America Makes

Driven by… NCDMM NATIONAL CENTER FOR DEFENSE MANUFACTURING AND MACHINING

TRX WEBINAR SERIES

11/10/2021

Computational Modeling as an Aid in Metal AM Qualification & Certification

Presented By: VEXTEC

Host:
Nick Leone, America Makes

Approved for public release

TRX WEBINAR SERIES

Today's Webinar:

Computational Modeling as an Aid in Metal AM Qualification & Certification

Today's Presenters:

Michael Oja
VEXTEC

Emmanuel De Leon
Air Force Life Cycle Management Center / LPE

Animesh Dey
VEXTEC

Bob Tryon
VEXTEC

One of the biggest challenges facing widespread adoption of metal AM in critical industries like aerospace, automotive and medical devices is the issue of Qualification & Certification (Q&C). As AM technology matures and more complex components are built, there is a greater emphasis on developing rapid Q&C methods to be able to unlock the full potential of AM. Computational modeling, such as VEXTEC's ICME-based VPS-MICRO® software, can provide valuable information to decision makers when it comes to Q&C considerations in additive manufacturing.

Presentation Outline

- Introduction
- The need for ICME-based tools in qualification & certification (Q&C) schemes
- VEXTEC SBIR work with Air Force Rapid Sustainment Office (RSO)
- VEXTEC demonstration project with Air Force Life Cycle Management Center – Propulsion Directorate at Tinker Air Force Base
  - Evaluation of replacing a legacy engine component with an AM candidate using VPS-MICRO® Software

Acknowledgements

The work was supported by

USAF contract FA8684-20-C-1005

Dr. Howard Sizek (AFRL/RXMS) TPOC

VEXTEC Introduction

Headquarters

Nashville, TN – 20+ years in business

VPS-MICRO® Software

Predicting fatigue durability and risk of metallic products and systems

Value Proposition

Supplement physical testing for increased confidence in accelerated qualification of parts

VPS-MICRO is:
Validated by US Government research programs
Utilized globally by commercial industries
Backed by 7 US Patents

Why Our Clients Work with Us

We help our clients to ***save time and money*** by:

Reducing

physical testing burden for qualification of new materials/sources

Accelerating

push of Additive Manufacturing into standard production

Identifying

causes of component fatigue failure

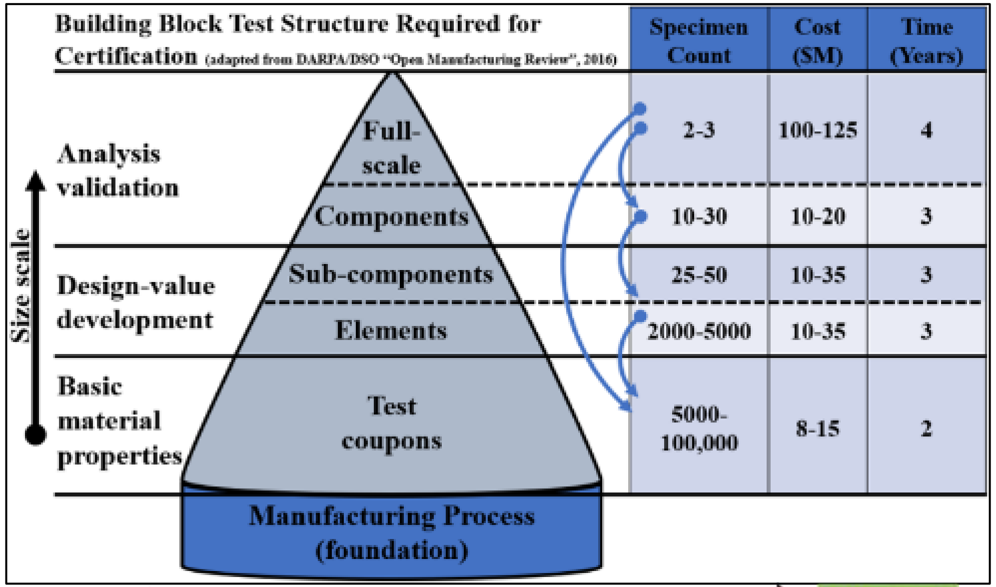
Metal Additive Manufacturing: What Do We Know?

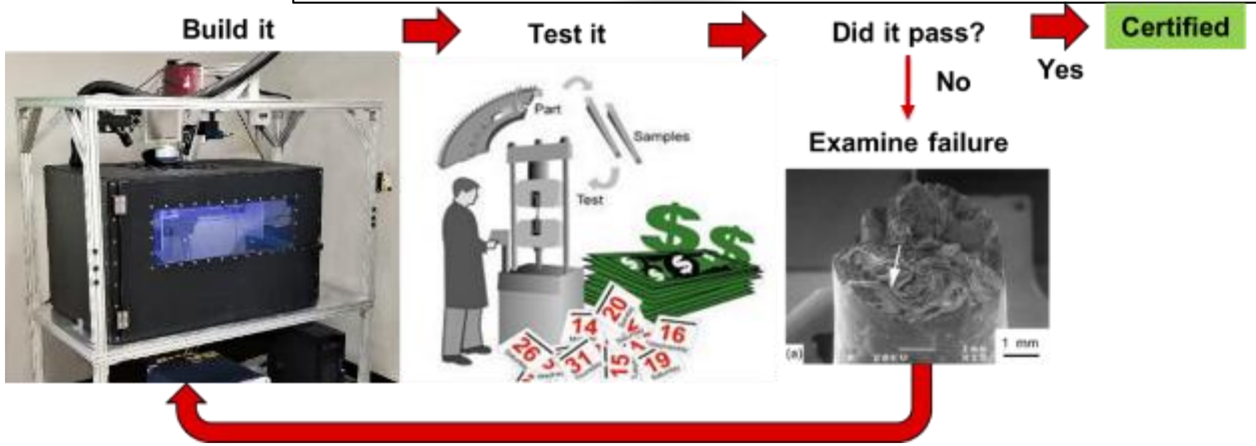
- It is not a material replacement issue *only*
  - Often AM requires component re-design for AM
  - It can also warrant creating new design allowable properties

- Build process and post-build treatments play a significant role in AM component reliability
- All of the above issues legitimately impose a high cost (and time) burden in adoption of AM as a replacement strategy for *structurally critical components*

Certification in Additive Manufacturing

- Current AM development / qualification and certification process is iterative, costly and slow
  - Build, test, analyze, repeat
- Long lead times and high development costs
  - Design allowable databases
  - Machine manufacturer-specific
  - NDE and post-process inspection

