Science & Technology Facilities Council

Advanced Manufacturing applied to Cryocoolers for Space Applications

M Crook

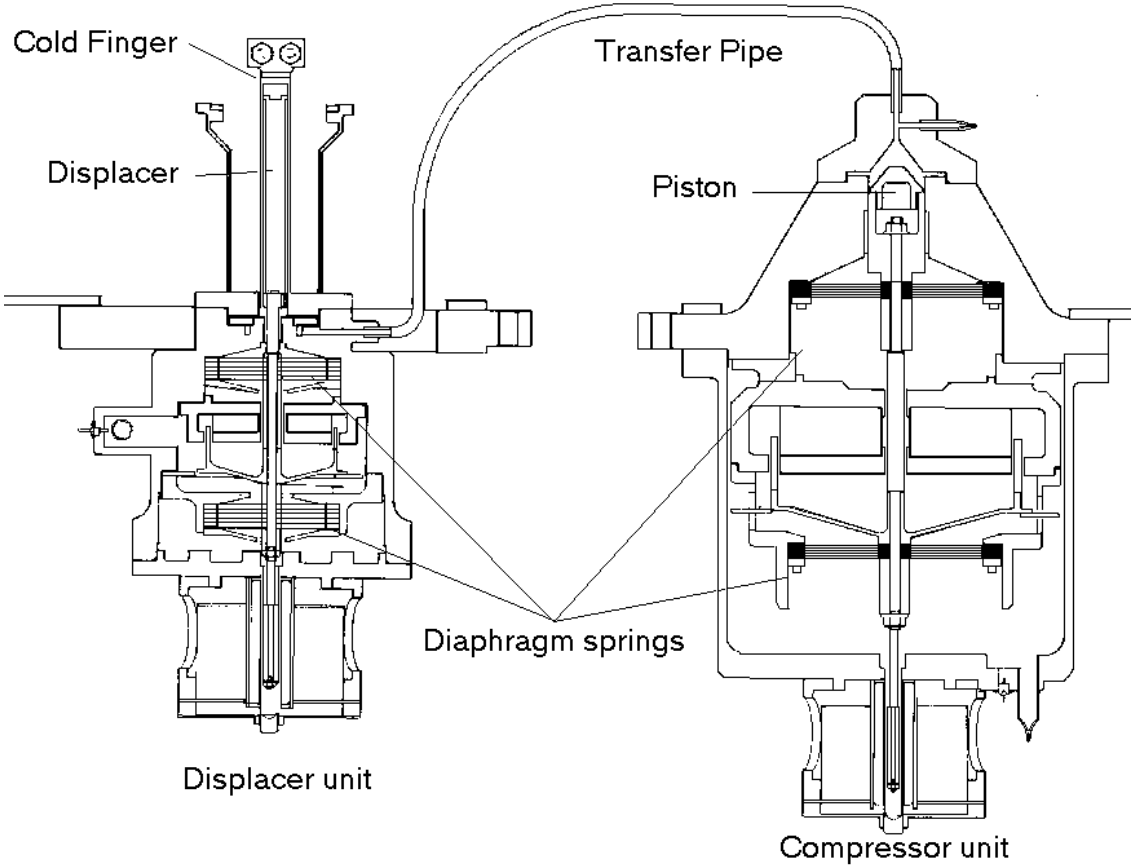
CEOI Challenge Workshop 11th Feb 2016 RAL

Science & Technology Facilities Council
Technology
Rutherford Appleton Laboratory

Science & Technology Facilities Council

Cryocooler Overview

- **Early example of single stage 50-80K split Stirling cycle cooler for ESA**
  - Linear motor mechanisms with flexure bearing suspension
  - No lubrication - non contacting pistons with 10µm clearance
  - 40Hz operation +10years lifetime with zero maintenance

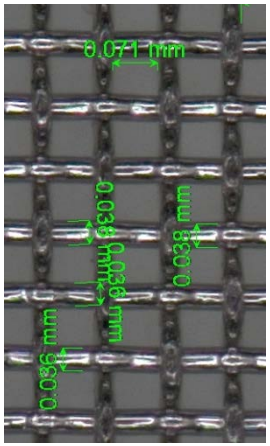


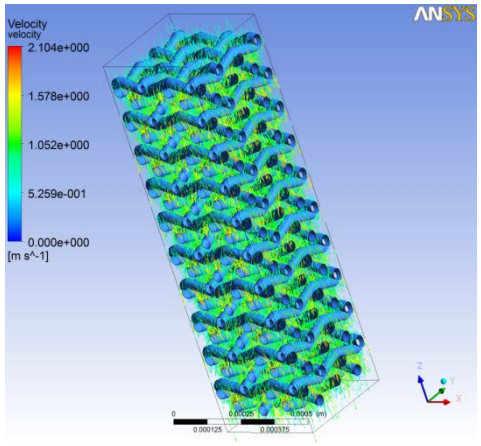
- Conventional manufacturing techniques are slowing progress

