



METAL ADDITIVE MANUFACTURING

Nov 7, 2019

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UTC Additive Manufacturing COE

UTC Aircraft Systems



Our future



**United
Technologies**

Raytheon

MERGING TO CREATE RAYTHEON TECHNOLOGIES

**A premier systems provider
with advanced technologies
that will define the future of
aerospace and defense**

PRATT & WHITNEY

SALES: ~\$21B



COLLINS AEROSPACE

SALES: ~\$22B



**INTELLIGENCE, SPACE &
AIRBORNE SYSTEMS⁵**
SALES: ~\$18B



**INTEGRATED DEFENSE &
MISSILE SYSTEMS⁶**
SALES: ~\$16B



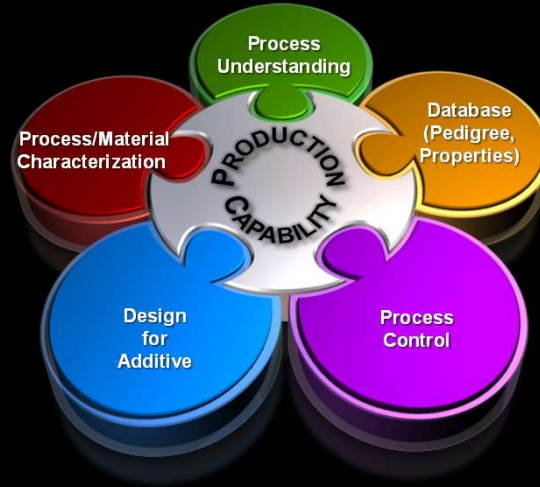
UTC ADDITIVE MANUFACTURING COE

Mission

Accelerate certification of additive materials and processes

Establish a tool chain to enable design-for-additive

Develop additive training curriculum and deploy across UTC



Location

UTC Research Center
East Hartford, CT



450+ employees

Advanced methods and test capabilities



Defining the cutting edge

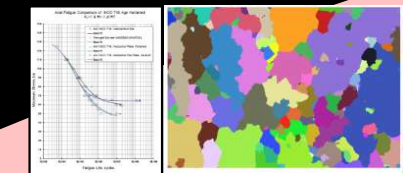
- Advanced Manufacturing
- Aerodynamics & Acoustics
- Applied Mechanics
- Autonomy & Controls
- Combustion
- Cyber Physical Security
- Data Science
- Embedded Intelligence
- Materials
- Networks & Communications
- Power Electronics
- Thermal Management

Capabilities



9 Metal powder bed machines from 4 OEMs; Open test bed*; 3 Polymer machines; Post processing: Wire EDM, powder removal, stress relieve, & machining; Training Center w/ 20 desktop machines