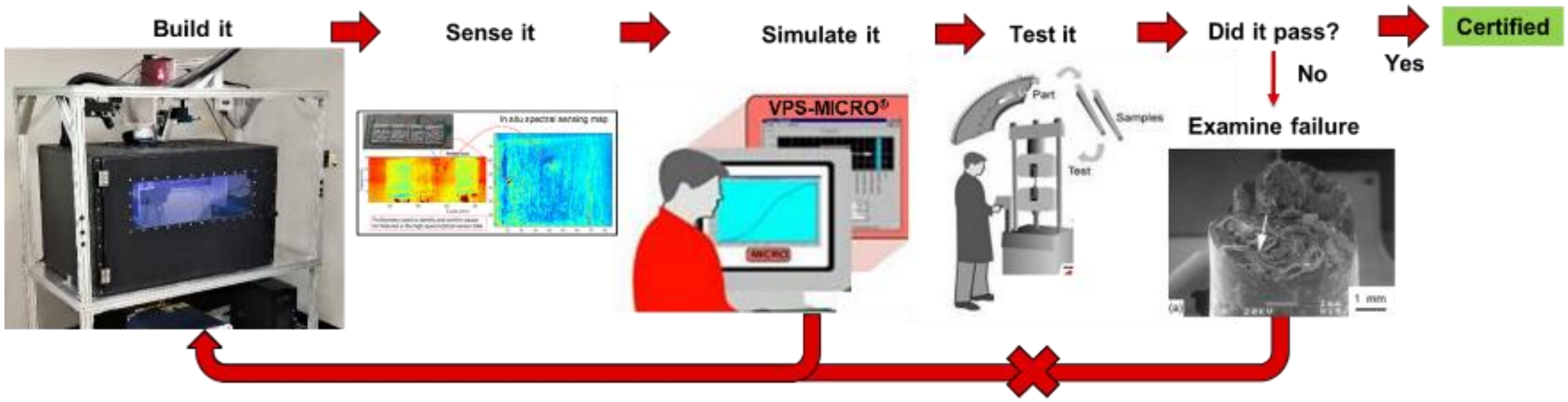




Integrated Computational Material Engineering (ICME) tools can accelerate adoption of AM as a replacement strategy.

ICME-Based Certification in AM

- No change in the required elements of the certification process; instead simulating important aspects
- Build and sense what is happening layer-by-layer, point-by-point, to create a high fidelity 3D model of local properties
- Simulate the testing of the model to evaluate performance
- Only physically test the part when there is high confidence it will pass the test reducing costly repeats



Phase II SBIR (2019-21) with Air Force Rapid Sustainment Office (RSO)

SBIR Topic: “Rapid Qualification for Metal Additive Manufactured Parts”

- Development of an AM-ICME framework tool to link:
  - In-process monitoring data
  - Non-destructive part evaluation
  - Destructive materials data
  - VEXTEC’s commercial fatigue prediction software VPS-MICRO®
- During this program, a demonstration opportunity was identified at US Air Force Life Cycle Management Center (AFLCMC) Propulsion Directorate at Tinker AFB

RAPID SUSTAINMENT OFFICE RSO

University of Dayton Research Institute

ARCTOS All In.™

Approved for public release: AFLCMC-2021-0240

SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

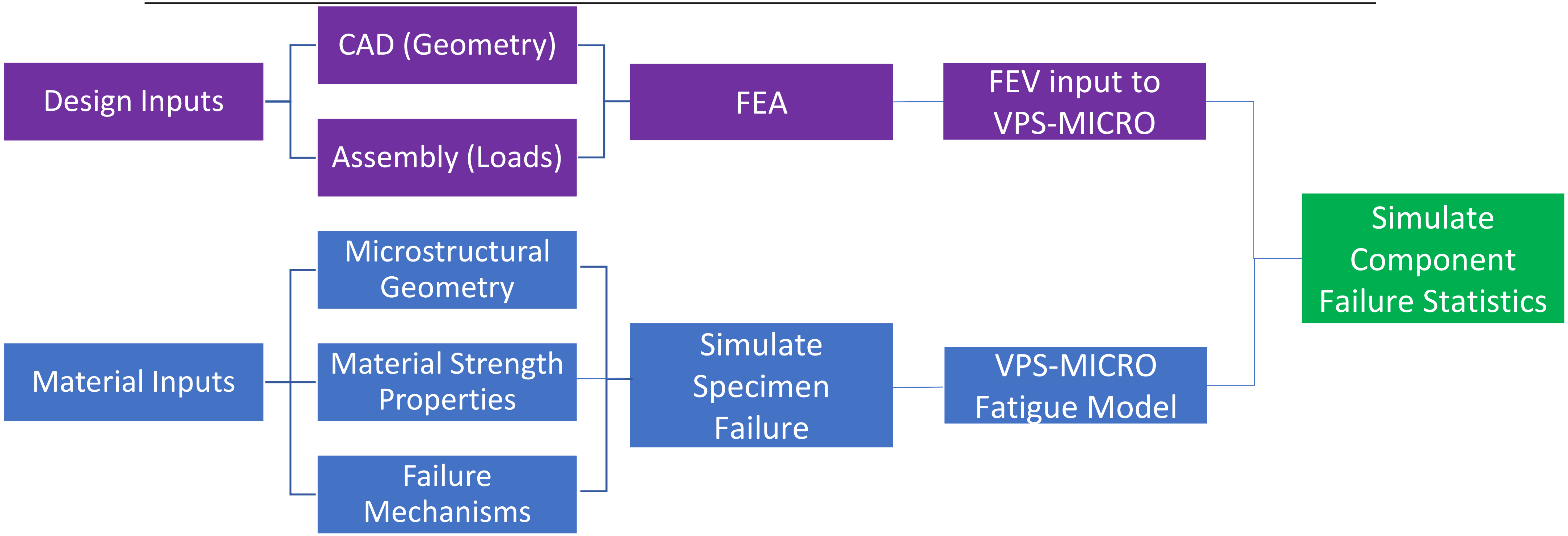
Air Force LCMC/LPS Goals

- Enhance organic USAF capability to analyze AM candidate
  - Develop confidence in-house evaluating the structural durability of AM candidate
  - Develop confidence in comparing AM material candidate with conventional material
  - Develop process to understand the part performance
- Assess of risk of AM integration including
  - PoF (Probability of Failure)
  - Impact of additional testing
  - Fatigue capability
- Demonstrate the above on an example aeroengine bell crank component

Modeling and Analysis Procedure

- Bell crank part selection from list of USAF-identified parts for AM
- Gather technical data
  - Drawings: materials, dimensions
  - Application on engine for loads and usage conditions
- Develop CAD of the bell crank part using the gathered technical data
- Structural/material model development and fatigue analysis process:
  - Estimate bounds on loads provided by the tech data & discussions with USAF equipment specialist
  - Perform FEA on part and identify areas of critical stress
  - Collect material properties for legacy part (410 SS) and candidate part (AM Co-Cr)
  - Use FEA results and material modeling in VPS-MICRO to simulate fatigue capability of legacy and candidate parts