Case study - Regenerator

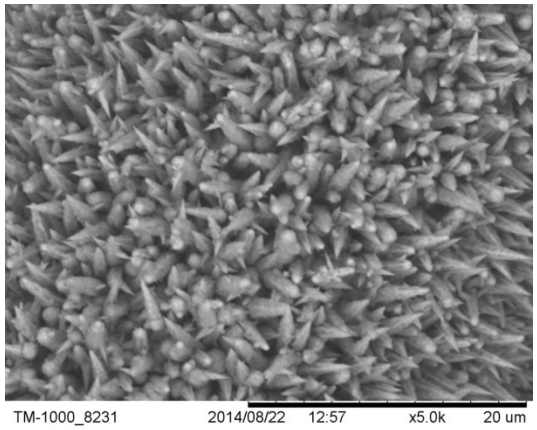
Science & Technology Facilities Council

- **Example: Regenerator (most critical cryocooler component for performance)**
- Conflicting requirements
  - low pressure drop
  - high heat transfer area
  - low axial thermal conductivity
  - high radial thermal conductivity
  - high heat capacity (exotic materials)

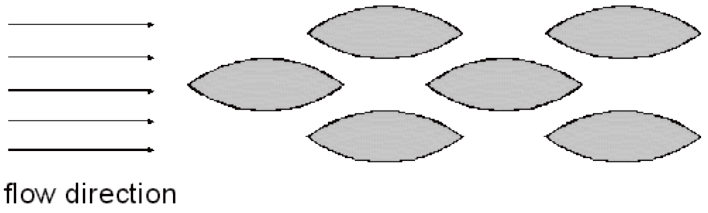




- **Widely used compromise is woven wire mesh which offers a trade-off between heat transfer area and flow pressure drop losses as well as low axial thermal conductivity**



- **Advanced manufacturing possibilities**
- copper dendroid coating on conventional mesh to increase surface area
- Geometries previously studied by CFD* could now be realised by additive manufacturing micro-matrix techniques
- typical dimension required is 40um



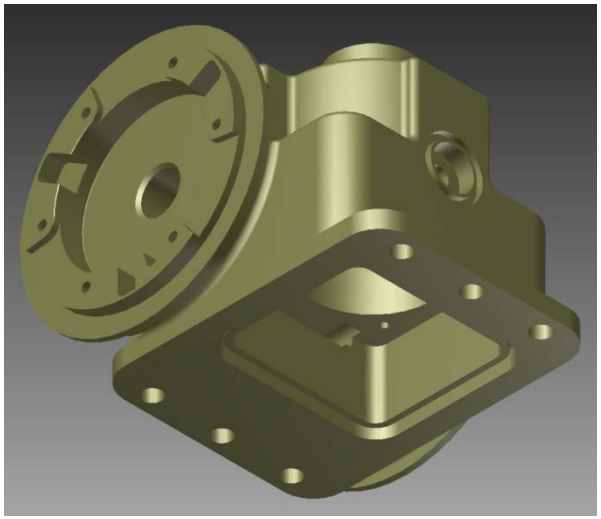
* eg see Ruhlich & Quack Cryocoolers 10 1999

