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Advanced Heat Exchangers for Enhanced Air-Side Performance: A Design and Manufacturing Perspective

Dr. Arun Muley

Boeing Research and Technology, Huntington Beach, CA, USA

in

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Presentation Outline

- **Introduction**

- **Current SOA and Need for "Next Generation HX Technology"**
  - Selective examples: aerospace, automotive, process and power
    - Air-side performance improvement
  - Design Considerations
    - System requirements and integration
  - "Next Generation" Cooling Technology Development
    - Multidisciplinary approach for technology and product roadmap

- **Closing Remarks**

Advanced Thermal Management Systems

- **High performance, compact, low cost heat exchanger technology needed for increasing heating and cooling requirements in various TM systems**

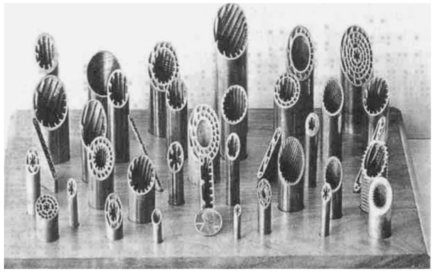
- **Novel compact heat exchangers solutions are needed in**
  - **Aerospace**
    - Environmental control, avionics and engine oil cooling systems
  - **Automotive**
    - Waste Heat Recovery and Exhaust gas recirculation system
  - **Power**
    - Thermal management for microturbine and fuel cell systems
  - **Process**
    - Heating /cooling and waste heat recovery systems

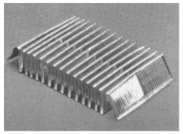
- **Design and fabrication innovations need to address**
  - Accommodate demand for increased performance with minimum pressure loss
  - Reduced size (volume, envelop dimensions, aspect ratio) and/or weight
  - Affordable, **modular** and/or scalable

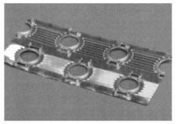
Enhanced Heat Transfer Techniques for Compact Heat Exchangers

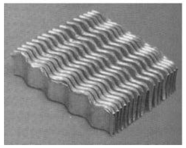
- **Enhanced heat transfer (EHT) techniques provide**
  - Reduction in thermal resistance (1/hA) of a conventional design
    - With or without surface area increase (as obtained from extended /fin surfaces)
- **EHT classification include two major categories**
  - Passive enhancement - most commonly used method
  - Active enhancement - direct input of external power
  - Compound enhancement - use of two or more methods
- **Effectiveness of particular method depends on**
  - Mode of heat transfer and flow regime
    - Single or two phase flow, free or forced convection, laminar or turbulent flow
    - Type of application (two-fluid HX vs. single fluid HS)

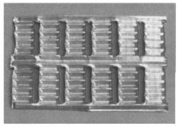
Passive	Active
Treated Surfaces Rough Surfaces Extended Surfaces Displaced enhancement devices Swirl flow devices /surfaces Coiled tubes Surface tension devices Liquid gas additives	Mechanical aids Surface vibration Fluid vibration Electrostatic fields Injection Suction Jet impingement