Value stream approach to development and production



Quality & Inspection

Quality & Inspection



Qualification & Certification

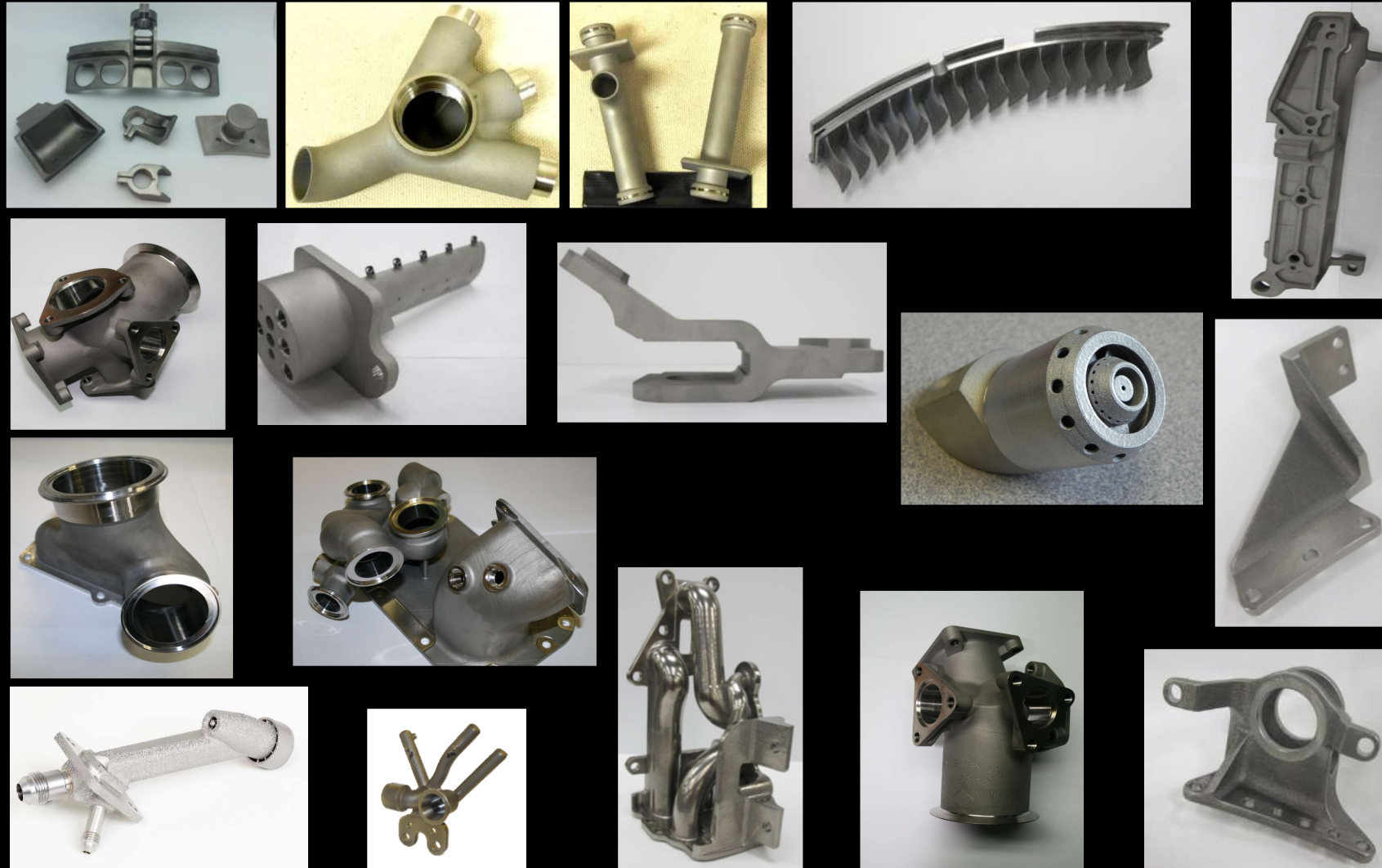
Qualification & Certification

A word cloud visualization of the top 100 terms from the 'Additive' category. The words are arranged in a circular pattern, with 'Additive' being the largest and most central word. Other prominent words include 'Process', 'Design', 'Tools', 'Certification', 'Standards', 'Inspection', 'Training', 'Variability', 'Bulk', and 'Local'. The words are color-coded, with 'Additive' in yellow, 'Process' in blue, and others in various shades of green, orange, and red.

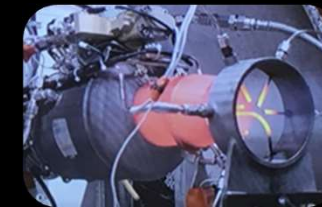
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UTC ADDITIVE JOURNEY