VPS-MICRO Computational Flow Diagram

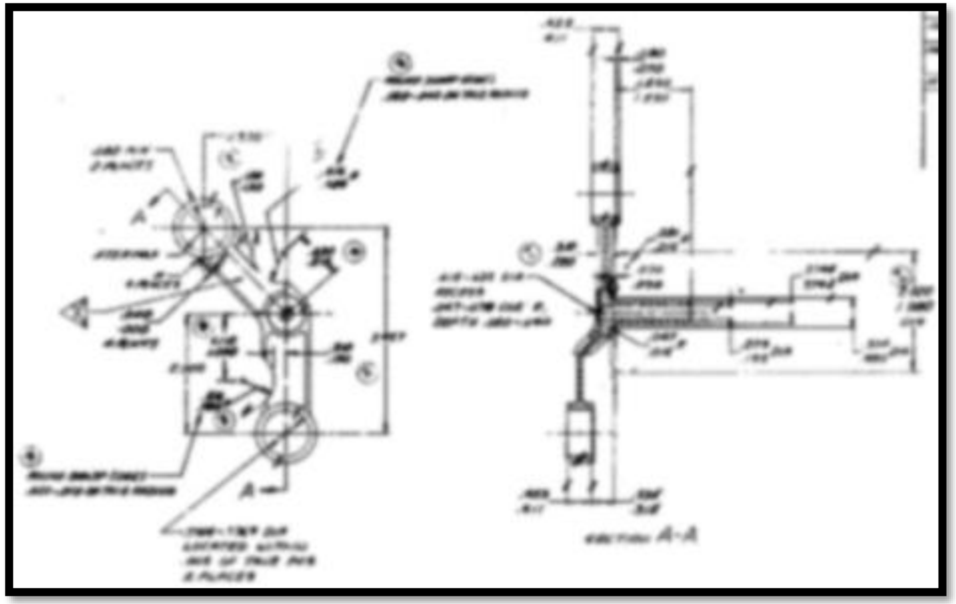


- ***Perform design analysis once***
- ***Perform material analysis for original and replacement material***
  - ***Start with estimates of material parameters from literature***
- ***Compare failure statistics of original and replacement material***
  - ***For low-risk components, literature data may be adequate***
  - ***For high-risk components, additional data gathering is required***

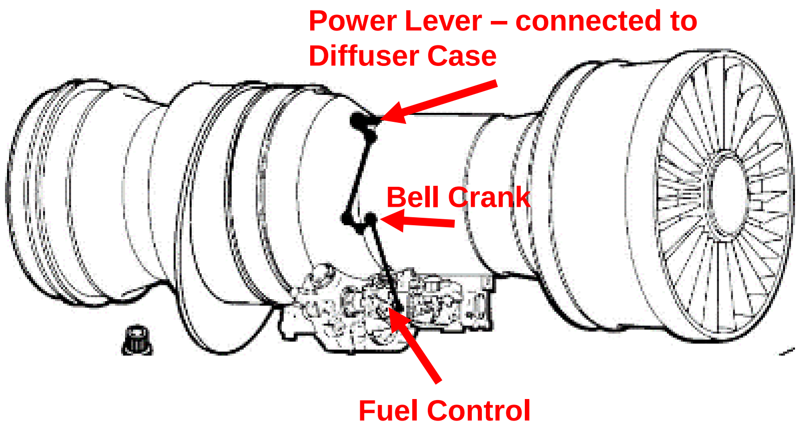
Approved for public release: AFLCMC-2021-0240

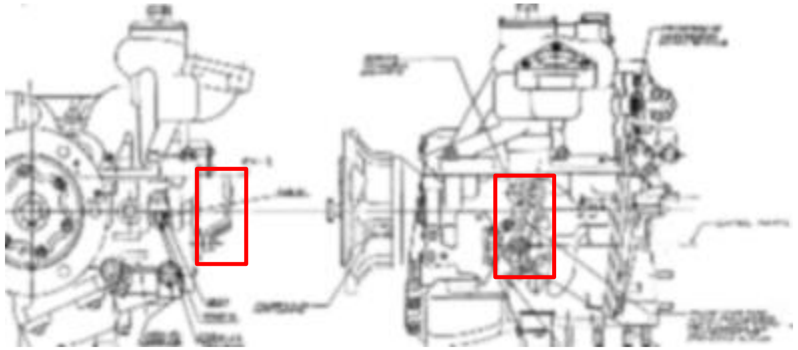
Aeroengine Bell Crank Data Collection

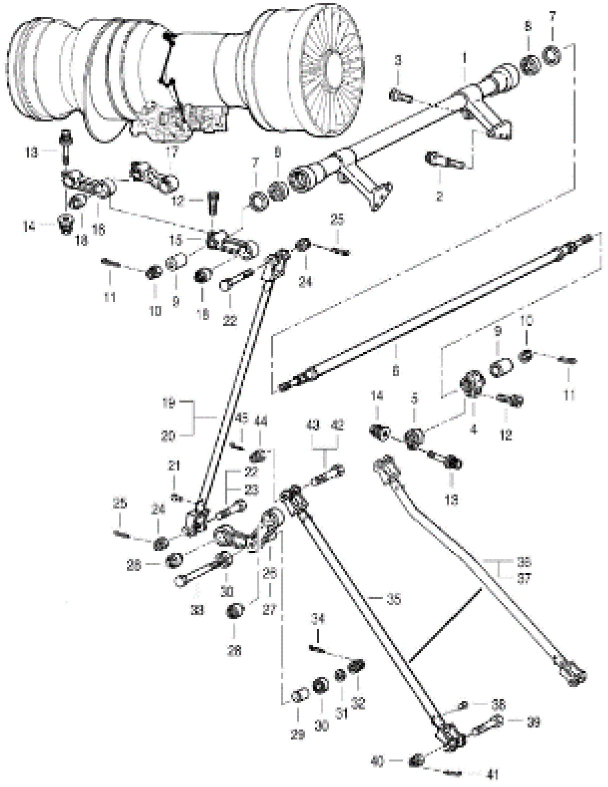
- Drawing was comprehensive for the purpose of demonstration



Bell Crank Drawing







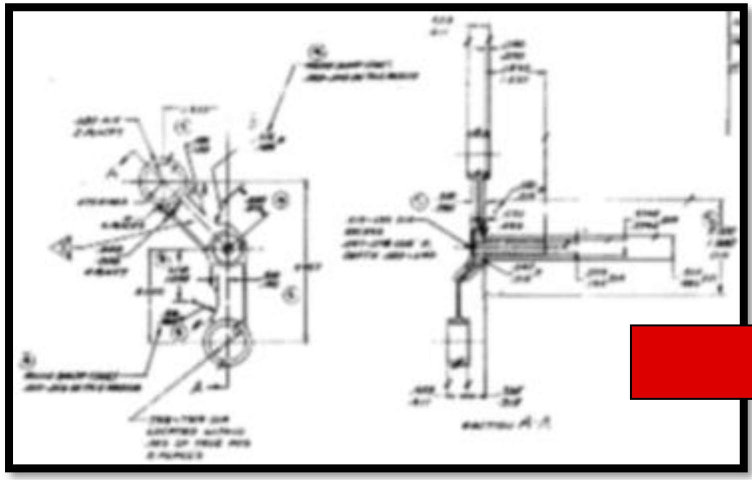
Application of bell crank in power control assembly

