Fracture Control for Additive Manufactured Spacecraft Structures

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BACKGROUND: FRACTURE CONTROL

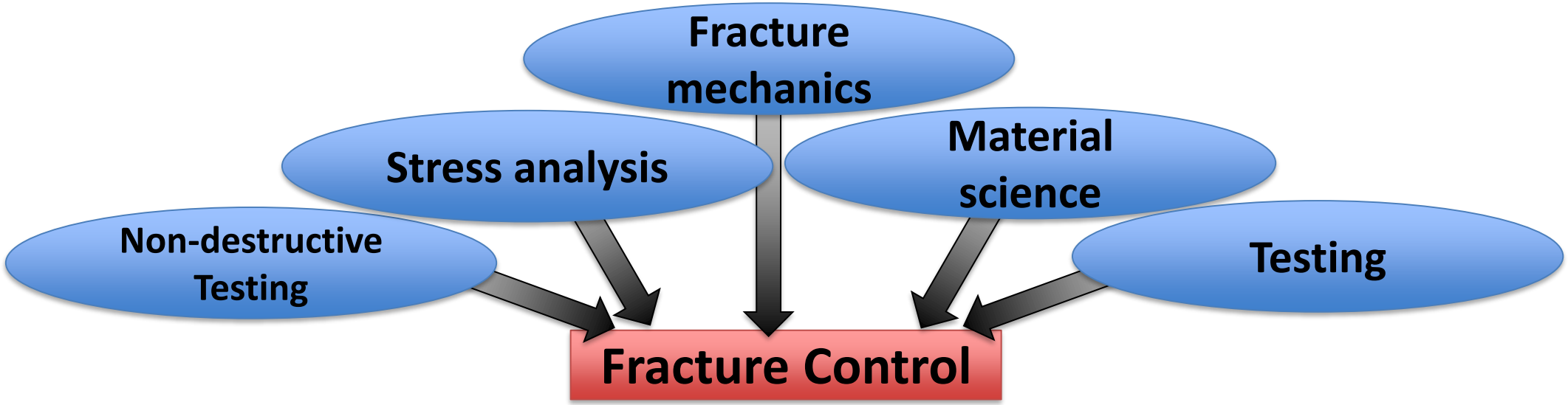
Static Strength

- **Design load x FS < Allowable**
- One load cycle
- Nominal material state

Organization or project may invoke fracture control

Service Life

- Accounts for pre-existing and/or accumulated damage in load carrying capacity
- Defines strength with damage present
- Determine safe interval of operation



Board of experts from each technical discipline

BACKGROUND: FRACTURE CONTROL

Implementation of fracture control

Classify parts and identify those that are “fracture critical”