>3000 parts for visual, rig, and engine tests



Recent Successes



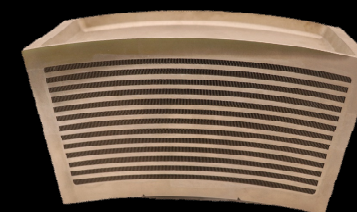
Attritable Engine

99% reduction in part count
Operability; 2X mission life



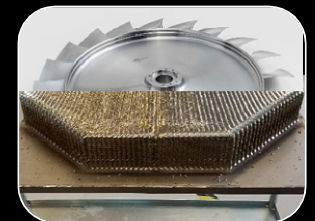
Engine Oil System

Met performance objectives
27-days from concept to delivery



Conformal Heat Exchanger

Designed for additive
20+% reduction in size



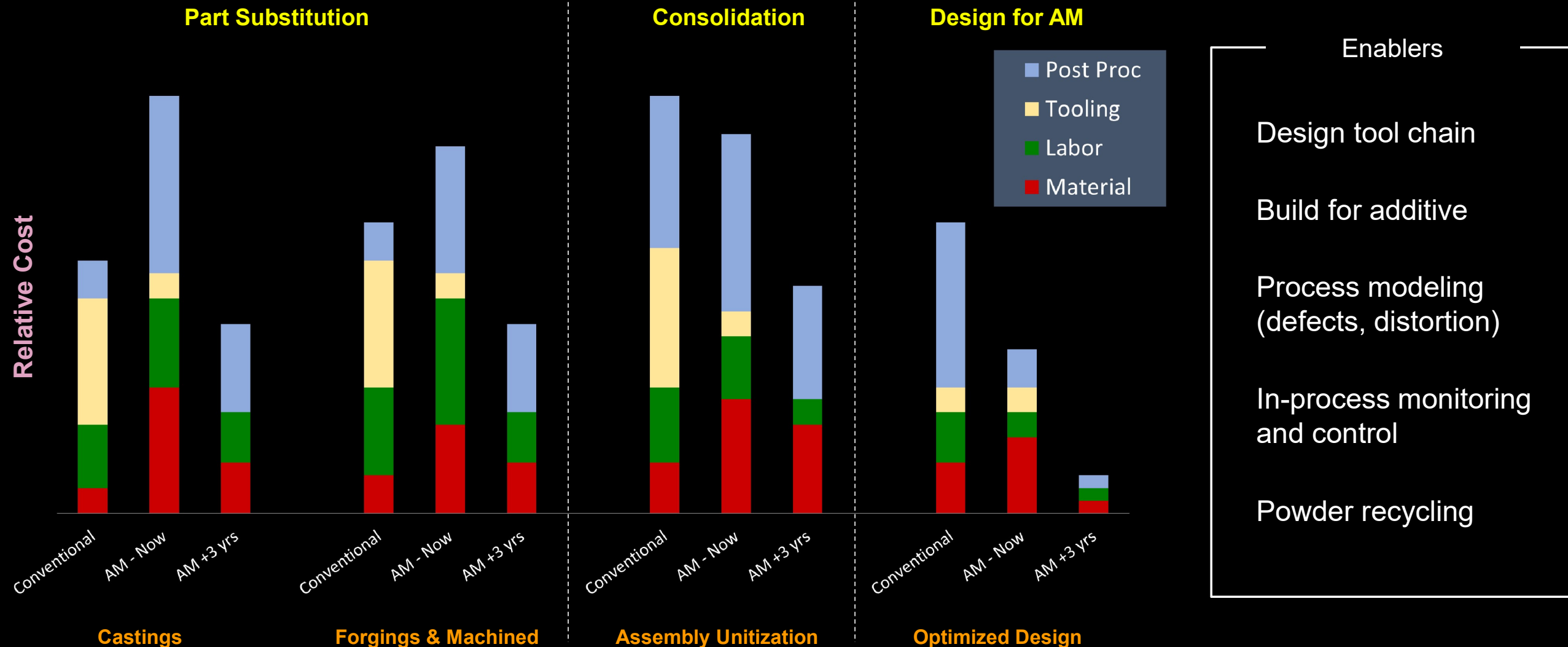
Integrally Bladed Rotor (IBR)

Preform in 3-months
100% red-line speed

ECONOMICS

COST COMPARISON

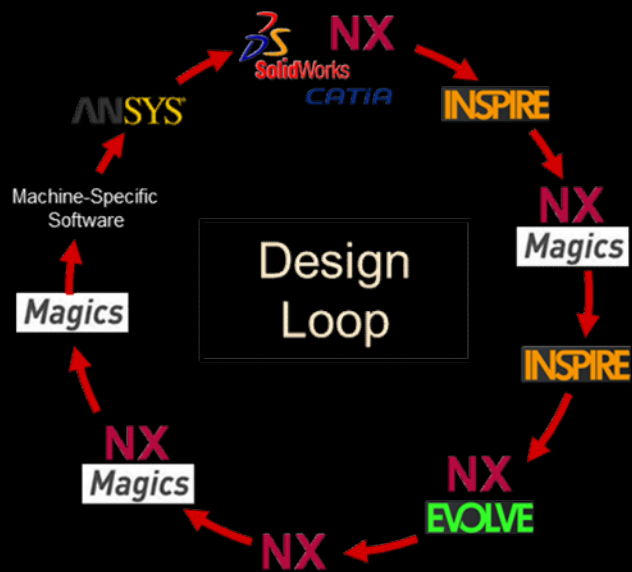
Additive poised to be cost competitive in 3-years



