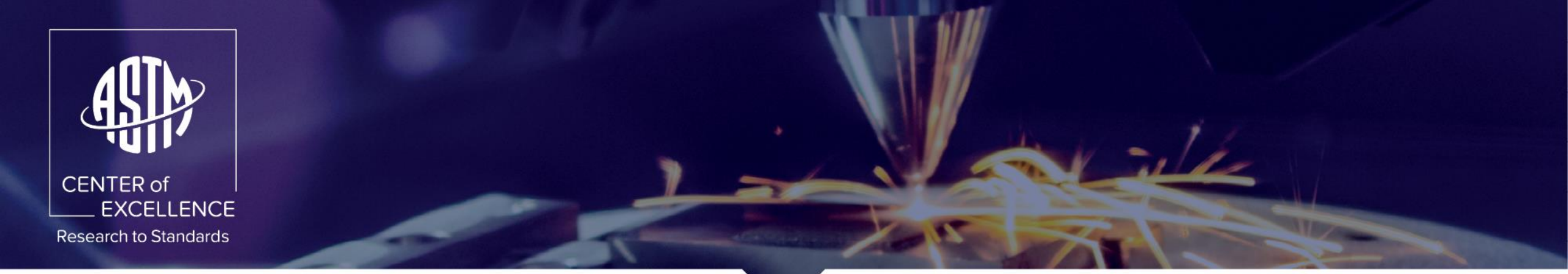

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Fracture Control and Structural Certification Guidance for Additive Manufactured Spacecraft Structures

Mark McElroy (NASA Johnson Space Center)
October 7-10, 2019
Gaylord National Resort and Convention Center

www.amcoe.org

Outline

CENTER of EXCELLENCE Research to Standards
ADDITIVE MANUFACTURING

Background

Industry Survey

Fracture Control and Structural Certification

Closing Remarks

Background

Applicable NASA Standards for AM Part Certification

- **Materials and Processes (M&P)**
  - MSFC-STD-3016 (Laser Powder Bed Fusion)
  - MSFC-SPEC-3017 (Laser Powder Bed Fusion)
  - NASA-STD-6016

"downstream" M&P

- **Structural Certification**
  - NASA-STD-5001 (Structural Test & Design Factors)
  - JSC65828 (Structural Design Requirements)
- **Fracture Control**
  - NASA-STD-5019 (Fracture Control Requirements)

Gaps…

Other Material Types
Other AM Techniques

New AM Standard in-work via NASA Marshall Space Flight Center & NASA Engineering Safety Center

No mention of AM
Are new guidance or requirements needed?

Discussion ongoing at NASA Johnson Space Center & NASA Engineering Safety Center

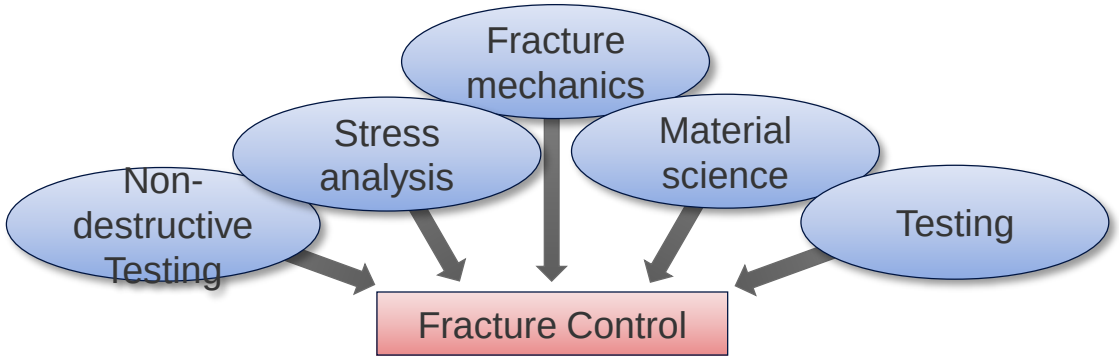
Background

Structural Certification

- Static Strength, stiffness, and fatigue
- Nominal material state (damage not considered)
  - Modifications for service temperature or other environmental effects
- Acceptance testing for certain types of components
  - Pressure vessels and components
  - Non-metallic
  - Structural bonds
- Static Strength and Stiffness
  - **Withstand design limit load x Ultimate Factor of Safety**
  - **No detrimental yield at limit load x Yield Factor of Safety**
  - **No detrimental deformations at limit load**
  - One load cycle
- Fatigue

