JOINT ADVANCED MATERIALS & STRUCTURES
CENTER OF EXCELLENCE

Ceramic Matrix Composite Materials Guidelines for Aircraft Design and Certification

John Tomblin, Wichita State University
Rachael Andrulonis, Wichita State University
Matt Opliger, Wichita State University

JAMS 2018 Technical Review
May 23-24, 2018

Ceramic Matrix Composite Materials Guidelines for Aircraft Design and Certification

- Motivation and Key Issues
  - Expanded use of CMCs in engine and other hot section applications
  - CMCs require their own set of rules separate from more established PMCs
  - No “fully approved” data in CMH-17
  - Similar complexity to PMCs in terms of anisotropy, fiber architecture, high strength/stiffness fibers, and production process sensitivity and variability, they are also different in many ways such as:
    - Composite constituents
    - Degradation, damage, and failure mechanisms
    - High temperature life predictions
    - High temperature bonding challenges
    - NDI challenges
    - Repairability

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Development of Qualification Program

- **Technical Monitor**: Ahmet Oztekin

- **NIAR Contacts**: John Tomblin, Rachael Andrulonis, Matt Opliger
- **Industry Partners**: Axiom Materials (prepreg), AC&A (panel), 3M (fiber and fabric), several steering committee members

- **Overall Goals**
  - Primary goal: To develop a framework for the qualification of new and innovative composite material systems including guidelines and recommendations for their characterization, testing, design and utilization.
  - Secondary goal: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

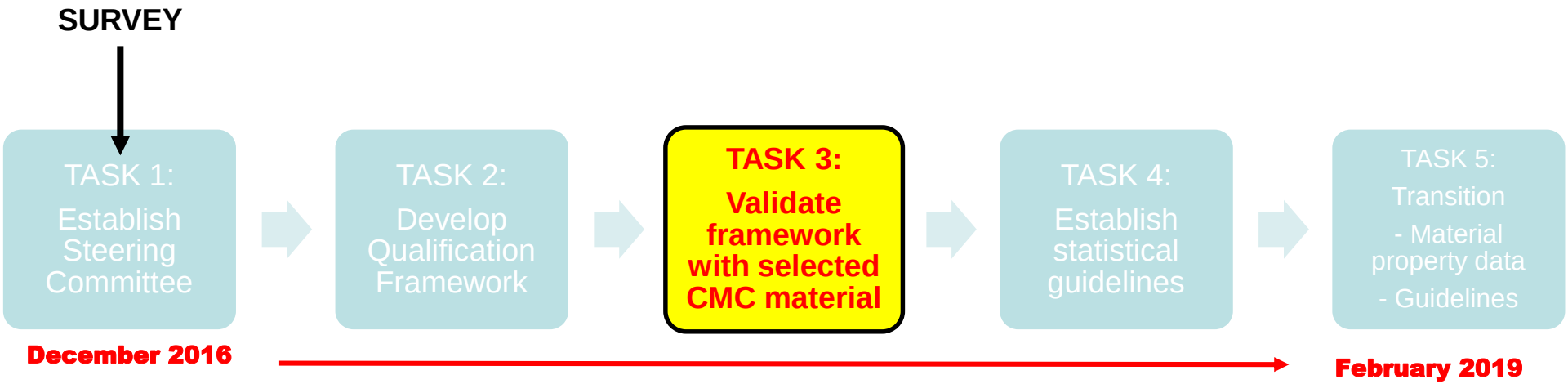
CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Technical Approach

- Develop a framework to advance CMC materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.



CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Task 1: Steering Committee

- Steering committee formed with interested individuals
- Kick-off meeting was held in December 2016, Monthly meetings
- Collaboration with CMH-17
- Includes participants from industry (Pratt & Whitney, Free Form Fibers, Honeywell, Rolls Royce, Boeing, GE, 3M) and government (NASA, AFRL, FAA)
- Review and provide feedback on qualification plan, documents and resulting data
  - Overall test plan
  - Material specification
  - Process specification
  - Pedigree/documentation
  - Data
  - Statistical analyses

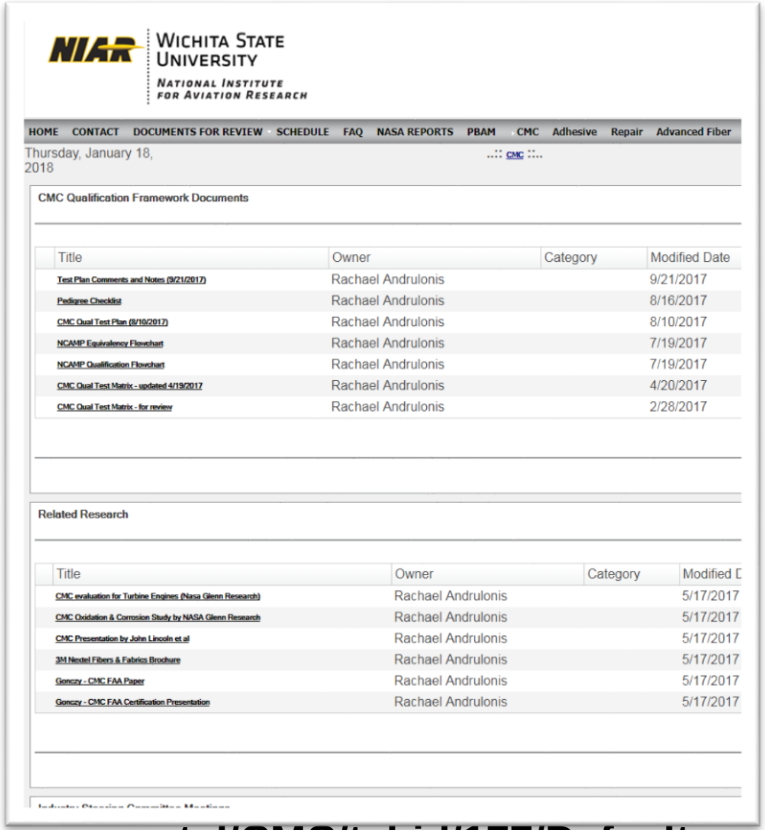
CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

NCAMP Portal

- All members of the Steering Committee have access
- Monthly meeting charts
- Documents for review
- Related research



http://www.niar.wichita.edu/ncampportal/CMC/tabid/177/Default.aspx

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Task 2: Development of Qualification Program

GOAL: Generate the framework for a qualification test program including material and process specifications, test matrices, and documentation requirements.

Objectives:

- Select an established CMC material and process to initially develop this framework. The material will be selected with input from the steering committee.
- Determine the critical process parameters and how they affect material properties.
- Address quality aspects of the selected CMC process and the framework for a quality assurance program.
- Draft material and process specifications for selected CMC material. *These will be very specific – material, material supplier, processing.*
- Develop CMC test matrix including required physical and mechanical data.
- Generate substantial mechanical property test data necessary for development of statistical guidelines using accepted test standards for CMC materials.