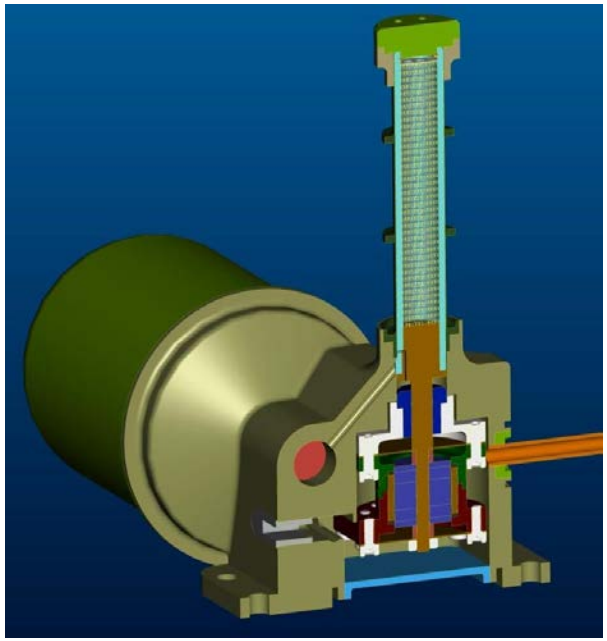
Science & Technology Facilities Council

Case study - Cooler Body

- **Eg: Small Scale Cooler (600g 145x70x 60mm)**
- Complicated shape
  - driven by mass and size reductions
- Interface for moving mechanisms
  - high bore tolerances (5µm cylindricity and perpendicularity, <0.8µm surface finish)
- Mechanical and Thermal interface
  - temperature gradient >200°C
  - joining of different materials (need good and bad thermal conductors)
  - cold finger 100µm wall thickness
  - pressure containment vessel
- Awkward internal gas flow channels
  - flow losses could be reduced
- Awkward electrical wire routing
  - part count reduction
  - easier assembly

- **Compromises in geometry and materials have been made to enable manufacture with conventional techniques**

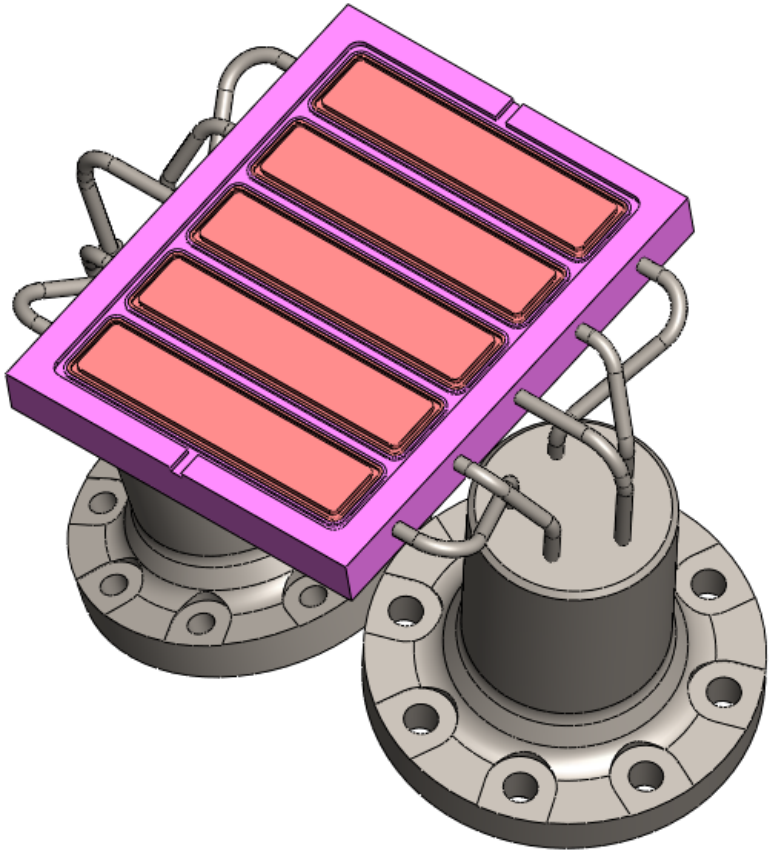




Science & Technology Facilities Council

Case study – Heat Exchanger

- **Example: Stirling Engine Hot Heat Exchanger operating at 650°C**
- ESA project for power generation in space from radioisotopic heat source
- conventional manufacturing techniques complicated to obtain fluid flow and heat transfer



Heater
Inconel 718 housing with six pockets having a heat transfer/fluid flow element welded into each pocket

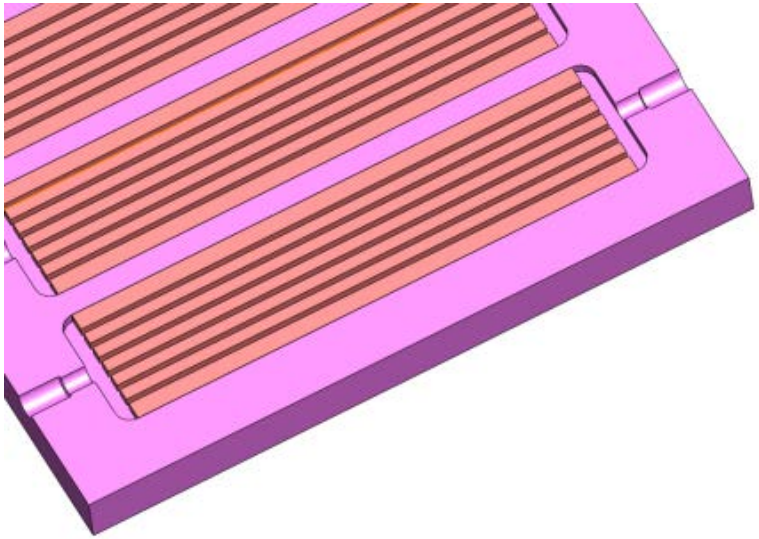
Transfer pipes
Inconel 718 inlet and outlet pipes into two manifolds attached to the Stirling engine hot finger. All pipes equal lengths

