

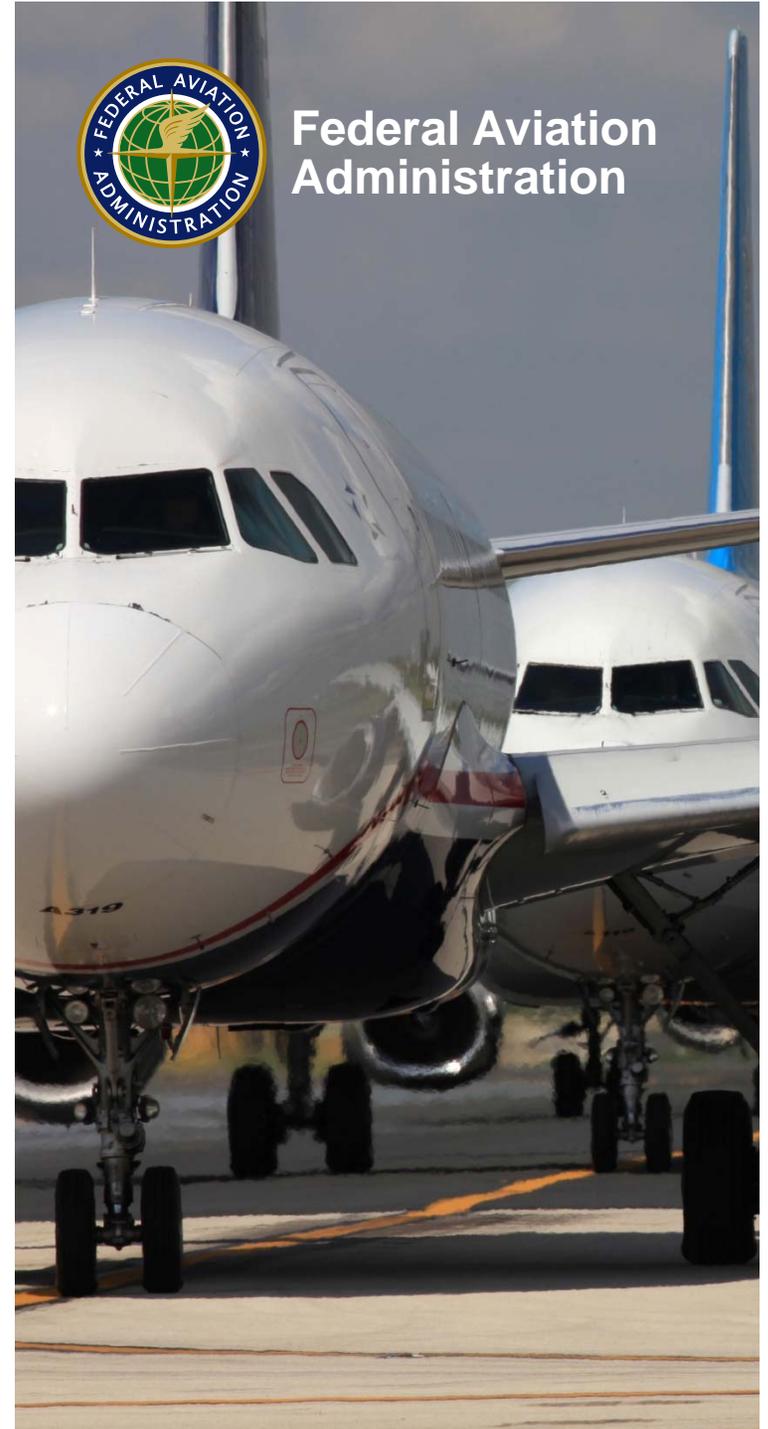


# Ceramic Matrix Composite (CMC) Workshop

Presented to: CLEEN Consortium

By: Rhett Jefferies

Date: November 8, 2012



# CMC Way Ahead

- **Ground test demos of CLEEN CMC techs in 2013**
  - Turbine blade tracks
  - Acoustic nozzle
- **CLEEN CMC components are projected to be commercialized 2016-2018**
  - A wide range of issues to address prior to certification
  - Aircraft/engine CMC components outside of CLEEN are in development
- **CMC technical community is gaining more experience and test data**
- **Using CMH-17 CMC Sub-committee (Volume 5) to coordinate efforts**