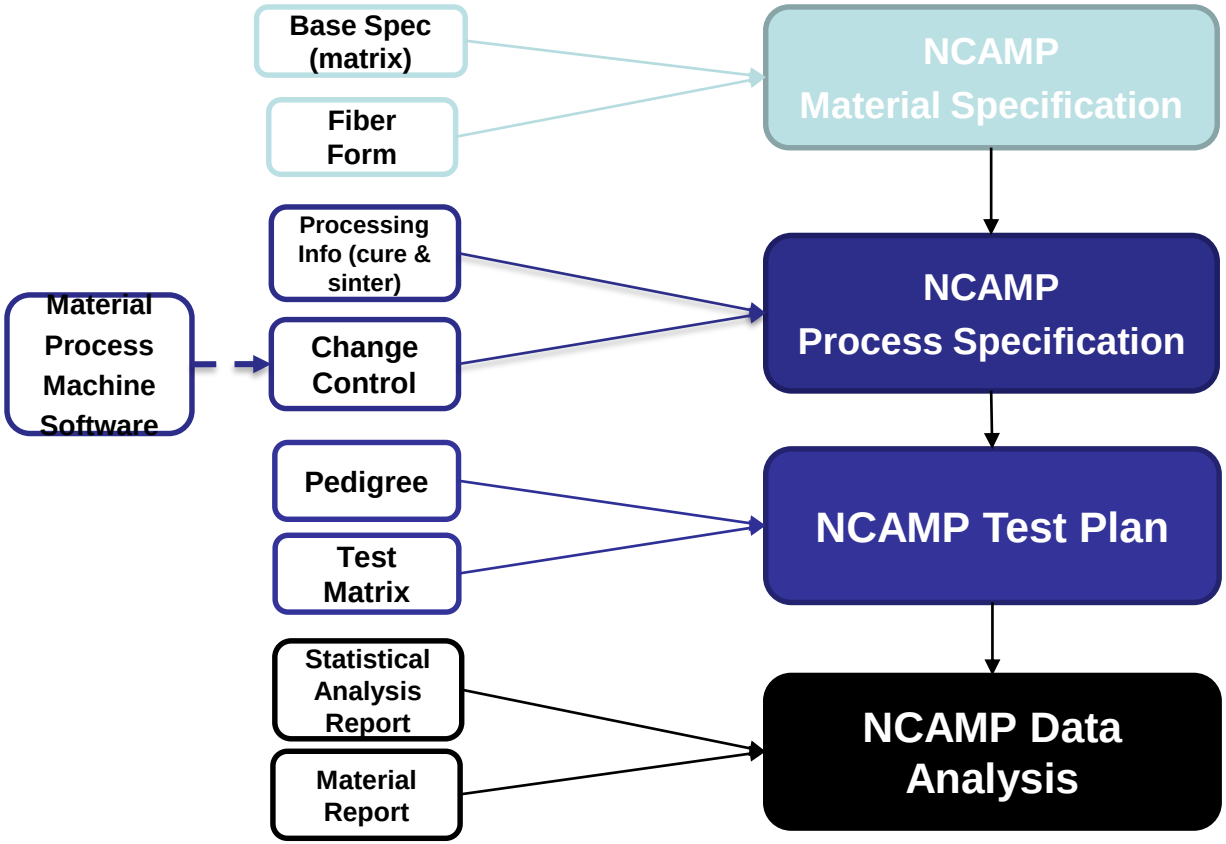
Material Selection and Process

Aluminum Silicate Slurry

Autoclave and sintering

- **Prepreg production and panel fabrication is ongoing**
- **Screening tests are concluding at NIAR**
- **Site visit/audit at Axiom took place in November 2017 – PCD has been signed**