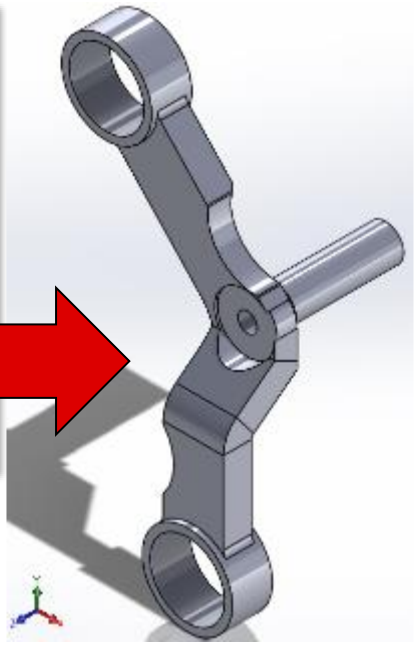
Approved for public release: AFLCMC-2021-0240

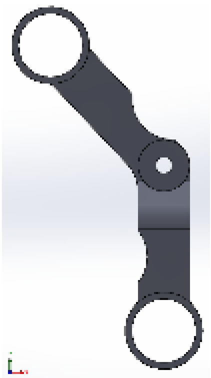
SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

Bell Crank CAD Model

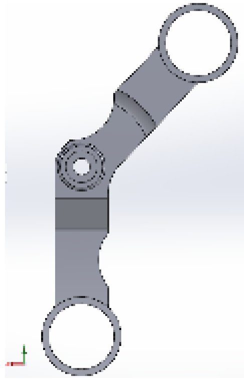
- CAD in SolidWorks based off nominal dimensions



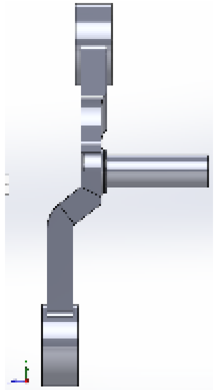




Front View



Back View



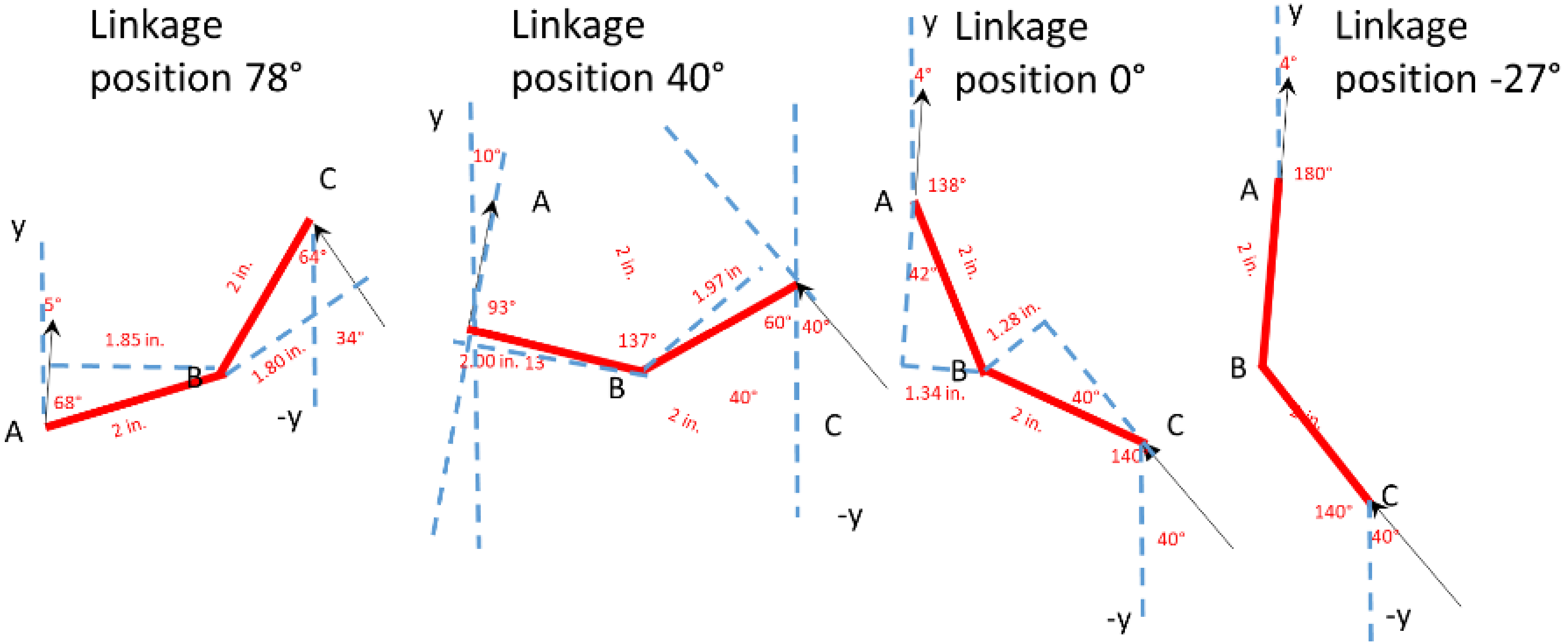
Right View

Approved for public release: AFLCMC-2021-0240

SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

Force and Loading Analysis

- Relative position of linkage taken from assembly drawing, drawing notes, equipment specialist communication, and engine photographs

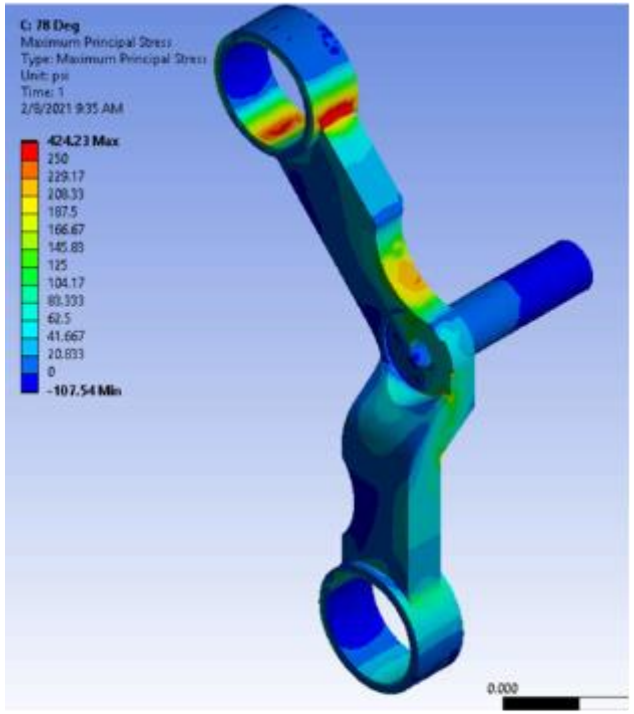


Bounds on loading. Upper rod (A) yields at 2300 lbs. Lower rod (C) buckles at 182 lbs. Load applied by pilot at power lever is divided among engines for 45 lbs. per engine.

