Update on CMH-17 Volume 5—Ceramic Matrix Composites

Kaia David, The Boeing Company, Huntington Beach, CA
Jennifer Pierce, UDRI, Dayton, OH
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Greg Wilson, GE Aviation, Cincinnati, OH

39th Annual Conference on Composites, Materials and Structures
January 26, 2015
CMH-17 Mission

The Composite Materials Handbook (CMH) organization creates, publishes and maintains proven, reliable engineering information and standards, subjected to thorough technical review, to support the development and use of composite materials and structures.

CMH-17 Vision

The Composite Materials Handbook will be the authoritative worldwide focal point for technical information on composite materials and structures.

Vol. 1-3: PMC: Polymer Matrix Composites
Vol. 4: MMC: Metal Matrix Composites
Vol. 5: CMC: Ceramic Matrix Composites
Handbook History

2013  Release of Vol. 6, 4B – CMH-17 Handbooks
2012  Release of Volumes 1-3 Rev G – CMH-17 Handbooks
2006  Transition from Army to FAA as Primary Sponsor
      Established Roadmap to New Composite Materials
      Handbook “Release G”
2004  Joint Meetings with CACRC, SAE-P17
2002  MIL-HDBK-17 Vol. 1F, 2F, 3F, 4A, 5
      Commercial Publication through ASTM
1999  MIL-HDBK-17 Vol. 2E, Vol. 4
1998  Joint Meetings with ASTM D-30
1997  MIL-HDBK-17 Vol. 1E, 3E
1996  CMC Coordination Group Formed
1993  MMC Coordination Group Formed
1990  First PMC Data Set Approved
1988  MIL-HDBK-17B Vol. 1 Release
1986  Secretariat Added
1978  Coordination Group Formed
1971  MIL-HDBK-17A Plastics for Aerospace Vehicles
1959  MIL-HDBK-17 Plastics for Air Vehicles
1943  ANC Bulletin 17 Plastics for Aircraft

First (and latest) CMC handbook issued ~13 years ago

PMC: Polymer Matrix Composites
MMC: Metal Matrix Composites
CMC: Ceramic matrix Composites
Ceramic Matrix Composite (CMC) Components For Commercial Aircraft Require Certification

• CMC components are projected to enter service in commercial aircraft in 2016.

• A wide range of issues must be addressed prior to certification of this hardware.

• The FAA (Federal Aviation Administration) is working with the CMC Community to identify the tasks required to support these components and to establish a timeframe for certification.
Ceramic Matrix Composite (CMC) Components
For Commercial Aircraft Require Certification

• The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites is being revised to support FAA certification of CMCs for hot structure and other elevated temperature applications.

• The handbook supports the development and use of CMCs through publishing and maintaining proven, reliable engineering information and standards that have been thoroughly reviewed.

• Volume 5 will contain detailed sections describing
  - CMC Materials / Processing,
  - Design / Analysis Guidelines,
  - Testing Procedures, and
  - Data Analysis and Acceptance.
The CMH-17 Organization

~ 300 total members on PMC, CMC, and MMC rosters

Handbook Chairs
Larry Ilcewicz, FAA
Curtis Davies, FAA

Executive Group
(PMC, MMC & CMC WG Chairs)

CMC Coordination Group
Curtis Davies, FAA

PMC Coordination Group
Larry Ilcewicz, FAA

MMC Coordination Group
John Kleek, WPAFB
Brad Lerch, NASA

Permanent Working Groups

Data Review
Rajiv Naik, Pratt & Whitney

Design and Analysis
Mitch Petervary, Boeing
David Thomas, Rolls-Royce

Guidelines
Curtis Davies, FAA

Materials & Processes
Kaia David, Boeing
Doug Kiser, NASA GRC

Testing
Jennifer Pierce, UDRI
William Keith, Boeing
Greg Wilson, GE Aviation

Working groups are meeting at this conference on Wed. from 5 - 6:30 pm and on Thurs. from 12-1:30 pm (pizza lunch available)
Volume 5 Handbook Outline

- Handbook grouped into 4 sections – each linked to specific working groups
  - *Part A: Introduction and Guidelines*
    - Materials and Processes WG
  - *Part B: Design Supportability*
    - Design & Analysis WG
  - *Part C: Testing*
    - Testing WG
  - *Part D: Data Requirements and Data Sets*
    - Data Review WG
CMH-17 Vol. 5 Tentative Publication Timeline