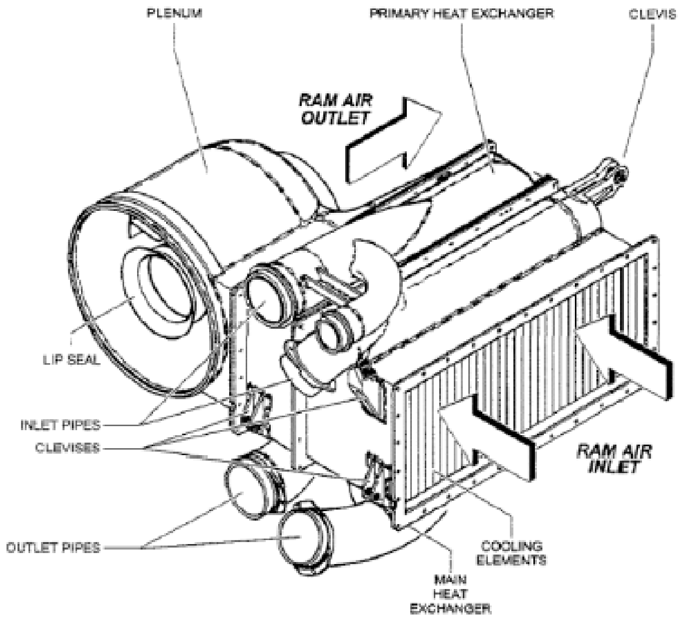




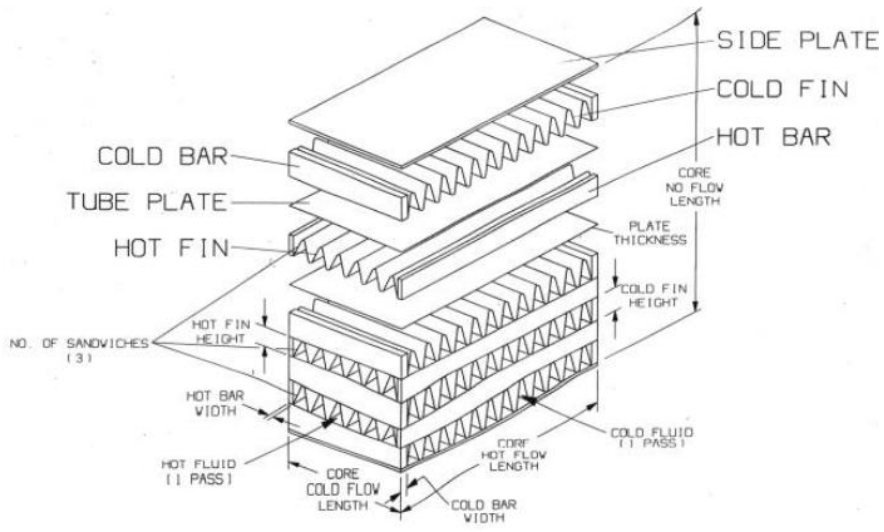


Aerospace Applications – ECS Heat Exchanger

- **Heat transfer enhancement techniques and novel design concepts allow**
  - Increase in performance for fixed size and/or Weight, or conversely
  - Reduction in heat exchanger size and/or weight
    - Reduction in size and weight are not the same



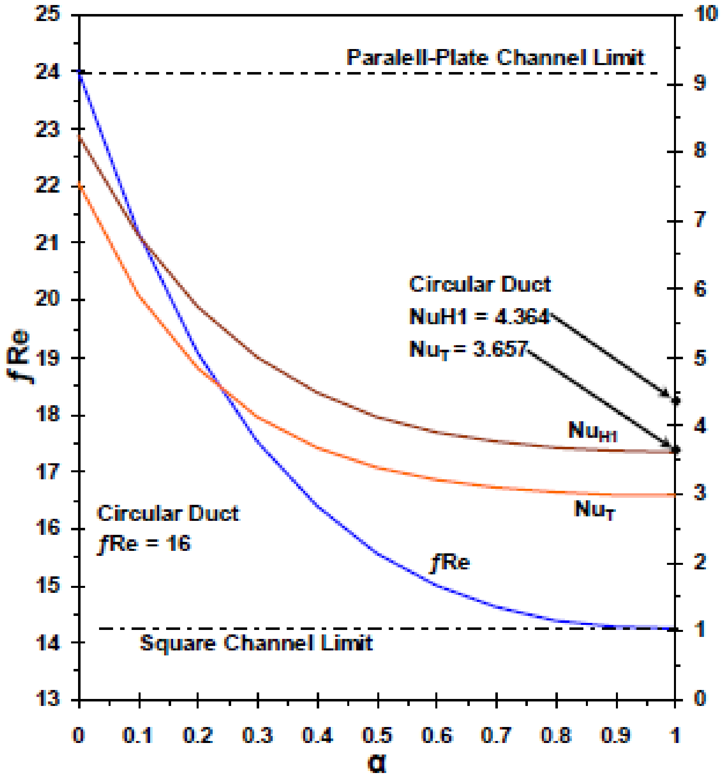
HX layout in a typical Aircraft Air Conditioning (ACS) Pack

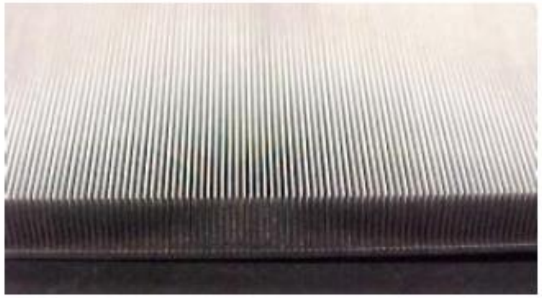
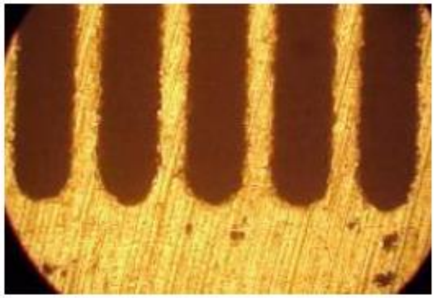


