Harnessing Thermoacoustic Power with Bi-Directional Turbines: A Path to Efficient Energy Conversion

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Agenda

- Thermoacoustic Background and Need
- Thermoacoustic Traveling Concepts
- In-house System and Previous Results
- Bi-directional Turbine Background
- Base Turbine CFD Study and Results
- In-house Turbine Testing and Results
- Summary

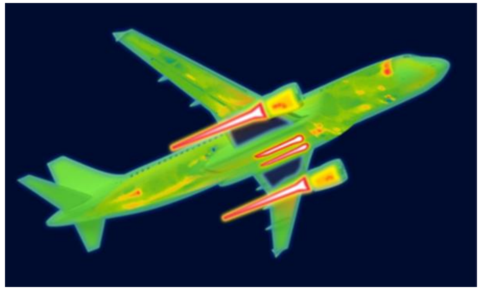
Thermoacoustic Background and Need

Electric Aircraft

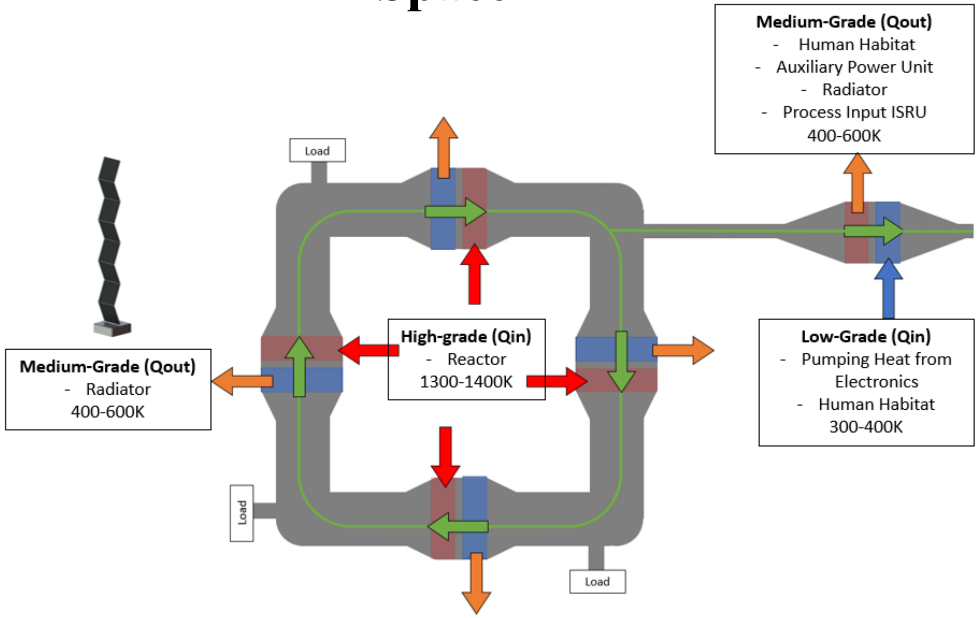
Thermal Management Technology	Disadvantage
Ram air HX	Adds weight, aircraft drag, displaces fuel capacity
Convective skin cooling HX	Adds weight, drag, and requires liquid pumping losses
Sinking heat into fuel	Limited thermal capacity due to coking and volume
Sinking heat into lubricating oil	Limited 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 by much which impacts mass and efficiency

