Wichita State University

National Institute for Aviation Research

WHERE TEST PLANS BECOME RESULTS

Polymer-Based Additive Manufacturing Guidance for Aircraft Design and Certification

John Tomblin, Wichita State University

Paul Jonas, Wichita State University

Chris Holshouser, Wichita State University

Rachael Andrulonis, Wichita State University

Royal Lovingfoss, Wichita State University

November 5, 2019

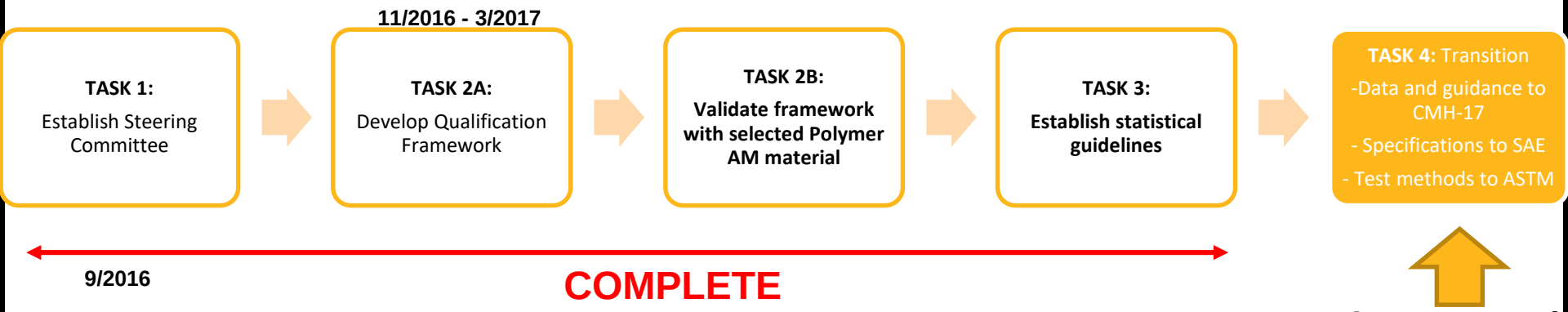
The NCAMP Approach for Polymer AM

- Additive Manufacturing is quickly moving from development → production
  - Reliable design allowables are required
  - Process for generating allowables is critical
  - Working with industry and regulators provides a unique perspective on allowable development, status and issues.
- NCAMP is a proven process for allowables
- Equivalency aspect allows manufacturers to qualify installations assuring a known output and quality.
- CMH-17 is an established repository of advanced material data that works closely with NCAMP to publish data

No existing public qualification of an additive material prior to this program.

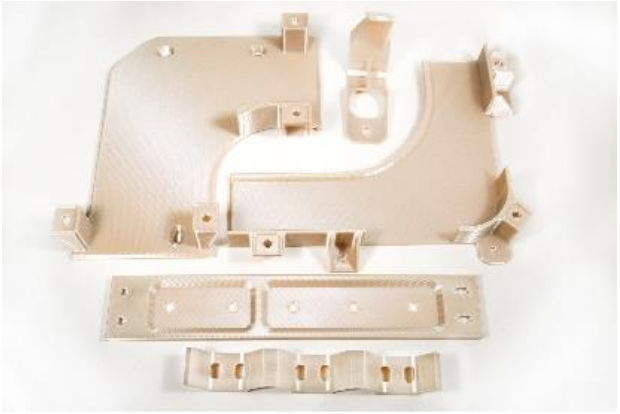
Qualification: *Technical Approach*

- Develop a framework to advance polymer-based additively manufactured 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
- Transition the data and guidelines to CMH-17
- *Note: Program is in collaboration with America Makes (see objectives on following slide)*



4

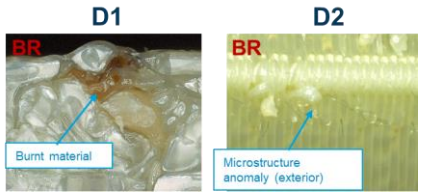
Technical Approach and Methodology



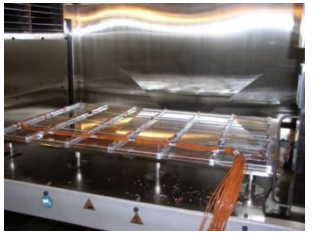
- **Demonstrate machine repeatability through process specification implementation.**
- **Quantify material variability through process.**
- **Quantify other design variables through process (environmental conditions, build location, build orientation, etc…)**