Fracture Control

- Mitigate catastrophic failure due to growth of an unknown crack-like defect
- Accounts for pre-existing and/or accumulated damage in load carrying capacity
- Defines strength with damage present
- Determine safe interval of operation



Industry Survey

Motivation

- Need for AM fracture control and structures certification guidance (internal and external)
- Limited implementation in NASA spaceflight vehicles
- Structural and fracture control certification approach is undefined and largely untested
- NASA guidance/standard development effort should be cognizant of industry practices and capabilities

Scope

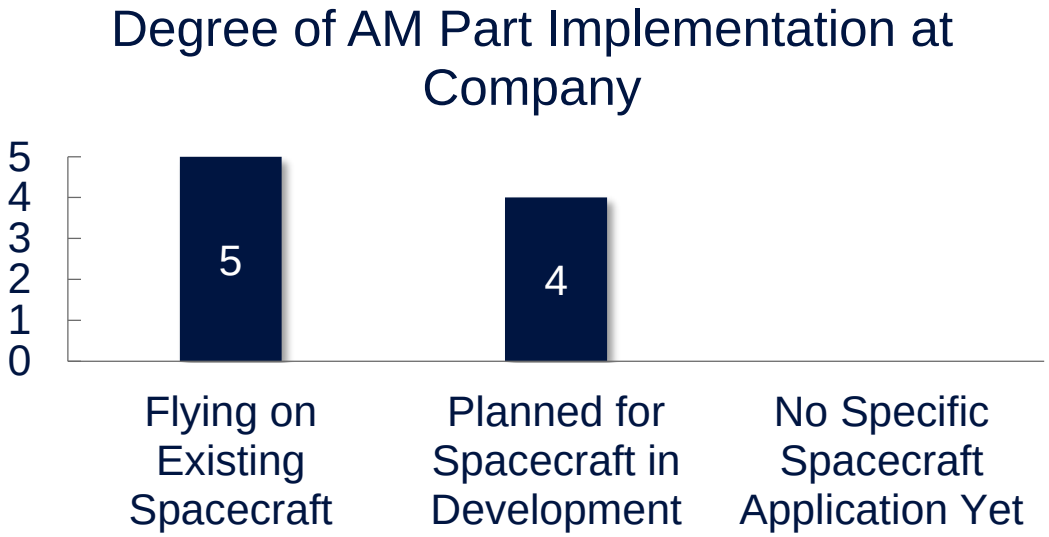
- Title: Guidance for Structural Assessment and Fracture Control of Additively Manufactured Spacecraft Hardware A Survey of Development Needs
- Themes
  1. Industry experience and spacecraft applications
  2. How to handle fracture control and structural certification
  3. Need to mature guidance and/or requirements
  4. Interest in collaboration with NASA to mature requirements/guidance
- Format
  - Ten questions
  - Posted as NASA Request for Information (open to public)
  - Outreach to approximately thirty space industry companies
- Outcome: nine companies responded