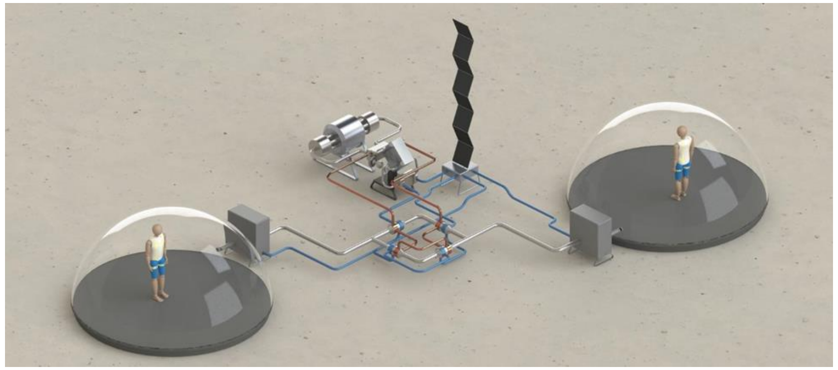
Waste Heat: 200 KW to 6 MW

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

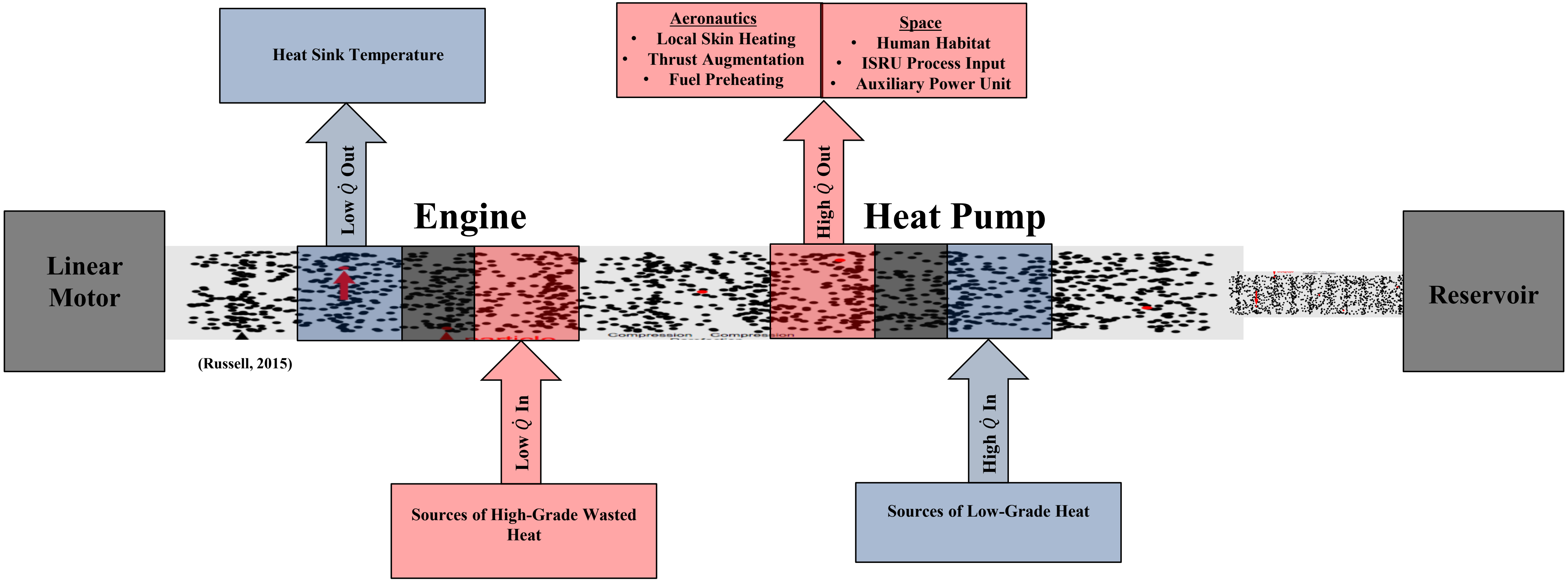


Space



