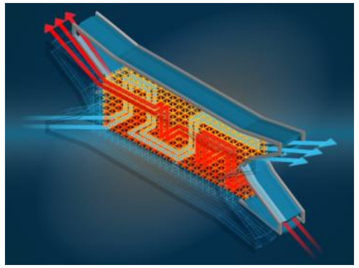


Developing an Ultra-Compact, Topology-Optimized Heat Exchanger using Additive Manufacturing

Ram Ranjan, Raytheon Technologies Research Center

Project Vision

By integrating advanced design methods with physics-based AM process models, we have demonstrated an ultra-compact, fully optimized 50 kW heat exchanger.

10X smaller than SOA, 40X more durable than SOA

Brief Project Overview

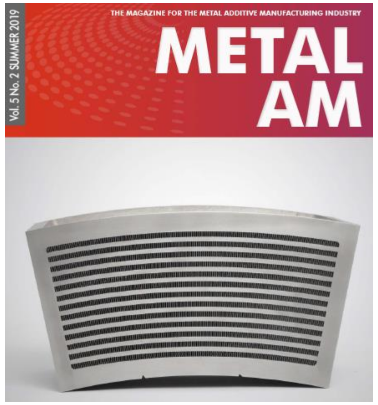
Fed. funding:	$2.2M
Length	33 mo.

Raytheon Technologies | RunToSolve (Get the answer.) | WISCONSIN UNIVERSITY OF WISCONSIN–MADISON | Collins Aerospace

Team member	Location	Key Personnel	Role in project
Raytheon Technologies Research Center	East Hartford, CT	Dr. Ram Ranjan, Dr. Katie Kirsch, Dr. Paul Attridge, Mr. Alex Cadar, Mr. Bob Dold, Dr. Joe Turney	Project lead, HX design, process modeling, and fabrication
RunToSolve, LLC	Baltimore, MD	Dr. James Guest	HX design optimization
University of Wisconsin Madison	Madison, WI	Dr. Mark Anderson	HX testing

Context/history of the project

- RTRC and RTS have participated in prior ARPA-E programs.
- RTRC has been developing additive HXs for propulsion applications over the last decade.

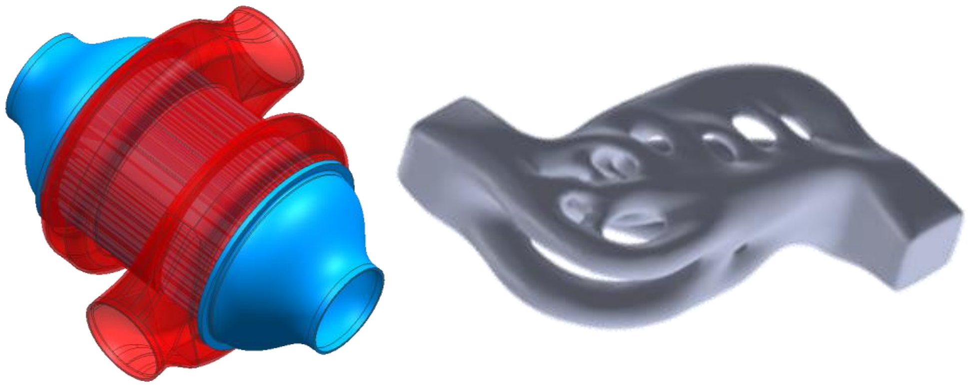


Progress Against Tasks

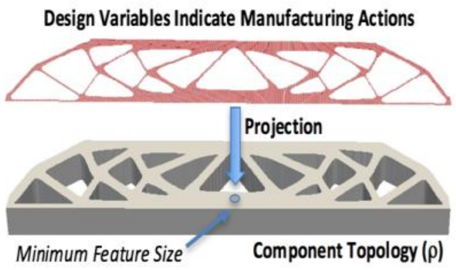
Phase	Major Tasks and Go / No-Gos
Critical Risk Reduction 9 months	Task 1: HX Design & Requirements
	Go / No-Go: HX design completion for FOA targets
Sub-scale HX Demonstration 12 months (complete June 2021)	Task 2: AM process modeling & sub-scale fabrication
	Task 3: Material and HX coupon testing
	Go / No-Go: Sub-scale HX Testing Completion & Performance
Full-scale HX Demonstration 12 months (End May 2022)	Task 4: Full scale HX design, fabrication, testing
	Task 5: Technology to Market
	Task 6: Program Management (TRL/MRL Review)