Qualification Documentation



STATUS

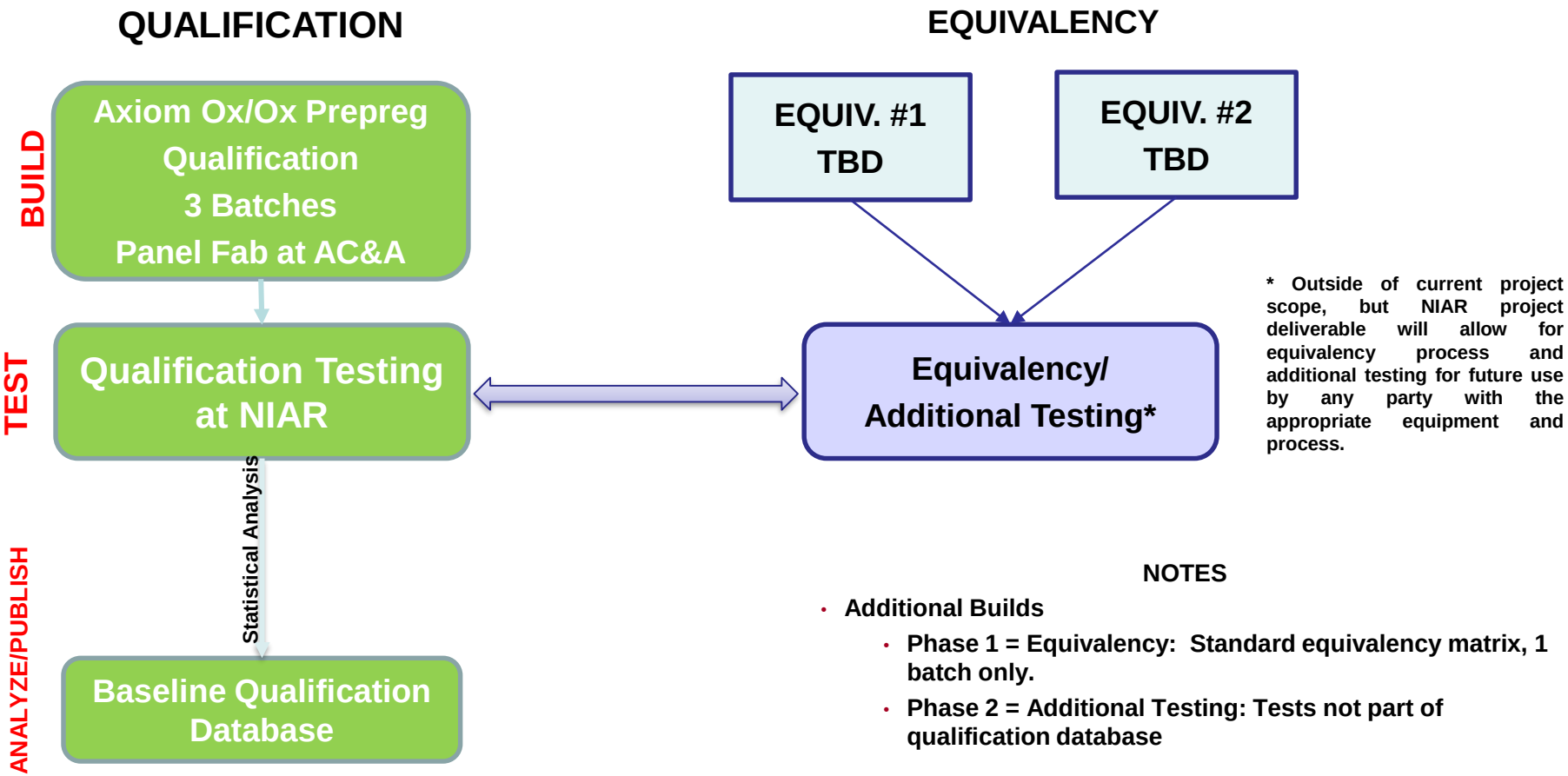
- Material selection complete
- Material Spec – complete
- Process Spec – complete
- Test Matrix – complete
- Test Plan – released

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Qualification Program



* Outside of current project scope, but NIAR project deliverable will allow for equivalency process and additional testing for future use by any party with the appropriate equipment and process.

NOTES

- Additional Builds
  - Phase 1 = Equivalency: Standard equivalency matrix, 1 batch only.
  - Phase 2 = Additional Testing: Tests not part of qualification database

