CMH-17
COMPOSITE MATERIALS HANDBOOK

Update on CMH-17 Volume 5—Ceramic Matrix Composites

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Jennifer Pierce, UDRI, Dayton, OH
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39th Annual Conference on Composites, Materials and Structures
January 26, 2015

Composite Materials Handbook-17

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

What is the Importance of CMH-17 Volume 5— Ceramic Matrix Composites ?

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Ceramic Matrix Composite (CMC) Components
<u>For Commercial Aircraft Require Certification</u>

- **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.**

Federal Aviation Administration

What is the Importance of CMH-17 Volume 5— Ceramic Matrix Composites? *(continued)*

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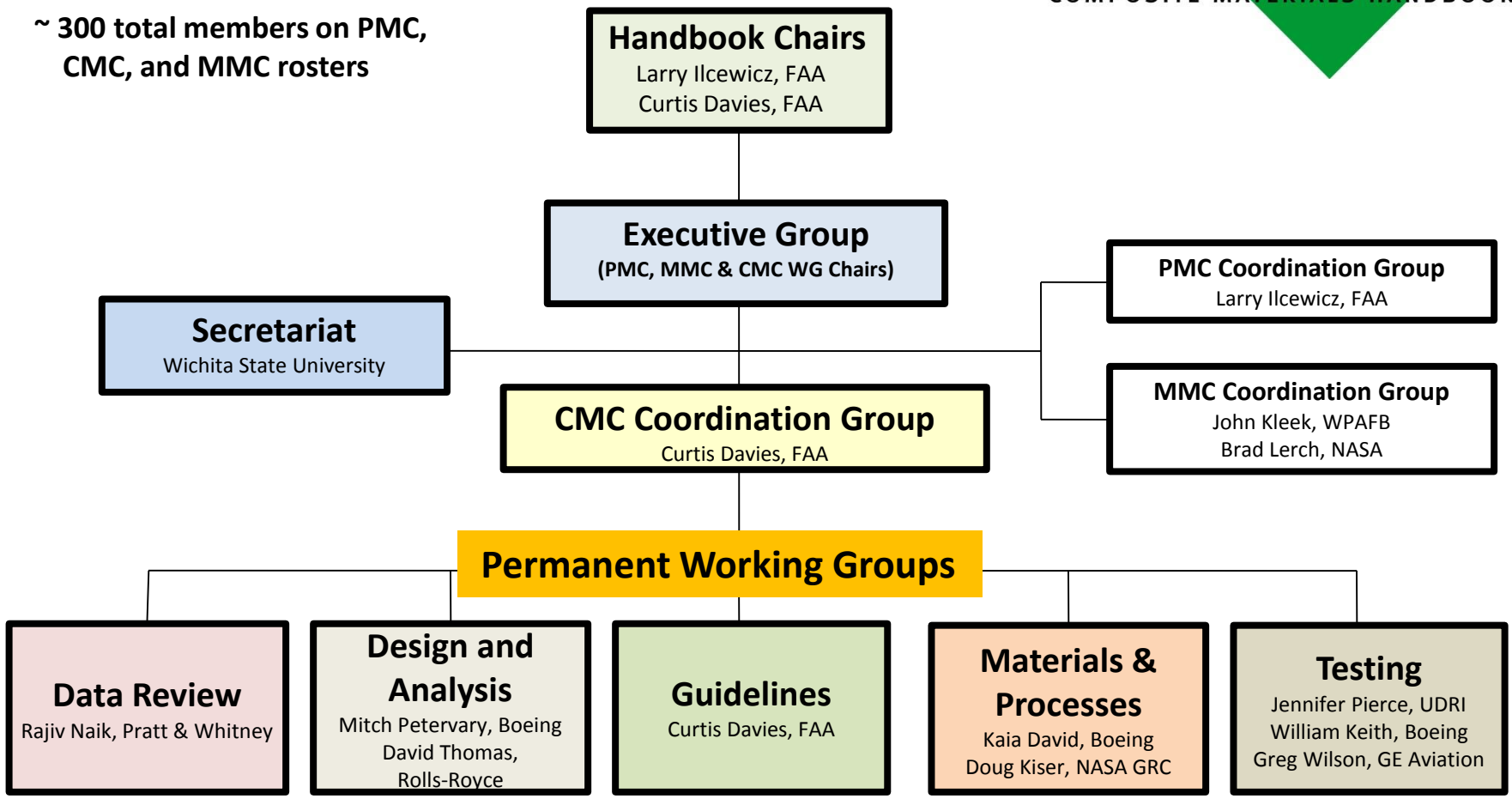
Ceramic Matrix Composite (CMC) Components For Commercial Aircraft Require Certification

