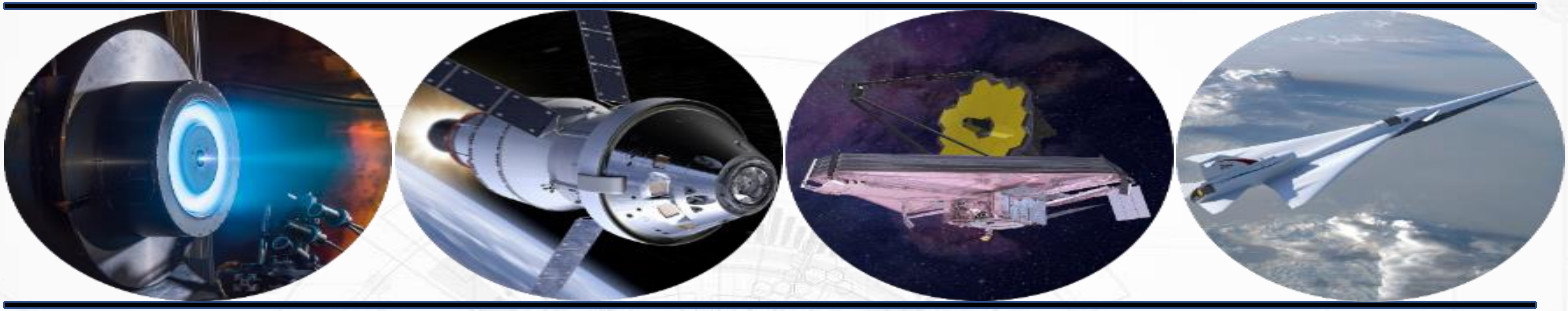
FY20 CIF/IRAD Midterm Review
April 7-9 and 14, 2020

National Aeronautics and
Space Administration



Title: Autonomous Self-Awareness: Safety and Reliability for ODM Vehicles through Embedded Sensors and Probabilistic NDE

PI Name: Patrick Leser

Date: April 9, 2020

CIF- IRAD Midterm Presentation

- **Project Title**: Autonomous Self-Awareness: Safety and Reliability for ODM Vehicles through Embedded Sensors and Probabilistic NDE
- **PI:** Patrick Leser (D309)
- **D309 Branch Head:** Stephen Smith
- **External collaborator:** Adam Hehr (Fabrisonic LLC)
- **Student interns:** Joshua Daniels (NC State University), Sean Lai (Portland State University)

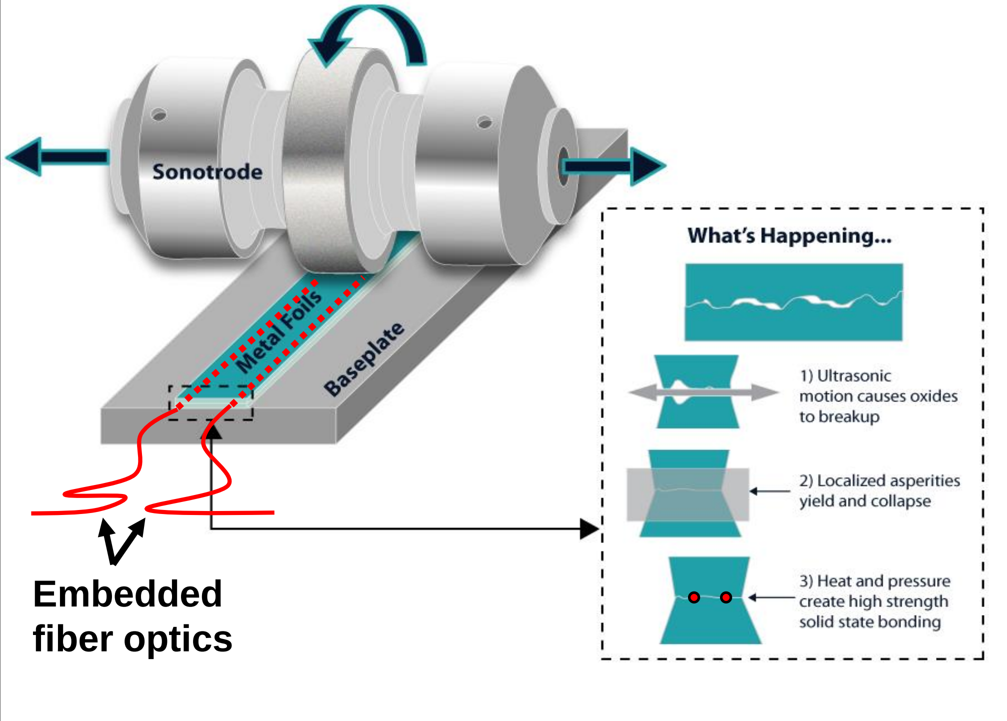
CIF- IRAD Midterm Presentation: Problem Statement