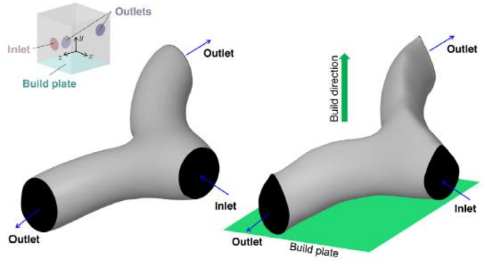
Heat Exchanger Design Summary

- Novel aspects compared to the state of the art
  - Novel core geometries that survive high pressure conditions
  - Topology optimized features in the header and core to improve performance
- Performance metrics
  - > 10 kW/kg (full HX power density), dP <2% of inlet pressure, >10,000 hr durability, < $200 /kW
- Risks progression
  - Design risk for structural performance reduced, material property and build quality proven at sub-scale level, manufacturing scale risk undergoing reduction



Counter-flow topology optimized configurations





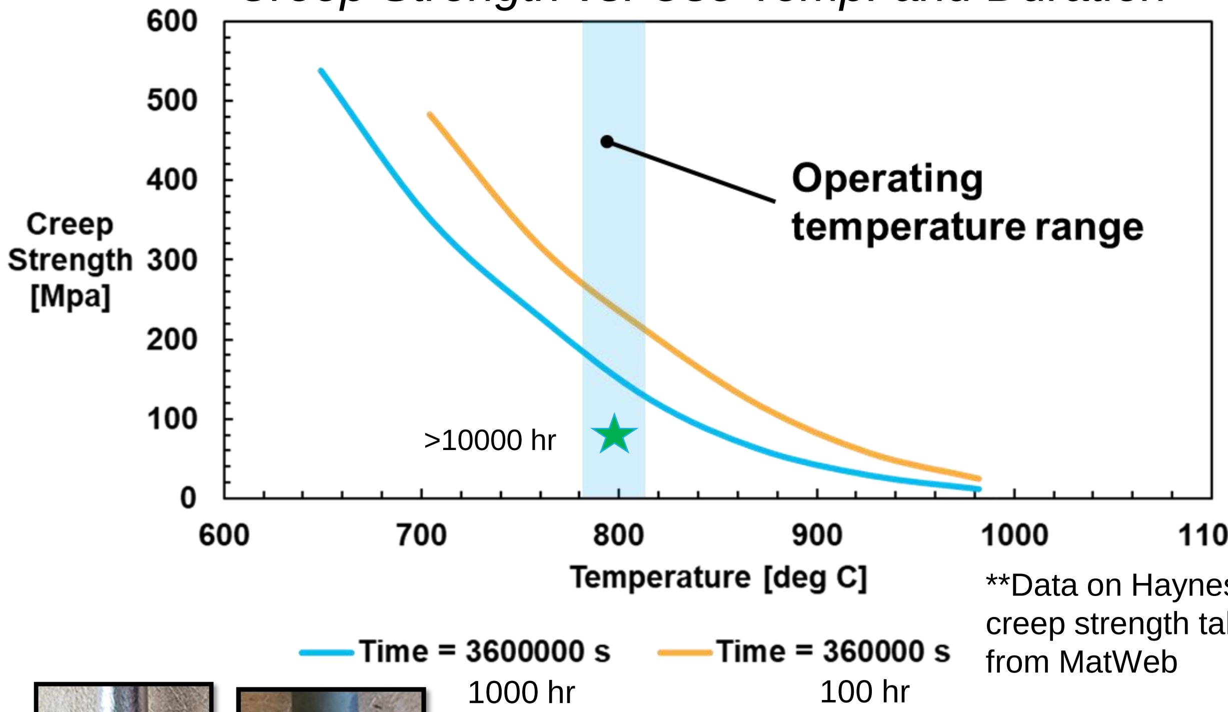
Self-supporting structures created during optimization process based on build direction

