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 will develop a non-intuitive, 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: 30 mo.

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.

Team member | Location | Key Personnel | Role in project
--- | --- | --- | ---
Raytheon Technologies Research Center | East Hartford, CT | Dr. Ram Ranjan, Dr. Katie Kirsch, Dr. Jeongwoo Kim, Dr. Paul Attridge, Dr. Alex Cadar, Dr. Ranadip Acharya, 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, Dr. Xiaoping Qian | HX testing & validation; HX design optimization
SLM Solutions NA | Detroit, MI | Dr. Aaron LaLonde | Process monitoring and control

This document has been publicly released and is not subject to export controls
Brief Project Overview

AI-Enhanced Topology Optimization Design

AM Process Optimization for Topology Optimized HX

Sub-scale and full-scale testing

Commercialization

This document has been publicly released and is not subject to export controls
Heat Exchanger Design Details

- 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
- Anticipated performance metrics (power density (indicate if it is just core or full heat exchanger), effectiveness, pressure drop, durability, cost.?)
  - > 6 kW/kg (full HX power density), dP <1% of inlet pressure, >10,000 hr durability, < $200 /kW
- Risks progression
  - Design risk for structural performance reduced, material property and build quality proven at coupon level, manufacturing scale up risk undergoing reduction
- What tools are you developing and employing to support the design and analysis?
  - Custom topology optimization tools, high fidelity flow, thermal, and stress analysis

Counter-flow configurations
Material Selection Updates

- **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
- **What has been derisked so far? What challenges remain?**
  - Property testing provided confidence in HX survivability and durability prediction
  - Exposure to sCO2 and its impact on material composition under investigation

**Data on Haynes 282 creep strength taken from MatWeb**

This document has been publicly released and is not subject to export controls
Manufacturing Process Development Updates

- How will you manufacture your heat exchanger for this project? What is novel in your manufacturing approach (if relevant)?
  - Additive manufacturing (laser bed powder fusion)

- What are the main manufacturing process features? Advantages/Disadvantages?
  - Design freedom more than conventional process, AM constraints increase design cycle time
  - ~100% density, microstructure (dendritic solidification and elongated grains)

- What has been derisked so far? What challenges remain?
  - Sub-scale HX fabricated
  - Microstructure and creep properties in HX walls
Technology-to-Market Updates

- Technology-to-Market strategy is focusing on applications for RTX Collins and Pratt & Whitney components and systems.

- General application markets are waste heat recovery, power generation and aircraft advanced heat exchangers.

- Cost modeling includes raw material, machine time, post processing cost: ~$80-100/kW, powder reuse can reduce cost by 30-40%

- Anticipated first markets
  - Aerospace power generation applications, TRL5-6 demo in ARPA-E REEACH program

- Key to aerospace commercialization: durability and power density

This document has been publicly released and is not subject to export controls
Risk Update

Major risks with respect to structural requirements and fluid leakage reduced through design-build-test iterations

<table>
<thead>
<tr>
<th>Risk</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural requirements not met</td>
<td>1</td>
</tr>
<tr>
<td>Fluid leakage</td>
<td>2</td>
</tr>
<tr>
<td>AM post processing</td>
<td>3</td>
</tr>
<tr>
<td>Cost too high</td>
<td>4</td>
</tr>
<tr>
<td>Scalability</td>
<td>5</td>
</tr>
</tbody>
</table>

- Almost Certain
- Likely
- Moderate
- Unlikely
- Rare

Consequences:
- Insignificant
- Minor
- Moderate
- Major
- Catastrophic

This document has been publicly released and is not subject to export controls
Progress Against Tasks – Timetable

Critical Risk Reduction
9 months

Sub-scale HX Demonstration
12 months

Full-scale HX Demonstration
9 months

<table>
<thead>
<tr>
<th>Major Tasks and Go / No-Gos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1: HX Design &amp; Requirements</td>
</tr>
<tr>
<td>Go / No-Go: HX design completion for FOA targets</td>
</tr>
<tr>
<td>Task 2: AM process modeling &amp; sub-scale fabrication</td>
</tr>
<tr>
<td>Task 3: Material and HX coupon testing</td>
</tr>
<tr>
<td>Go / No-Go: Sub-scale HX Testing Completion &amp; Performance</td>
</tr>
<tr>
<td>Task 4: Full scale HX design, fabrication, testing</td>
</tr>
<tr>
<td>Task 5: Technology to Market</td>
</tr>
<tr>
<td>Task 6: Program Management (TRL/MRL Review)</td>
</tr>
</tbody>
</table>

This document has been publicly released and is not subject to export controls
Q & A

https://arpa-e.energy.gov

This document has been publicly released and is not subject to export controls