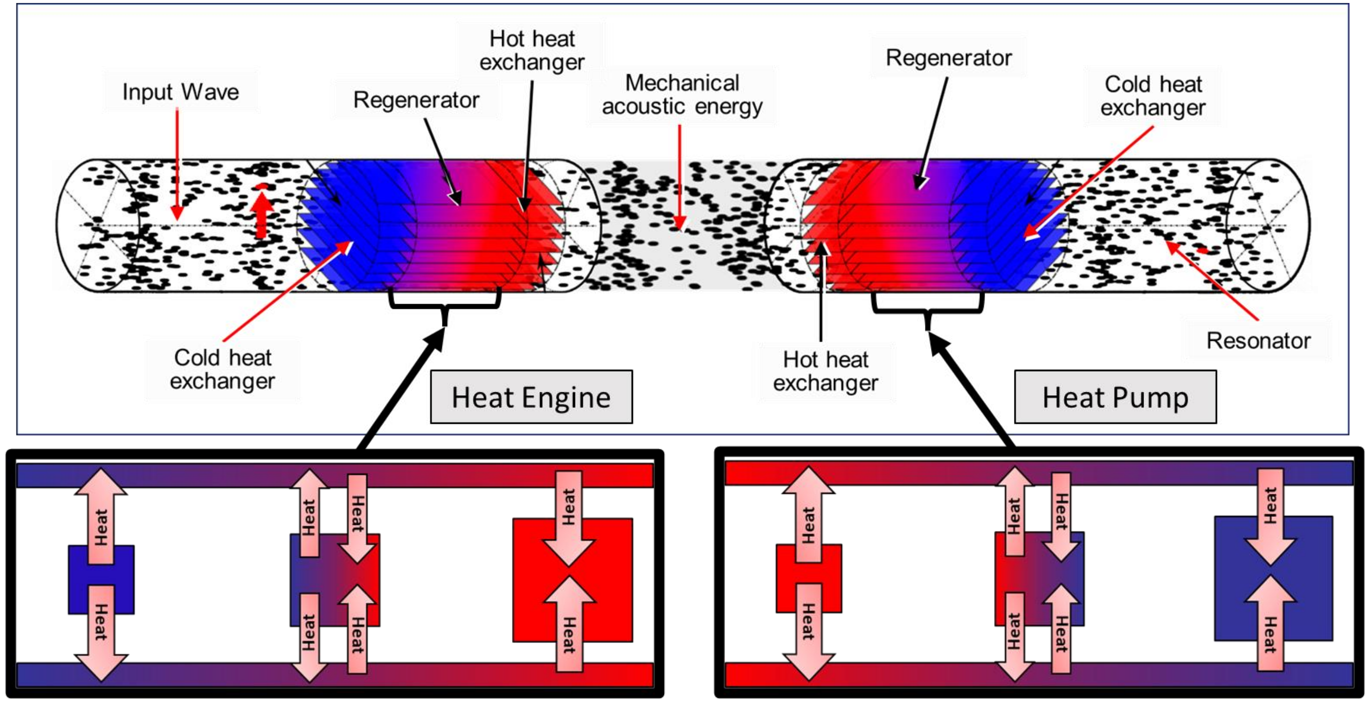


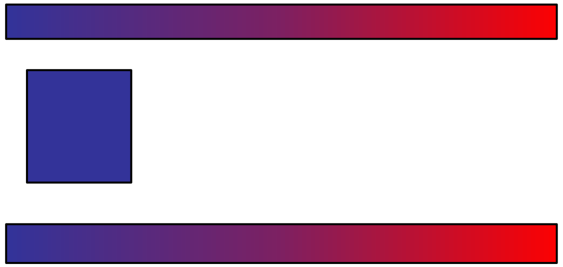
Traveling Wave Concepts



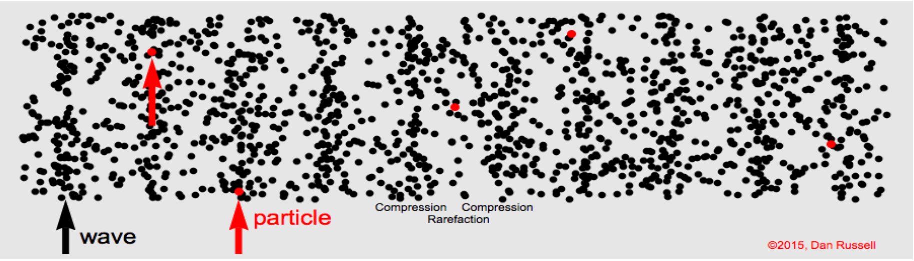
Additional Traveling Wave Concepts

(Dyson, 2020)





