National Aeronautics and Space Administration

Thermoacoustic Thermal Management for Electric Aircraft

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NASA Glenn Research Center

Sci-Tech Forum, 6-10 January 2025

Agenda

- Electric Aircraft Thermal Management Need
- TREES Traveling Wave Concepts
- High- and Low-Grade Sources
- TREES 1.0: Initial Low Power System
- TREES 2.0: Acoustic Thermal Amplification
- TREES 2.0: Optical Measurements Utilizing Schlieren System
- Summary
- Acknowledgments
- Questions

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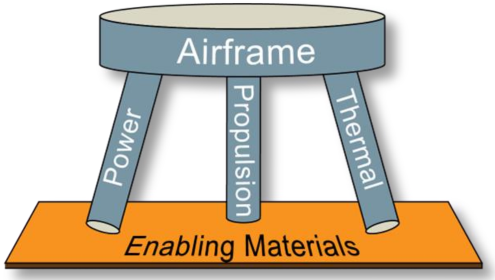
Electric Aircraft Thermal Management Need

Thermal Management Technology	Disadvantage
Ram air HX	Adds weight, aircraft drag, displaces fuel capacity
Convective skin cooling HX	Adds weight, drag, and requires liquid pumping losses
Sinking heat into fuel	Limited thermal capacity due to coking and volume
Sinking heat into lubricating oil	Limited thermal capacity, Low delta T adds HX mass
Active cooling	Reduces propulsive efficiency, Adds weight and maintenance
Phase change cooling	Limited thermal capacity, Adds weight
Heat Pipe, Pumped Multiphase	Does not increase Exergy which impacts mass and efficiency

(Dyson, 2020)



Preferred technology : TREES

(Thermal Recovery Exergy Efficient System)

- improves fuel efficiency
- reduces emissions
- removes heat from:
  - small core engines, more electric composite aircraft, and high-power electric propulsion systems
- reduces vehicle mass
- reduces thermal signature for military

Waste Heat: 200 KW to 6 MW

(VTOL, General Aviation, Small Turboprop, Regional Turboprops/Turbofans, and Single Aisle)

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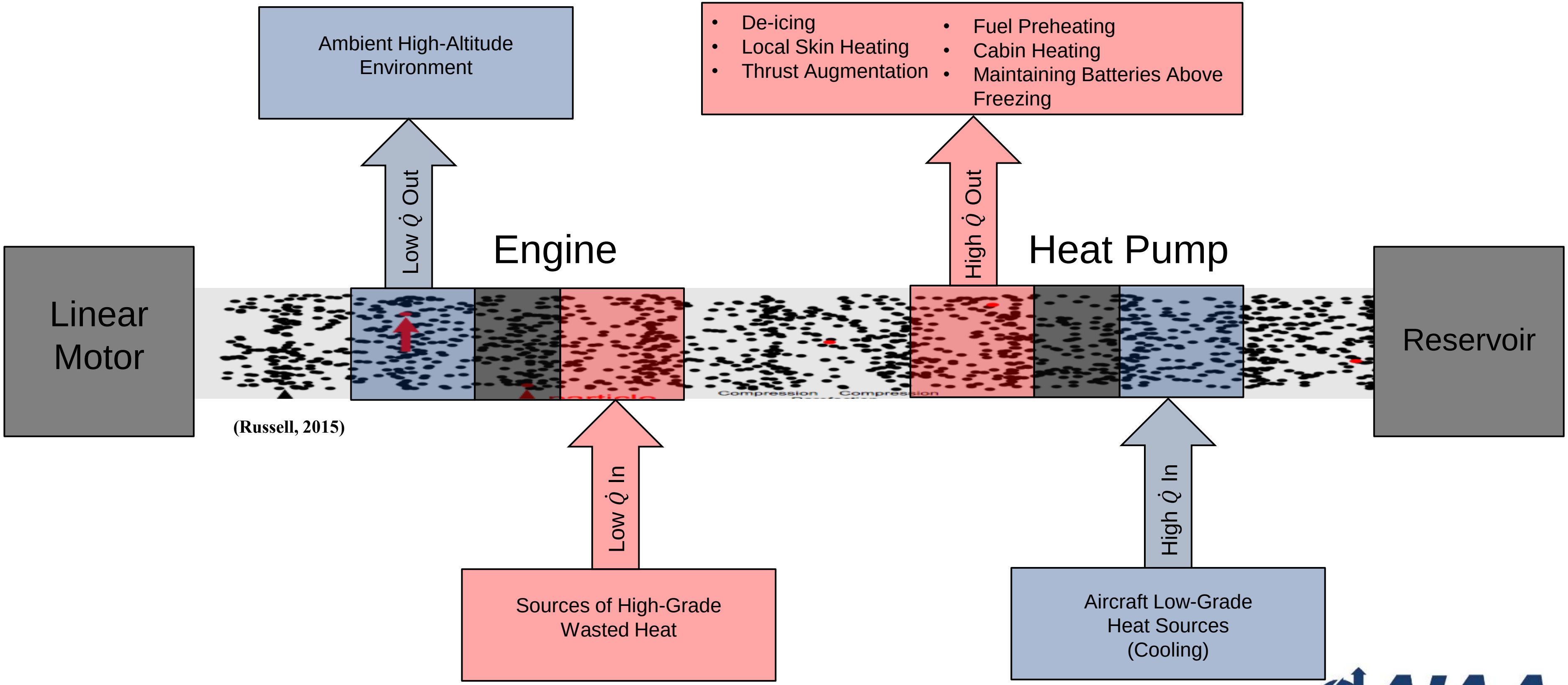
TREES Traveling Wave Concepts



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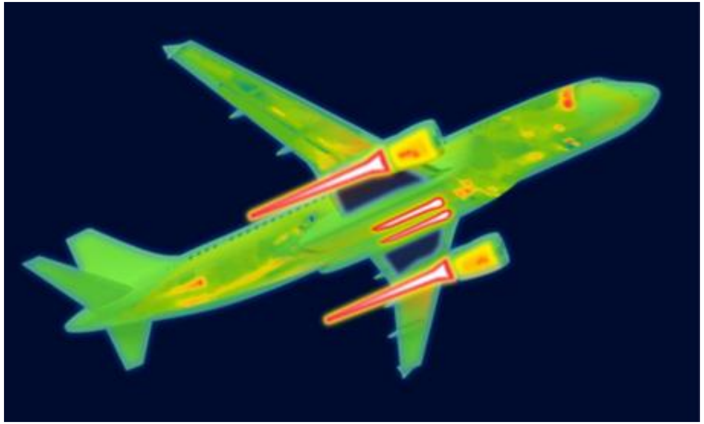
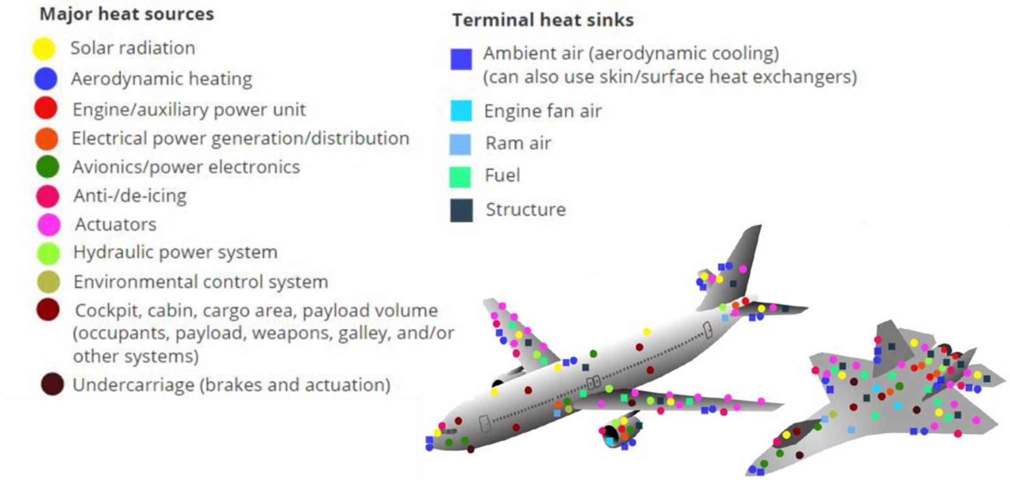
High and Low Exergetic Sources