CECAM

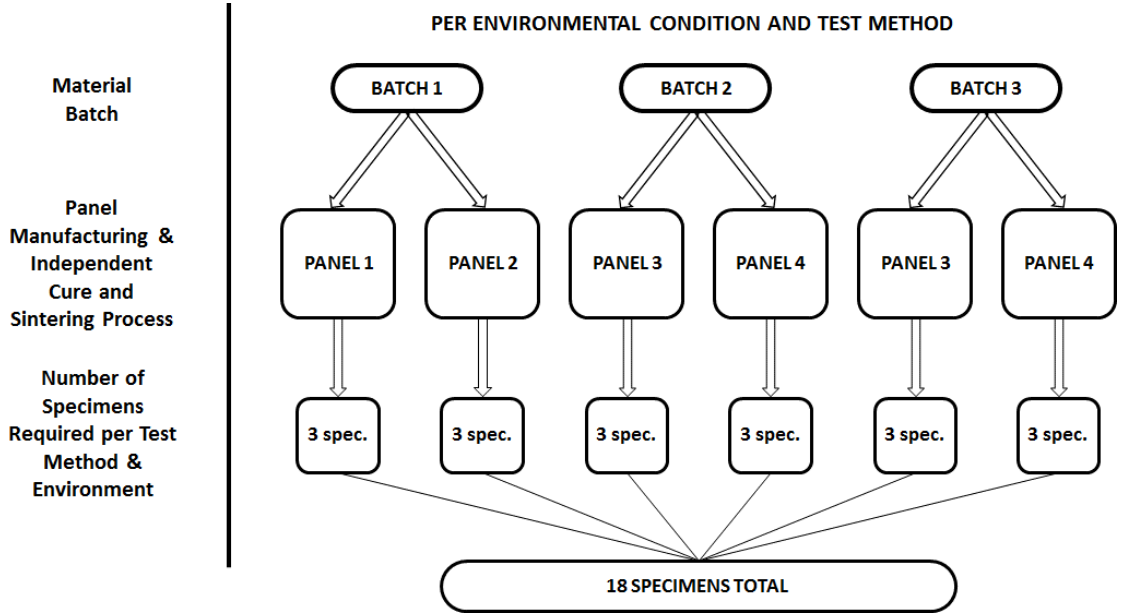
JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

AMTAS
A Center of Excellence
Advanced Materials in Transport Aircraft Structures

Test Plan Overview

- Resources:
  - Steering Committee
  - PMC NCAMP test matrix
  - CMH-17 Volume 1 and 5
  - DOT/FAA/AR-03/19
  - DOT/FAA/AR-06/10
  - DOT/FAA/AR-02/110
- Selected property and/or conditions for preliminary studies

Process Definition



CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Lamina Level Mechanical Tests

Layup	Test Type and Direction (See Note 9)	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens	
				Test Temperature	
				RTD	ETD
$[0]_{5S}$	Warp Tension (See Notes 1, 7, 8, and 10)	Strength, Modulus, and Poisson's Ratio (RTD Only)	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
$[90]_{5S}$	Fill Tension (See Notes 1, 7, 8, and 10)	Strength and Modulus	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
$[0]_{6S}$	Warp Compression (See Notes 2, 7, 8, and 10)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[90]_{6S}$	Fill Compression (See Notes 2, 7, 8, and 10)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[45/-45]_{2S}$	In-Plane Shear (45/-45 Tension) (See Notes 3 and 8)	Strength and Modulus (RTD Only)	ASTM D3518	3x2x3	3x2x3
$[0]_{7S}$	In-Plane Shear (V-Notch Shear) (See Notes 4 and 8)	Strength and Modulus	ASTM D5379	3x2x3	
$[0]_{7S}$	Interlaminar Shear (Double-Notch Shear) (See Note 5)	Strength	ASTM C1292 (RTD) ASTM C1425 (ETD)	3x2x3	3x2x3
$[0]_{28}$	Interlaminar Shear (Short-Beam Strength) (See Note 6)	Strength	ASTM D2344	3x2x3	

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Laminate Level Mechanical Tests

Layup (See Note 12)	Test Type and Direction (See Note 10)	Property	Test Method	Number of Batches x No. of Panels x No. of Specimens	
				Test Temperature	
				RTD	ETD
$[0]_{7S}$	Flexure (See Notes 1, 9, and 11)	Strength and Modulus	ASTM C1341	3x2x3	
$[0]_{10}$	Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)	Strength	C1468	3x2x3	
$[0/90]_{5}$	Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)	Strength	C1468	1x1x6	
$[0/90]_{14}$	Interlaminar Shear (Short-Beam Strength)	Strength	ASTM D2344	1x1x6	
$[45/0/-45/90/-45/90]_{S}$	Unnotched Tension (See Notes 3, 9, and 11)	Strength and Modulus	ASTM C1275 (RTD) ASTM C1359 (ETD)	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{S}$	Unnotched Compression (See Notes 4, 9, and 11)	Strength and Modulus	ASTM C1358	3x2x3	3x2x3
$[45/0/-45/90]_{2S}$	Open-Hole Compression (See Notes 5 and 11)	Strength	ASTM D6484	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{S}$	Open-Hole Tension (See Notes 6 and 11)	Strength	ASTM D5766	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{S}$	Filled-Hole Tension (See Notes 7 and 11)	Strength	ASTM D6742	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{S}$	Single Shear Bearing (See Note 11)	Strength	ASTM D5961 (Procedure C)	3x2x3	3x2x3
$[45/0/-45/90/-45/90]_{S}$	Tension After Impact (See Notes 8 and 11)	Strength	ASTM D7136 ASTM D5766	1x2x3	1x2x3

CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Other Test Types Included

- Uncured Physical Tests
- Cured and Sintered Physical and Thermal Tests
- Fluid Sensitivity Tests
  - Short beam strength on $[0]_{28}$
  - Includes extended contact, short duration and control tests
  - Post-immersion conditioning – require 60 minutes minimum at 1650°F

Task 4: Guidelines and Recommendations

GOAL: To provide guidelines to industry for the collection of statistically meaningful critical data that designers need to utilize CMC materials potentially including:

- Creation of a shared CMC database including test data, material and process specifications and statistical analysis methods.
- Development of handbook data and guidelines (i.e., CMH-17).
- Coordinate with other standards and specification organizations to develop specifications from this program.

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Status – Based on FY2017 Deliverables

	Activity	Target Date	Milestone / Deliverable	Complete?
1.2	Industry Steering Committee - Establish group of participants - Create online portal for document sharing and data repository	12/15/2016	Milestone	✓
1.3	Preliminary drafts of qualification framework - Material and process specifications - Test plan - Conformity documentation	6/30/2017	Deliverable	✓
1.4	Qualification Audit	11/10/2017	Milestone	✓

Status – Based on FY2017 Deliverables

	Activity	Target Date	Milestone / Deliverable	Complete?
1.1	Trial / Screening Studies (ongoing) - Perform physical and mechanical tests to assist in final test matrix development and selection of machining and NDI methods - Present data to FAA, Industry Steering Committee, NCAMP Partners	1/15/2018	Milestone	✓
1.2	Qualification Material - Site audit complete (scheduled for 11/7-11/8/2017) - Panels built and delivered to NIAR	2/1/2018	Milestone	Panels in process
1.3	Qualification Testing - Perform physical and mechanical testing on qualification panels. – Generate test data for qualification program.	8/31/2018	Milestone	
1.4	Develop Statistical Guidelines based on qualification data	10/1/2018	Milestone	
1.5	NCAMP Reports on Qualification Data - Material technical report - Statistical analysis technical report	12/31/2018	Deliverable	
1.6	CMH-17 - Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)	2/28/2019	Deliverable	
1.7	Final Report - Final Technical Report on the Guidelines for CMC Qualification.	2/28/2019	Deliverable	

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Looking forward

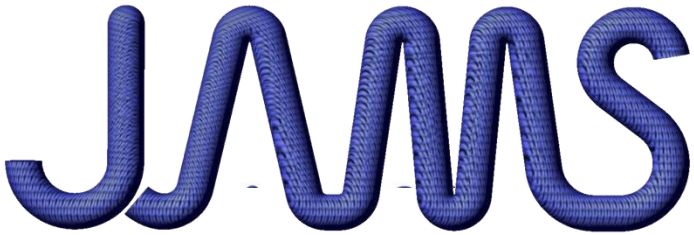
- Benefit to Aviation
  - Publically available CMC data linked to M&P specs
  - Addition to CMH-17 handbook
  - CMC – PCD and process spec guidelines

- Future needs
  - Validate qualification data with equivalencies
  - Trial studies needed:
    - Processing effects on CMCs
    - SiC/SiC or C/SiC composites
    - Effects of thermal and environmental barrier coating

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures



JOINT ADVANCED MATERIALS & STRUCTURES
CENTER OF EXCELLENCE