- **Technology gap:** On-demand mobility (ODM) will require vehicles that are:
  - Self-adjusting
  - Capable of reacting to changes in both the environment (e.g., wind-induced loads) and system health (e.g., damage)
- **State-of-the-art:** advanced sensing and real-time modeling; e.g. *Digital Twins*
  - Self-adjustment: easier said than done
  - Minimize number of sensors while providing ability to detect damage and changes in environment

CIF- IRAD Midterm Presentation: Innovation

- Innovation:
  - Use novel additive manufacturing technique to embed fiber optic strain sensors into a metallic component
  - Throughout vehicle's life cycle:
    - Monitor loads
    - Detect and quantify fatigue cracks
    - Predict residual strength
  - Use state-of-the-art probabilistic algorithms to quantify uncertainty given acquired data

Ultrasonic Additive Manufacturing (UAM) Process



Images and Descriptions courtesy of Fabrisonic LLC

CIF- IRAD Midterm Presentation: Relevance

- Impact to NASA
  - Demonstrates the potential of embedded sensors coupled with computer models and uncertainty quantification in a metallic component
- Relevance
  - Langley Strategic Technology Investment Plan Grand Challenges
    - STIP 1: Safe and Reliable On-Demand Mobility (ODM)
      - Enable travel for people and goods “wherever, whenever, and however they choose”
      - New modes of transportation “more mainstream and pervasive.”
      - Ensure safe and reliable operation of ODM vehicles through **self-adjustment** to vehicle/environmental conditions

Self-adjustment requires **self-awareness!**

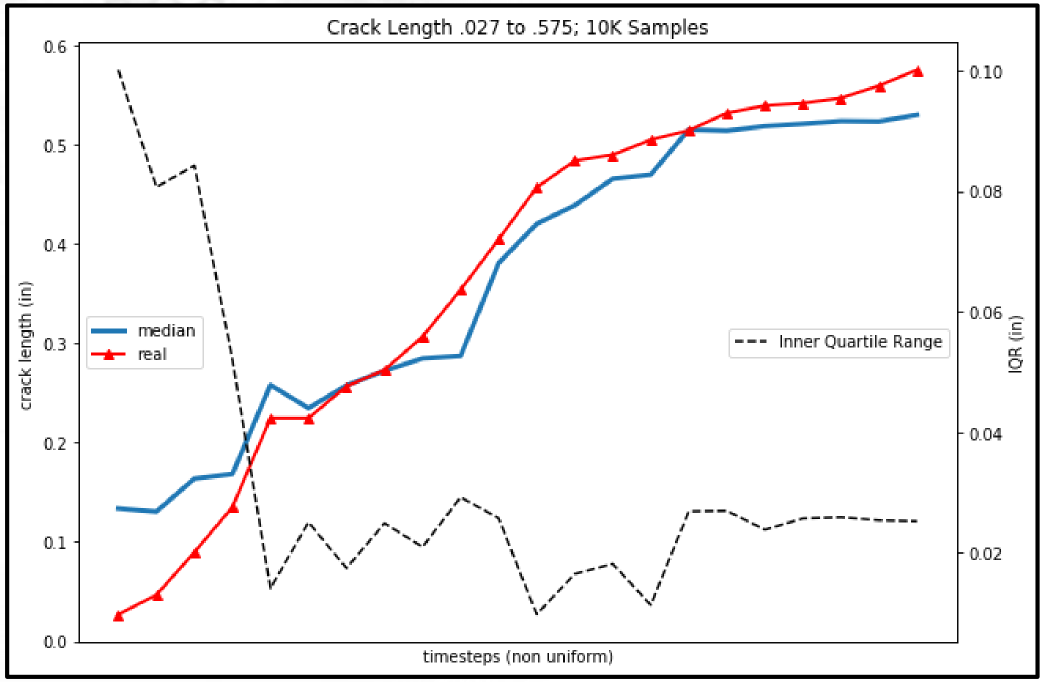
CIF- IRAD Midterm Presentation: Approach