(Dyson, 2020)



(Heerden et al., 2022)

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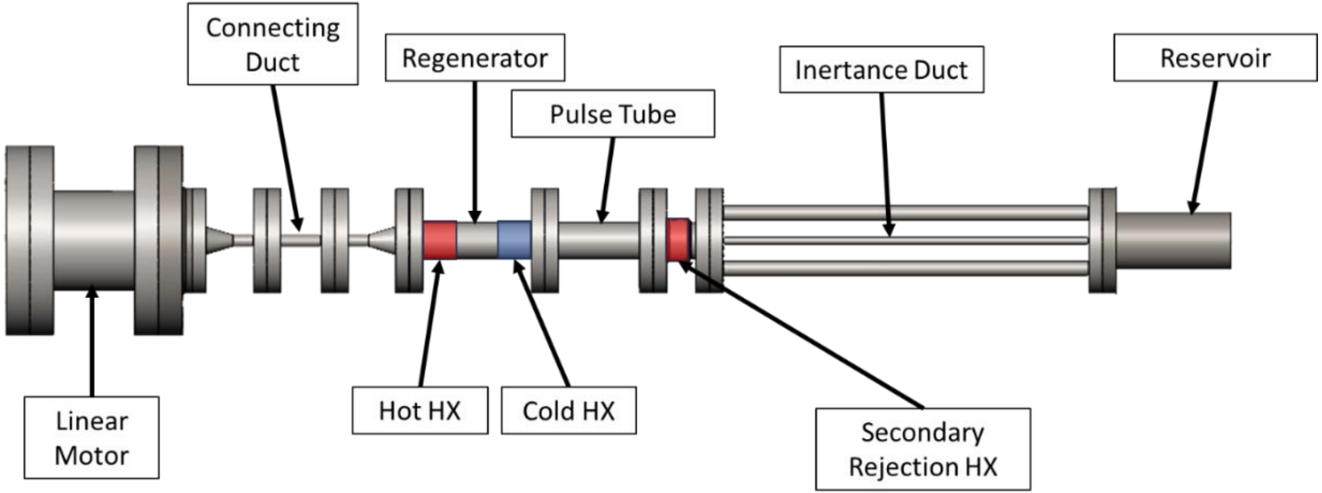
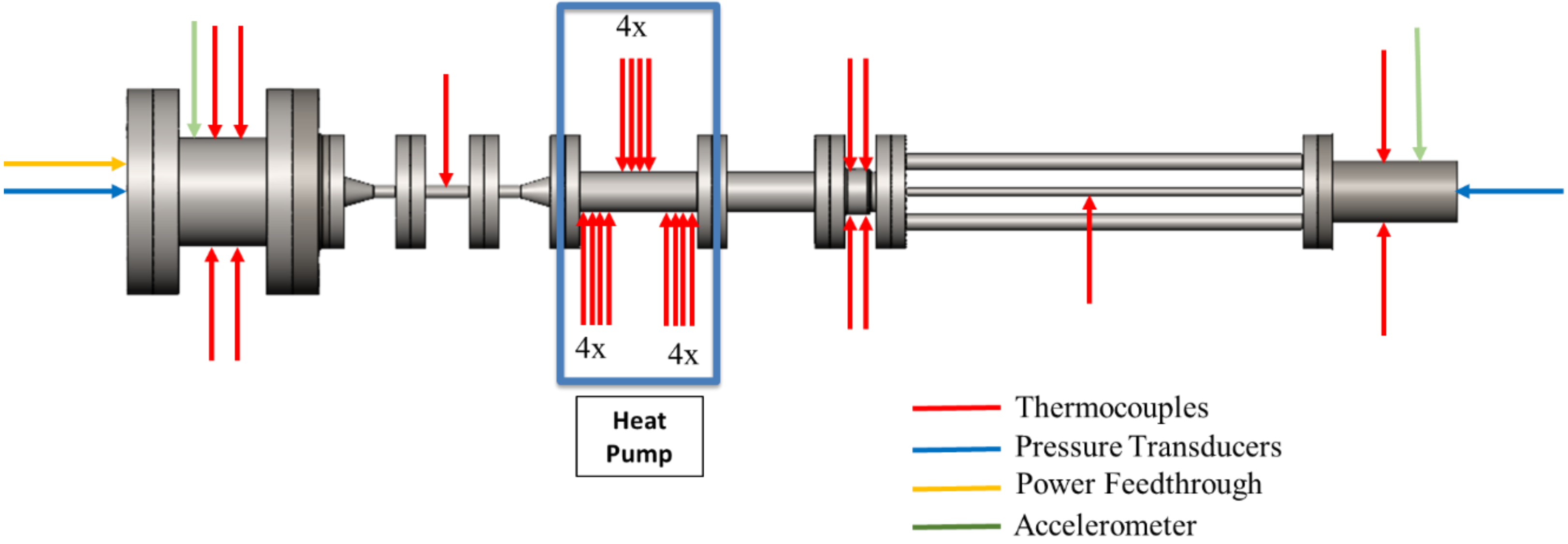
TREES 1.0: Initial Low Power System