Schematic of a typical single-pass, cross-flow, platefin heat exchanger

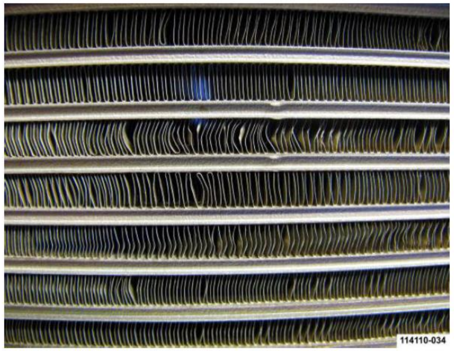
Aerospace Applications– Microchannel Heat Exchangers

- **Flow channel geometry /shape is important for high performance Microchannel HXs**
- **Additive manufacturing or improvements in conventional fabrication methods are needed to resolve current challenges**
- **Additional benefits can be obtained by incorporating compound enhancement methods**



Fabricated Microchannel Fin with AR = 0.069

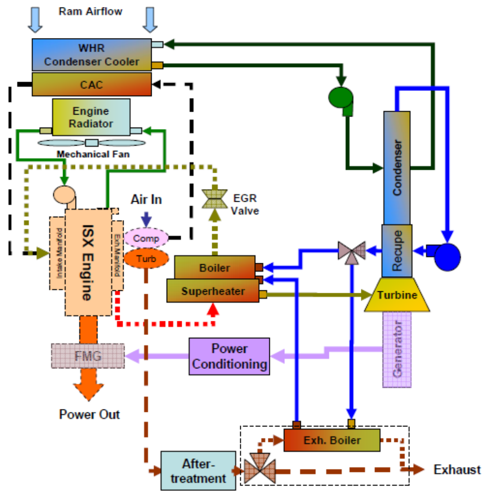



Subscale Microchannel Heat Exchanger

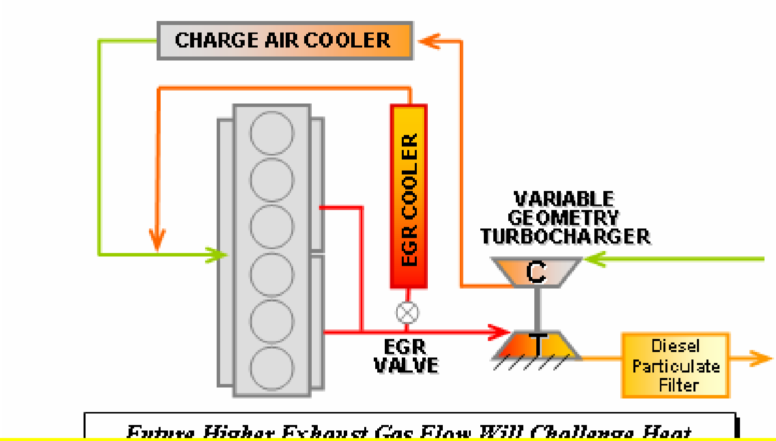
Enhanced microchannel HXs could provided appreciable (20 - 50%) volume / weight improvement over current SOA designs

Automotive Applications :

Organic Rankine Cycle – Cummins System



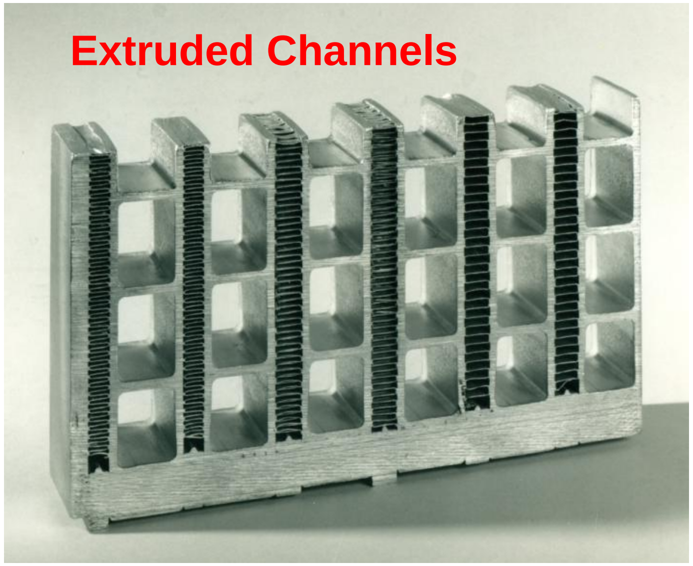
EGR Cooler for a Typical High Pressure EGR System