Industry Survey

1. What types of additively manufactured spacecraft hardware products does your company produce?

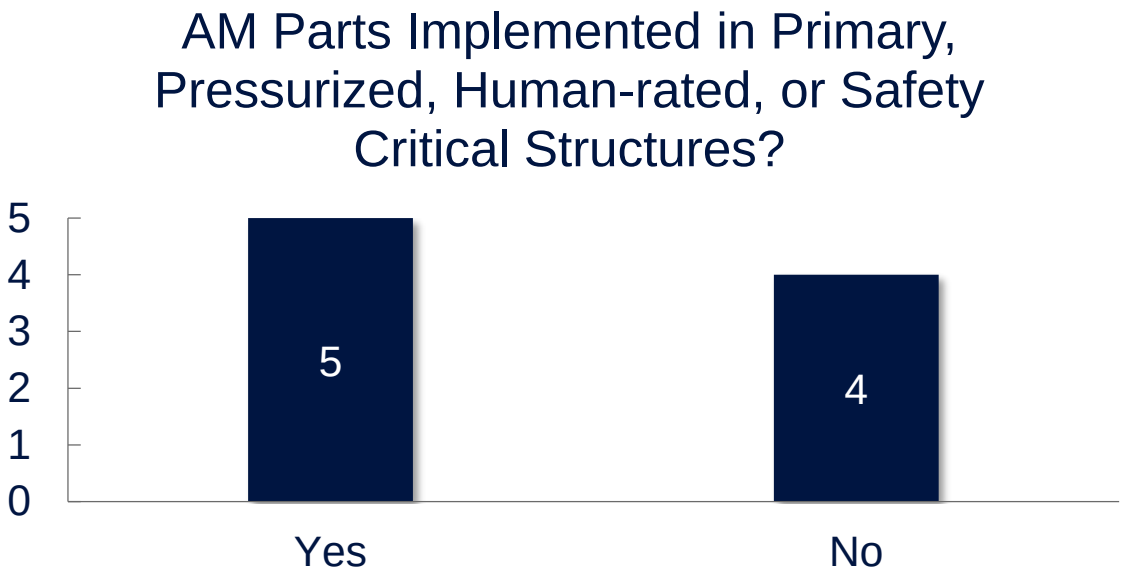
- Rocket Components: nozzles, combustion chamber, injectors, heat exchanger, turbo-machinery
- Pressurized: propellant tank, tubing, manifolds, valves
- Secondary structure: brackets, covers, housings, fittings
- Satellite structures: antennae, CubeSat frames
- Ground support hardware
- Rapid Prototypes, R&D

2. To what degree has your organization implemented additively manufactured spacecraft hardware? For example: (1) flying on existing spacecraft, (2) planned for specific spacecraft that are in development, (3) AM technology application in development, but no specific vehicle implementations identified yet.

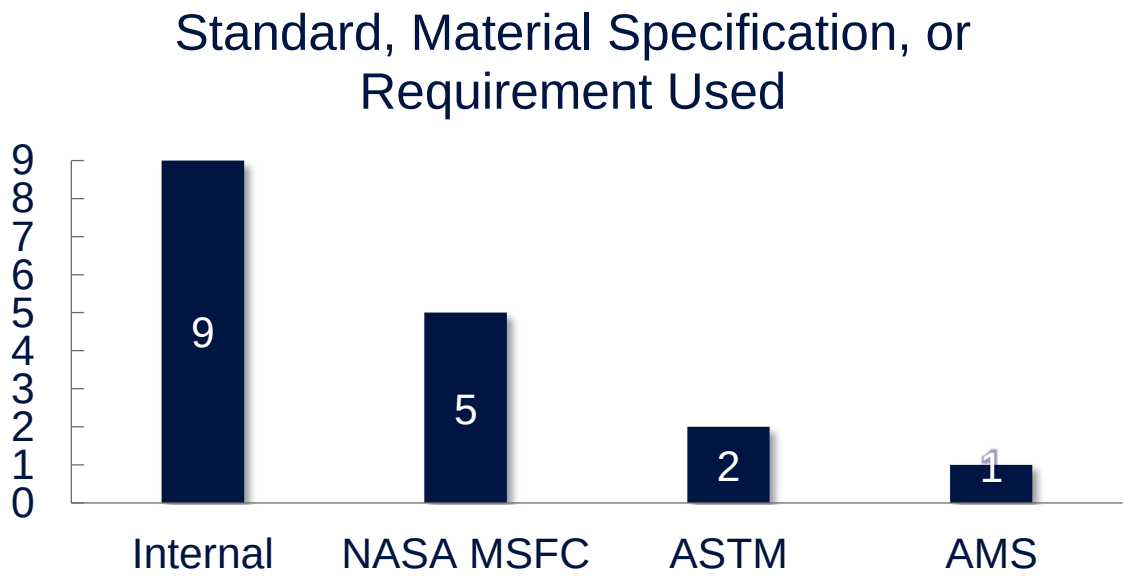


Industry Survey

3. Has your organization implemented additively manufactured hardware for primary structure, pressurized hardware, human rated structures, or other safety critical parts?