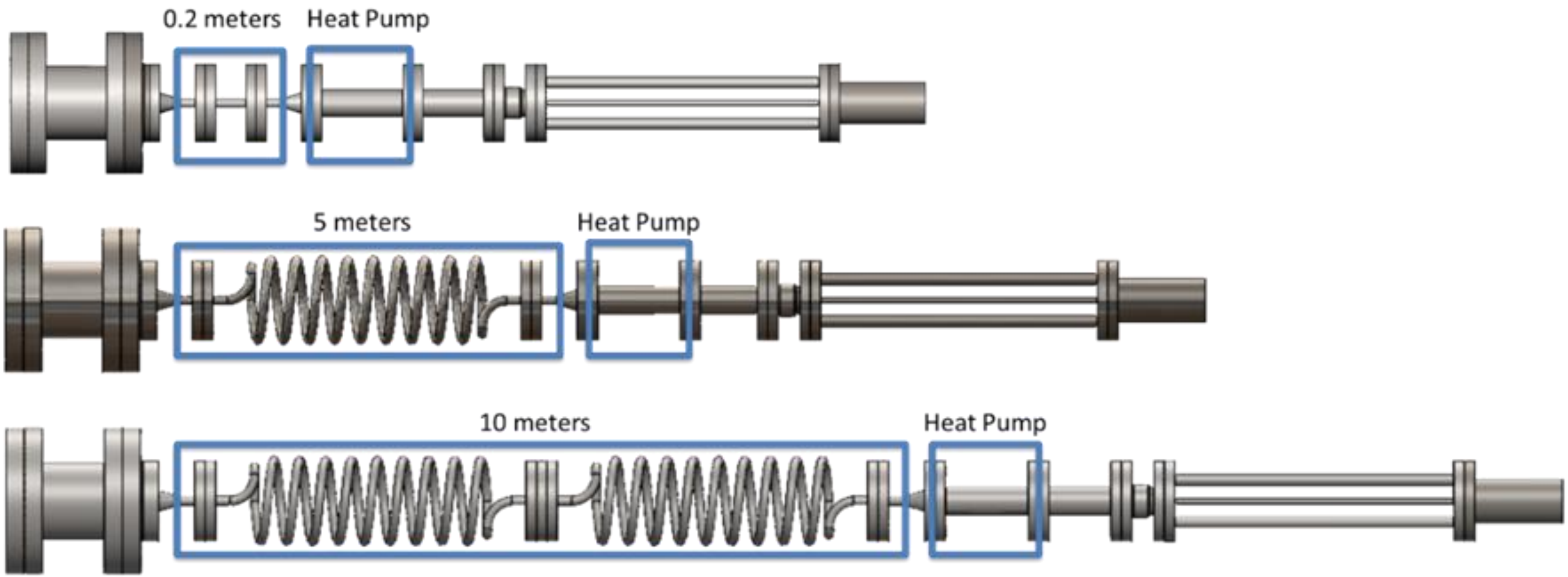


Frequency: 60 HZ
Pressure: 3 MPa
Working Fluid: Helium

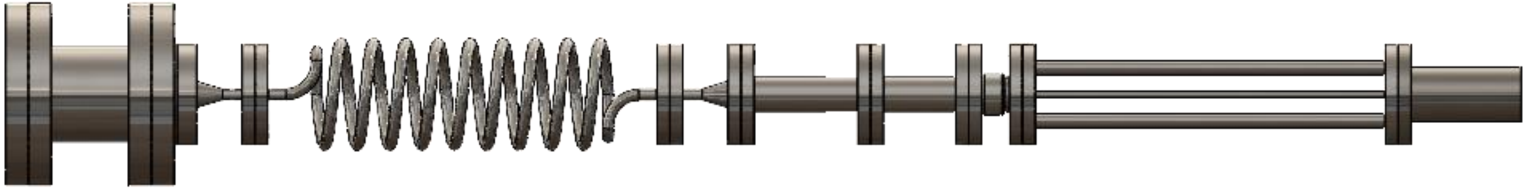
TREES 1.0: Instrumentation



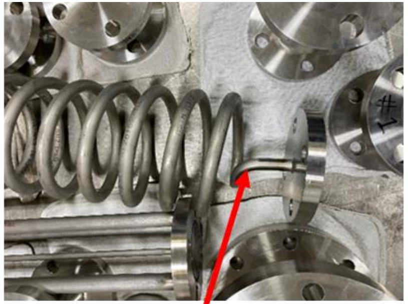
TREES 1.0: Test Campaign



TREES 1.0: 5 Meter Duct Transitions

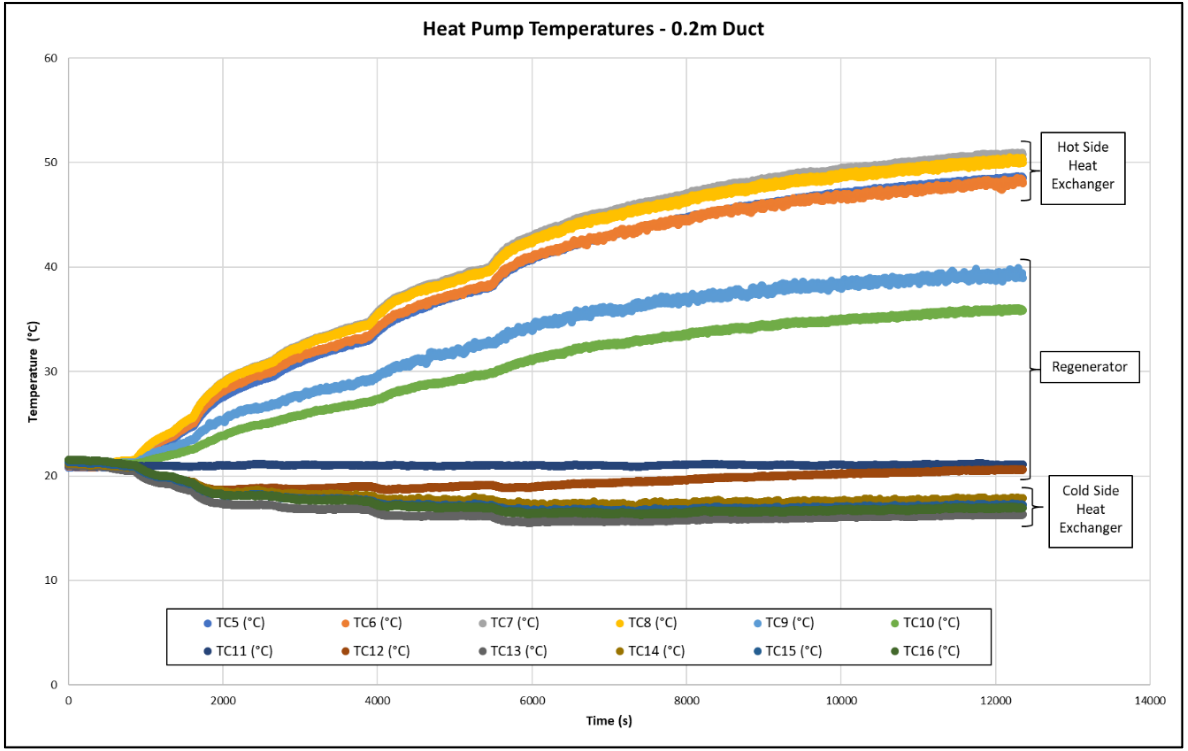


(a) : 90-degree elbows were added at each end of the helical tube component