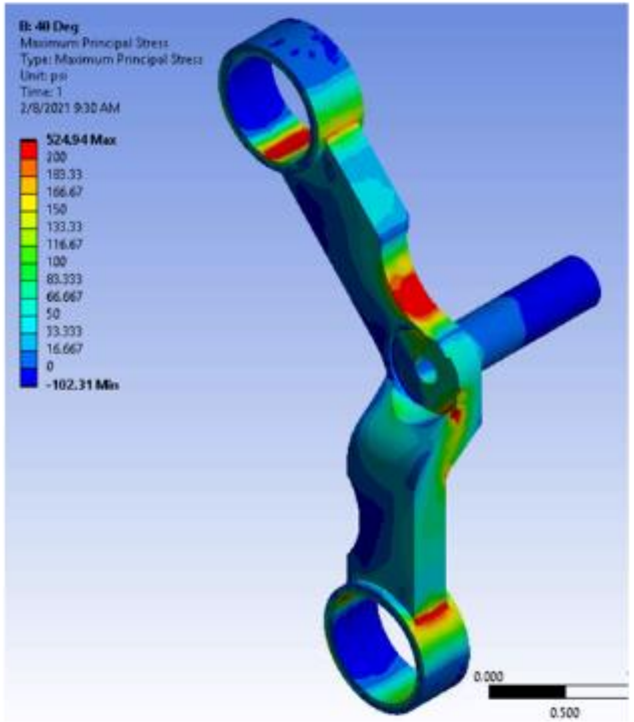
Finite Element Analysis

- FEM of each relative position with 1 lb. load at upper rod. Max stress ~ 0.2 to 0.5 ksi. Different positions had high stresses in different locations. AM material properties can vary with location.