4. Are there any standards, material specifications, or other requirements that your organization follows when producing and certifying additively manufactured spacecraft hardware? If so, are they sourced from a government/industry standard or sourced internally at your organization?



Industry Survey

5. Does your organization see advantages in having comprehensive government/industry standard practices and guidance for structural assessment and fracture control to work from to certify AM spacecraft hardware? Are there disadvantages?

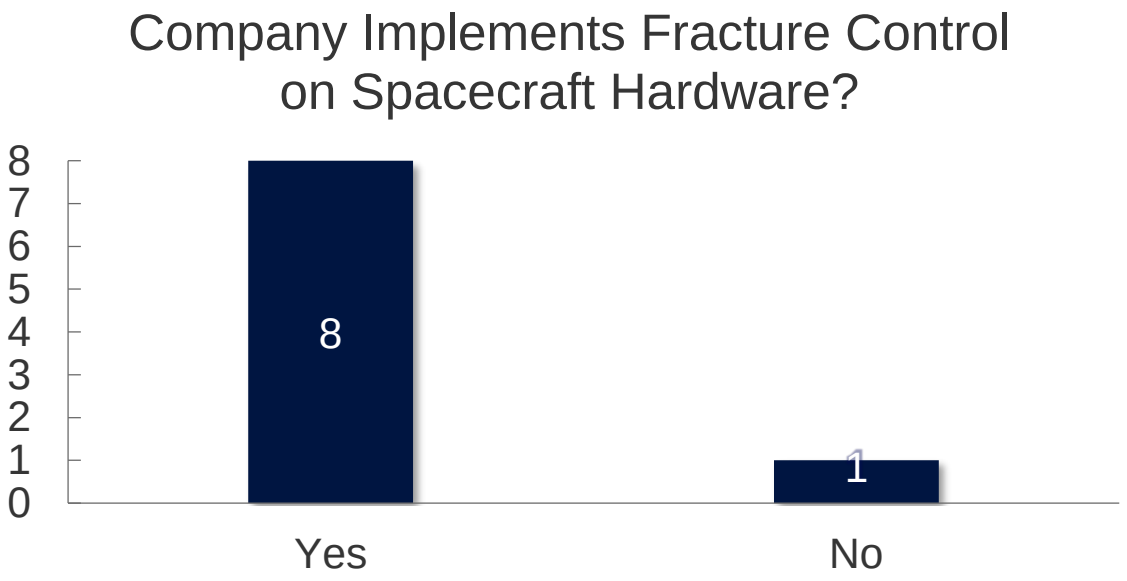
- All responded “yes”
- Advantages
  - Clear path to customer compliance
  - Clarify limits of applicability
  - Benchmark expectations in bid competition
  - Consolidate lessons learned
  - Acceptable assumptions, test methods
- Disadvantages (potential)
  - Impractical restrictions and limitations
  - Restricting viable applications
  - Excessive development time & cost, undermine benefits
  - Impractical because authors don’t have applied experience

6. What technical disciplines do you think are most important to have government/industry standards for certification of additive manufactured spacecraft hardware?

- Materials & Processes
- Non-destructive Evaluation
- Manufacturing
- Structures
- Fracture Control (3 total)

Industry Survey

7. Does your organization implement fracture control on any spacecraft hardware? Why or why not?



Why? – Most responded because of customer requirements

8. What advantages does your organization see in an interactive government-industry collaboration for developing and maturing standard practices and guidance for the assessment of additively manufactured spacecraft hardware? Are there perceived disadvantages?