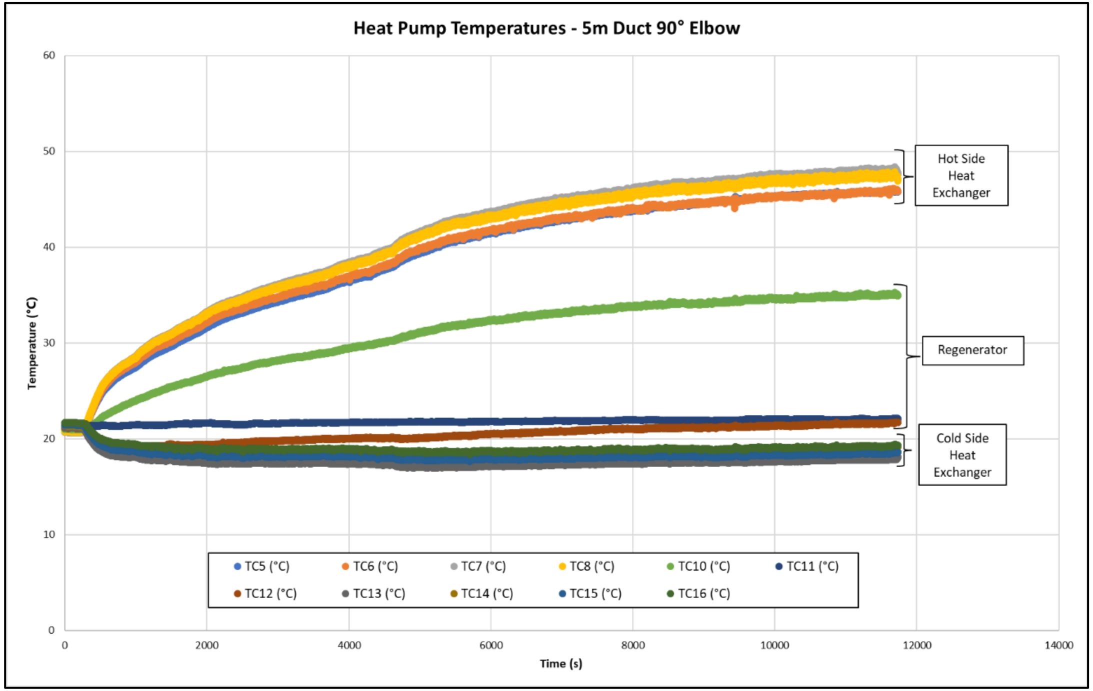
(b) : No 90-degree elbows on the 2nd iteration of helical tube component

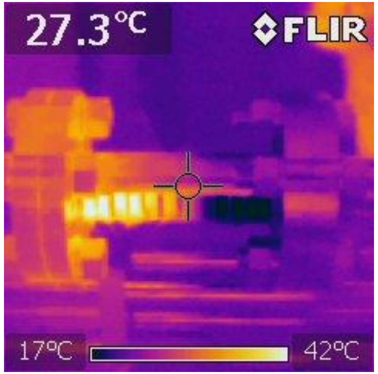
TREES 1.0: Heat Pump Temperature Distribution – 0.2m Duct

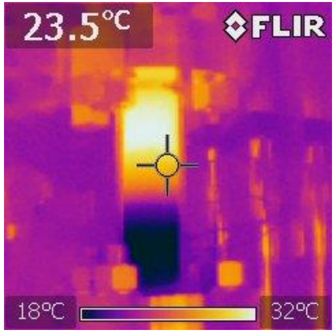


Maximum Temperature (ºC)	Minimum Temperature (ºC)	Δ Temperature (ºC)
50.83	16.42	34.42