- Initial drafts created
- Circulate within Working Groups
- Approved at the Working Group level
- Yellow Pages – multiple review cycles (~6 weeks each)
- Update sections based on Coordination Group feedback
- Working draft updated and posted on website

Vol. 5 Working Groups
1/2014 -12/2015

Vol. 5 Working Groups
1/2016 -6/2016

CMH-17
7/2016

Vol. 5

- Final review
  - Consistency review
  - Technical review

- PUBLICATION

THE CLOCK IS TICKING
Working Group Progress

- Materials and Processes
- Design and Analysis
- Testing
- Data Review
Materials & Processes Working Group Goals

- To complete the M&P text required to allow CMH-17, Volume 5 to be the primary and authoritative “open literature” source for information on the composition, fabrication, quality control, and characterization of CMC engineering materials and structures.

- To provide a comprehensive overview of ceramic matrix composite (CMC) technology, outlining the types of CMCs, commercial aircraft applications, benefits, methods of fabrication, quality control, and supportability.

- To define the essential elements of information on composition, structure, and processing of CMCs necessary to support design, selection, fabrication, certification, and utilization of CMC structures.

- To specify the methods and procedures to be used in the characterization of ceramic matrix composites, their coatings, and their constituents. Efforts will be coordinated with the Testing Working Group.
M&P Working Group Approach

Assemble and maintain a team of selfless CMC, Coatings, Quality, Inspection, and Certification experts dedicated to writing, revising, and updating the CMC M&P sections in the handbook.

2.0 Intro, History and Overview
3.1 CMC Systems, Processing, Properties & Applications
3.2 Fiber/Reinforcement Systems and Technology
3.3 Interphase/Interface Technology and Approaches
3.4 Fabrication and Forming of Fiber
3.5* External Protective Coatings
3.6*† Characterization Methods
3.7† NDE Methods for CMC
3.9† Machining
4.0*† Quality Control
5.0 Applications, Case Histories, Lessons Learned

* Reserved for Future Use (i.e., in existing document: currently blank)
† Critical for Certification
M&P Working Group Approach

- Monthly Working Group Coordination Meetings to review and discuss progress, with a focus on specific sections, and to determine the agenda for upcoming meetings (usually 3rd Friday of the month at 1 pm ET).

- Face to face Working Group Meeting at Cocoa Beach conference.

Section Review Cycle (can start any time)
1. Section drafted
2. Internal review within M&P WG and Review Team, if identified
3. Yellow Page Review (Voting by designated CMC membership)
4. Cleanup by Wichita State Univ. (WSU – CMH-17’s Secretariat)
5. Ready for inclusion in Rev A of CMH-17 V5
# M&P Section Reviews

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<thead>
<tr>
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<th>Title</th>
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<tr>
<td>2.0</td>
<td>Intro, History &amp; Overview</td>
<td>0%</td>
<td>4 pgs</td>
<td>Not started</td>
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<tr>
<td>3.1</td>
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<td>20 pgs</td>
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<td>17 pgs</td>
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<td>TBD pgs</td>
<td>In work</td>
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<td>Blank</td>
<td>Team forming now</td>
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Notes: *Reserved for Future Use (i.e., currently blank)
## M&P Section Reviews

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<th>Section</th>
<th>Title</th>
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<th>Section Length</th>
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<td>3.5.2*</td>
<td>External Protective Coatings for Oxide CMCs</td>
<td>100%</td>
<td>19 pgs</td>
<td>Complete – In Yellow Pages Review</td>
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<tr>
<td>3.6†</td>
<td>Characterization Methods</td>
<td>10%</td>
<td>In work</td>
<td>Team forming now</td>
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<tr>
<td>3.7†</td>
<td>NDE Methods for CMC</td>
<td>20%</td>
<td>8 pgs</td>
<td>In work</td>
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<tr>
<td>3.9†</td>
<td>Machining</td>
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<td>4.0†</td>
<td>Quality Control</td>
<td>100%</td>
<td>17 pgs</td>
<td>Drafted - Outside Reviewers</td>
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<tr>
<td>5.0</td>
<td>Applications, Case Histories, Lessons Learned</td>
<td>100%</td>
<td>31 pgs</td>
<td>Ready for Yellow Pages Review</td>
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Notes: *Reserved for Future Use (i.e., currently blank); †Critical for Cert
Materials & Processes Working Group