(Russell, 2015)

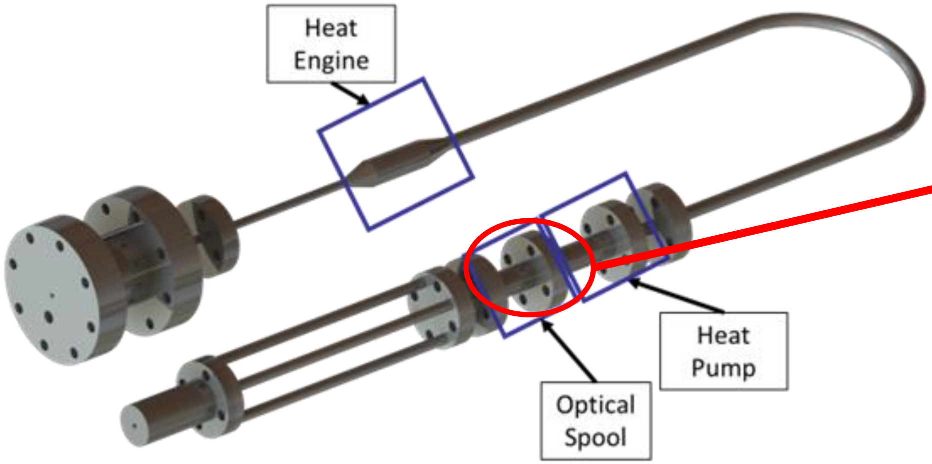


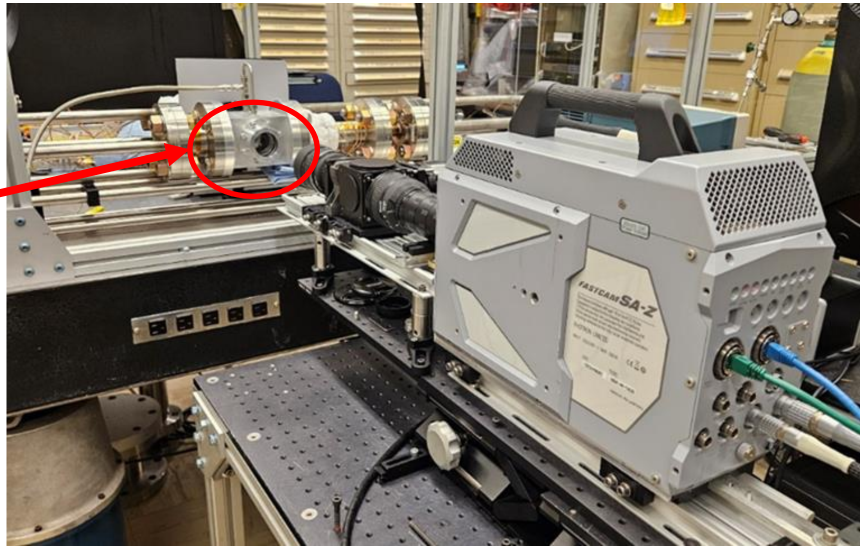
KEY PROPERTIES

Can be used for thermal energy conversion:

- **Heat to mechanical power**
- **Mechanical power to cooling**
- **Heat engine and heat pump**