TREES 1.0: Heat Pump Temperature Distribution – 5m Duct 90° Elbow

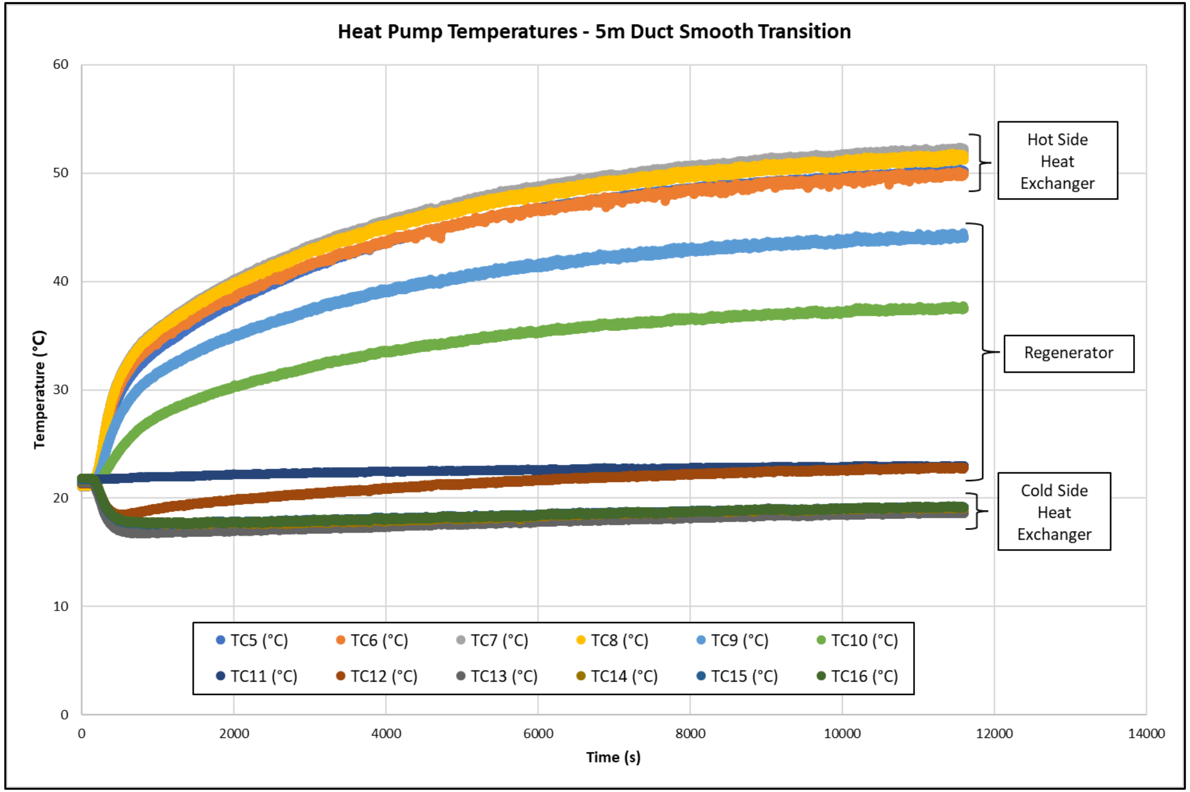






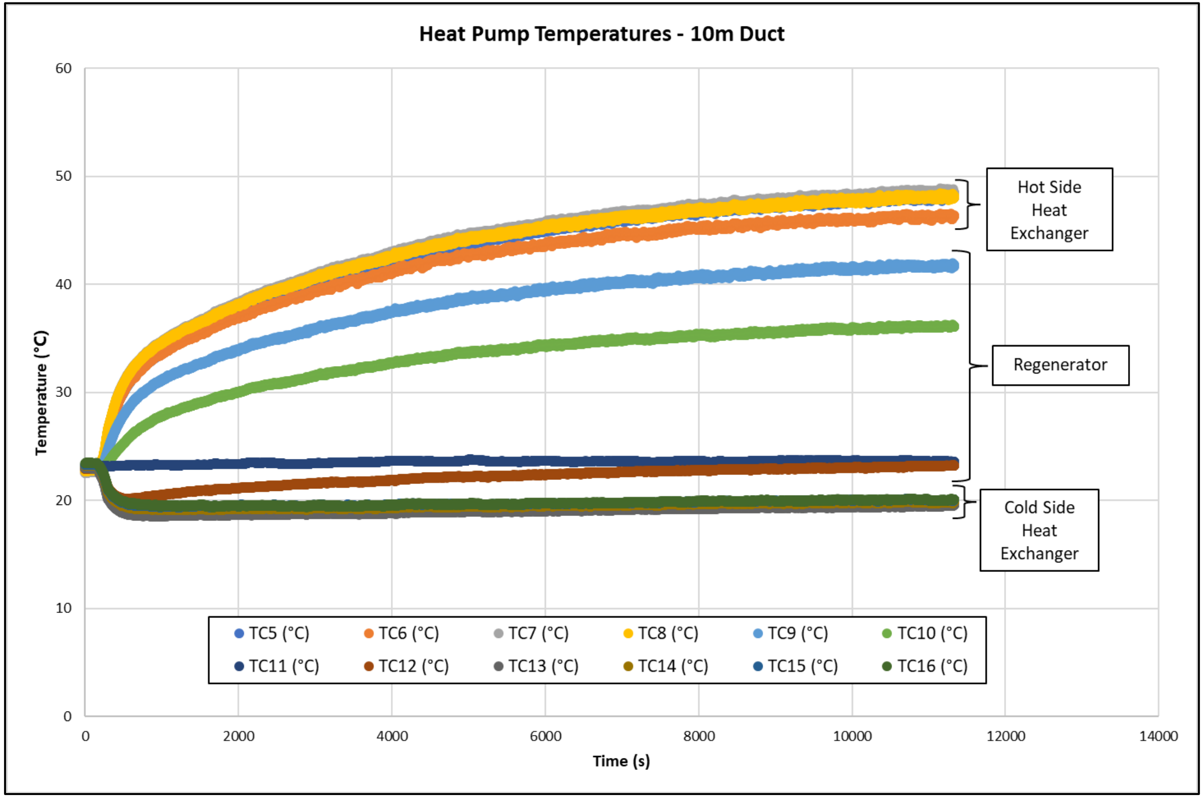
Maximum Temperature (°C)	Minimum Temperature (°C)	Δ Temperature (°C)
47.62	18.06	29.56

TREES 1.0: Heat Pump Temperature Distribution – 5m Smooth Duct



Maximum Temperature (ºC)	Minimum Temperature (ºC)	Δ Temperature (ºC)
51.53	18.56	32.97

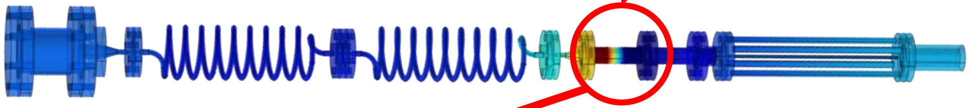
TREES 1.0: Temperature Distribution – 10 m Duct

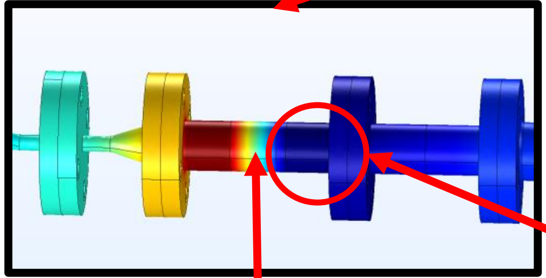


Maximum Temperature (ºC)	Minimum Temperature (ºC)	Δ Temperature (ºC)
48.38	19.53	28.85

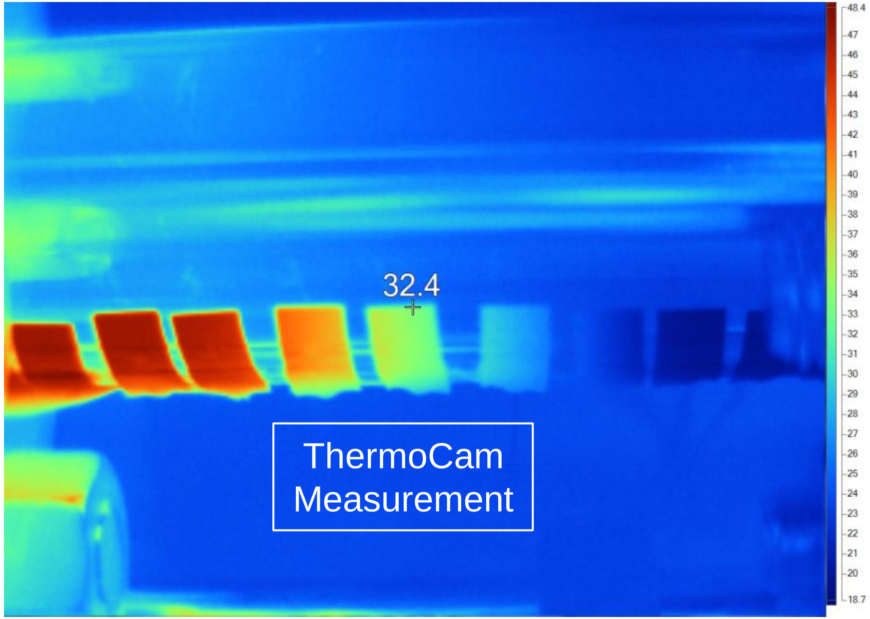
Connecting Duct Length (m)	Maximum Temperature (°C)	Minimum Temperature (°C)	ΔT (°C)
0.2	50.83	16.42	34.42
5 (90° Elbow)	47.62	18.06	29.56
5 (Smooth)	51.53	18.56	32.97
10	48.38	19.53	28.85