- **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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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



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

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **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

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vol. 5 Working Groups

1/2014 -12/2015

- 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

1/2016 -6/2016

- Final review
  - Consistency review
  - Technical review

CMH-17

7/2016

- **PUBLICATION**

Vol. 5

Working Group Progress

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

Materials & Processes Working Group Goals

CMH-17
COMPOSITE MATERIALS HANDBOOK

- 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.

Volume 5 Handbook

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **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.**

<u>Section Review Cycle (can start any time)</u>

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

Page 1 of 2

Section	Title	% Comp	Section Length	State
2.0	Intro, History & Overview	0%	4 pgs	Not started
3.1	CMC Systems, Processing, Properties & Applications	5%	20 pgs	Not started
3.2	Fiber/Reinforcement Systems & Technology	20+%	17 pgs	Team forming now
3.3	Interphase/Interface Technology & Approaches	0%	8 pgs	Not started
3.4	Fabrication and Forming of Fiber Architectures	90%	TBD pgs	In work
3.5.1*	External Protective Coatings for Non-Oxide CMCs	0%	Blank	Team forming now
Notes: *Reserved for Future Use (i.e., currently blank)				

M&P Section Reviews

CMH-17
COMPOSITE MATERIALS HANDBOOK

Page 2 of 2

Section	Title	% Comp	Section Length	State
3.5.2*	External Protective Coatings for Oxide CMCs	100%	19 pgs	Complete – In Yellow Pages Review
3.6*†	Characterization Methods	10%	In work	Team forming now
3.7†	NDE Methods for CMC	20%	8 pgs	In work
3.9*†	Machining	15%	In work	In work
4.0*†	Quality Control	100%	17 pgs	Drafted - Outside Reviewers
5.0	Applications, Case Histories, Lessons Learned	100%	31 pgs	Ready for Yellow Pages Review
Notes: *Reserved for Future Use (i.e., currently blank); †Critical for Cert				

Materials & Processes Working Group

Recruitment Plug

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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

<u>Benefits include:</u> Networking; Access to the CMH-17 members website; and An opportunity to make a critical contribution to the commercialization of CMCs

Working Group Progress

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

Design and Analysis Working Group

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COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

Testing Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

Current Working Outline of Vol. 5, Part C

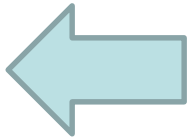
Draft Completed – **Bold Type**
Assigned/Working – ***Bold-Italic Type***

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

Testing Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

- 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

Testing Working Group

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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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

Data Review Charter

CMH-17
COMPOSITE MATERIALS HANDBOOK

- 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

CMH-17
COMPOSITE MATERIALS HANDBOOK

- Rajiv Naik – Pratt & Whitney, Working Group Chair.
- John Koenig, Southern Research Institute.
- Rich Foedinger, Materials Sciences Corporation
- Jim Bartlett, AED Propulsion Division
- Shinji Muto, IHI Corporation
- Rachael Andrulonis, Wichita State University

Data Review WG Key Issues

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COMPOSITE MATERIALS HANDBOOK

- 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

CMH-17
COMPOSITE MATERIALS HANDBOOK

- 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

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COMPOSITE MATERIALS HANDBOOK

Currently not ITAR restricted

Composite Name	Composite Description	Producer
9/99 EPM SiC/SiC	Sylramic™/BN-Si/MI SiC	**Ceramic Composite Products**
Enhanced SiC/SiC	CG Nicalon™/Carbon/CVI SiC	
Carbon/SiC	T300/Carbon/CVI SiC	
Hi-Nicalon/MI SiC	Hi-Nicalon™/BN/MI SiC	
AS-N720-1	Nextel 720/alumino-silicate	**COI Ceramics**
Sylramic S-200	CG Nicalon™/BN/PIP Si_3N_4-SiC	

- 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

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **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**

Summary

CMH-17
COMPOSITE MATERIALS HANDBOOK

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)