1. Build a digital twin of complex test specimen

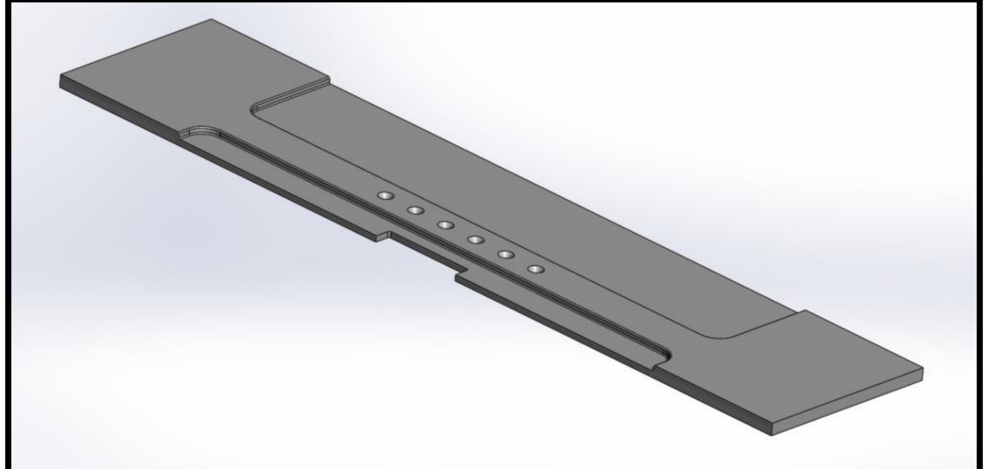
CIF- IRAD Midterm Presentation: Approach