Improved material, hybrid HX core designs coupled with compound enhancement offer potential for appreciably (~30%) higher performance

Process Applications

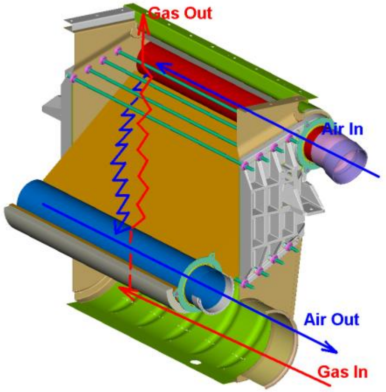
- **Air-Cooled Condensers / Heat Exchangers**
  - Distillation processes and cooling process streams in oil refining and petrochemical industries
  - Organic Rankine Cycle (ORC) of geothermal specifically enhanced geothermal system (EGS) for locations with scarcity of water
  - Emerging power cycle, such as SCO2
  - Heat integrated chemical reactors with high heat of reaction followed by recovery of process heat

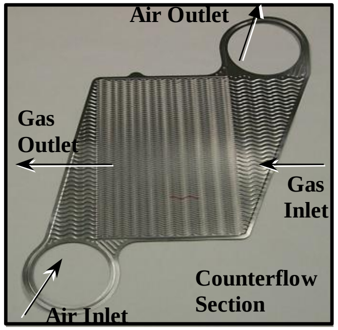


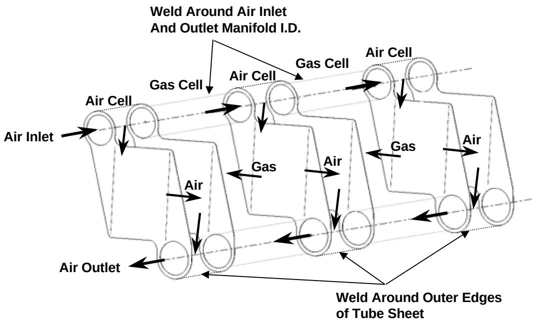
Brazed AL PF Heat Exchanger

Power Generation Applications - Prime Surface Recuperator

- **Several innovative designs have been considered**
  - Plate fin, Tubular and Prime surface
- **Requirements**
  - Thermal-Hydraulics
    - High thermal effectiveness (~90%)
    - Low pressure loss (dP/P < 5%)
  - Mechanical design
    - Long operating life (~40,000 hours)
    - Steep start and shutdown temperature transients
- **Typical recuperator operating conditions**
  - Flow rates: 40-100 lbm/min
  - Temperature: ~1200 °F; Pressure: ~ 60 psi
- **Wide variety of heat transfer surfaces:**
  - Offset, wavy, plain extended fin surfaces and enhanced tubes
  - SOA design based on a corrugated wavy channel due to high performance and suitability suitable for low-cost high volume production
  - Compared to brazed offset plate-fin 40% smaller volume and 70% lower material cost