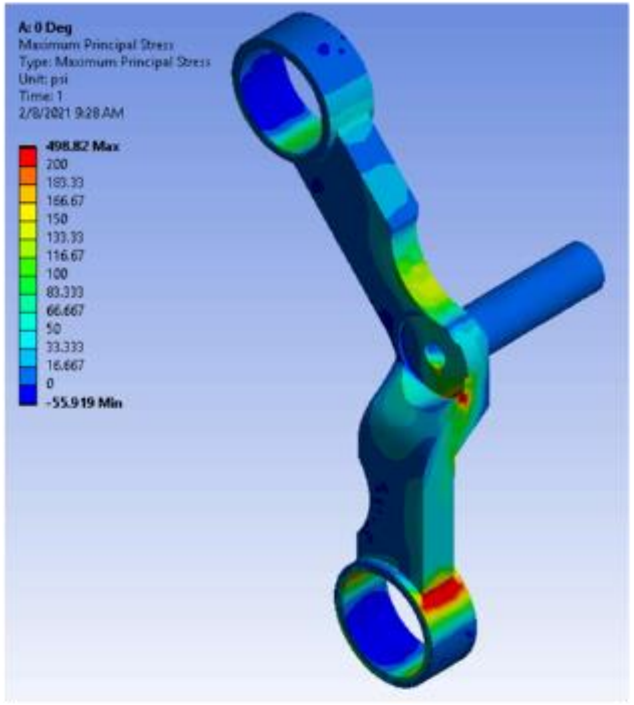
78°



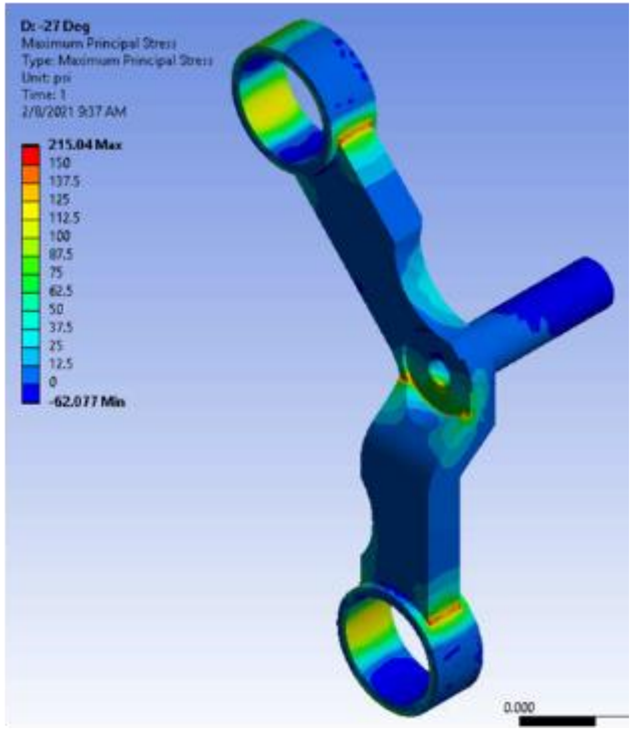
40°



0°



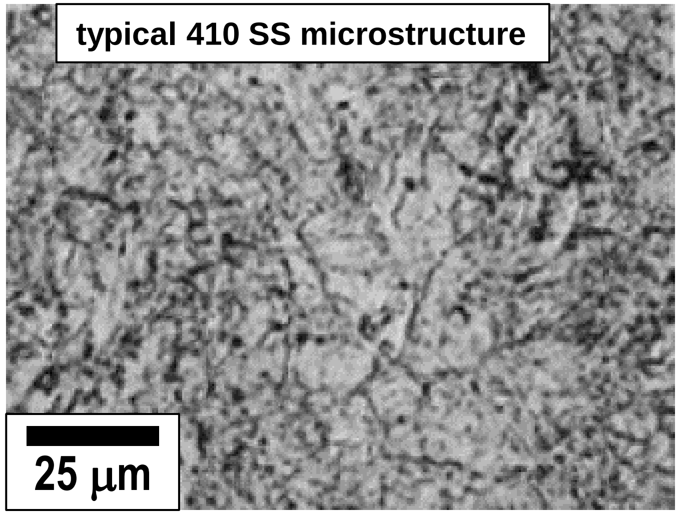
-27°

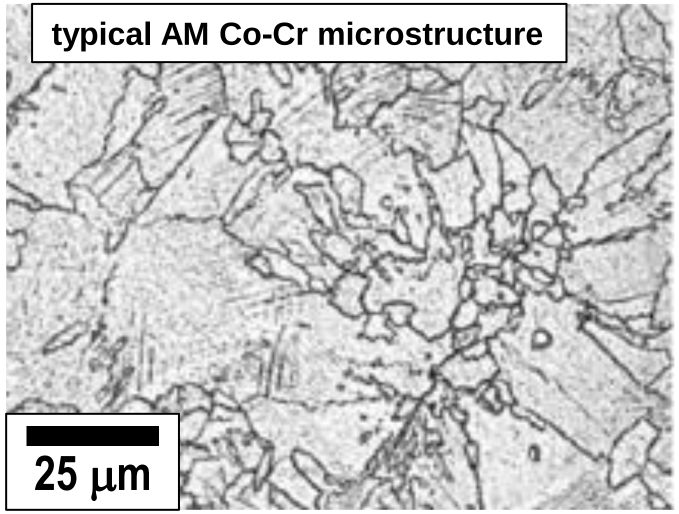


Approved for public release: AFLCMC-2021-0240

VPS-MICRO – Microstructure-Based Fatigue Analysis

Material Model Parameter	410 Stainless Steel	AM Cobalt Chrome
Shear Modulus	11,328 ksi	11,045 ksi
Poisson's Ratio	0.28	0.275
Grain Boundary Strength	2.02 ksi√in	3.0 ksi√in
Short Crack Coefficient	0.01	0.01
COV on Micro Stress	0.15	0.31
Specific Fracture Energy	2.466 kip/in	1.741 kip/in
Grain Orientation	"Martensite"	"Schmid" (FCC)