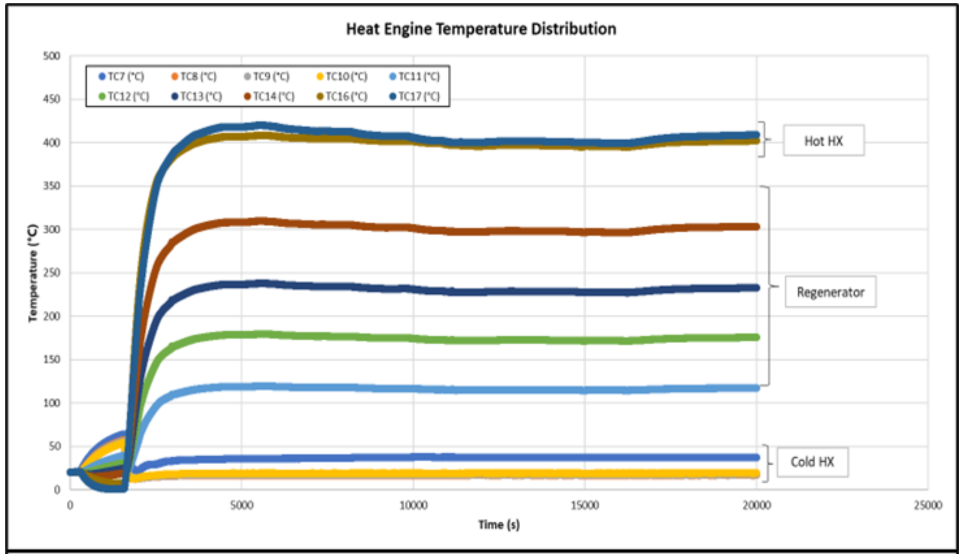
In-House System

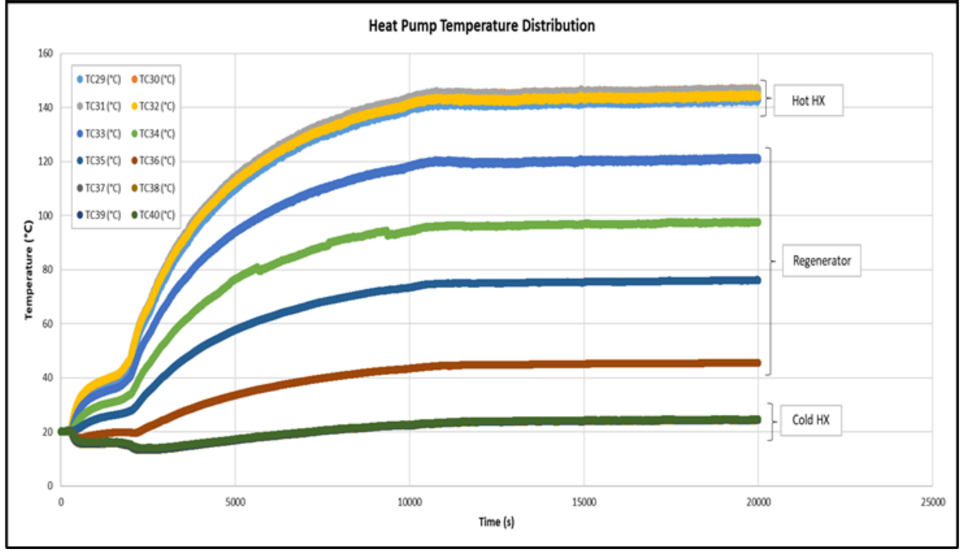