- Advantages
  - Identify critical issues to address for spaceflight applications
  - Achieve optimal balance of technical rigor and pragmatism
  - Share lessons learned
  - Collaboration leads to common acceptable approaches
  - Opportunity to influence requirements
- Disadvantages
  - Sacrifice of competitive advantage for greater good
  - Unequal contributions
  - Cost of active participation
  - Risk government will set requirements contrary to team input

Industry Survey

9. Would your organization be interested in participating in a NASA-led effort aimed at the development of standardized practices and guidance in the structural assessment and fracture control disciplines to aid in the certification of additively manufactured spacecraft hardware?

- All responded “Yes”
- Comments
  - “Yet another” volunteer spec development group may find resources/personnel already stretched thin

10. If your organization was included in such an effort, what would your main goals be in participating?

- Improve overall knowledge, insight, practices
- Improve product development efficiency
- Help tailor requirements
- Become informed on requirement rationale
- Exchange lessons learned
- Learn what NASA will be expecting
- Offer feedback on cost/schedule impacts
- Align internal processes with standards
- Ensure specific gaps/challenges are addressed
- Enable higher criticality applications
- Ensure new requirements in-line with existing practices
- Forecast forward work scope

Industry Survey

Survey Conclusions

- AM parts already widespread, mostly non-critical applications
- Industry wants better certification standardization for spacecraft AM hardware in the areas of structural and fracture control certification
- Most companies willing to participate at some level in developing documentation to address this gap
- Industry wary of new requirements that are impractical
- Industry interested in expanding AM applications

Next Steps

- Publish AM fracture control guidance at International Astronautical Congress (October 21-25, Washington, DC)
- Solicit feedback on publication
- Continue internal discussion on structural certification
- Decide how to involve industry
- Document in formal NASA publication

Fracture Control and Structural Certification

Fracture Control Certification Methodologies

- Goal is to meeting intent of existing requirements
  - Guidance/Handbook?
  - New requirements?
- Three methodologies in-work
  1. NDE + Fracture Analysis
  2. Full scale damage tolerance test
  3. Proof test

Structural Certification Options Under Discussion at NASA

- No change to requirements needed
  - M&P covers AM-specific risks
  - Guidance on acceptable structural verification approaches
- Design Factors of Safety (FoS)
  - “AM factor” similar to casting factor?
  - Should FoS be a function of consequences of part failure?
- Pressurized components
  - New proof/burst factors?
  - Proof test requirement??
- Fatigue life
  - Current scatter factor = 4
  - Is a new factor needed?

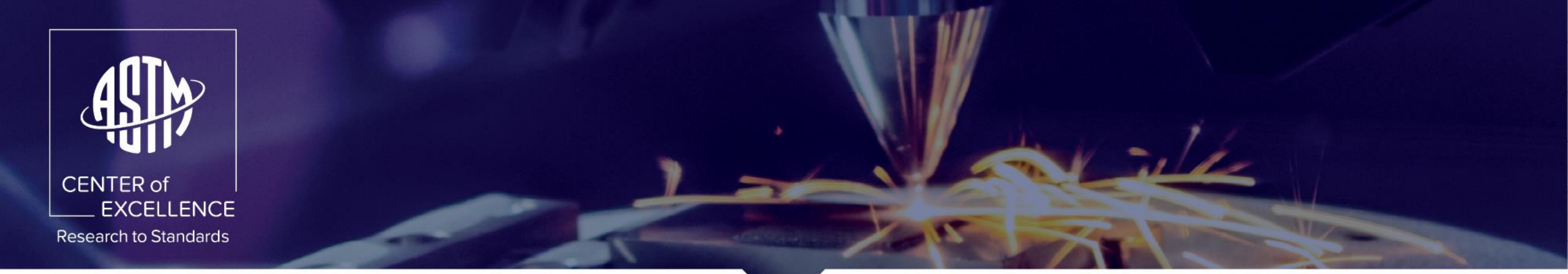
Closing Remarks

Current State of NASA AM Standards

- Limited M&P NASA standards available for AM parts
- No fracture control or structural certification standards
- Industry uses internal standards for now, wants common standard for all to use
- Industry interested in participating with NASA in maturing standards

Going Forward

- Expanded M&P standard in-work
- Guidance for fracture control and structural certification in discussion



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