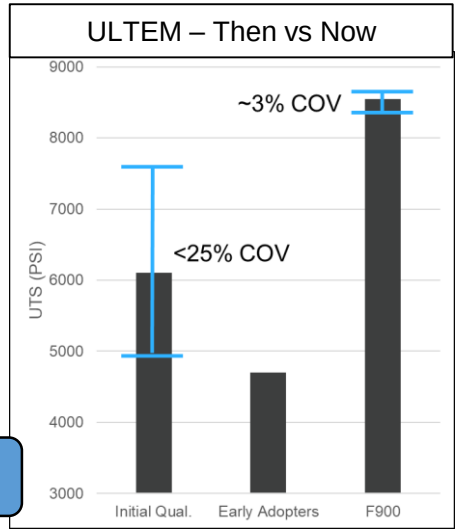
ULTEM 9085™ NCAMP Qualification

- NIAR demonstrates first AM material/process ready for distributed manufacturing
  - M&P specifications – process control driven, NCAMP published
  - Shared b-basis allowables – equivalency proven from two additional build sites
  - $1.7M (federal) + $2.7M (industry), 24 month effort
- Broad Community Participation
  - Co-Funded by FAA and America Makes (OSD/DMS&T)
  - Government Steering Committee
  - Industry Technical Advisory Team
- Record Transition
  - Deliverables used in TDPs and WOs for Air Force and Army
  - Generating *first* four SAE specs for Polymer AM
  - Machine OEM (Stratasys) commercializes dedicated product
  - CMH-17 Additive Volume to house data, test methods, and design guide
  - Characterization methods used feeding new ASTM F-42 and D-20 industry standards



Effect of Defects


Process Control

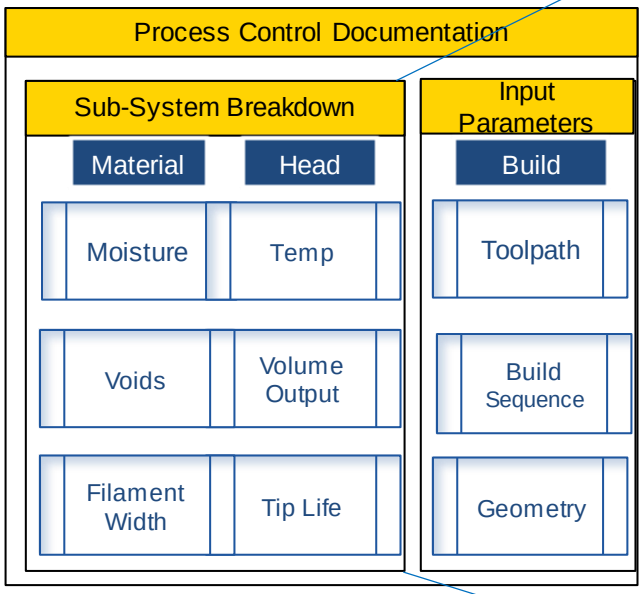


- 3 Lots
- 2 Machines
- 4 Orientations
- 4 Chamber Zones
- 3 Env. Conditions
- 12 Standards
- 2 Equivalencies
- **3292 Specimens**

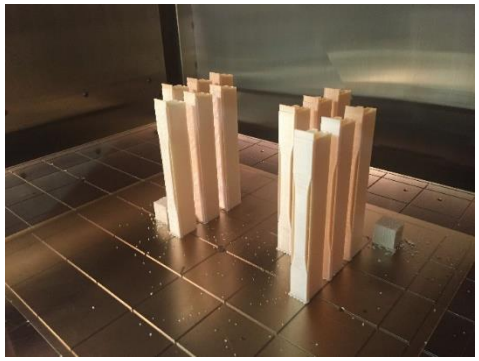
NIAR Shows AM Can Be Qualified Through NCAMP