DESIGN METHODOLOGY

DESIGN METHODOLOGY

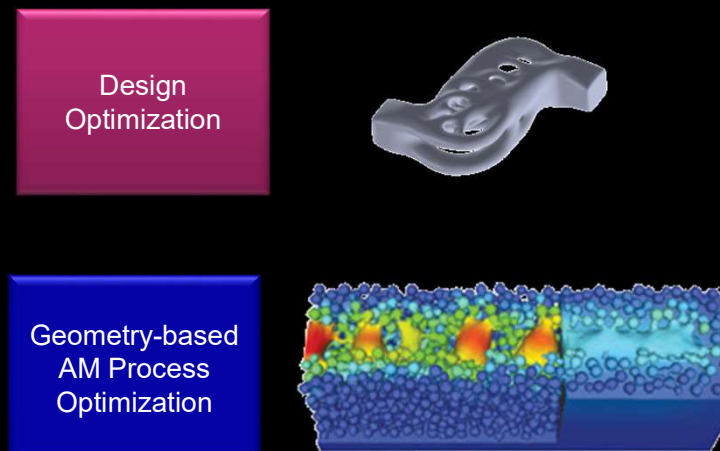
Topology Optimization



7 Software tools; 9 data exchanges
Combine tool functions

Now

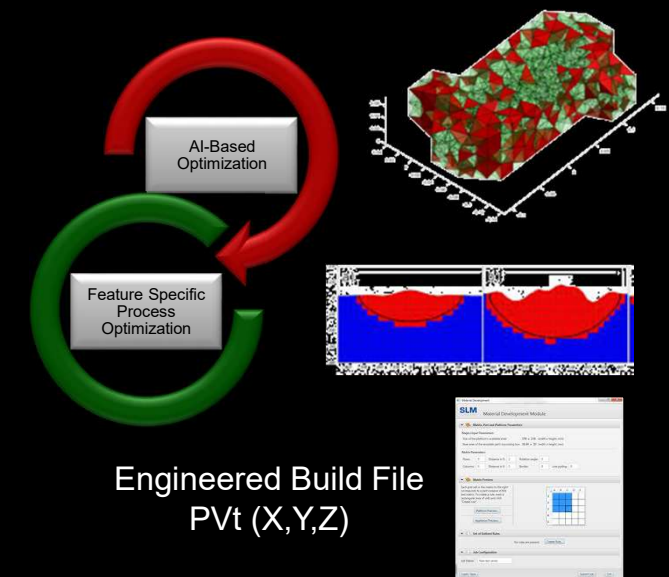
Design and Process Optimization



Cloud based multi-physics analysis
Physics-based process tools

Near-term

Virtual Qualification



Generative design with build file
Single point-of-use tool

Future

QUAL AND CERTIFICATION APPROACH

QUAL AND CERTIFICATION APPROACH

Transition from part-based to physics guided process-based

Part based



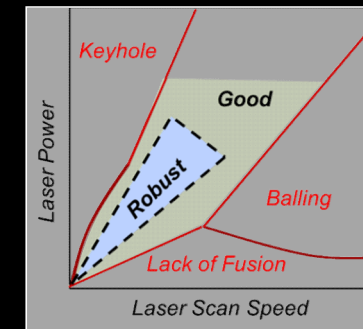
Single part
Material & machine S/N specific
Fixed ("Frozen") process parameters

Part-family based



Similar part complexity
Functional requirements and post-processing alike
Identified key process parameters