1. Build a digital twin of complex test specimen
   - Leverage previous work!

Preliminary results: correlating model to observed crack growth



Photograph of specimen manufactured using UAM

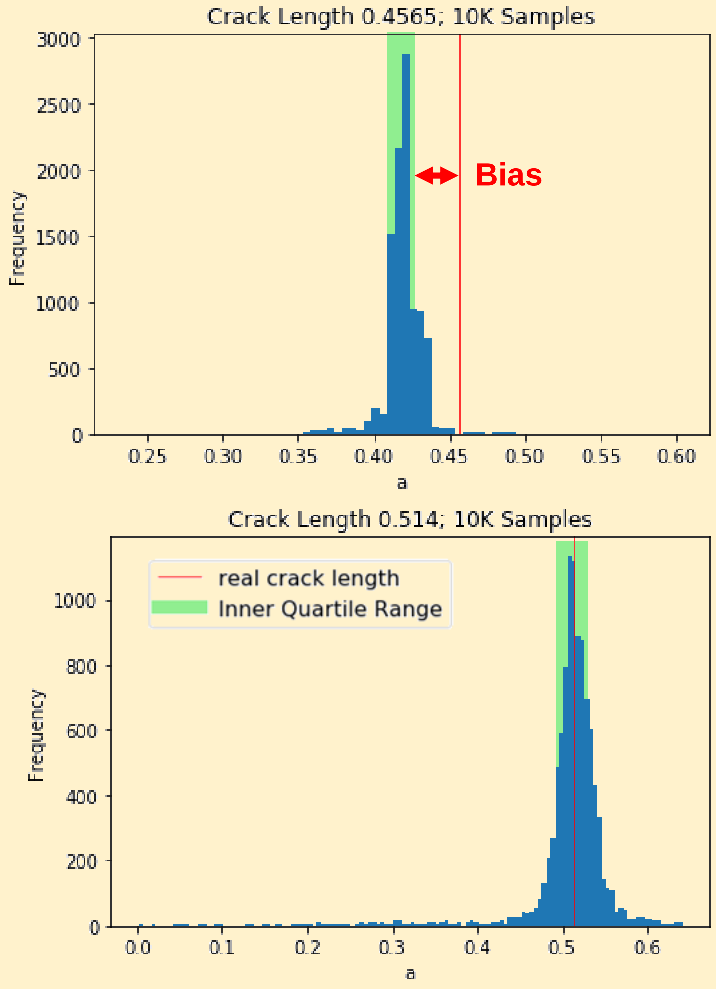


Digital Twin model for predicting strains at fiber locations

CIF- IRAD Midterm Presentation: Approach

1. Build a digital twin of complex test specimen
   - Leverage previous work!

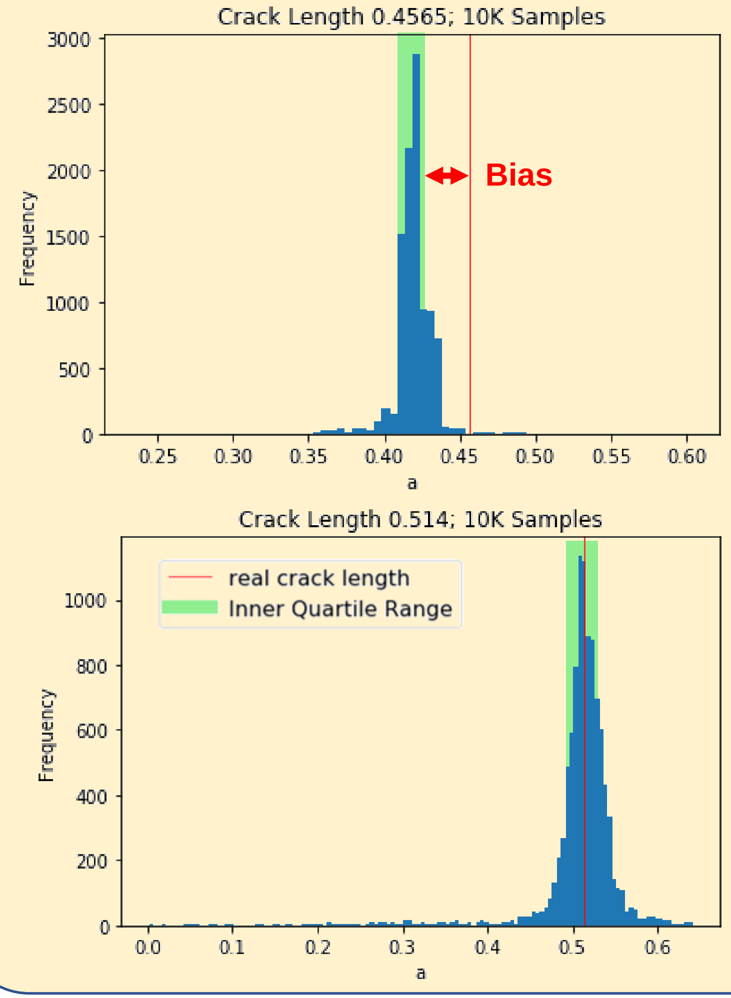
Bias Evident in Preliminary Results



CIF- IRAD Midterm Presentation: Approach

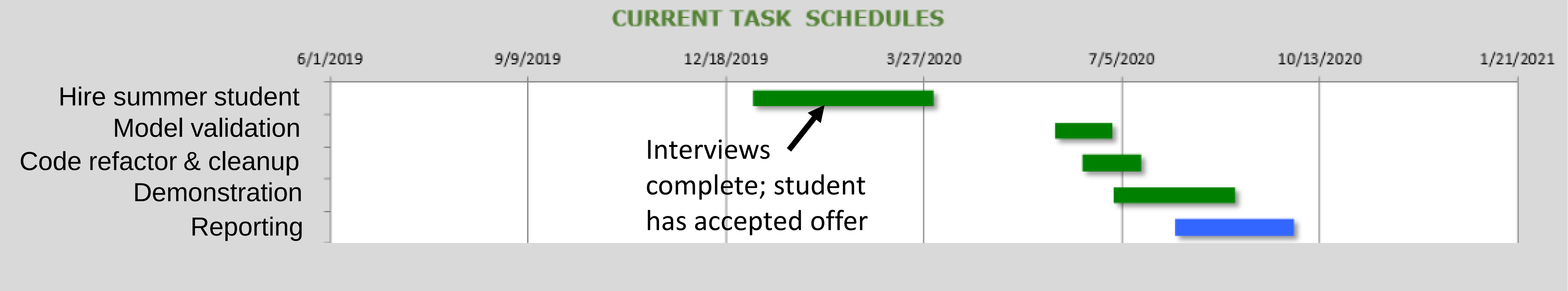
1. Build a digital twin of complex test specimen
   - Leverage previous work!
2. Verify & validate finite element model
3. Incorporate uncertainty in sensor locations
4. Explore potential for real-time analysis
   - Advanced UQ methods
   - High performance computing
   - Full-fidelity vs. reduced-order model

Bias Evident in Preliminary Results



CIF- IRAD Midterm Presentation: Accomplishments (exp.)