# Existing CMH-17 Vol 5 Working Groups

- **Materials and Processes**
- **Data Analysis and Review**
- **Structural Analysis & Design Codes**
- **Testing**
- **Guidelines**



# CMC Workshop Agenda

10:00 AM - 10:15 AM	Introduction (CMC session) – Rhett Jefferies
10:15 AM – 10:45 AM	Overview of CMH-17 Vol 3, Chapter 3 – Larry Ilcewicz
10:45 AM – 11:00 AM	Overview of CMC breakout groups – Tasks and objectives – Rhett Jefferies
11:00 AM – 2:00 PM	Breakout group discussion --WORKING LUNCH--
2:00 PM – 2:45 PM	Report & discussion on outcome of breakout groups
2:45 PM – 3:00 PM	--BREAK-- Note: After the break CMC Workshop attendees will rejoin the Plenary Session in the CoVE room (next door)



# What We Want from the Workshop

- **Link certification areas in Vol 3, Chp 3 to Vol 5 outline**
  - Confirm initial links and refine as necessary
  - Identify certification areas unique to CMCs
- **Prioritize work activities in each CMC working group**
  - Focus on certification areas
  - What new Vol 5 sections are required?
  - Identify experts to work on priority activities
- **Identify gov't reports that could be added to Vol 5**
  - Current efforts in FAA, NASA, DoD, DoE, etc.
  - Past efforts that could



# Certification Areas Linked to Vol 5

<b>Design</b>	<b>Volume 5 Sections</b>
D.1. Process documentation	3
D.2. Materials and adhesives qualification	3.2,3.6,3.8,4.3,9,10,11,12,13
D.3. Structural bonding materials and processes	3.2,3.3,3.4,6.6,10,12
D.4. Tooling & Part Cure Processes	3.1,3.2,3.9,15
D.5. Structural conformity	4,13
D.6. Detecting and Addressing defects	3.7
D.7. Environmental Exposure	3.5,13.3
D.8. Proof of Structure - Static	6.2,6.3,6.5,6.6,8,13.2,13.9
D.9. Proof of Structure - Fatigue and Damage Tolerance	6.2,6.3,6.5,6.6,8,13.2,13.9
D.10. Proof of Structure - Flutter, Dynamics, Addt'l. Considerations	6.2,6.3,6.5,6.6,8,13.2
D.11. Flammability/Thermal Issues	13.5
D.12. Lightning Protection	13.6
D.13. Crashworthiness	13.8
D.14. Protection of Structure	13.8
<b>Production (Fabrication and Production Substantiation)</b>	
P.1. Implementation (defining manufacturing process)	3
P.2. Manufacturing Quality Control and Inspection	3.7,3.8,4
P.3. Defect Disposition	3.7,7
P.4. Modifications in the production process	
<b>Maintenance (Continued Airworthiness)</b>	
M.1. Teamwork between engineers, inspectors and technicians	7
M.2. Damage Detection and Characterization	3.7,7
M.3. Repair Design and Process Substantiation	7



# Materials & Processes Working Group

## CMH-17 CMC [WG] Priorities

**CMH17**

COMPOSITE MATERIALS HANDBOOK

Priority	Description of Activity	Vol. 3 Design Certification Topic	Volume 5 Sections
1	Quality Control of Final Products		4.0
2	Quality Control of Starting Materials		3.8
3	NDE Methods for CMC		3.7
4	Characterization Methods		3.6
5	Machining		3.9
6	Note: All other sections are required, to allow Volume 5 to be the comprehensive document facilitating certification		November 8, 2012 Telecon