Process based



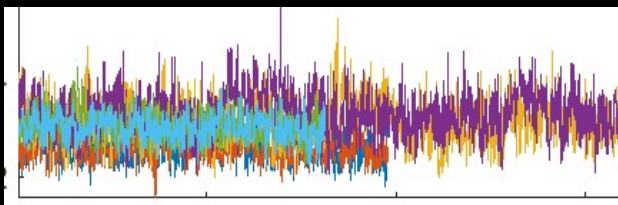
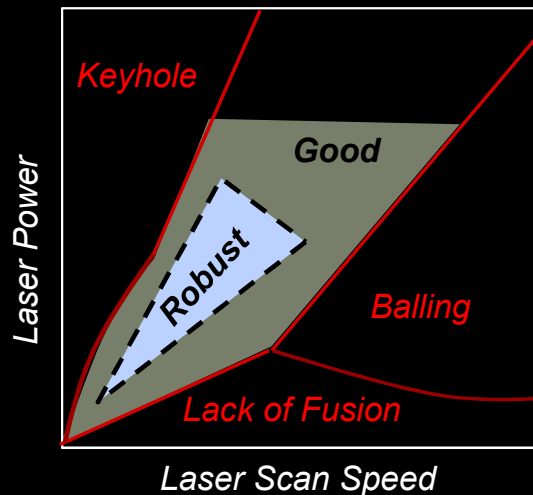
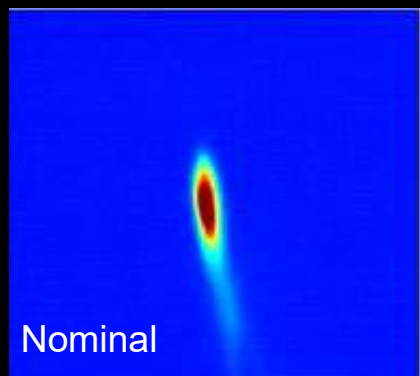
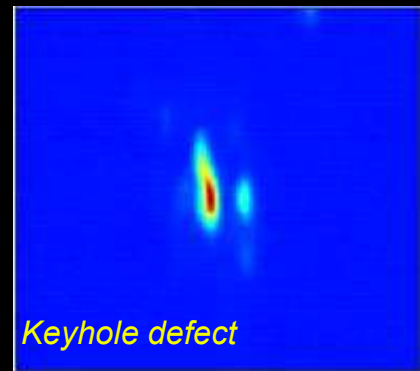
In-depth process understanding with primary and secondary KPCs
Machine agnostic physics-based models defines process envelope

PROCESS-BASED QUAL & CERTIFICATION

Sensors and advanced analytics being developed for anomaly detection

Thermal monitoring

On-axis photodiodes and melt pool imaging



Optical detection

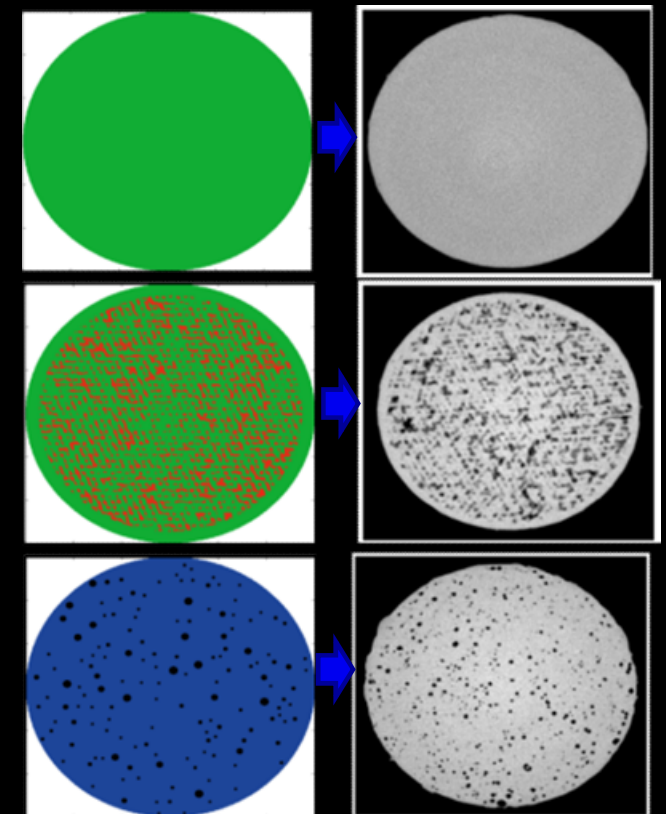
Powder spreading



- a Recoater hopping
- b Recoater streaking
- c Debris
- d Super-elevation
- e Part failure
- f Incomplete spreading