- Planned work:



- Measuring Success:
  - Predict three quantities of interest accurately (e.g., reduce bias) and with quantified uncertainty:
    1. Applied loading
    2. Fatigue crack length over time
    3. Residual strength
- Planning to produce at least one conference and/or journal paper

CIF- IRAD Midterm Presentation: Internships

- Internships
  - Leveraging previous work by Joshua Daniels (NC State University)
    - Worked on initial proof-of-concept
  - Hired Sean Lai (Portland State University) for Summer 2020

CIF- IRAD Midterm Presentation: Risks

- Programmatic Risks:
  - Potential for COVID-19 cancellation of summer internships
    - Would have a significant impact on ability to complete milestones
    - Limited CS resources; project relies on added workforce to generate results
- Risk mitigation:
  - Pending additional impact from COVID-19, possible that CS could leverage FTE from alternate sources to complete a subset of the milestones (e.g., model validation and regeneration of surrogate-based results)

Autonomous Self-Awareness: Safety and Reliability for ODM Vehicles through Embedded Sensors and Probabilistic NDE

National Aeronautics and Space Administration

FY20 CIF IRAD Midterm Review

Patrick Leser (D309)

Annual Funding: $ 21.8k

Problem

- Ensuring safe and reliable operation of ODM vehicles through *self-adjustment* to vehicle / environmental conditions.
- Autonomous self-adjustment requires self-awareness.

Impact to NASA

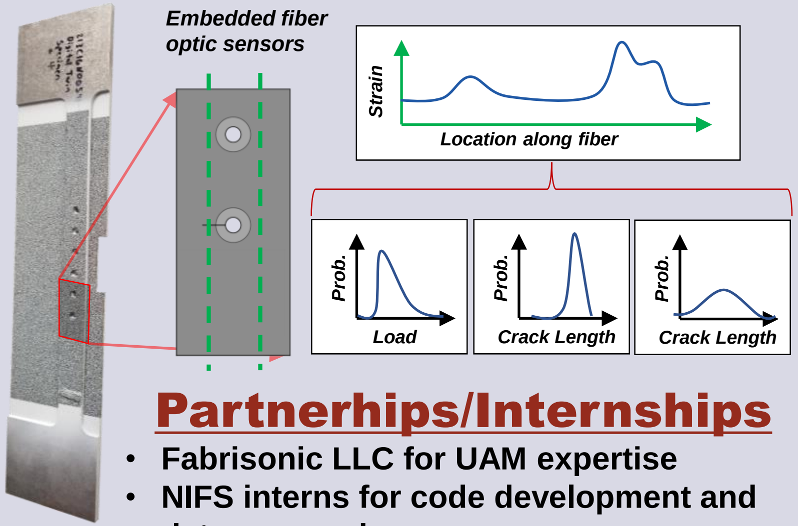
- Demonstrate feasibility of new self-awareness tech for metallic components

Goal/Objective

- Develop means for feasible and certifiable ***structural self-awareness*** for autonomous On-Demand Mobility (ODM) vehicles
- Work will leverage existing test data, reducing overall project cost while increasing probability of success.

Innovation

- To achieve self-awareness, a vehicle must detect and quantify changes to itself and the environment within the vehicle's reaction time window
- Use *ultrasonic additive manufacturing (UAM)* to embed fiber optic sensors
- Detect environmental changes and damage to vehicle as it operates



Partnerhips/Internships

- Fabrisonic LLC for UAM expertise
- NIFS interns for code development and data processing:
  - Joshua Daniels (North Carolina State University)
  - Sean Lai (Portland State University)

Technical Approach

3 Months, 0.1 FTE, $3k Procurement

Two challenges: (1) sensor deployment and (2) uncertainty quantification:

1. Utilize UAM to *embed* lightweight fiber optic sensors into a structure
2. Fuse state-of-the-art uncertainty quantification (UQ) algorithms, models, and sensor data to provide self-awareness

Leverage existing work and test data to produce high impact from small budget

First year project

Start TRL/End TRL: 3/5

LSTIP Grand Challenge: STIP 1 On-demand Mobility

Key Milestones/Deliverables

Demonstrate ability to *probabilistically*

1. Predict applied loading
2. Detect and characterize fatigue cracks
3. Predict residual strength.