Grain Size	Lognormal Dist. mean = 3.543E-4 in, COV = 0.3	Lognormal Dist. mean = 2.681E-3 in, COV = 0.3
Frictional Strength	Lognormal Dist. mean = 102.3 ksi, COV = 0.3	Lognormal Dist. mean = 121.4 ksi, COV = 0.15
Long Crack Growth (Paris Equation $da/dN = C\Delta K^n$)	n = 3.4525; C Lognormal Dist. mean 5.86E-11, COV = 0.45	n = 3.24; C Lognormal Dist. mean 8.015E-11, COV = 0.45





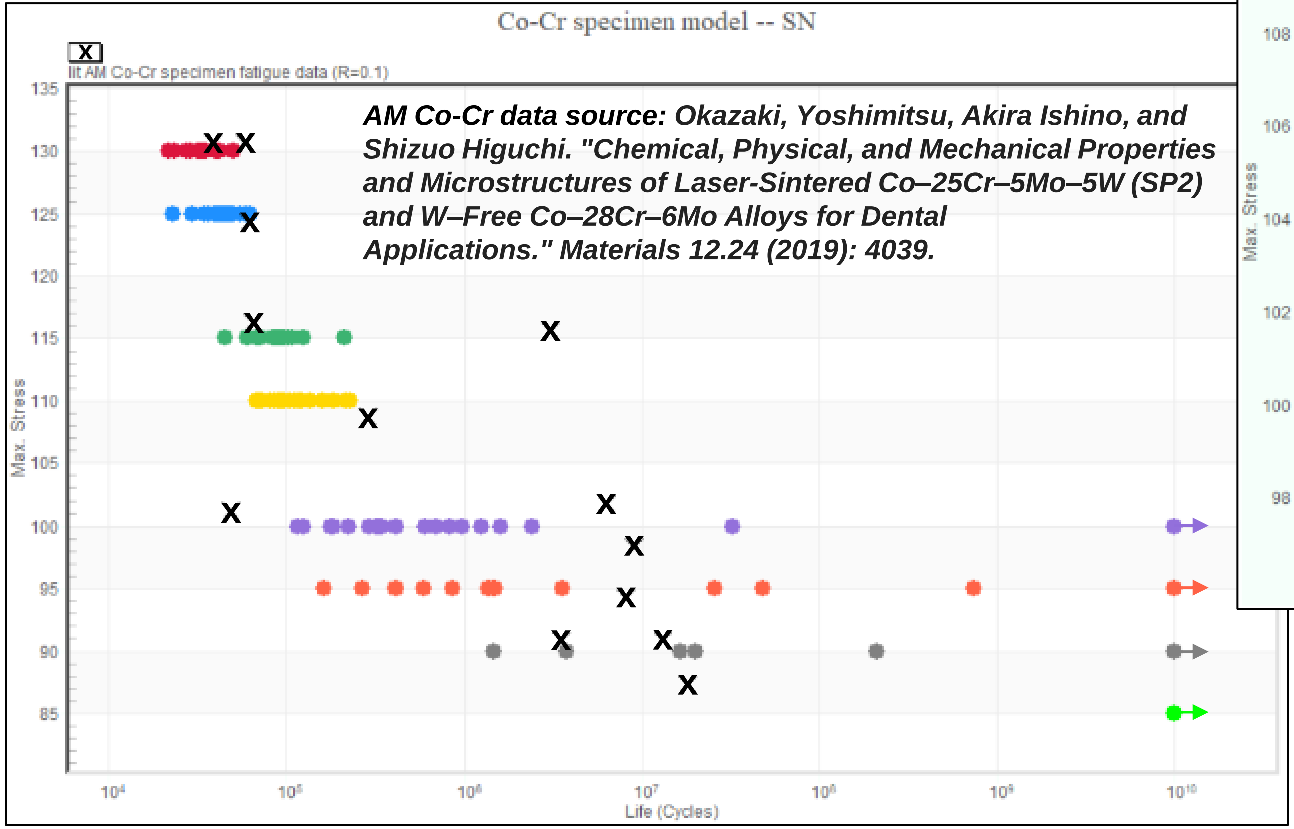
Irrespective of the metal (conventional or AM), VEXTEC has a standard set of inputs for its fatigue model

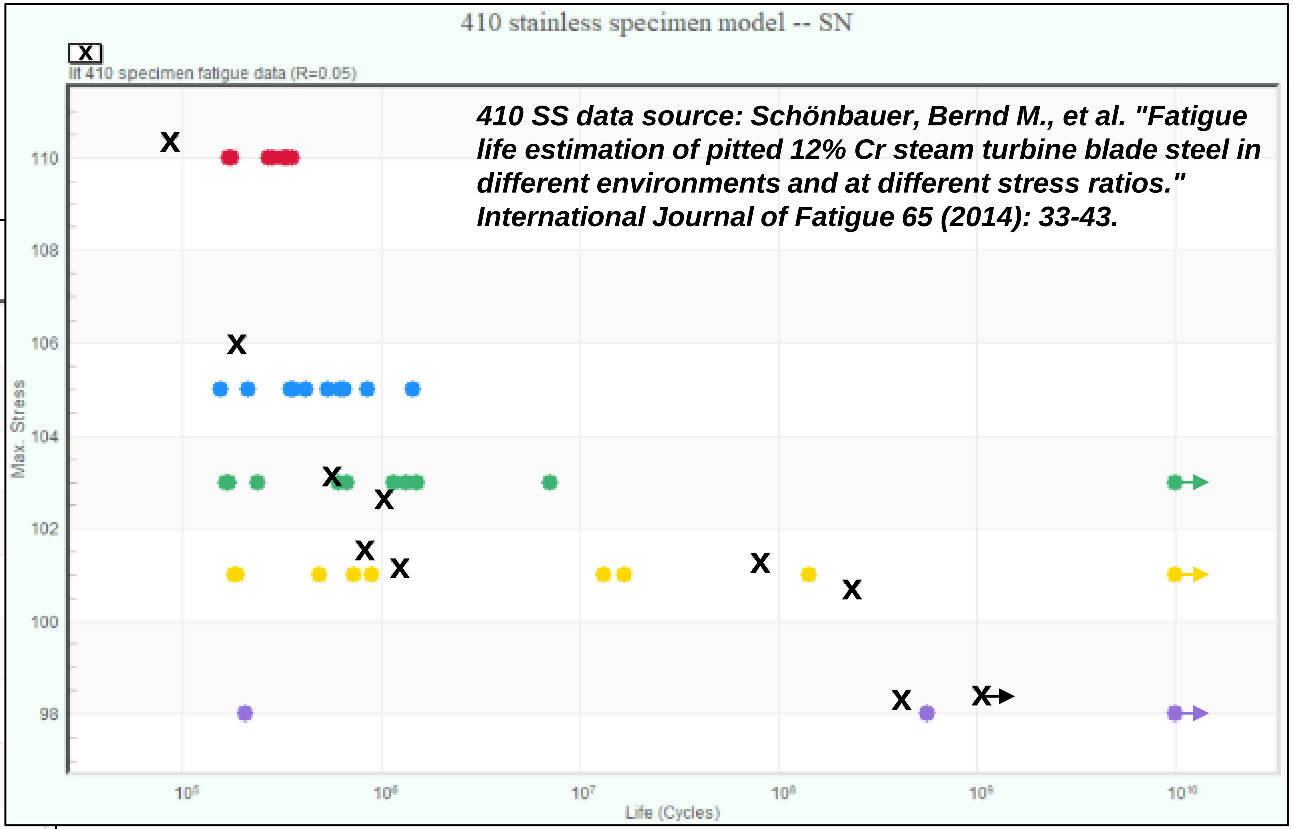
Approved for public release: AFLCMC-2021-0240

SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

VPS-MICRO Analysis Results – Specimen Geometry

- VPS-MICRO predictions track well with literature-sourced specimen fatigue test data



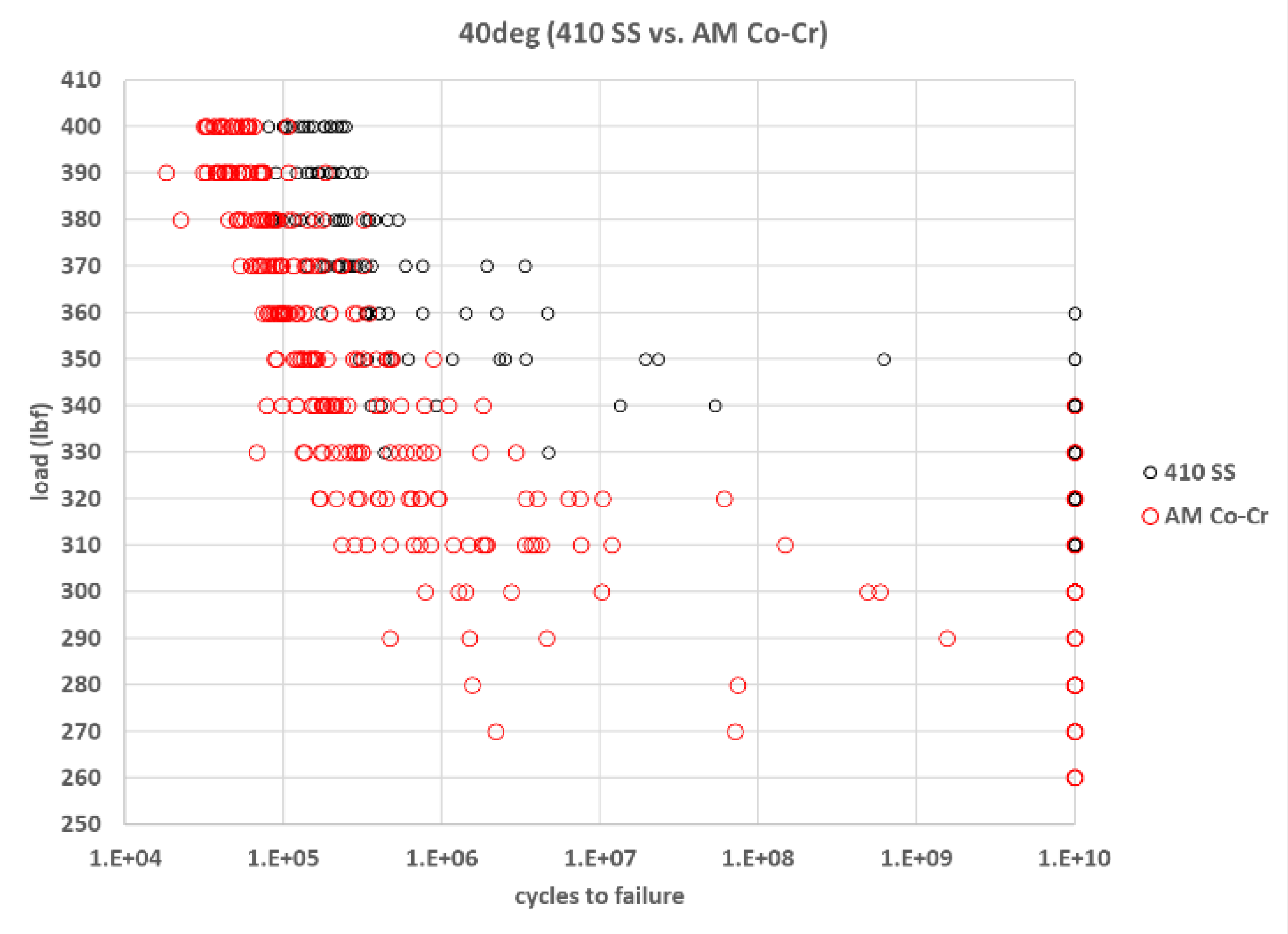


Approved for public release: AFLCMC-2021-0240

SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

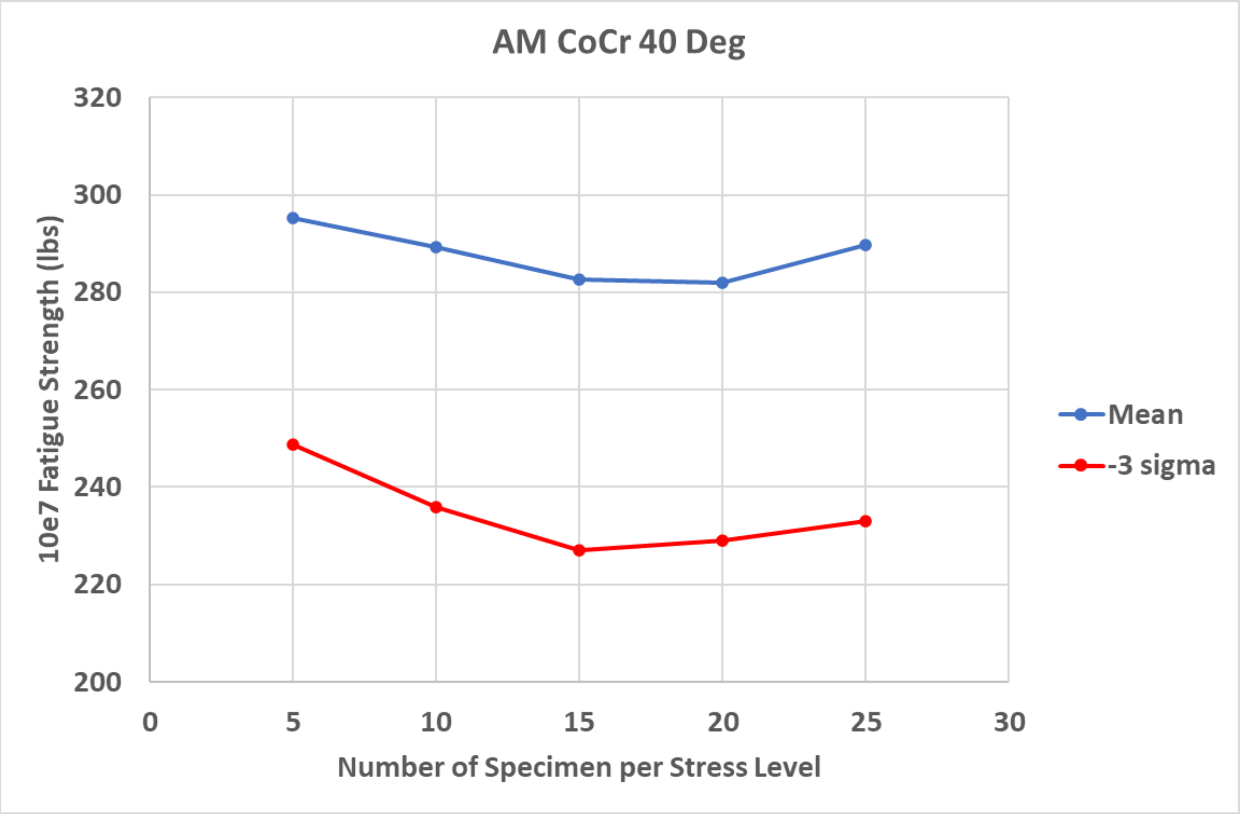
VPS-MICRO Analysis Results – Bell Crank Geometry

- Bell crank simulated S-N curves at 40 degree operational position
- Conventionally-processed 410 SS vs. AM Co-Cr
- AM Co-Cr fatigue strength is lower than 410 SS
- These quantitative results were achieved before AM parts were built or specimen test data were gathered



Critical Predictions for AM Qualification & Certification

- Probability of Failure (PoF) analysis
- Although the Co-Cr bell crank's fatigue strength is lower, the probability of loading the bell crank to the fatigue limit load is very low
  - The +3σ pilot load is about 45 lbs.
  - The -3σ fatigue strength is greater than 220 lbs.
  - It is unlikely the demonstration AM Co-Cr bell crank will fail in fatigue



Steps for Fatigue Critical Parts

- Destructive examination to determine microstructure and hardness
  - Examine a used bell crank
  - Examine AM Co-Cr material for similar size specimen
- Calibration
  - Build and laboratory test a limited number of calibration Co-Cr fatigue specimens
  - Calibrate model to fatigue tests
- Validation
  - Use calibrated model to simulate specimen fatigue test at a different test condition
  - Build and laboratory test validation fatigue specimens at same condition
  - Compare simulations to test results

Preliminary Conclusions

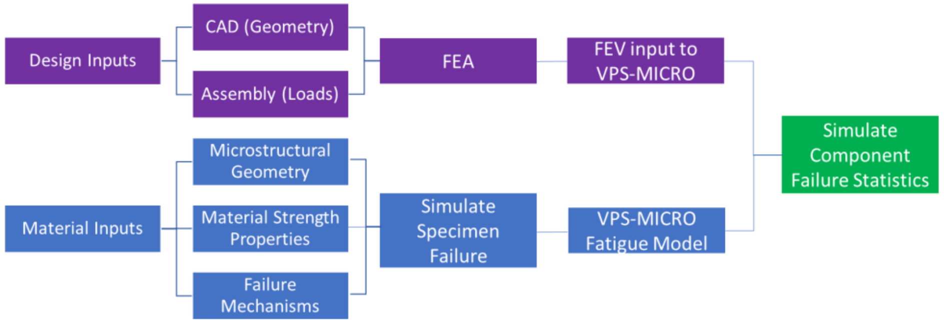
- VPS-MICRO can be used to asses AM material substitution
  - Simulate and compare the reliability of legacy products made with current material and proposed AM material
  - Perform virtual sensitivity studies to calibrate to different microstructural variations (based on different build parameters)
  - Gain early confidence before proceeding to test actual components

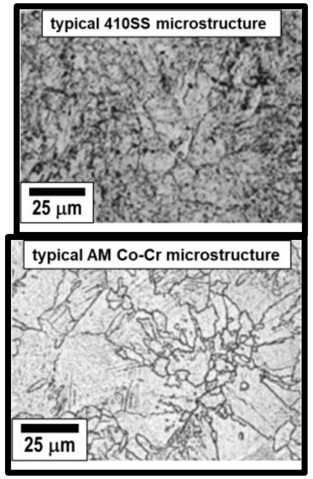
Summary: Bell Crank AM Material Substitution

Bell Crank Component Candidate for AM

- Study feasibility of substituting Additive Manufacturing materials & processes
- AM part should have the same or better quality & reliability as the conventional part

VPS-MICRO® Part of Computational Workflow

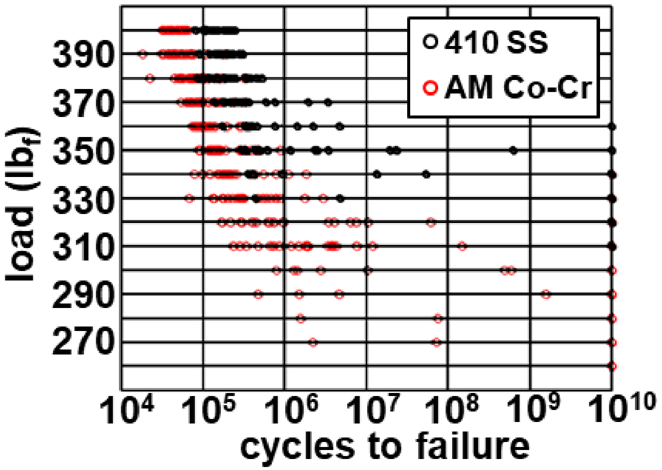




- VPS-MICRO used structural analysis and material data from literature sources

Results

- Quantitative comparisons between the two materials' fatigue performance
- AM material properties can vary widely, driving scatter in fatigue



Benefits

- Using VPS-MICRO can provide actionable information before any parts are built, or any data is gathered in the design stage
- Engineering teams can use the simulation results to aid in assessments of risk
- Virtual studies performed with multiple materials on the same structural analysis

SBIR data rights are protected by U.S. FAR 52.227-20 and U.S. DFAR252.227-7018.

Approved for public release: AFLCMC-2021-0240

DEC 1 & 2, 2021

Join VEXTEC and the rest of the AM community (free registration!)

TRX WEBINAR SERIES

Today's Webinar:

Computational Modeling as an Aid in Metal AM Qualification & Certification

QUESTIONS?

Please type your questions into the Q&A section of the WebEx screen and we will do our best to answer them all.

If you have additional questions that require a more in-depth conversation, please contact Michael Oja directly via moja@vextec.com.