Model validation

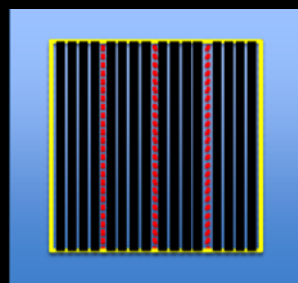
Defect location & size



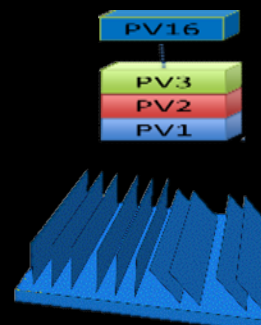
CASE STUDY: HEAT EXCHANGERS

Feature-based design & process development enabled performance increase

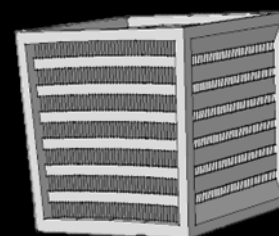
Single tracks



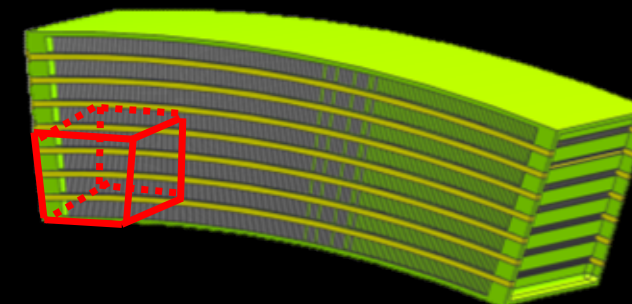
Features



Sub-scale HX



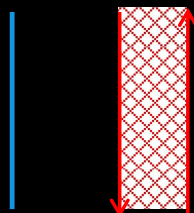
Full-scale Heat Exchanger



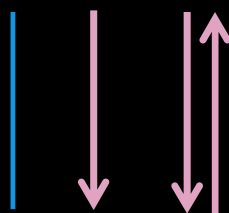
Build Orientation and Fin Scan Strategy Optimization



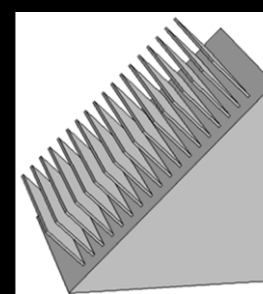
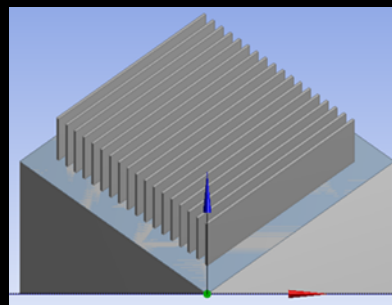
Hatch only



