



Presenter Name
Date

HAL STRUMPF
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Honeywell
THE POWER OF **CONNECTED**

High-Temperature Heat Exchangers for Aerospace Applications

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**ARPA-E High-Efficiency, High-Temperature
Modular Power Workshop**

Falls Church, Virginia

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High-Temperature Heat Exchangers

- For the Purpose of this Workshop, 'High-Temperature' is Associated with > 700 deg C (~ 1300 deg F)
- It Is Important to Realize that at this Temperature Heat Exchanger Design, Configuration, and Material Selection Will Vary with Application and Specific Requirements
- As such, Different Potential Markets for the Modular Power System May Result in Different Heat Exchanger Concepts

Heat Exchanger Requirements and Optimization

- To Efficiently Develop Advanced High-Temperature Heat Exchangers it Is Necessary to Define the Requirements (that Will Vary from Platform to Platform) and the Optimization Goals
- Defined Optimization Goals Are Critical
 - It Is Unlikely that a New Advanced Heat Exchanger Can Be Lighter, Smaller, Less Expensive, Higher Performing, and Have Longer Life than State-of-the-Art Technology
 - Optimization Goals Would Likely Vary for Different Platforms

High-Temperature Aerospace Heat Exchangers

- Honeywell Is World Leader in High-Temperature Aerospace Heat Exchangers for Military and Commercial Applications
- Three Most Recent Commercial Transport Bleed Air System Precoolers—A350, B737MAX, B777X
- Plate-Fin (Lower Pressure) and Tubular (Higher Pressure) Designs
- These Heat Exchangers Are Almost Always Life-Limited by Thermal Fatigue—Caused by Continual Rapid Temperature Transients Due to Aircraft Takeoff, Landing, and Other Operations
- Honeywell Has Developed Special Design Features to Minimize Thermal Fatigue Failures as Well as Detailed Thermal Fatigue Life Prediction Tools—Validated by Test
 - Designs Typically Undergo Analysis and Qual Testing

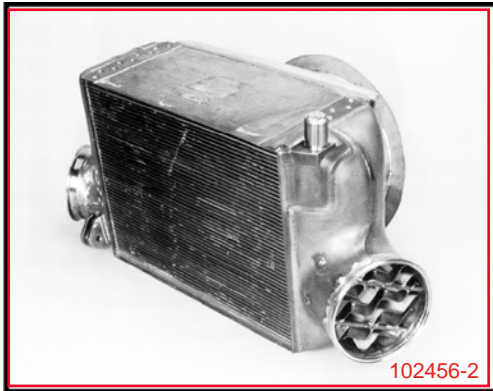
Heat Exchanger Material

- Typical Material for Honeywell High-Temperature Heat Exchangers Is Inconel 625
 - Stainless Steel Fins May Be Used on Plate-Fin Heat Exchangers to Improve Fin Thermal Conductivity
 - Temperature Limit ~ 1400 deg F (760 deg C)
- Honeywell Program for AFRL Developed a Heat Exchanger Using Haynes 282
 - Temperature Limit ~ 1500 deg F (815 deg C)
- Years Ago Honeywell Developed Ceramic Heat Exchangers
 - Silicon Nitride and Silicon Carbide
 - Temperature Limit ~ 2000 deg F (1090 deg C)

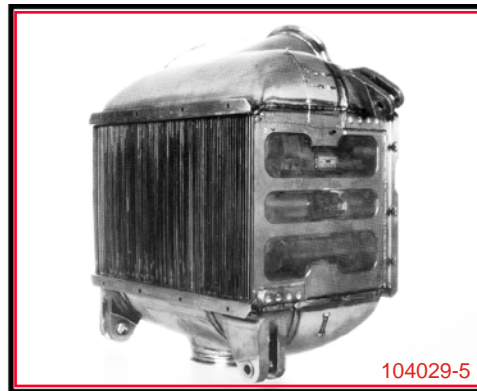
High-Temperature Heat Exchanger Life

- The Question Is Often Asked—What Is The Life of Honeywell High-Temperature Heat Exchangers?
- At Honeywell, Life Is Treated as a Design Requirement—Just Like Thermal Performance
- There Are No “Catalog” Heat Exchangers and Each One Is Custom-Designed to Meet Requirements
- It Isn’t Always Possible to Meet All Requirements, Depending on Design Restraints
 - For Example, Longer-Life Designs May Not Meet Weight or Size Requirements
- Honeywell Commercial Precoolers Are Typically Designed for Much Longer Life Than Military Heat Exchangers but Conditions Are Usually Less Severe

Precooler Inconel 625 Heat Exchangers



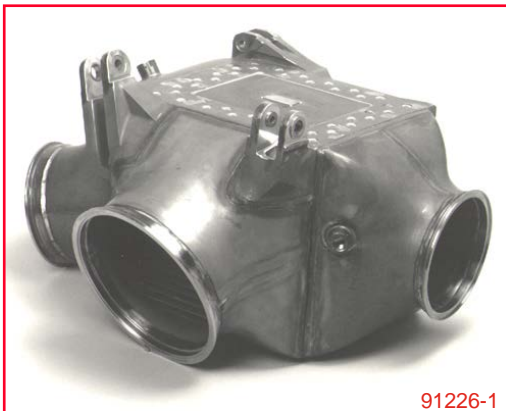
777 PW Precooler
(Plate Fin)