Custom topology optimization tools, high fidelity flow, thermal, and stress analysis

Material Selection and Property Testing

- Material update
  - Haynes 282 tensile and creep property measurements completed
    - Tensile properties up to 900 C within +10% of published wrought properties
    - Creep strength slightly inferior (within -10%) to published wrought data
- Material properties with additive
  - Property testing provided confidence in HX survivability and durability prediction
  - Exposure to sCO_2 and its impact on material composition similar to wrought samples

Creep Strength vs. Use Temp. and Duration



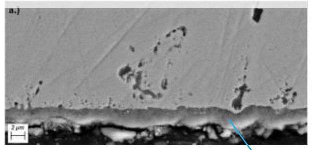
**Data on Haynes 282 creep strength taken from MatWeb

Sample 22
RT

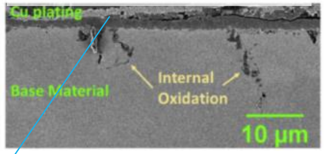
Sample 50
900C

Failure more brittle at high temperature

AM H282 Sample



Bulk H282 Sample



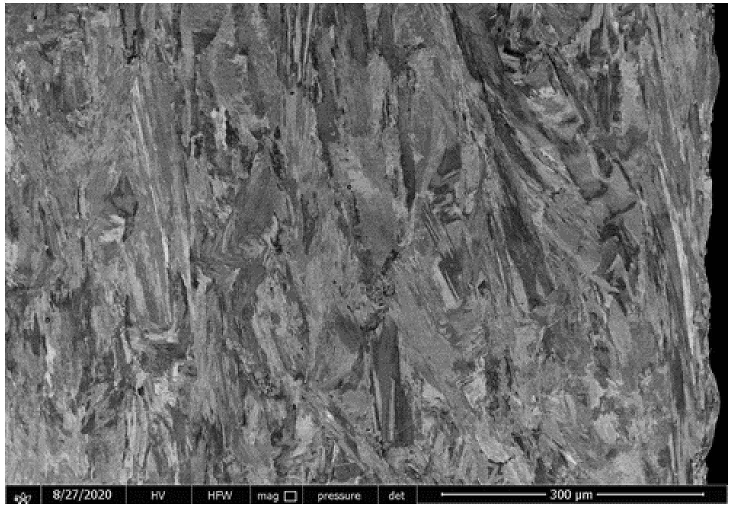
Oxide layer thickness is similar between AM and bulk

sCO_2 exposure autoclave testing

CHANGING WHAT'S POSSIBLE

Manufacturing Process Development

- Manufacturing process
  - Additive manufacturing (laser bed powder fusion)
  - Design freedom more than conventional process but AM constraints increase design cycle time
  - ~100% density, microstructure (dendritic solidification and elongated grains)
- Manufacturing risk reduction
  - Coupon, features and full sub-scale HX fabricated
  - Microstructure and creep properties at elevated temperatures and thin features investigated



