting
- **Teleconference/ Web Meeting October 29, 2012**
 - presented overview and results
 - Decided to plan European meeting in Cologne
 - Additional workshop in the US separate from the PMC meeting
- **Teleconference/ Web Meeting December 12, 2012**
 - Outline for European meeting presented by Simon Waite
 - Decided to move forward and invite European participants
- **CMH-17 60th PMC meeting in Seattle, WA, April 9, 2013**
 - presented overview

Accomplishments

- **Develop charter for our group (Ilcewicz, Thevenin, Krueger)**
 - To identify, describe and address the phenomenon associated with facesheet/core disbonding and core fracture, the ***Sandwich Disbond Growth Team*** was established as a group of experts within the ***CMH-17 Disbonding and Delamination Task Group***.
 - **Following core objectives of the team have been defined:**
 - Identify and prioritize key handbook chapters on testing and analysis for sandwich facesheet/core disbonding
 - Establish a forum where engineering data, design issues, service experience, past failures and accidents can be shared openly with team members
 - Increase the knowledge on the subject and the awareness of consequences
 - Identify and prioritize research topics
 - **The *Sandwich Disbond Growth Team* will report about its activities and progress by posting information to the bulletin board and by presentations to the *CMH-17 Disbonding and Delamination Task Group* at *PMC Coordination Meetings*.**

Accomplishments - continued

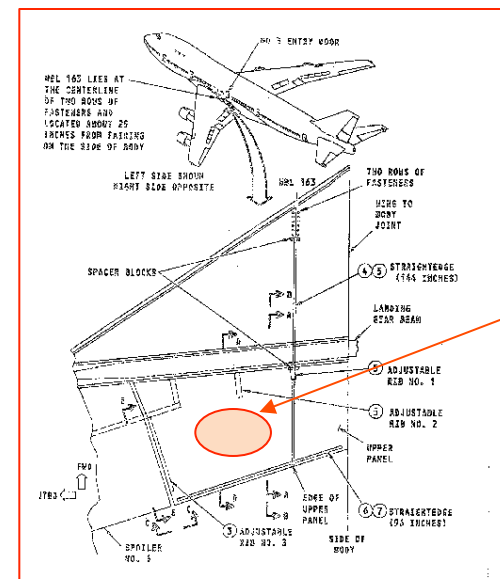
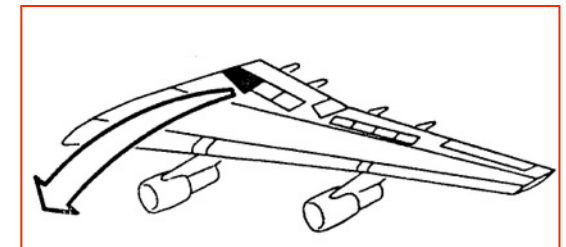
- Seek out additional lessons learned
 - NASA e.g. X-33 (Rick Young, James Reeder)
 - James Reeder, *X-33 Hydrogen Tank Failure*, presented at the CMH-17 Forum, Cambridge, MA, August 19, 2012.
 - “Final Report of the X-33 Liquid Hydrogen Tank Test Investigation,” Marshall Space Flight Center, May 2000.
 - Glaessgen, E.H., J.R. Reeder, D. Sleight, J.T. Wong, I.S. Raju, and C.E. Harris: “Failure of Composite Sandwich Structures with Internal Pressure,” *Journal of Spacecraft and Rockets*, Vol. 42, No. 4, pp. 613-627, 2005.
 - Rivers, H. K., Sikora, J. G., Sankaran, S. N.: “Detection of Micro-Leaks Through Complex Geometries Under Mechanical Load and at Cryogenic Temperature,” *AIAA Paper* 2001-1218, 2001.