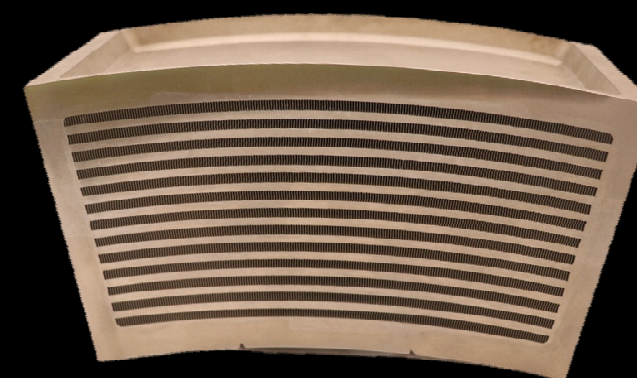
Hatch + Contour scan



Single and Double pass scans



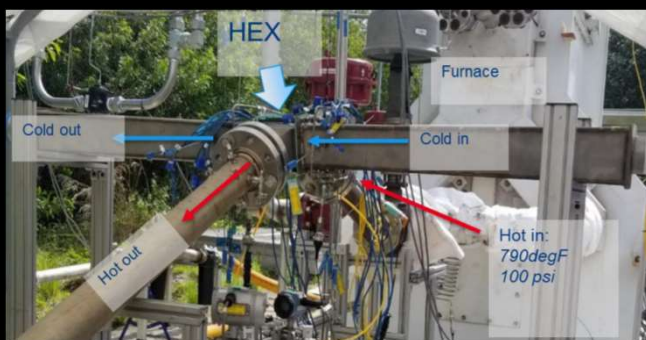
Conformal Heat Exchanger



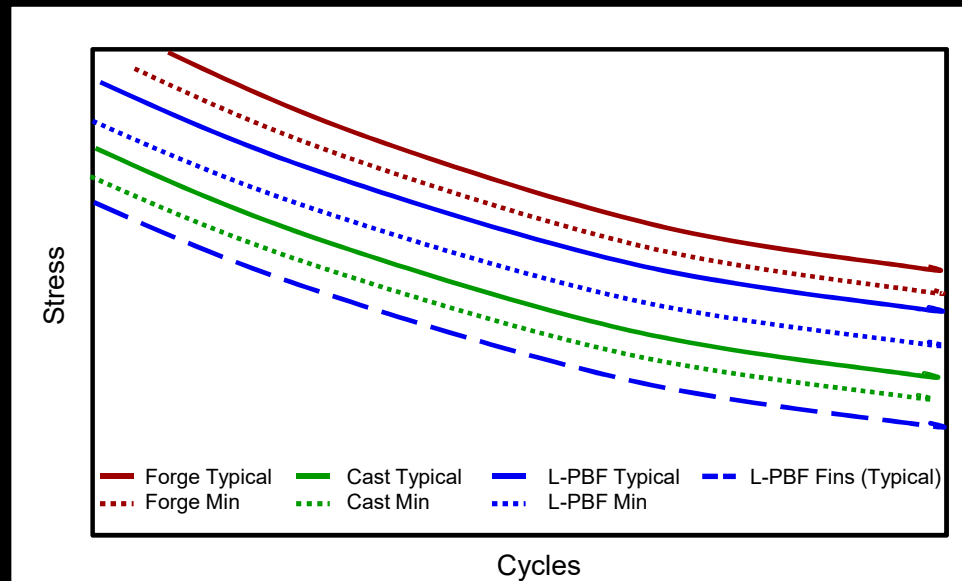
CASE STUDY: HEAT EXCHANGERS

Design system considerations

Conformal Heat Exchanger



Full scale testing demonstrated 50% reduction in pressure drop and 20% increase in heat transfer



*Statistical properties are required but not sufficient.....
Need to incorporate process understanding and effects
on local microstructure and properties*

Design allowables

Bulk versus local

Feature-based properties but... path dependent

Effect of build orientation on surface roughness and properties

Critical flaw size and inspection methods



SUMMARY

Qual and certification approach need scientific understanding of the process

Current State

Part-based certification methodology driven by statistics

Machine and OEM specific process parameters
[“frozen process” approach]

Stand-alone CAD-centric design tools for topology optimization

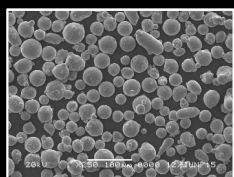
Desired State

Process-based certification approach enabled by physics-driven models

Feature-based process maps and location specific defect prediction

End-to-end tool chain that includes multi-physics, part geometry, and additive process constraints

Additive Value Stream



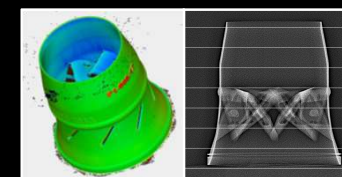
Feedstock Powder



Build Themes and Part Builds



Materials Characterization



Quality & Inspection



Qualification & Certification



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