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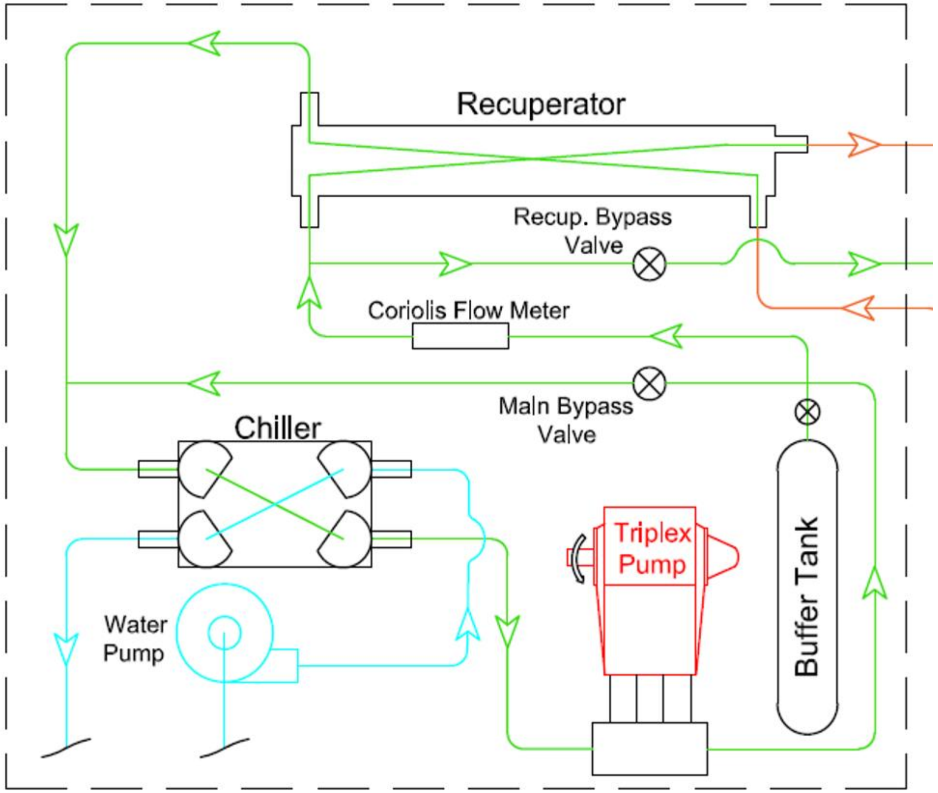
Testing Progress and Plan

WisCO$_2$ Loop Capabilities
$\dot{m}$ = 0.015 - 0.8 kg/s
P = 1000 - 3600 psi
T ≤ 800°C (at Test HX)

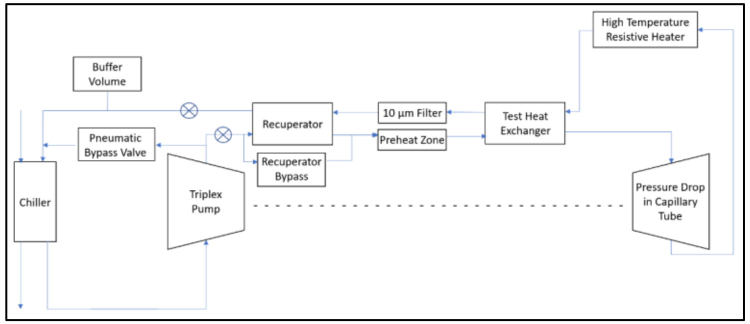


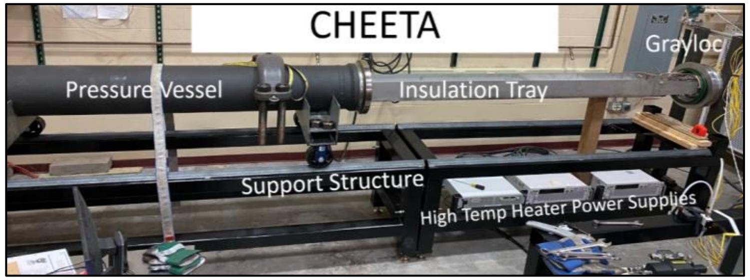
Test loop for recuperator testing:
Completed sub-scale HX testing in Q2 of 2021