NIAR Wichita State University National Institute for Aviation Research

TECHNICAL APPROACH

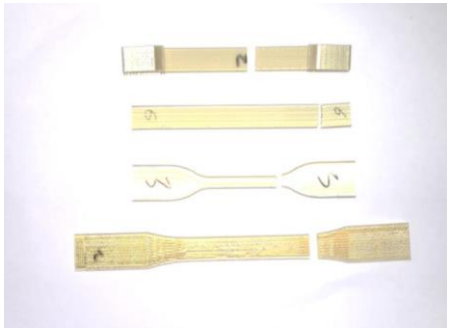


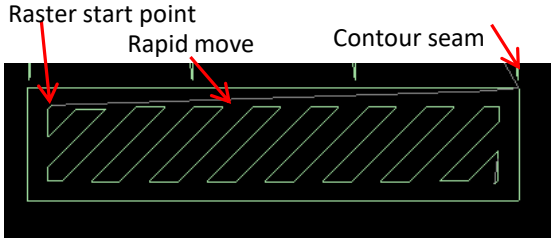
Chamber Location



Defect Characterization

Coupon Geometry





Toolpath Planning

Over 300 Inputs and Parameters Studied to Measure, Improve, and Control

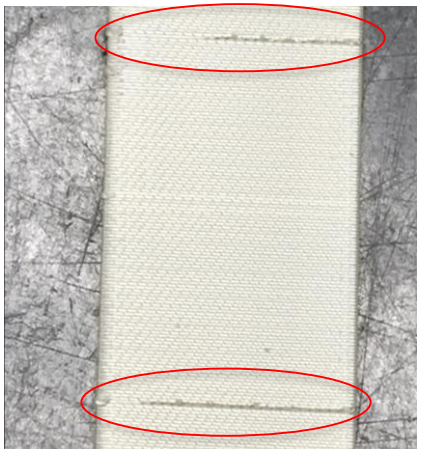
NIAR Wichita State University National Institute for Aviation Research

Defined Process and QA Limits

Examples – Dispositioned versus Acceptable Specimens

Dispositioned

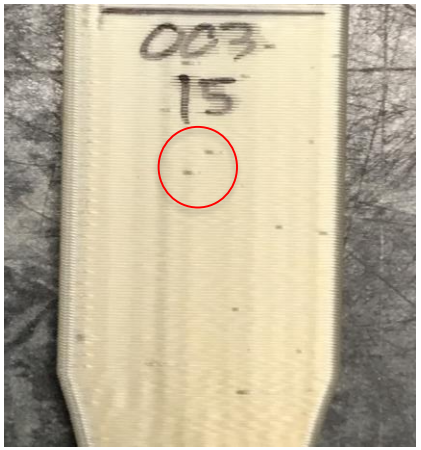
Embedded Support



Extrusion Lagging and Purge Blobs

Acceptable

Color Striation



Bubbles

***Sample dispositioning has occurred at all 3 printing locations throughout the coupon manufacturing process.**

8

Statistical Analysis Approach

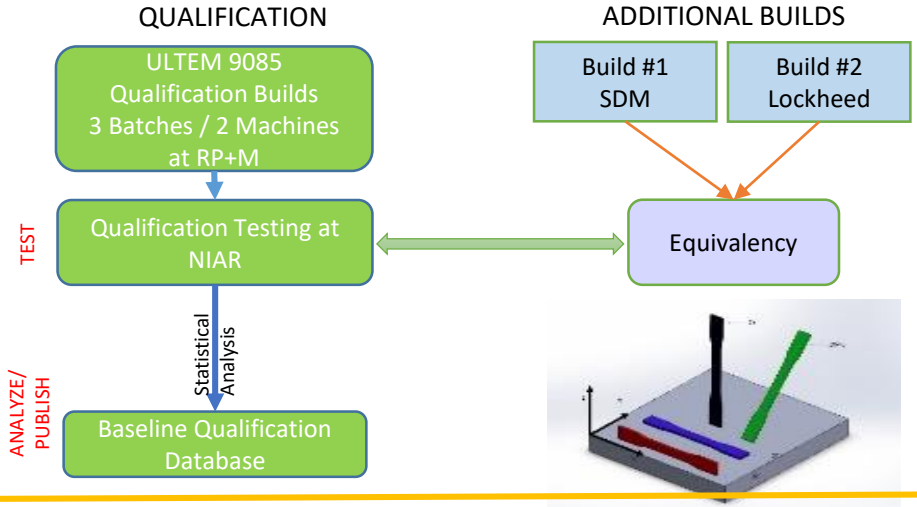
- CMH-17 Unstructured (no significant differences between batches, machines, production sites, etc.)
  - Normal distribution
  - Lognormal distribution
  - Weibull distribution
  - Non-parametric – no underlying distribution assumed
- CMH-17 Structured
  - ANOVA analysis with each machine-batch combination treated as separate group
- Modified CV (not yet evaluated with respect to AM)
  - Increases CV to a set percentage of the property mean
  - Included in the statistical analysis report
- Multivariate Generic Approach
  - This is a new approach and is not included in statistical analysis report