for fracture critical parts…

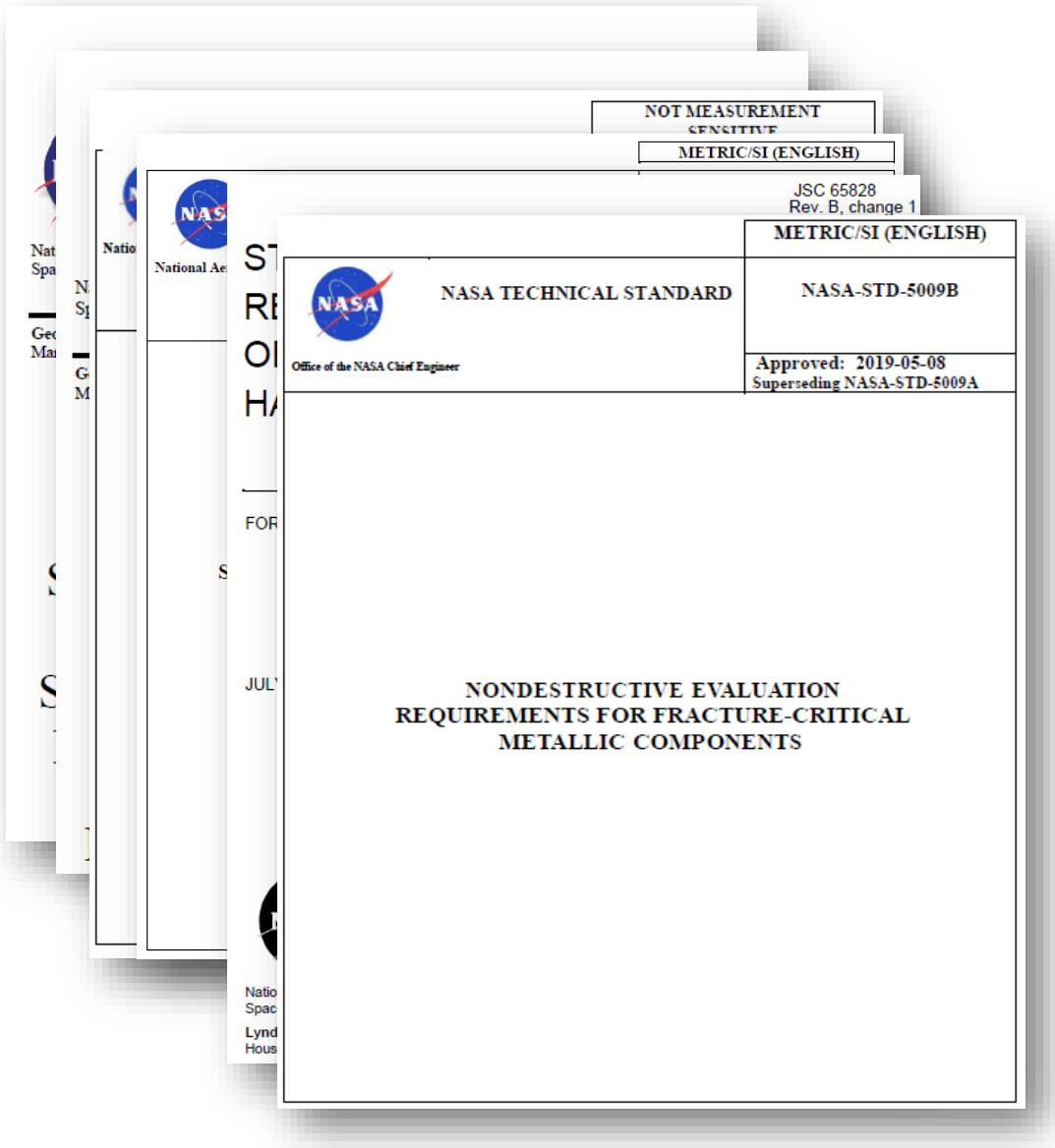
Perform Non-destructive evaluation (NDE)

Demonstrate damage tolerance

<u>Questions to Address Today:</u>

1. What gaps exist in current NASA standards related to implementation of fracture control on additive manufactured (AM) parts?
2. What AM-specific challenges exist in fracture control implementation and how can the intent of existing standards be met?

BACKGROUND: EXISTING STANDARDS



- MSFC-STD-3716 Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals
- MSFC-SPEC-3717 Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes
- NASA-STD-5019 Fracture Control Requirements for Spaceflight Hardware
- NASA-STD-5001 Structural Design and Test Factors of Safety for Spaceflight Hardware
- JSC 65828 Structural Design Requirements and Factors of Safety for Spaceflight Hardware
- NASA-STD-5009 Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components

Discipline	NASA Requirement Gap
"M&P"	Non-metallic materials
"M&P"	Other AM techniques
Fracture Control	Implementation of Fracture Control
Structures	Structural Certification
NDE	Detectable flaw size

FRACTURE CONTROL IMPLEMENTATION

✓ Classify parts and identify those that are “fracture critical”

for fracture critical parts…

X Perform Non-destructive evaluation (NDE)

X Demonstrate damage tolerance

- Technology is immature
- Tools are immature
- Test methods immature
- Standards are immature

Fracture Control Certification Methodology (FCCM)

FCCM-1: Damage Tolerance Fracture Analysis

FCCM-2: Damage Tolerance Simulated Service Life Test

FCCM-3: Proof Test

Assumptions

- Process control: consistent and repeatable properties
- Accurate material and fracture properties available

Disclaimer: FCCMs should not be interpreted as proposed requirements, early drafts of requirements, or pre-approved by NASA to meet NASA-STD-5019.