# CMH-17 CMC Testing WG Priorities



Priority	Description of Activity	Vol. 3 Design Certification Topic	Volume 5 Sections
1	Non-Ambient Testing	D.2, D.8, D.9, D.10	8.2.8
2	Test Methods – guidelines for testing	D.2	Test Method Requirements - 9.4
		D.2	Material and Process Specification Requirements – 9.2
		D.2	Data Sampling Requirements – 9.3
3	New Sections – Machining, Wear Testing and Coupon Design	D.4	Machining – Chapter 15
		D.2, M.2	Wear Testing - TBD
		D.2, D.8, D.9, D.10	Coupon Design - TBD
4	Evaluation of constituents	D.2, D.3	Evaluation of Reinforcements – Chapter 10
		D.2	Evaluation of Matrix Materials – Chapter 11
		D.2, D.3	Evaluation of Interface Material – Chapter 12
		D2., D.5	Evaluation of Composites – Chapter 13

# CMH-17 CMC [Data Review WG] Priorities



**CMH-17**

COMPOSITE MATERIALS HANDBOOK

Priority	Description of Activity	Vol. 3 Design Certification Topic	Volume 5 Sections
1	Write Chapter on Statistical Methods	---	Ch. 17
2	Revamp Section on Data submission Format	---	Sec. 16.3
3	Write Section 16.4 on Design Properties	---	Sec. 16.4
4	Review NASA MAPTIS Database	---	Ch. 18 – electronic repository of CMH-17 CMC data
5	Write Section 18.1 (and subsections) on CMC Property Data	---	Sec. 18.1
6	Reformat CMC Property Data Tables in Section 18.2 to make them consistent with PMC and MMC format	---	Sec. 18.2

# CMH-17 Vol. 5 D&A WG Priorities

CMH-17

COMPOSITE MATERIALS HANDBOOK

Priority	Description of Activity	Vol. 3 Design Certification Topic	Volume 5 Sections
1	Proof of Structure	D8, D9, D10	TBD
2	Environmental Exposure	D7	Design Requirements
3	Detecting & Addressing Defects; Defect Disposition;	D6, P3, ??	Maintainability & Supportability
4	Repair – substantiation for cert of repaired structure	P3, ??	Maintainability & Supportability
5	Design/Process definition – drawings, etc linkage to manufacturing process	????	

# Requested output

- **Please select a spokesperson**
- **A few slides summarizing results of discussions**
- **Recommended next steps**
- **Summary of action items and responsible party**



# Guidelines Working Group

- **Certification education recommended - can take 6 hr tutorial before CMH-17 mtgs or Vol 3, chp 3 (Level 1)**
  - Next one around Apr 2013 in Seattle
- **Industry SME s would benefit by interacting with experienced company certification experts; specific application will drive checklist**
- **CLEEN CMC technology SMEs should discuss their specific application with their own company certification experts**
- **Strive to move past coupon level research as soon as possible to scale up to a relevant component - helps to address issues specific to application in more complete form and help focus research**



# Guidelines Working Group

- **Certification requirements and associated technical issues are strongly dependent on specific parts in an application, e.g. critical components vs noncritical.**
- **CMH-17 Vol 5 work areas should focus on areas are non-application specific since they will benefit multiple applications (e.g. test standards, specific material and process controls, coupon test databases, lessons learned, safety-related data/advice, export control considerations)**



# Materials & Processes (M&P) Working Group

**CMH-17 Volume 5 Update Activity**

**CMC Materials Workshop**

**November 8, 2012 Telecon**

# Contents

- M&P Working Group Goals
- M&P Working Group Approach
- Team Members and Expanding the Team
- Initial Section Reviews
- Identification of “Critical for Certification” Sections
- Tentative Schedule and Philosophy
- Standard Team Meeting Time

# 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.

November 8, 2012 Telecon

# Materials & Processes Working Group

## Approach

- Assemble and maintain a team of selfless CMC/Coatings/Quality/Certification experts dedicated to revising/updating the existing CMC M&P sections in the handbook.
- Prepare the Introduction section (history, applications, benefits, CMC systems, etc.) of the CMC handbook.
- Prepare the Materials, Processing, Fabrication, and Supportability sections of the CMC handbook.
- Define the materials and processing data elements and formats for the CMC data sheets.
- Define materials and processing data package requirements, in terms of nomenclatures, methods, formats, and priorities.
- Provide detailed guidance on/references for methods and procedures for characterizing CMC composites and their constituents.
- Define/describe the quality control approaches that Industry will utilize. These are critical to the certification of CMC components.