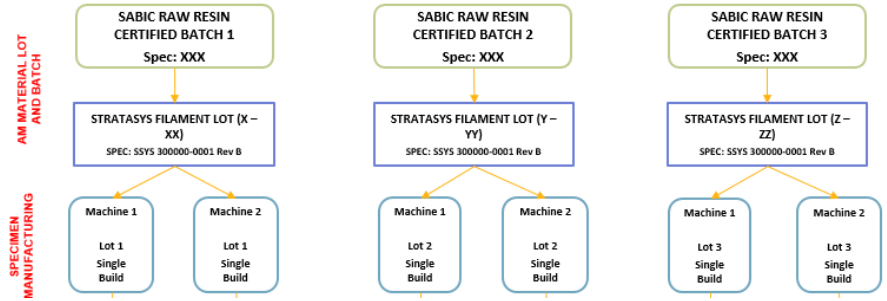
Example Basis Values Table Using CMH-17 Methods

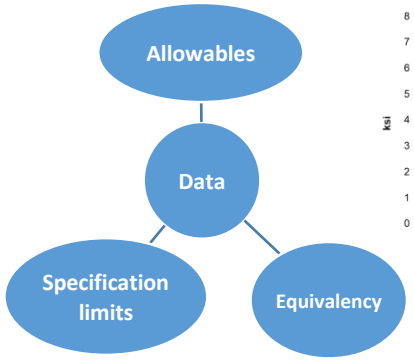
Dogbone Tension (DT) Basis Values and Statistics - CTD Condition									
	0.2% Offset Yield Strength					Strength			
Axis	X-Axis	Y-Axis	Z45-Axis	Z-Axis	X, Z45 & Z Axes	X-Axis	Y-Axis	Z45-Axis	Z-Axis
Mean	6.714	7.792	6.606	6.804	6.708	12.965	13.594	9.768	10.720
Stdev	0.710	0.499	0.549	0.398	0.565	0.665	0.926	0.466	0.667
CV	10.582	6.407	8.314	5.855	8.424	5.131	6.814	4.773	6.225
Mod CV	10.582	7.204	8.314	6.927	8.424	6.565	7.407	6.386	7.112
Min	5.557	6.762	5.837	6.194	5.557	11.465	11.584	8.848	8.730
Max	8.917	8.582	7.780	7.512	8.917	14.501	15.050	10.877	11.880
Batches	3	3	3	3	3	3	3	3	3
Machines	2	2	2	2	2	2	2	2	2
No. Spec.	24	24	24	24	72	24	24	24	24
Basis Values and Estimates									
B-Basis	5.398	6.868	5.149	6.066	5.642	11.733	11.879	8.648	9.374
A-Estimate	4.455	6.205	4.139	5.537	4.866	10.849	10.649	7.866	8.025
Method	Normal	Normal	ANOVA	Normal	ANOVA	Normal	Normal	ANOVA	Weibull
Modified CV Basis Values and Estimates									
B-Basis	NA	6.752	NA	5.931	NA	11.387	11.728	8.612	9.307
A-Estimate		6.007		5.305		10.257	10.391	7.784	8.294
Method		Normal		Normal		Normal	Normal	Normal	Normal

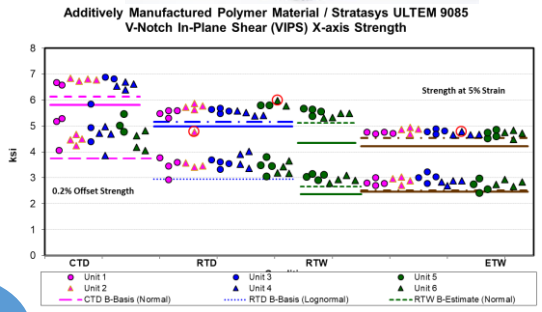
ESTABLISHED FRAMEWORK FOR AM QUALIFICATION

- Demonstrate machine repeatability through process specification implementation.
- Quantify material variability through process.
- Quantify other design variables through process (environmental conditions, build location, build orientation)