CHANGING WHAT'S POSSIBLE

Fabrication of Protype Heat Exchangers and Testing

10 kW HX successfully tested in Q2, 2021 at full program conditions





Test setup at University of Wisconsin at Madison

Hot Inlet
T=799.5 +/- 1.5 C
P=8.23 +/- 0.06 MPa

Cold Outlet
T=7xx C
P=24.8x MPa

Cold Inlet
T=301.8 +/- 1.5 C
P=24.84 +/- 0.07 MPa

Hot Outlet
T=3xx C
P=8.2x MPa

Experimental results from 10 kW sCO_2 HX test at HITEMMP full program conditions

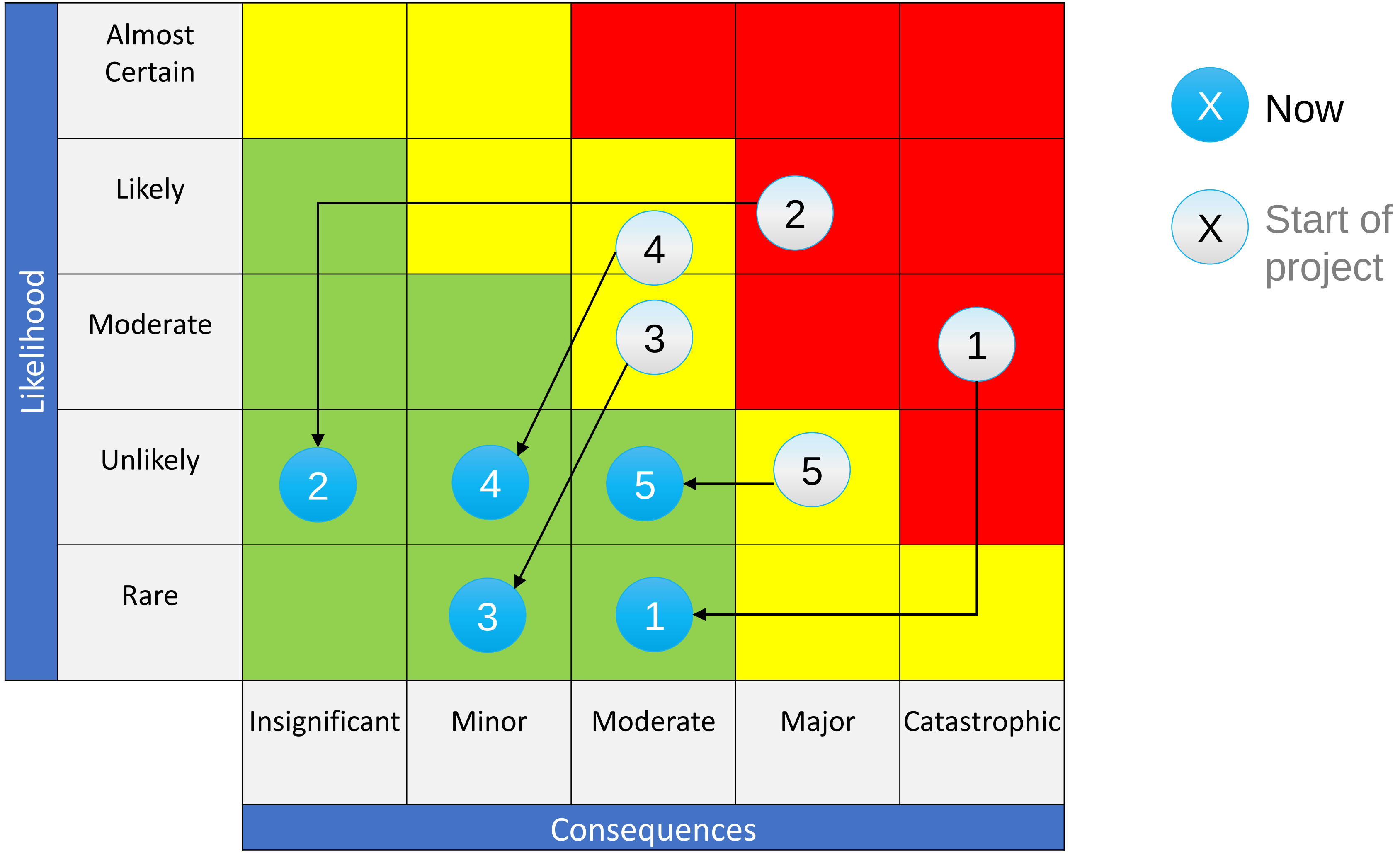
Measure heat transfer (10 kW) within 3% of predictions/design

dP < 0.2% of inlet pressure on both sides

Risks

All program major risks reduced through design-build-test iterations

Risk	#
Structural requirements not met	1
Fluid leakage	2
AM post processing	3
Cost too high	4
Scalability	5



Q & A

https://arpa-e.energy.gov