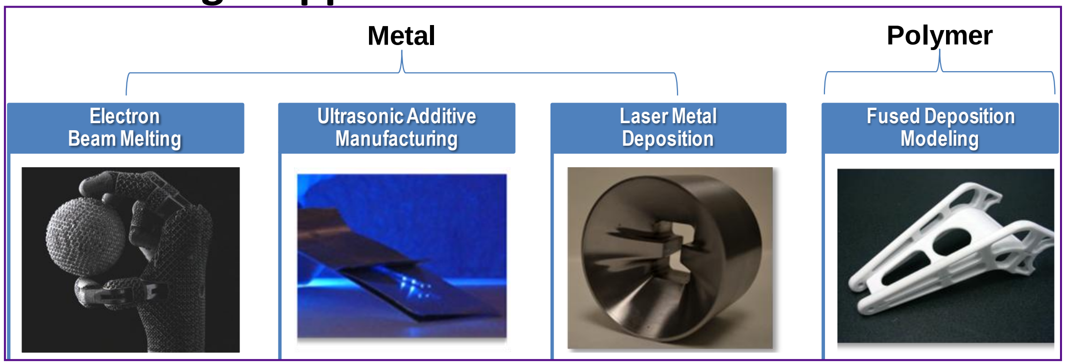


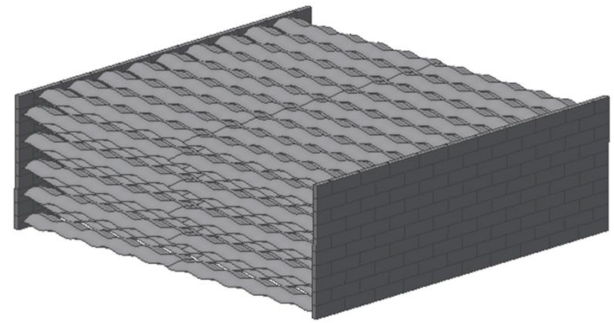




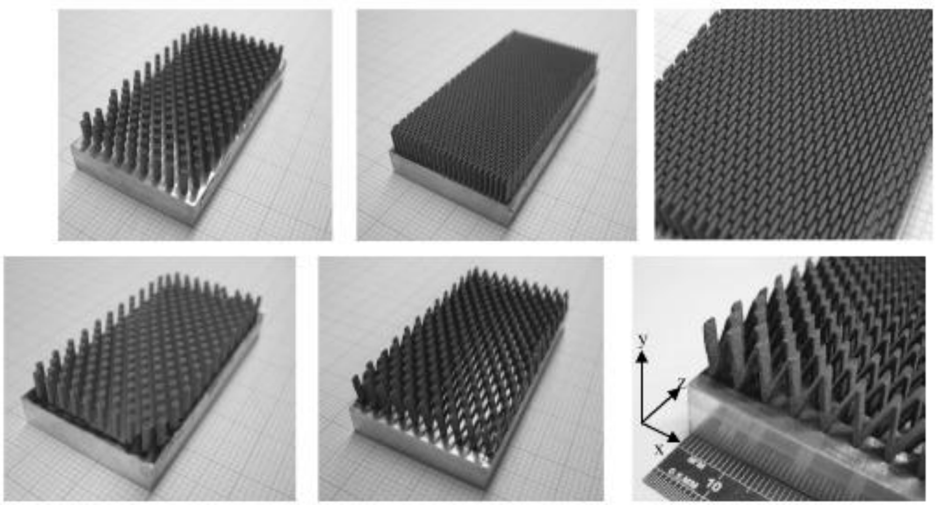
Additive Manufacturing

- **Collaborate with AM equipment providers to develop high-performance materials, low-cost feedstock, processing techniques and in-situ characterization and controls for heat exchanger applications**

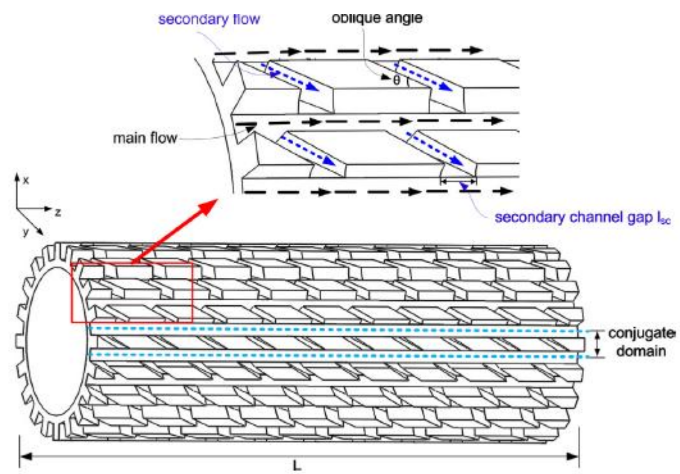




3D Printed Microtruss HX Core



SLM fabricated Pin, Diamond, Ellipse and V-Ellipse Al6061 HS



Cylindrical Oblique Microchannels

Additive Manufacturing is crucial for developing "Next-Generation" heat exchangers

Closing Remarks

- **Air Side heat transfer enhancement plays a critical role in broad heat exchange application across several industries**
- **Novel “Next Generation” technology**
  - ***Heat transfer augmentation – compound enhancement methods***
  - ***Material advancement – High performance, non-metals, superalloys and hybrid materials***
  - ***Fabrication Innovations- Low cost, advanced manufacturing methods***
- **Integrated technology and product development roadmap is needed**
- **Innovations in conventional fabrication methods in conjunction with suitable use of Additive Manufacturing are crucial in obtaining effective cooling solutions for power plant and other TM systems.**

Multidisciplinary and modular Heat Exchanger technology development

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Thank You