***Recruitment Plug***

We are in need of folks with knowledge of

- Processing of CMC materials
- Interphase/interface technologies
- Environmental barrier coatings (EBCs)
- NDE

We welcome other members with CMC backgrounds

- To expedite progress—due to the approaching need for component certification
- To assist in technical reviews

Benefits include: Networking; Access to the CMH-17 members website; and An opportunity to make a critical contribution to the commercialization of CMCs
Working Group Progress

- Materials and Processes
- Design and Analysis
  - Charts provided by Dave Thomas, Rolls-Royce
- Testing
- Data Review
Design and Analysis Working Group

Goals:

• To provide information on design and analysis methods and options, the level of substantiation required, and presentation formats required in validation and certification processes

• To ensure future relevancy of the handbook by maintaining an up to date survey of the current state of the art capabilities within the design, analysis and lifing communities for CMCs
Design and Analysis Working Group

Challenges:

• Creating a document that contains meaningful and valuable content for both industry and government entities while honoring the highly proprietary nature of corporate design practices
Design and Analysis Working Group

Current Membership:

• Small working group (9 members), predominantly from industry
• Open to new members (especially academia and government)
• If interested in participating contact:
  – David Thomas (david.j.thomas@rolls-royce.com)
  – Rachael Andrulonis (rachael@cmh17.org)
Working Group Progress

- Materials and Processes
- Design and Analysis
- Testing
- Data Review
Testing Working Group

Overview

• Responsible for content of CMH-17, Vol. 5, Part C - Guidelines for Testing Ceramic Matrix Composites

• Diverse group of folks with experience in testing CMCs
  • Government
  • Industry (material fabricators, test labs, end users)
  • Academia

• Meetings: monthly telecoms, USACA
  • Coordinate the creation of Part C content
  • Discuss issues regarding testing of CMCs
  • Monthly focused topic areas
Testing Working Group

Vision Statement
• To be the primary and authoritative source for recommended/required methods for testing characterization of CMCs & their constituents

Goals
• To identify appropriate existing consensus standard test methods for CMCs and their constituent materials
• To assist in the identification/development of appropriate standard test methods for CMCs and their constituent materials, where no such standards exist
Testing Working Group

Approach

- Provide "guidelines" for testing CMCs, leave the detailed definition of methods to other sources, e.g. ASTM
- Focus on issues unique to CMCs
- Provide Lessons Learned
- Align with FAA certification guidance

Challenges

- Participation
- Limited base of ASTM and other standards (but the number is increasing!)
- Techniques/procedures are considered IP
- Knowledge/guidance on certification requirements needed
Testing Working Group

Current Working Outline of Vol. 5, Part C

8. Overview
9. Specimen Design
10. Machining
11. Non-ambient Testing
12. A Review of CMC Test Methods
   Density, Fiber Volume Fraction, CTE, Diffusivity, Specific Heat, Tensile, Compression, Flexure, In-Plane Shear, Interlaminar Shear, Interlaminar Tension, Notched, Fracture Toughness, Crack Growth, Creep, Fatigue, Thermo-mechanical Fatigue, Wear, Bearing, Biaxial
13. In-Situ Measurement Methods
   Acoustic Emission, Electrical Resistivity, Digital Image Correlation
14. Constituent Testing
   Mini Composites, Fibers, Matrices, Interfaces/Interphases, Environmental Barrier Coatings

Draft Completed – Bold Type
Assigned/Working – Bold-Italic Type
Testing Working Group

• Applicability
• Test Methods
  – Table of References
  – Summary of referenced methods
• Considerations for Testing CMCs
  – Test Specimen(s)
    • Geometry
    • Size
    • Preparation
  – Material Condition
    • Coatings
    • Surface texture
    • Pre-exposed
  – Gripping / Alignment
  – Environment
  – Material Sample Size
• Analysis
• Data Reporting

General outline used
For each Testing Section
Tidbits

• Tensile Testing
  "For unidirectional material, a straight-sided specimen is typically acceptable. For all other layups, a dogbone specimen design is recommended......"