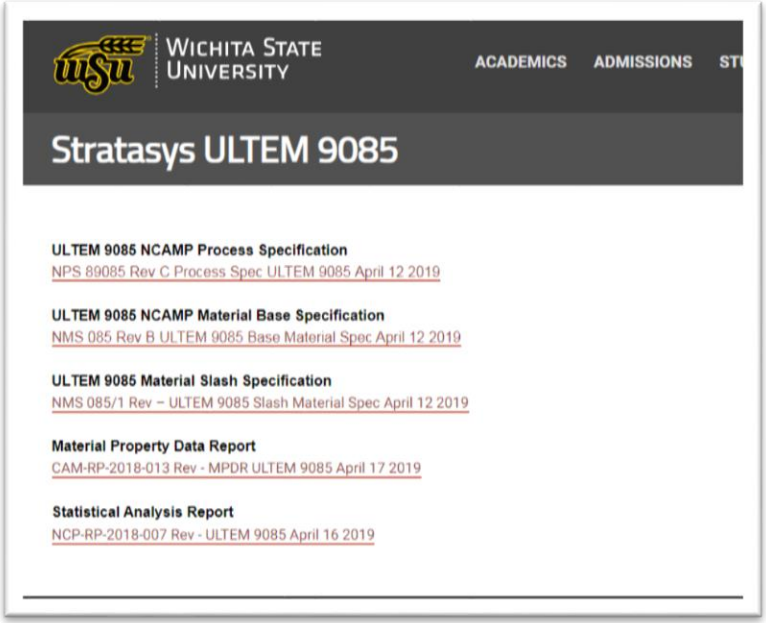






NCAMP Reports –*Published on 4/17/2019*

- **ULTEM 9085 NMS 085 (NCAMP Material Base Specification)**
- **ULTEM 9085 NMS 085/1 (NCAMP Material Slash Specification)**
- **ULTEM 9085 NPS 89085 (NCAMP Process Specification)**
- **ULTEM 9085 Material Data Report**
- **ULTEM 9085 Qualification Statistical Analysis Report**

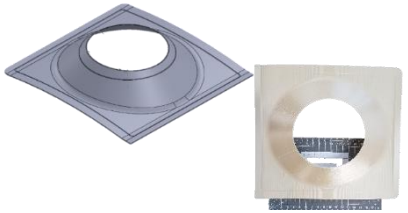


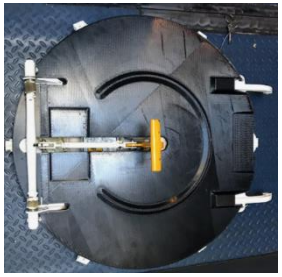
https://www.wichita.edu/research/NIAR/Research/ultem9085.php

INDUSTRY WIDE IMPACT

DoD and Commercial Suppliers

Implemented DoD parts enabled by AM qualification





C-5 Window Reveal

- Increasing the AM Install Base
  - Aircraft Interior Solution: Stratasys' Dedicated Product (block upgrade)
  - **107 units sold including: 50 AIS solution, 19 F900 pro, 38 AICS solution upgrades**
  - **~ 10 government units sold including: 2 US Air Force and 5 UDRI**
- Equivalencies - Reduced testing for per machine qualifications
  - 10 machines at different phases of equivalency since start of 2019*
  - Two completed, two actively printing, six in quoting and planning phase
- Supply Chain Effects – Benefits to Small / Medium Enterprises
  - RP+M added to major OEM QPL
  - SDM and RP+M seeing increased interest from DoD supply chain wanting to move into production using AIS.

C-17 Avionics Cooling Ducts

* NCAMP averages 1 equivalency a year per material for traditional composites

Expanding Supply Chain Opportunities, Preparing for Production

NIAR Wichita State University National Institute for Aviation Research

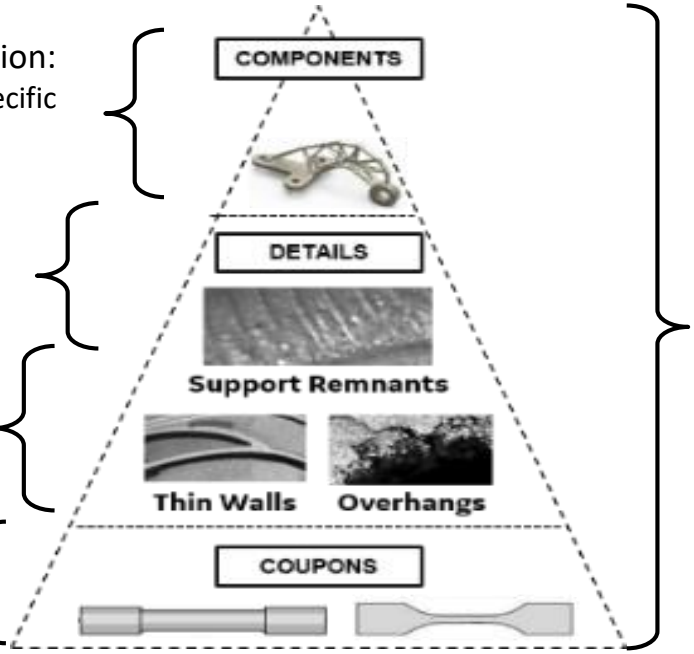
ENABLED RESEARCH AND FUTURE MATERIALS

Advanced Tools for Rapid Qualification: Characterizing higher order application specific requirements for depot printing