Self Aligned Focusing Schlieren System

Previous Work

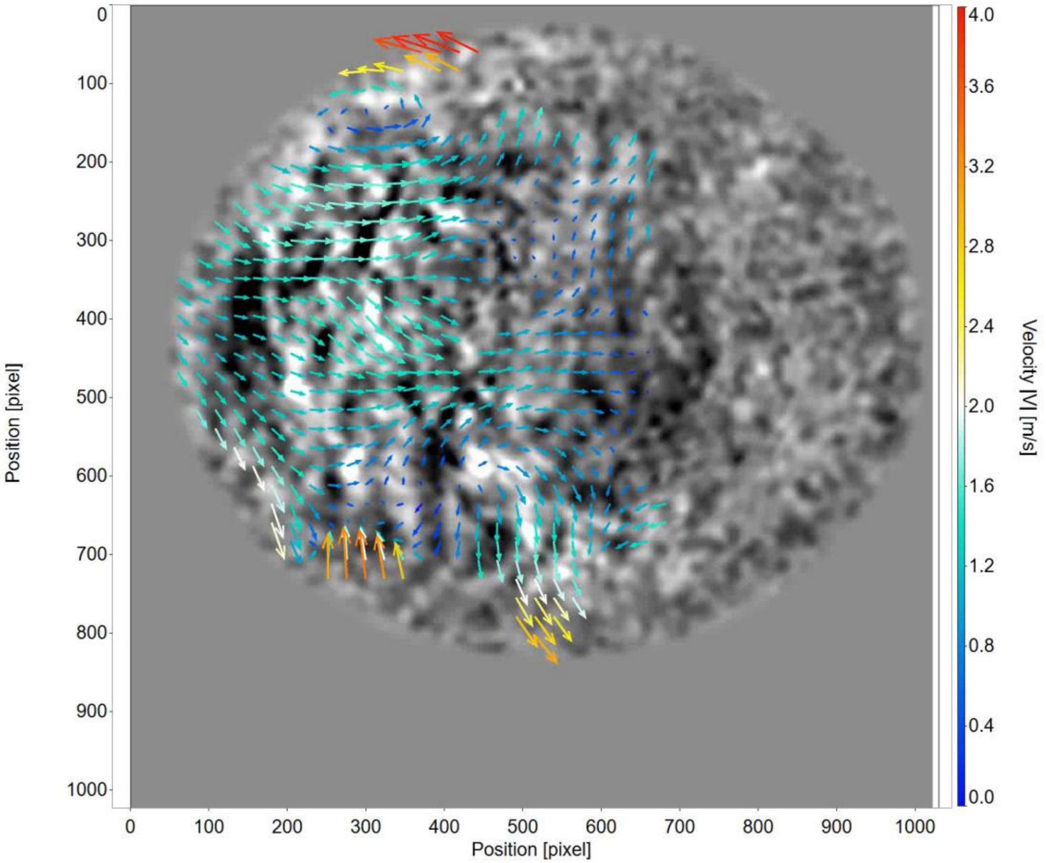




(Rodriguez, 2025)