FRACTURE CONTROL IMPLEMENTATION

FCCM-1: Damage Tolerance Fracture Analysis

- When to use
  - Test-validated fracture analysis tool is available
  - NDE can find Critical Initial Flaw Size at all locations of concern (90% reliability, 95% confidence)
- Summary
  - Perform damage tolerance flaw growth analysis
  - Assume minimum detectable flaw size at worst case location and orientation
  - Pressurized hardware: proof test and leak check according to FCCM-3
- Comments
  - Not appropriate if NDE cannot find CIFS
  - Option: CIFS can be increased locally by adding material to fall within NDE capability

FRACTURE CONTROL IMPLEMENTATION

FCCM-2: Damage Tolerance Simulated Service Life Test

- When to use
  - NDE cannot support FCCM-1
  - Fracture analysis tools unavailable
- Summary
  - Full-scale/flight-like part containing intentional defects subjected to flight load spectrum
  - Success criteria: no defects grow to cause a catastrophic hazard (i.e., structural failure, critical leak)
  - Initial defects correspond to CIFS at all locations of concern
  - May need ability to “pre-crack”
- Comments
  - Defect growth should be quantified
  - Fracture analysis may be calibrated with test data and applied elsewhere

FRACTURE CONTROL IMPLEMENTATION

FCCM-3: Proof Test

- When to use
  - Simple load or test fixture can replicate flight loading
  - NDE and/or fracture analysis cannot support FCCM-1
  - “Low duty cycle” applications
- Summary
  - Proof test enveloping flight limit load by a predetermined factor at all locations
  - Suggested proof factor: $proof\ factor = burst\ factor \times \frac{1.5}{2.0}$
  - Perform fracture analysis to verify CIFS is screened by proof test at all locations
  - Perform post-proof NDE
- Comments
  - Option: Increase CIFS locally by adding material so that it is screened by proof test

DESIGN FOR AM FRACTURE CONTROL

- Include fracture control considerations in AM design approach
  - Design for Non-fracture critical: Failsafe[1]
    - Multiple redundant load paths
  - Design for similar to NFC: Low Risk[1,2]
    - Combined stresses < 30% Ultimate Strength
    - Infinite fatigue life
  - Design for proof testing
    - Include test fixturing and/or load application features in part
    - Machine features off after proof test
  - Design for NDE
    - Iterate on design to provide CIFS that NDE can find at all locations
- AM design and optimization algorithms can include fracture control goals

[1]NASA-STD-5019 (Fracture Control Requirements for Spaceflight Hardware)

[2]Note: MSFC-STD-3716 prohibits a NFC: Low Risk classification per NASA-STD-5019 on any AM part

CLOSING REMARKS

- NASA Standards have gap regarding implementation of fracture control
  - New requirement needed??
  - Guidance/handbook sufficient??

- Implementation of fracture control on AM parts to meet intent of existing NASA standards
  - Fracture Control Certification Methodology-1: Damage Tolerance Fracture Analysis
  - Fracture Control Certification Methodology-2: Damage Tolerance Simulated Service Life Test
  - Fracture Control Certification Methodology-3: Proof Test

- Design for AM Fracture control

- Next Steps at NASA
  - Discuss fracture control implementation internally and with industry
  - Release AM fracture control guidance

Recent seminar: McElroy, M. Fracture Control and Structural Certification Guidance for Additive Manufacture Spacecraft Structures. Presented at 4th ASTM Symposium on Structural Integrity of Additive Manufactured Materials & Parts, October 7-11, 2019, Washington, DC.

- Results of an industry survey related to potential collaboration with NASA on maturing AM fracture control and structural certification standards
- Nine leading space industry companies participated
- Goals: hear industry perspective on current needs/gaps and prepare to consult on new NASA guidance
- Available upon request

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