Kansas Aviation Research & Technology: Kansas consortium driving adoption for interior cabin parts production; printer to aircraft workflow

JAMS: Increasing application space for ULTEM by opening up processing windows and validating test scalability

Joint Advanced Materials & Structures (JAMS): Expanding non-metallic framework with qualifications of filled and loaded polymers for higher performing/criticality parts



CCDC: Long range precision strike fires will further expand framework to include metal AM materials to be qualified using NCAMP processes; moving into application specific characterization

ULTEM QUALIFICATION – FOUNDATIONAL FRAMEWORK

NIAR Wichita State University National Institute for Aviation Research

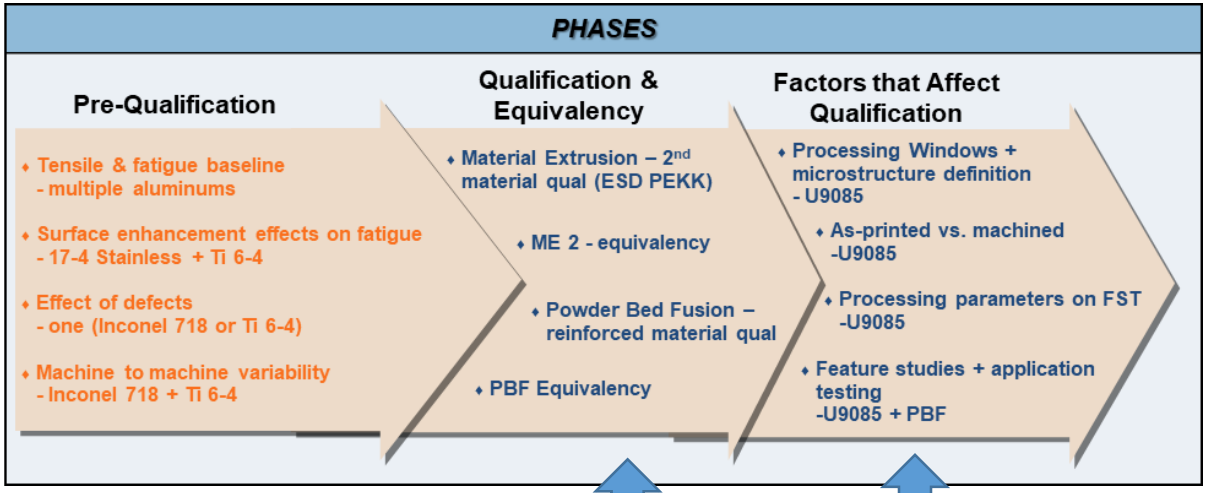
JOINT ADVANCED MATERIALS & STRUCTURES (JAMS)

The FAA's mission is to "provide the safest, most efficient aerospace system in the world."

- Safety is always our first priority

The FAA has created an AVS Composite Plan to identify and manage safety risks, opportunities to standardize means of compliance, and promote workforce education

- Plan updated annually
- Depends on industry deliverables (e.g., CMH-17 and SAE)
- Includes FAA research



NIAR research focusing in these two areas

Task 4: Guidelines and Recommendations

GOAL: To provide guidance to industry for the collection of statistically meaningful critical data that designers need to utilize polymer-based additive manufacturing materials potentially including:

- Creation of a shared polymer AM database including test data, material and process specifications and statistical analysis methods.
- Development of handbook data and guidelines (i.e., CMH-17) – *new Volume started in October 2018*
- Coordinate with SAE to develop specifications from this program – *Ongoing activity through the SAE AMS-AM non-metallic committee (AMS 7100 and 7101)*
- Coordinate with ASTM and NIST on test method development and modification – *ongoing and being coordinated through the ASTM Center of Excellence, F42, and D20*
- Collaborate with other organizations as needed

What is the Composite Materials Handbook?