**November 8, 2012 Telecon**

# Materials & Processes Working Group

## Team Members and Recruiting To Expand Capability

- We currently have eight active team members working to push the updating of the document forward.
- Current participants: Kaia David (Boeing), Steve Gonczy (Gateway Materials Tech.), Roberta Hines (HITCO), Wally Hoppe (UDRI), Dave Jarmon (UTRC), Doug Kiser (NASA Glenn), Andy Lazur (Rolls-Royce), and Mike Verrilli (GEAE)
- The revision of some sections of the existing document will require a significant amount of effort, while other sections are more developed but they'll require updating and reorganizing.
- Individuals interested in contributing to this group should please forward their contact information to Rachael Andrulonis [andrulonis@materials-sciences.com] . We are particularly in need of folks with knowledge of CMC quality systems (and their components), NDE, and external coatings (environmental barrier coatings).
- Having an increased number of dedicated contributors should allow the updating of the M&P sections to occur in a timely manner.

**November 8, 2012 Telecon**

# Materials & Processes Working Group

## Initial Section Reviews

- We've started to assess the state of the existing document by reviewing the M&P sections from the initial release of Volume 5.
- Individuals identified in the following slide currently have the primary responsibility for those sections. *New team members will be able to contribute based on their area of expertise. There is a lot of work to be done.*
- Unlisted sections are blank and will be worked in order of importance and/or as knowledgeable writers become available. *There is a lot of work to be done.*

# Materials & Processes Working Group

## Initial Section Reviews

- 2.0 Intro, History and Overview (& subsections) – Roberta Hines & Doug Kiser
- 3.1 CMC Systems, Processing, Properties & Applications (& subs except 3.1.1.5) – Andy Lazur & Steve Gonczy
- 3.1.1.5 Oxides (blank) – Kaia David & Steve Gonczy
- 3.2 Fiber/Reinforcement Systems and Technology (& subs) – Roberta Hines (nonoxides) & Kaia David (oxides)
- 3.3 Interphase/Interface Technology and Approaches (& subs) – Andy Lazur
- 3.4 Fabrication and Forming of Fiber Architectures (& subs) – Dave Jarmon and Doug Kiser
- 3.5\* External Protective Coatings (& subs) -- ?? Need experts
- 3.6\*† Characterization Methods (& subs) – Mike Verrilli
- 3.7† NDE Methods for CMC (& subs) – Wally Hoppe
- 3.8\*† Quality Control of Starting Materials - ?? Need experts
- 3.9\*† Machining - ?? Need experts
- 4.0\*† Quality Control of Final Products - ?? Need experts
- 5.0 Applications, Case Histories, Lessons Learned - ?? Need experts

\*Reserved for Future Use (i.e., currently blank)

†Critical for Cert

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# Materials & Processes Working Group

## Certification Focus:

- On July 9, Rhett Jefferies and Curt Davies emphasized that the working groups should be identifying sections within our responsibility area that are important to the certification effort, so that we can begin to focus on those.
- At least three M&P sections seem very critical to certification. Sections 3.8 (Quality Control of Starting Materials) and 4.0 (Quality Control of Final Products) are currently blank...and input from individuals with expertise in those areas will be needed. We also intend to build upon similar existing “mature” sections that address those topics for PMCs (Polymer Matrix Composites). NDE is also considered critical.
- The other M&P sections will contain important information, but the content could be considered more “educational”.
- We will continue to assess how each section relates to the certification effort.