777 GE Precooler
(Plate Fin)



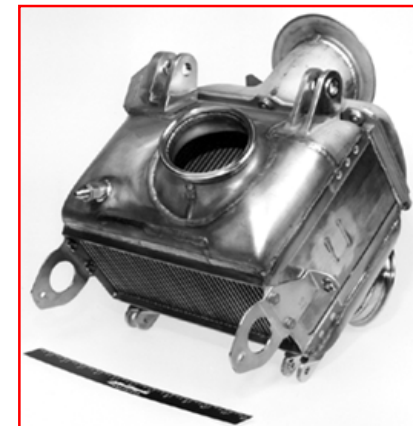
777 RR Precooler
Plate Fin



757-200 PW Precooler
(Plate Fin)



757-300 RR Precooler
(Plate Fin)



B737NG Precooler
(Plate Fin)

A350 Precooler



Haynes 282 Subscale Heat Exchanger

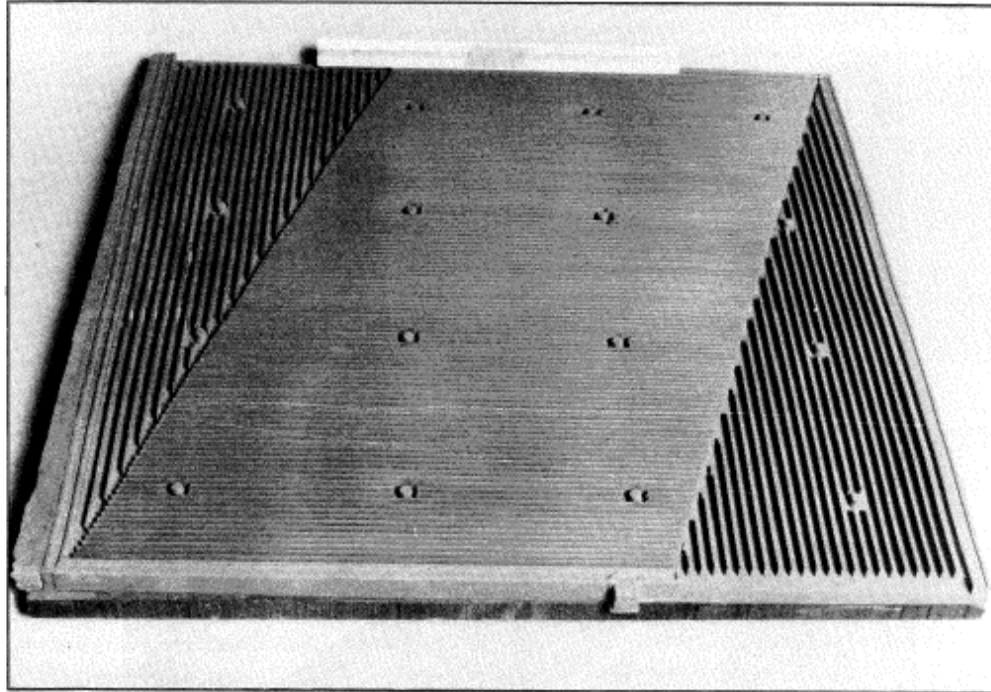


B11-230-95

Reaction-Bonded Silicon Nitride (RBSN) Recuperator Module



2-Ft-Sq Silicon Carbide Finned Plate



Silicon Carbide Tubular Heat Exchanger



F-40113

Heat Exchanger Additive Manufacturing

- Additive Manufacture (AM) of Heat Exchangers May Provide Some Benefits
 - It Is Not Yet Clear What those Benefits Really Are
 - Benefits Will Vary for Different Applications
- One Present Limitation for Aerospace Heat Exchangers Is that the Minimum Viable Material Thicknesses Are Considerably Greater than State-of-the-Art, Resulting in Unacceptable Weight Increases
- One Mitigating Factor Is that the Relatively Thick Walls that Will Be Required for the High-Temperature, High-Pressure Modular Power System Heat Exchangers May Be within AM Capability
- AM Heat Exchangers Must Be Designed for AM—Following the Industry Practice of DFM (Design for Manufacturing)

Heat Exchanger Additive Manufacturing **Honeywell**

Current Heat Exchanger Design and Fabrication Limitations

- Forming Techniques
 - ♦Rolling, Forging, Machining
- Joining Techniques
 - ♦Brazing, Welding, Mechanical Bonding
 - ♦Potential Points of Weakness Exist
- High Part Count
- Labor-Intensive--Potential Rework Needed
- Long Lead-Times

AM Heat Exchanger Design and Fabrication Opportunities

- Fabricate Multi-Piece Assemblies as One Part
 - ♦No Joining Techniques Required
- Greatly Reduced Lead-Times
- Greatly Reduced Part Count
- Potential for Conformal Shapes or Design Features that Are Not Currently Practical
- Automate the Build Process--Less Rework
- Reduce Weight

Challenges for Heat Exchanger AM

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Plate Fin and Tubular Heat Exchangers

- Building Leak-Proof Thin Heat Transfer Surfaces
 - ♦ Fins: 0.003-0.005" Thick; Tubes: 0.010-0.012" Thick (Typical)
 - Actual Thicknesses Would Depend on Heat Exchanger Requirements
 - Reduce Porosity (Fins Can Have Porosity)
- Printing Self-Supporting Structures During the Build Process
- Designing a Path for Powder Removal
- Improving Surface Finish
 - ♦ Roughness Can Be Very Deleterious to Pressure Drop
- Developing In-Process Sensing and Monitoring
- Performing Stress, Thermal, and CFD Analysis on Non-Traditional Designs
- Lack of Available Mechanical Property Data

Significant Potential Upside but at Low TRL **Honeywell**

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