• Interlaminar Tensile Testing
  "The results of the flatwise tensile test tend to be highly variable due to the probabilistic nature of the matrix and fiber/matrix bonding strength distribution, especially in materials with porous or micro-cracked matrices. Therefore, the number of tests performed should adequately capture the strength distribution...."

• Notched Testing
  "Currently, there are no test methods specifically written for testing CMCs with notches or damage. Yet, the methods written for PMCs can generally be used for CMCs......"
Testing Working Group

We Welcome New Members/Contributors

• Telecoms the second Monday of each month 12-1 p.m. EST
• Small time commitment
• Opportunity to learn and compare notes on the testing of CMCs
• Chance to be part of and contribute to CMC community

Contacts:

• Jennifer Pierce, jennifer.pierce@udri.udayton.edu
• William Keith, william.p.keith@boeing.com
• Gregory Wilson, gregoryscott.wilson@ge.com
Working Group Progress

• Materials and Processes
• Design and Analysis
• Testing
• Data Review
  – Charts provided by Rajiv Naik, Pratt & Whitney
Data Review Charter

• Formulate guidelines & requirements for submission (batch size, etc.), documentation, analysis, and review for all CMC data that are submitted for inclusion in the handbook.
• Review the data and the analysis of data sets that are submitted for inclusion in the handbook.
• Develop formats for presentation of data in the handbook and for its storage in electronic databases.
• Develop and document statistical methods for pooling and analysis of CMC data.
Data Review WG Members

- Rajiv Naik – Pratt & Whitney, Working Group Chair.
- Rich Foedinger, Materials Sciences Corporation
- Jim Bartlett, AED Propulsion Division
- Shinji Muto, IHI Corporation
- Rachael Andrulonis, Wichita State University
Data Review WG Key Issues

- Export classification of data that is submitted to the handbook
- Storage and dissemination of ITAR data
- Appropriate electronic Database choice for data storage and dissemination (with export restricted access as needed)
- Sources of new CMC data
Data Review WG Progress

• Revised and streamlined Chapters 16-18 on Data Submission, Format and Requirements, Statistical Data Analysis and Handbook Summary Data presentation formats.
• Chapters 16-18 are currently being reviewed in Yellow Pages process.
## CMC Property Database

**Currently not ITAR restricted**

<table>
<thead>
<tr>
<th>Composite Name</th>
<th>Composite Description</th>
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<tr>
<td>9/99 EPM SiC/SiC</td>
<td>Sylramic™/BN-Si/MI SiC</td>
<td>Ceramic Composite Products</td>
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<tr>
<td>Enhanced SiC/SiC</td>
<td>CG Nicalon™/Carbon/CVI SiC</td>
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<tr>
<td>Carbon/SiC</td>
<td>T300/Carbon/CVI SiC</td>
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</tr>
<tr>
<td>Hi-Nicalon/MI SiC</td>
<td>Hi-Nicalon™/BN/MI SiC</td>
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</tr>
<tr>
<td>AS-N720-1</td>
<td>Nextel 720/alumino-silicate</td>
<td>COI Ceramics</td>
</tr>
<tr>
<td>Sylramic S-200</td>
<td>CG Nicalon™/BN/PIP Si$_3$N$_4$-SiC</td>
<td></td>
</tr>
</tbody>
</table>

- Data Formats in Section 18.2 need to be revamped to make tables consistent with suggested new property table formats (submitted for Yellow Pages balloting).
- Contacted NASA Marshall MAPTIS database folks to explore possibility of using this as a vehicle to store/disseminate CMC data. Decision needs to be made at the Guidelines WG level.
Summary

- The *Composite Materials Handbook-17, Volume 5* on ceramic matrix composites is being revised to support FAA certification of CMCs for hot structure and other elevated temperature applications
  - CMC Materials / Processing,
  - Design / Analysis Guidelines,
  - Testing Procedures, and
  - Data Analysis and Acceptance.

- “The Clock is Ticking”

- WGs are making progress but need volunteers / input
Individuals interested in contributing to these groups should please forward their contact information to Rachael Andrulonis (rachael@cmh17.org)

and/or talk to any Working Group member

Working groups are meeting at this conference on Wed. from 5 - 6:30 pm and on Thurs. from 12-1:30 pm (pizza lunch available)