Accomplishments - continued

- **Seek out additional lessons learned – continued**

- **Canadian (Lucy Li)**
 - Open item
- **DoD (Curtis Davies)**
 - Open item
- **GA (Curtis Davies)**
 - Open item
- **European (Simon Waite)**
 - **B-747 inboard flying panel upper skin delamination**
 - UK AAIB (AAIB Bulletins 8/92, 2/95 and 10/96) and related Boeing Service Letter for flying panel failures
 - Many (200 ish) partial separations, 8 total separations
 - **More input expected at this workshop**



approx.
24 inch x
60 inch

Accomplishments - continued



- **Future Research Topics**
 - **Standardized Test Methods** (Ratcliffe, Adams, Carlsson, Berggreen)
 - Identify methods required and missing
 - **White paper** (Ratcliffe, Adams, Carlsson, Berggreen)
 - **Identify collaborators, contributors**
 - Collaboration through D30.09 SCB standard activity
 - Airbus sent specimens to University of Utah. Dan Adams returned test results to Airbus in 2012.
 - Martin Rinker from FhG spent one year at NASA LaRC
 - M. Rinker, J. Ratcliffe, D. Adams, R. Krueger: *Characterizing Facesheet/ Core Disbonding in Honeycomb*, NASA/CR-2013-217959, 2013.
 - [Presentation by Dan Adams on Friday morning](#)
 - [Presentation by Christian Berggreen Friday morning](#)
 - **Component Tests for GaG Cycle Testing** (Joe Fila, Ralf Hilgers)
 - **Activity stalled due to Joe Fila changing employers**
 - **Needs revitalization**
 - **Boeing** (Adam Sawicki, Al Fawcett)
 - **Bombardier** (Isabelle Paris, Claude Boucher)

Accomplishments - continued



- **Future Research Topics**
 - **Develop Design Space for Sandwich** (Boucher, Czabaj, Hilgers)
 - **Define approach, testing and analysis required**
 - Martin Rinker from FhG spent one year at NASA LaRC
 - M. Rinker, J. Ratcliffe, R. Krueger: *Analysis of an Aircraft Honeycomb Sandwich Panel with Circular Facesheet/Core Disbond Subjected to Ground-Air Pressurization*, NASA/CR-2013-217974, 2013.
 - [Presentation by Martin Rinker Friday morning](#)
 - **Loading scenarios other than GaG**
 - **Identify collaborators, contributors**
 - **Analytical Methods** (Krueger, Ratcliffe, Czabaj, Davila, Rose)
 - White paper in progress
 - Cheryl A. Rose, Carlos G Dávila, Frank A. Leone, *Analysis Methods for Progressive Damage of Composite Structures*, NASA white paper.
 - R. Krueger, K. Shivakumar, and I. S. Raju, *Fracture Mechanics Analysis for Interface Crack Problems – A Review*, AIAA-2013, 2013.

Unresolved Action Items

- **Open items**
 - **Additional case studies**
 - **Large scale GAG testing**
 - **Influence of temperature and environment**
 - **Appropriate analysis methods**

Path Forward for 2013

- Dan Adams and James Ratcliffe to continue the development of fracture mechanics test methods for sandwich composites
- **European Bonded Structures Meeting at EASA in Cologne, June 13-14, 2013**
 - **Get European participation**
 - **Sharing of incidents -> input for case studies and lessons learned**
 - **New ideas**
- **Teleconference/ Web Meeting following the European Meeting**
 - **Inform *Sandwich Disbond Growth Team* about European meeting**
 - **Plan 1-2 day workshop in Hampton, VA**
- **Workshop at NIA in Hampton, VA late summer/early fall 2013**
 - **Discuss results generated since last meeting**
 - **Revise and update action items**
 - **Plan future research activities**
- **61st CMH-17 meeting in Wichita fall 2013**
 - **Update the Disbonding/Delam TG on recent activities and progress**

Summary

- Provided an introduction and overview of the Disbonding/Delamination TG
- Introduced sections in CMH-17 Vols 1 and 3 which were written by members of the task group
- Presented a time line of events that led to the formation of the *Sandwich Disbond Growth Team*
- Summarized action items that were created during the workshop at NIA in Hampton in March 2011
- Highlighted accomplishments and discussed open action items
- Provided outlook and path forward
- Detailed presentations will be given over the next two days
 - Airbus overview (Roland Thevenin and Ralf Hilgers)
 - Development of the SCB test (Dan Adams)
 - GAG cycle analysis (Martin Rinker)