CMH-17 Mission

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

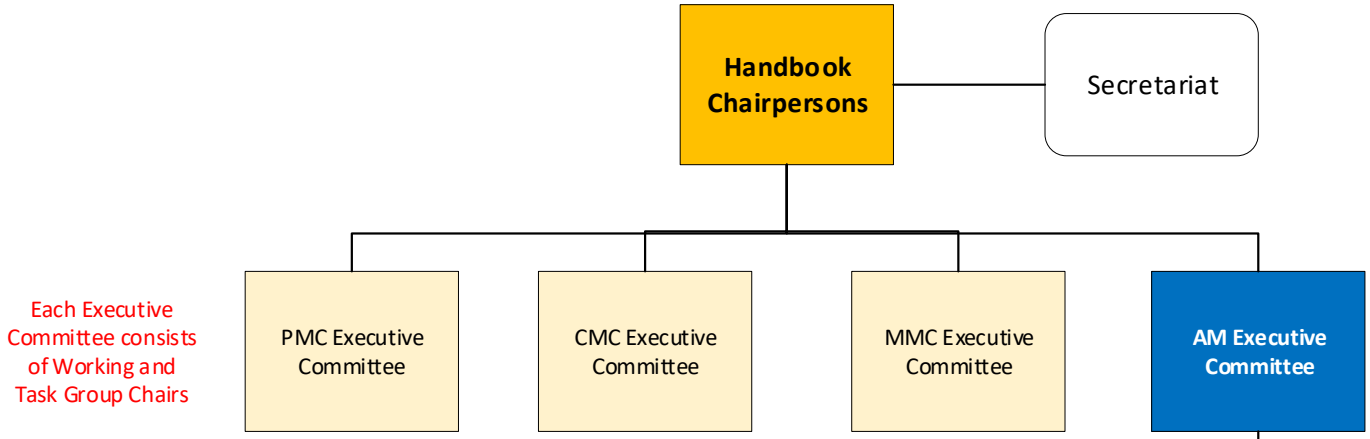
CMH-17 Vision

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

CMH-17 Goals

- The handbook has three goals/purposes:
  1. Provide material data
     - Physical and mechanical properties
     - Tied to a single material specification AND a single process specification
  2. Describe how to generate material data
     - Material and process control
     - Test matrices
     - Statistical methods
  3. Describe how to use material data
     - Design guide based on:
       - Proven methods / best practices
       - Includes information on manufacturing and maintenance

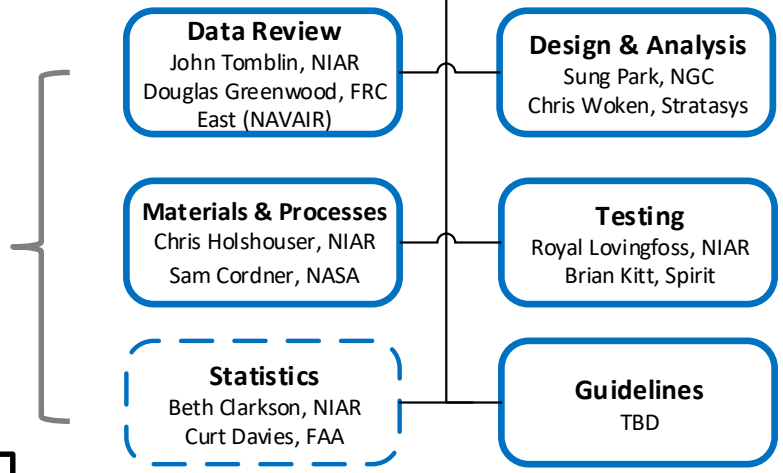
The CMH-17 Organization



The Exec Committee

- Sets goals and priorities for the handbook
- Establish knowledge transfer forum for evolving and mature handbook content