November 8, 2012 Telecon

# Materials & Processes Working Group

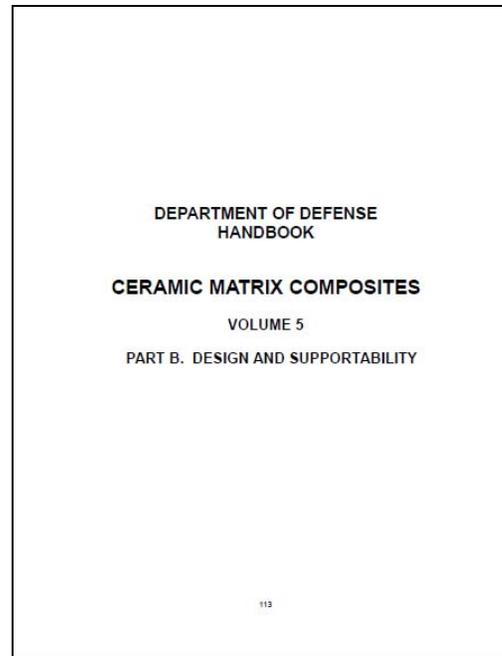
## Tentative Schedule and Philosophy

- K. David and D. Kiser provide M&P status updates at the CMH-17 V5 Monthly Meetings (telecons) with other working group leads and FAA leadership
- Providing status update at Nov FAA Consortium Meeting (Nov. 8)
- Providing status update at Cocoa Beach CMH-17 session (Jan. 31)
- M&P Monthly Telecon (this is a virtual team): “3<sup>rd</sup> Friday”—1pm
- **Goal:** Draft M&P text ready for higher level review by the end of 2013.
- **Philosophy:** There is a lot of work to be done, but with an expanded team of dedicated individuals, **the task can be completed**. Each person will focus on a discrete topic (if possible) and try to consistently make progress toward completing the required text. *How do you eat an elephant? One bite at a time.*
- Think long term—focus on the goal.

November 8, 2012 Telecon

# CMH-17 Vol. 5 Design & Analysis Working Group

## CMH-17 Volume 5 Update Activity



**CMH-17 Workshop  
FAA CLEEN Consortium  
Atlanta, GA  
November 8, 2012 Telecon**



Federal Aviation  
Administration

# CMH-17 Vol. 5 Design & Analysis WG

- **Summary of discussion**

- Current Vol 5 Outline focuses on education: “How to Use CMCs” – needs to move to “Defining scope of certification and structural substantiation”.
- Identified critical topics for certification focus on D8,D9,D10 –”Proof of Structure”
- Need to involve experienced certification folks



# CMH-17 Vol. 5 Design & Analysis WG

- **Recommended next steps**
  - Review and amend outline at top level
  - Complete detailed outline by Cocoa Beach F2F (Jan 2013)
  - Conduct WG membership drive at Cocoa Beach
  - Solicit draft authorship
- **Action items**
  - Send revised outline out to WG for review & edits (Petervary, Due 11/13/12)
  - Set up follow up telecons, first Thursday of each month, 12pm EST (Rachael)



# Revised Outline

- Introduction
  - CMC Material Mechanical Behavior
  - Typical Failure Modes
    - What is failure?
    - Failure criteria
  - Design challenges with CMCs
    - Environment
    - Attachments
    - Combine Thermal & Mechanical response
  - Overview of Manufacturing Process from a Design Perspective (recognize limitations and opportunities of current fabrication processes on design)
  - Certification Process & Terminology Overview (FARs, DDRs, )
- Definition of Application & Design Requirements
  - Classification of Criticality and Type
  - Establishment of Design Requirements (loads, environment, life cycles, duration, rtc)
  - Substantiation Plan (Validation & Verification Matrix)
  - Documentation requirements for FAA Certification



# Revised Outline

- CMC Component Design and Analysis Considerations, Options, Methods
  - Materials selection (how to align materials , fab processes, to application requirements)
    - Fiber, interphase, matrix, coatings?
    - Fiber architecture (uni, woven, 3D, braids, etc)
    - Considerations
      - Temps, environment, costs, fabrication capability/capacity
  - Verification by Analysis
    - Impact of environment on structural performance and life
    - Impact - Durability and Damage Tolerance
      - High velocity
      - Low velocity
      - BVID thresholds
      - Damage detection
      - Strength after Impact
    - Thermal mechanical coupling models
    - Oxidation & mechanical coupling models
    - Linear vs Non-linear analysis,
      - deterministic vs stochastic methods
    - Global FEM, local micromechanical models
    - Life prediction or use of end of life properties
    - Failure Modes & Effects Analysis
  - Verification by Test
    - Critical design feature test
    - Element, subcomponent
- Maintainability and Supportability
  - Inspection ability
  - Damage and Damage Tolerance
  - Repair
  - Life limitations and Placards
- Substantiation Package for Certification