TREES 1.0: COMSOL and Sage Comparison – 10m Duct





34 °C



<u>COMSOL Qlifted Result</u>
Qlifted : 9.42 Watts
Rig Motor Input : 37 Watts

<u>Sage Qlifted Result</u>
Qlifted : 16 Watts
Sage Motor Input : 37 Watts

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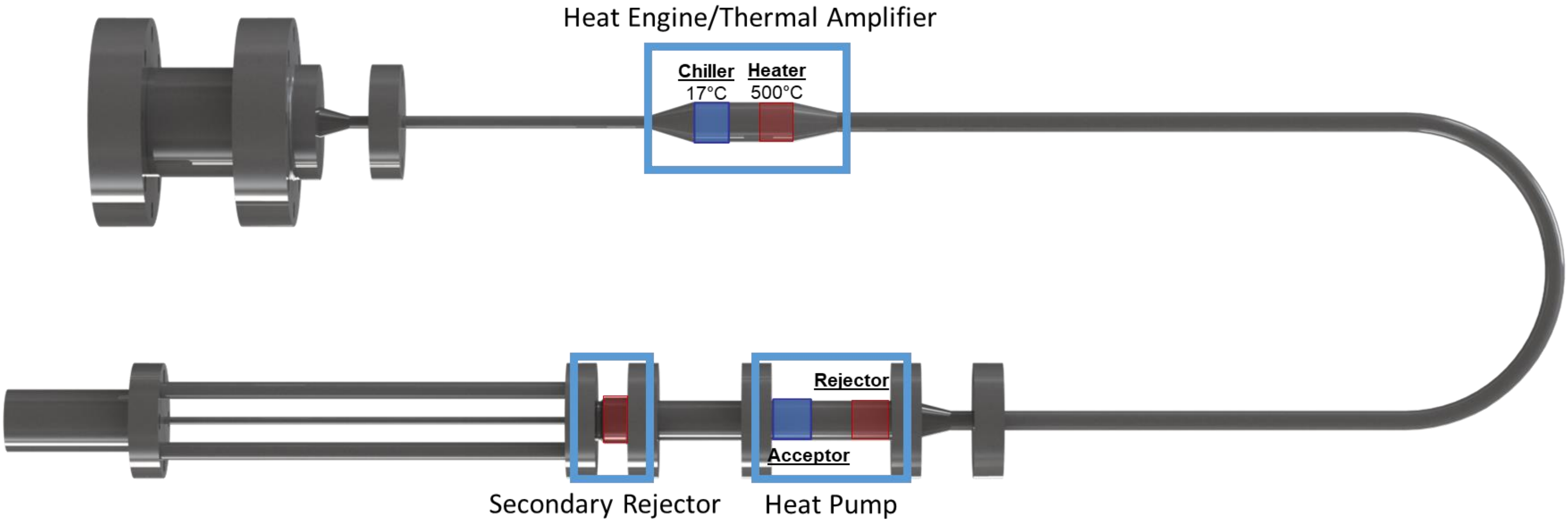
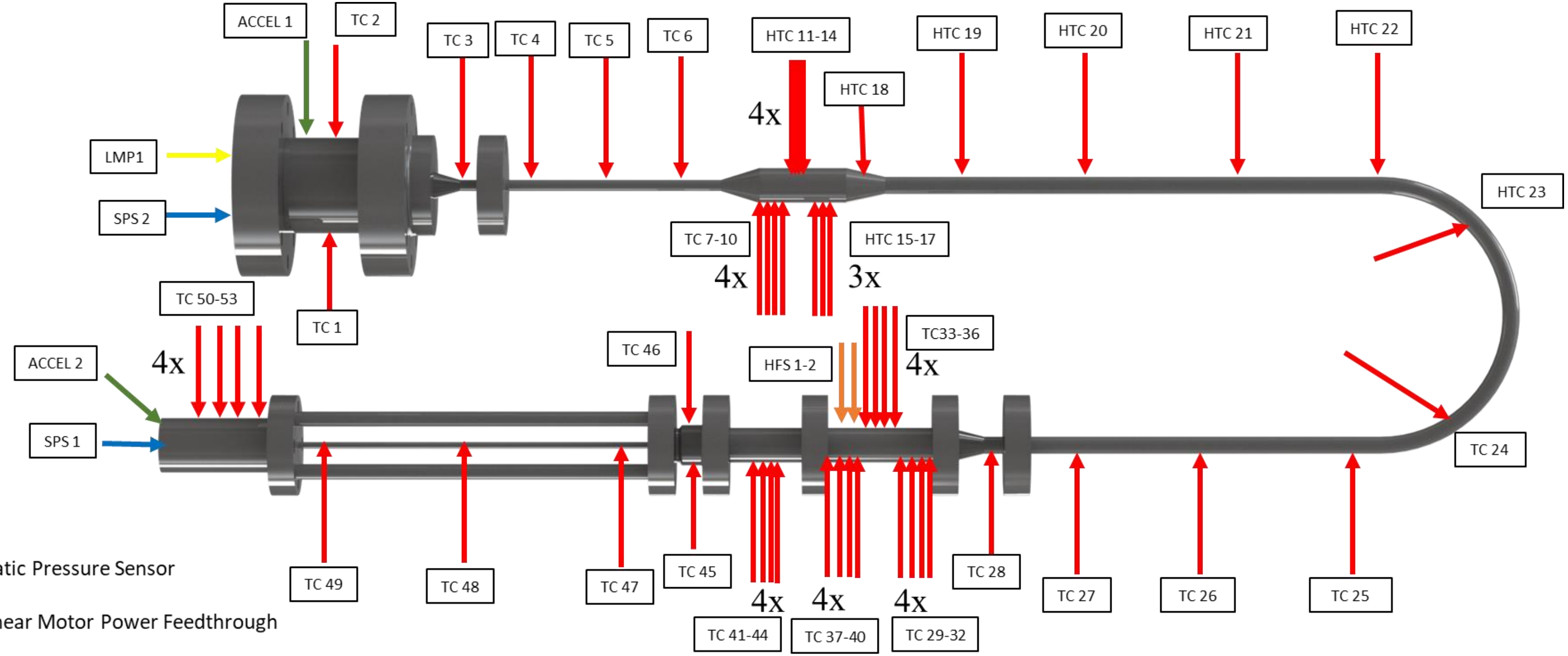
TREES 2.0: Acoustic Power Amplification