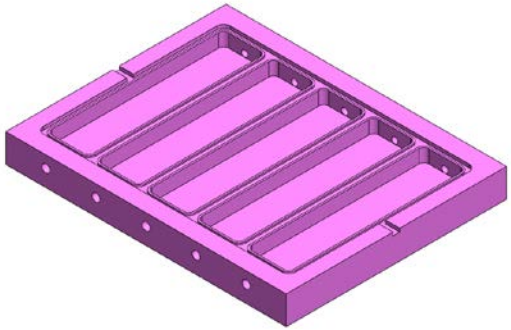
Case study – Heat Exchanger

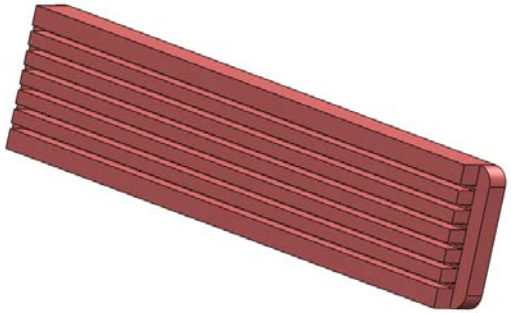
Science & Technology Facilities Council

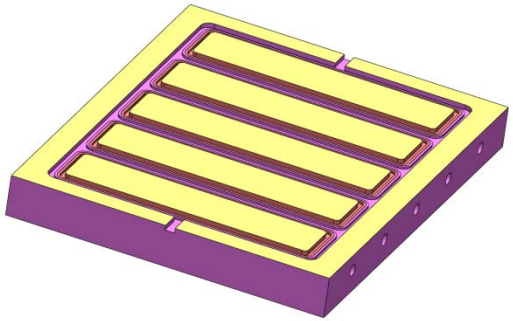
Conventional Manufacture

1. Machine housing
2. Machine overall shape of the element body
3. Wire EDM slots in element
4. Laser weld elements into body
5. Heat treatment for stress relief
6. Skim top and bottom faces for flatness
7. Manufacture inlet and exit flanges
8. Bend 12 OFF transfer pipes
9. Vacuum braze pipes/manifold/heater on suitable fixture