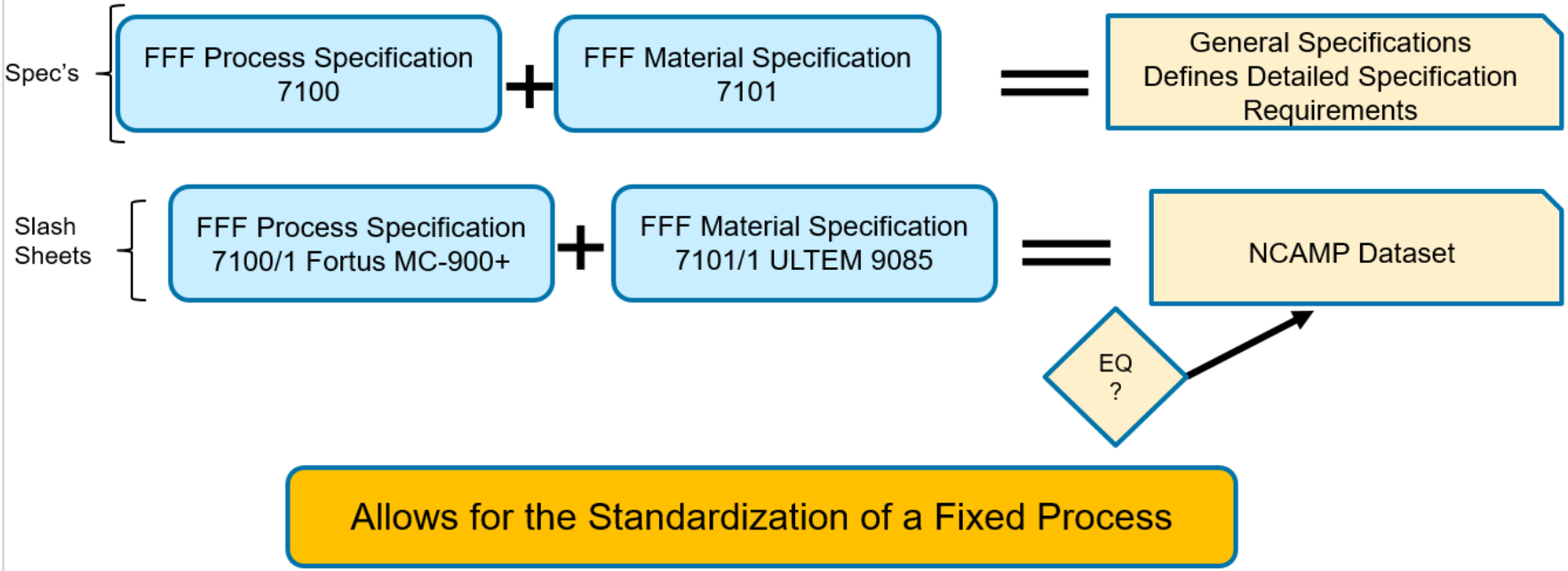
Initial focus of handbook input is on the ULTEM 9085 data set, M&P guidelines, test methods, and statistical guidelines.



Fall Meeting: October 10-11, 2019 in conjunction with the ASTM AM Symposium (National Harbor, MD)

https://www.cmh17.org/MEETINGS.aspx

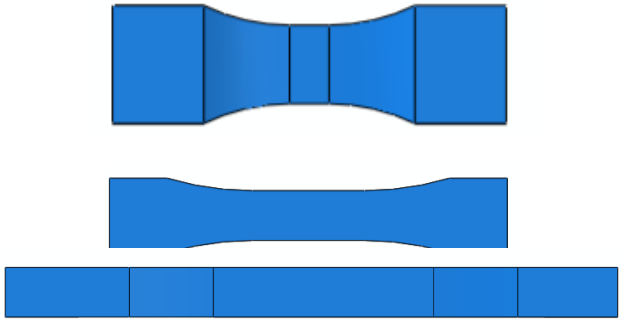
Other Transition Areas: SAE AMS-AM



NIAR Wichita State University
National Institute for Aviation Research

Other Transition Areas: ASTM (F42 and D20)

- Supporting ASTM F42 and D20 on mechanical test considerations
- ASTM WK66029: *New Guide for Mechanical Testing of Polymer Additively Manufactured Materials*
  - Rationale: The guide(s) will be used to augment the set of standards used for mechanical performance characterization of polymer AM materials so that process induced nuances can be accounted for prior to starting a qualification or testing program. Users consist of machine operators, printer OEMs, testing houses, ASTM sub-committee members, technology adopters/type-certification holders, and certification regulators.
- New guide will cover several test methods
- Best practices will be documented
- Selected test methods will be studied through a round robin test program
  - Alternative specimen geometries
  - Modified test fixtures
  - Machined vs As Printed specimens
  - Combinations of above



21

Looking forward

- Benefit to Aviation
  - First AM qualification database with M&P specs
  - Understanding of relevant considerations – how to qualify an AM process, parameters, sources of variability
  - Publicly available data and guidelines will be published in CMH-17
- Future research
  - Full investigation of equivalency failures
  - Qualification and equivalency on other AM materials, including filled/reinforced AM, or other processes (PBF)
  - Machine Variability – parameter-structure-property mapping & machine type investigation
  - Test Method Modifications and Guides
  - Scaling Studies: Building Block Correlation, Dynamic and Application Specific Characterization
  - Flame, Smoke, and Toxicity Studies

22

Questions

www.niar.wichita.edu

info@wichita.edu

www.facebook.com/niarw

@niar_wsu

NIAR Wichita State University
National Institute for Aviation Research