TREES 2.0: Instrumentation



: Static Pressure Sensor

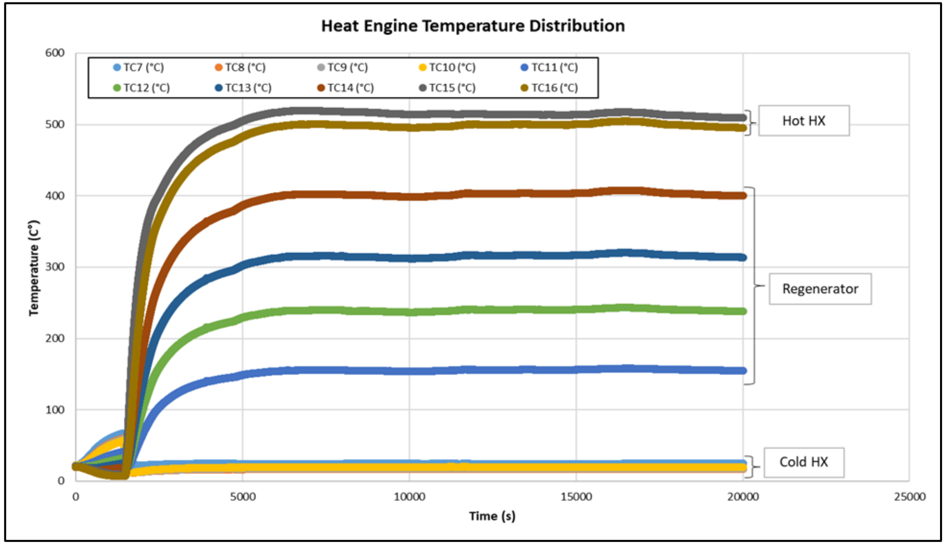
: Linear Motor Power Feedthrough

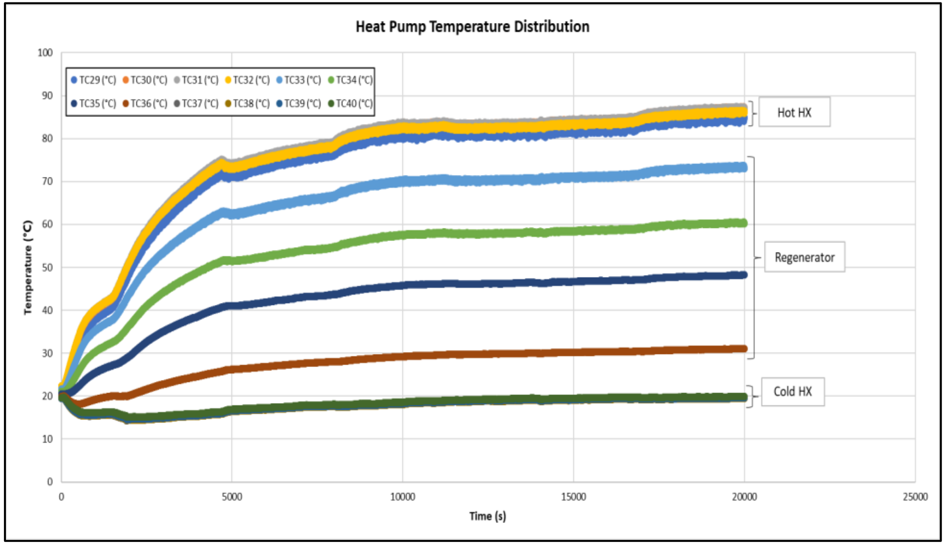
: Accelerometer

: Thermocouples

: Heat Flux Sensors

TREES 2.0: Max Temperature



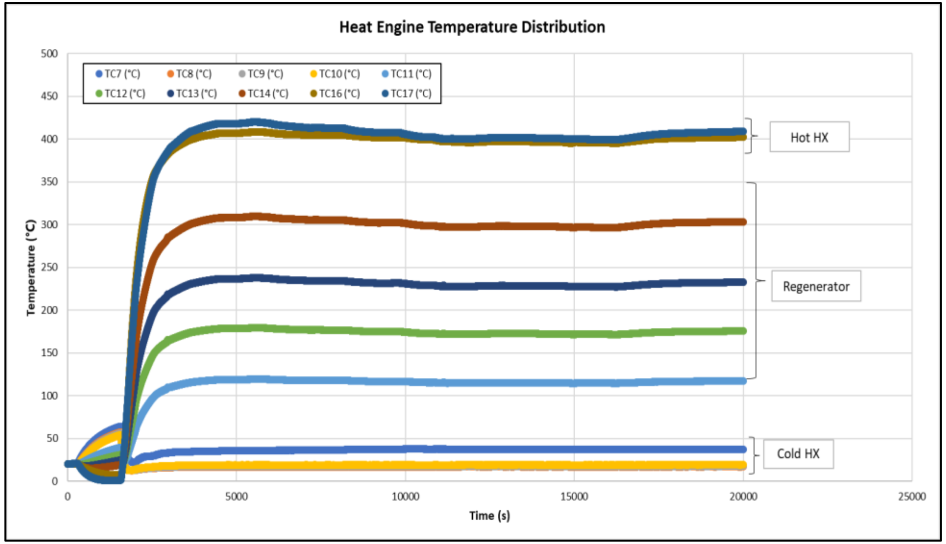


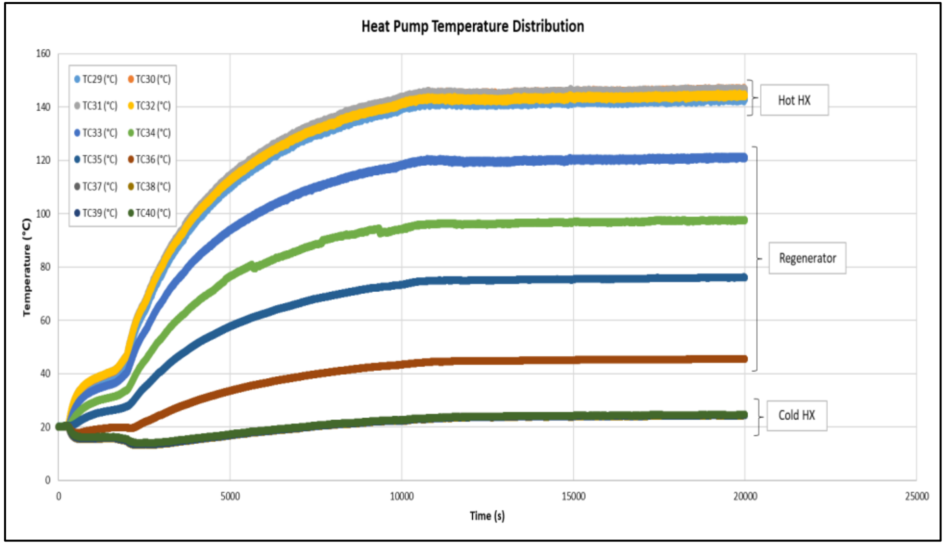
Maximum Temperature (°C)	Minimum Temperature (°C)	Δ Temperature (°C)
509.15	17.03	492.12

Maximum Temperature (°C)	Minimum Temperature (°C)	Δ Temperature (°C)
87.28	19.52	67.77

Engine Heater could only reach 500 °C at a voltage of ~28 Vrms. Power input was 48 Ws.

TREES 2.0: Max Power Input





Maximum Temperature (ºC)	Minimum Temperature (ºC)	Δ Temperature (ºC)
408.77	16.88	391.89

Maximum Temperature (ºC)	Minimum Temperature (ºC)	Δ Temperature (ºC)
145.94	24.35	124.59

Max Power and voltage input are ~160 Ws at ~46 Vrms rms respectively. Max Temp was ~ 400°C.

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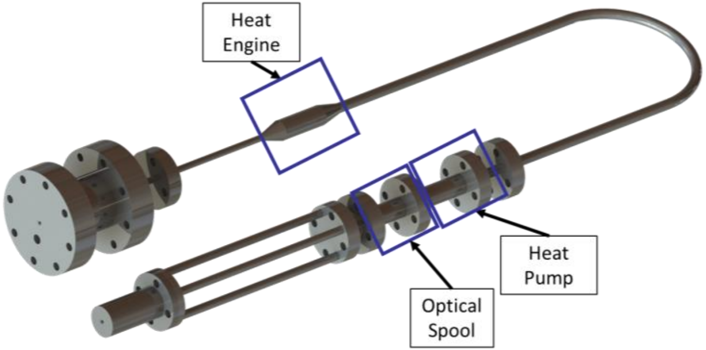
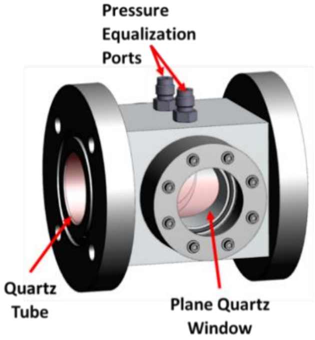
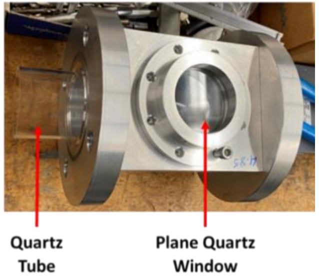