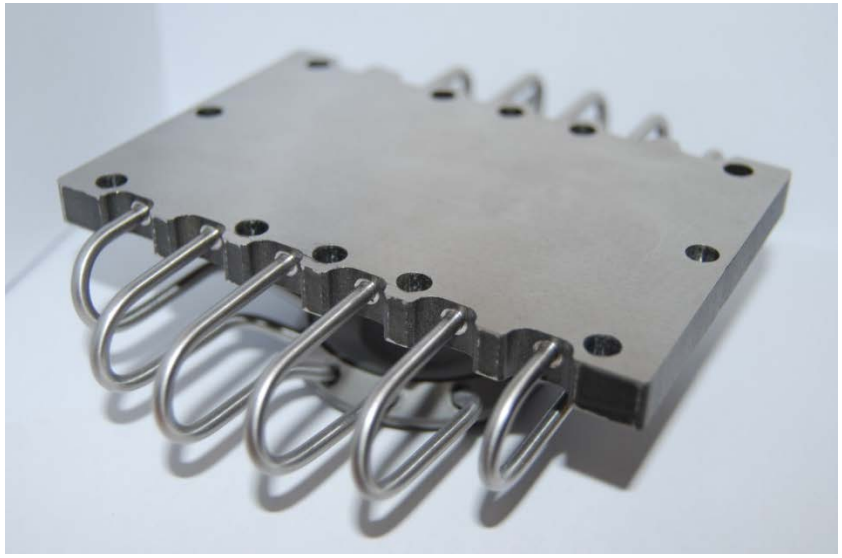


Science & Technology Facilities Council

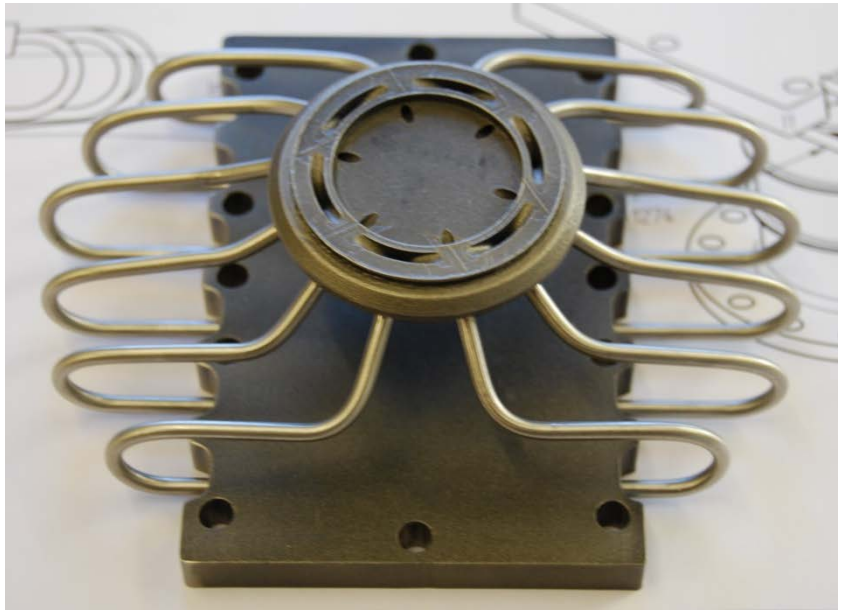
Case study – Heat Exchanger

Additive Manufacture (initial step)

Taking advantage of additive manufacturing possibilities to redesign the manifolds with shaped and separated inlet and exit channels in a single manifold to optimise performance



1. Manufacture heater in one piece
2. Inconel 718 heat treatment process
3. Skim top face for flatness
4. Manufacture inlet exit flange in one piece
5. Bend 12 OFF transfer pipes
6. Vacuum braze pipes/manifold/heater on suitable fixture

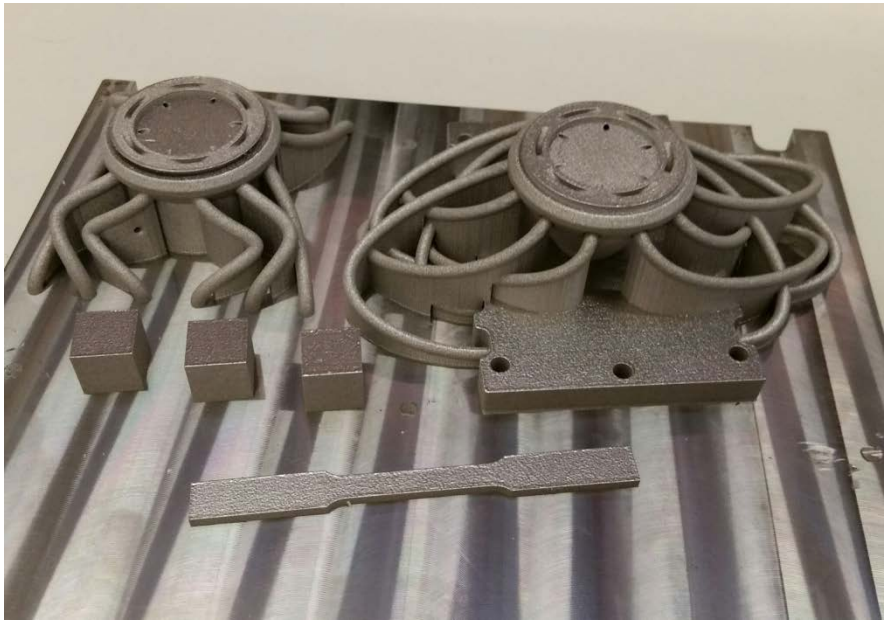


Science & Technology Facilities Council

Case study – Heat Exchanger

Additive Manufacture (next step)

Manufacture the full assembly in a single piece. Requires heat treatment and support removal.



Additive Manufacture (final step)

Re-design to incorporate a manifold and shaped flow splitter into the heater plate. Single pipe-in-pipe transfer line link (counterflow inlet/exit). manufacture in one operation, easy support removal, optimised flow channel geometry and superior mechanical performance

Science & Technology Facilities Council

Summary

- Miniature cryocoolers for space applications under development for +30years.
- Conventional manufacturing techniques are constraining our imaginations.
- Advanced manufacturing techniques now offer the possibility of realising in practice improvements that could only previously be theorised.
- Manufacturing cost reductions with performance improvements are opening commercial opportunities in terrestrial markets.

Science & Technology
Facilities Council

END