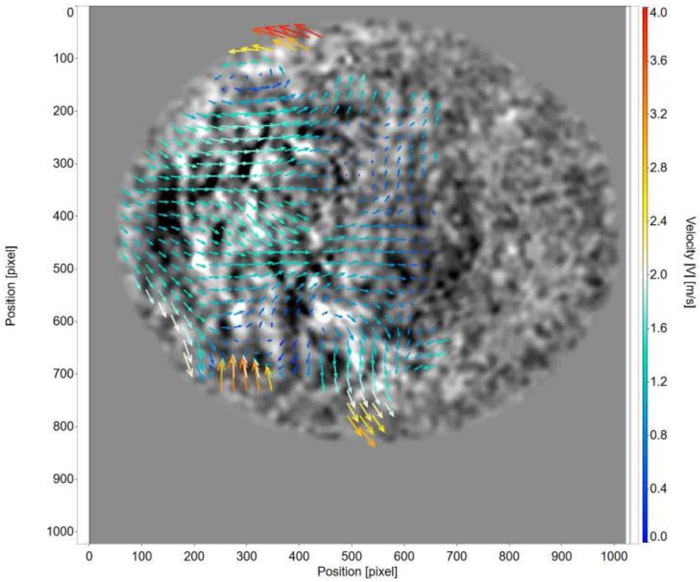


(a) : CAD of Optical Spool

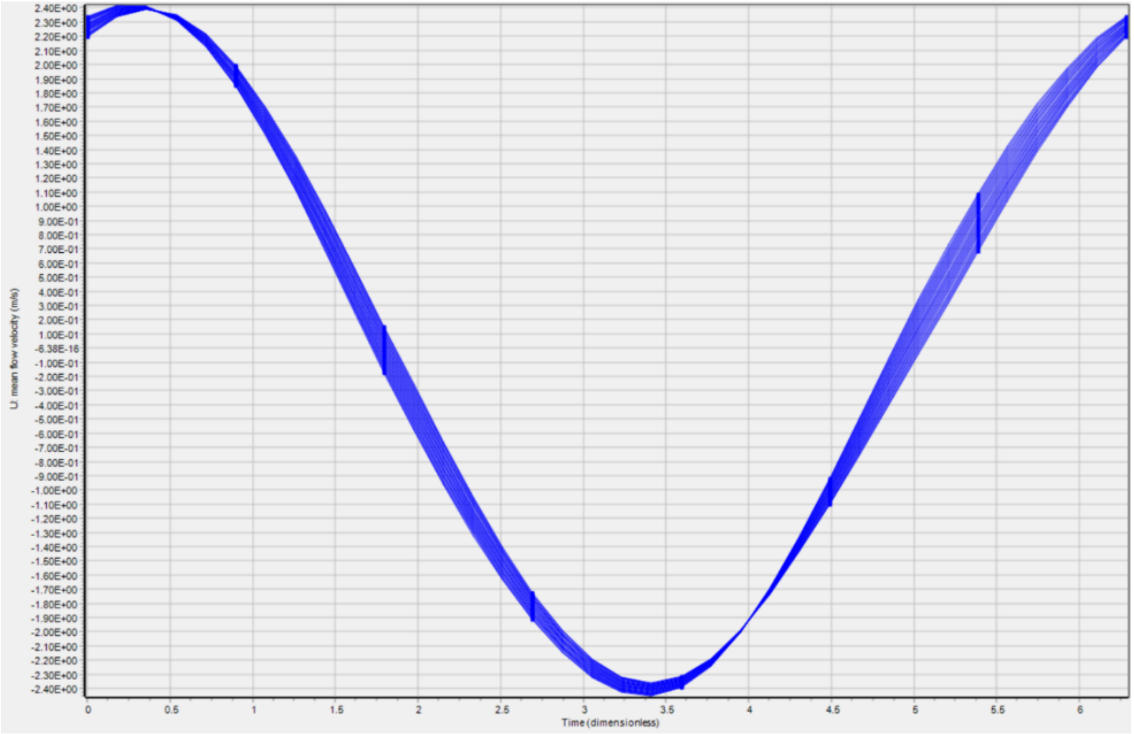


(b) : In-House Manufactured Optical Spool

TREES 2.0: Schlieren System Measurements

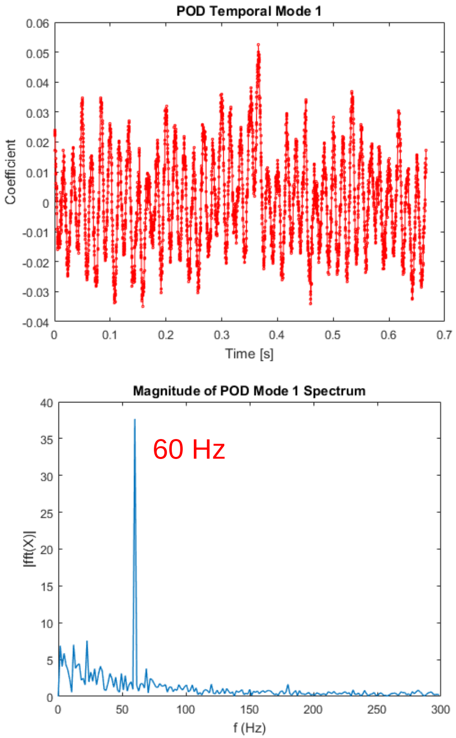


Optical Spool Density Gradient and Flow Trace DIC Measurements (High Speed Camera - 6kHz)

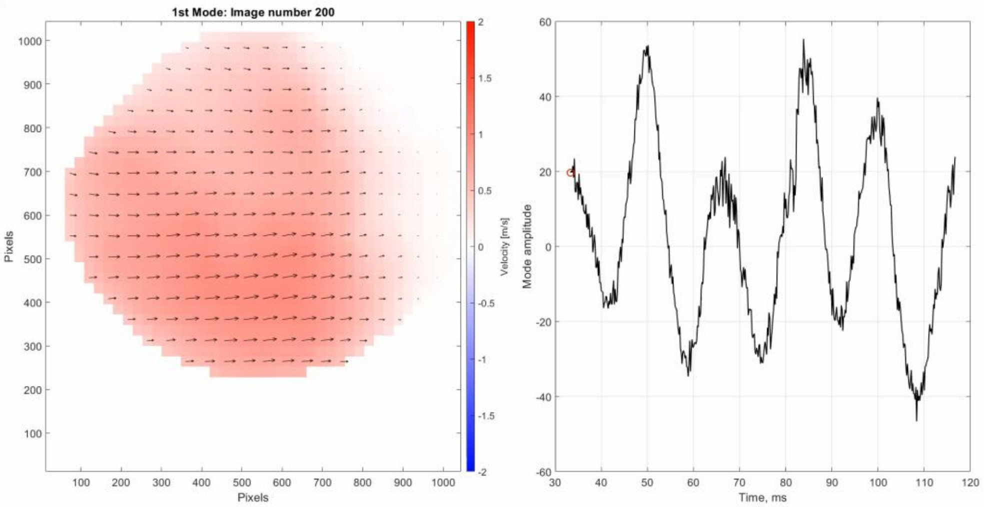


Sage Velocity within Optical Spool

TREES 2.0: Schlieren Video Analysis



Proper Orthogonal Decomposition (POD)



Oscillating Flow Field at 60 Hz

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Summary

- Traveling-wave thermo-acoustic rigs were designed and built as a new thermal management approach for electric aircraft.
- Experimental results show minimal acoustic power degradation between 0.2 m, 5 m, and 10 m distances, but 90° transitions combined with long distances can degrade acoustic power
- Demonstrated thermal amplification of acoustic waves
- Optical measurement were able to capture velocity and frequency of traveling wave.
- In-house testing informed aircraft sized TREES testing at ACT
  - Demonstrates that fully solid-state TMS is possible!

Acknowledgements

- Don Fong, Casey Theman, Frank Lam, Frank Gaspare, and David Hausser for their immense support and resources throughout this research.
- ACT for their successful work on the TREES full-scale fabrication and testing.
- Dr. Lee Mears for his assistance and helpful insights into the POD analysis.
- This work was sponsored by the Advanced Air Transportation Technologies project/Electric Aircraft Powertrain Technologies sub-project.

Questions

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