Δ Temperature (ºC)
391.89

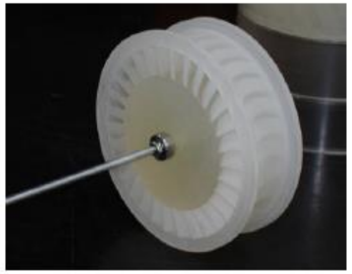
Δ Temperature (ºC)
124.59



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

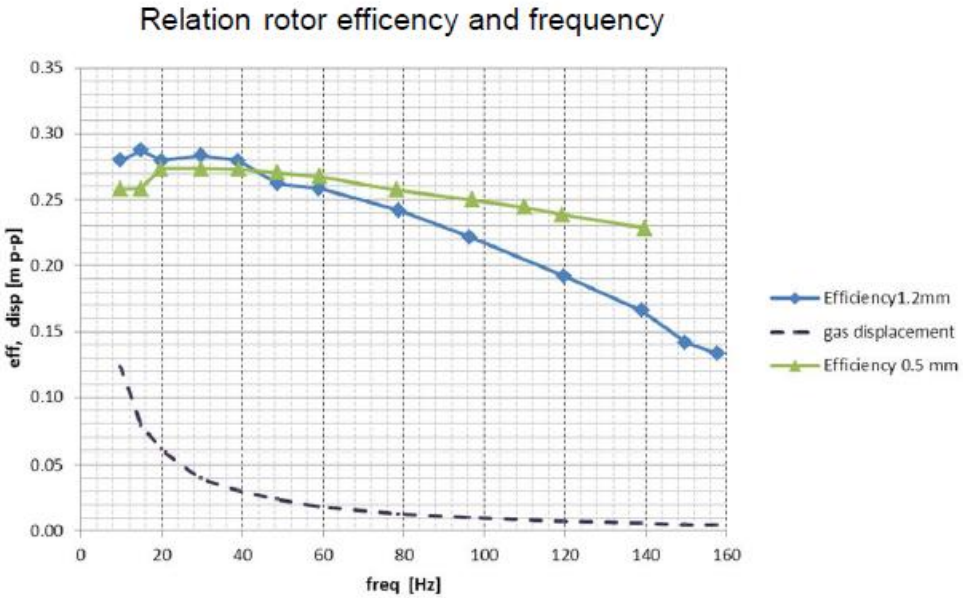
Previous Bi-directional Turbine Testing

Axial Impulse Turbine



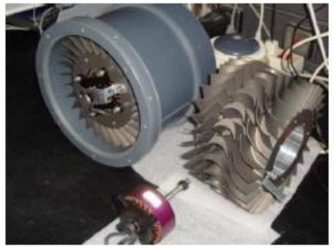
Rotor Diameter: 200 mm

(de Blok, 2014)



High Power Axial Impulse Turbine

(de Blok, 2014)



Turbine position inside the TAP

<u>100 KW TAP Rig</u>
Rotor Diameter: 200 mm
Rotational Speed: 2700 RPM
Power: 2KW

Efficiency in air at 0.8MPa of this axial bi-directional turbine is measured to be 80%

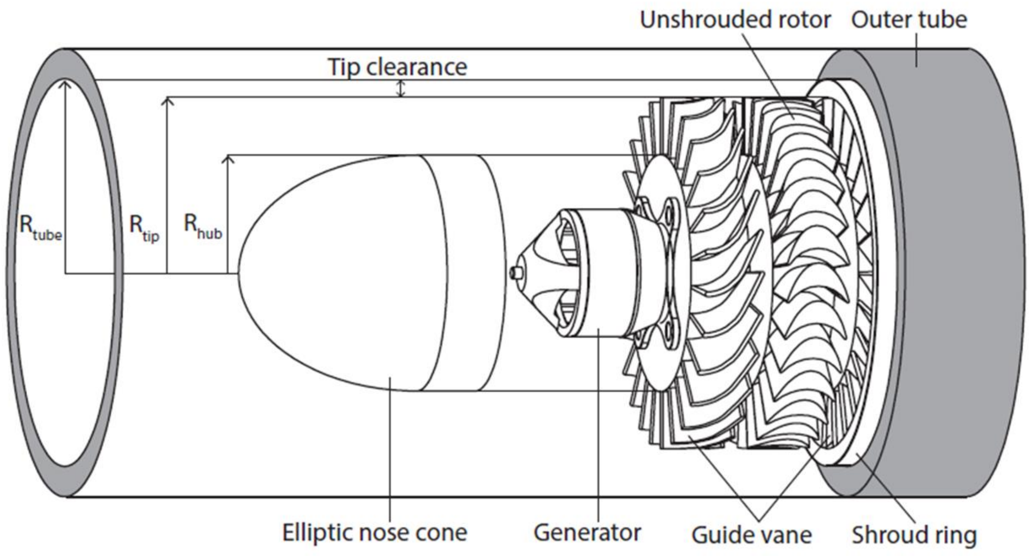
Turbine Operating Principles

- Generated acoustic pressure energy flows through the guide vanes and is converted to kinetic within the turbine.

- As a result of symmetry, the turbine will experience a torque in the same rotational direction, independent of the incoming axial flow.

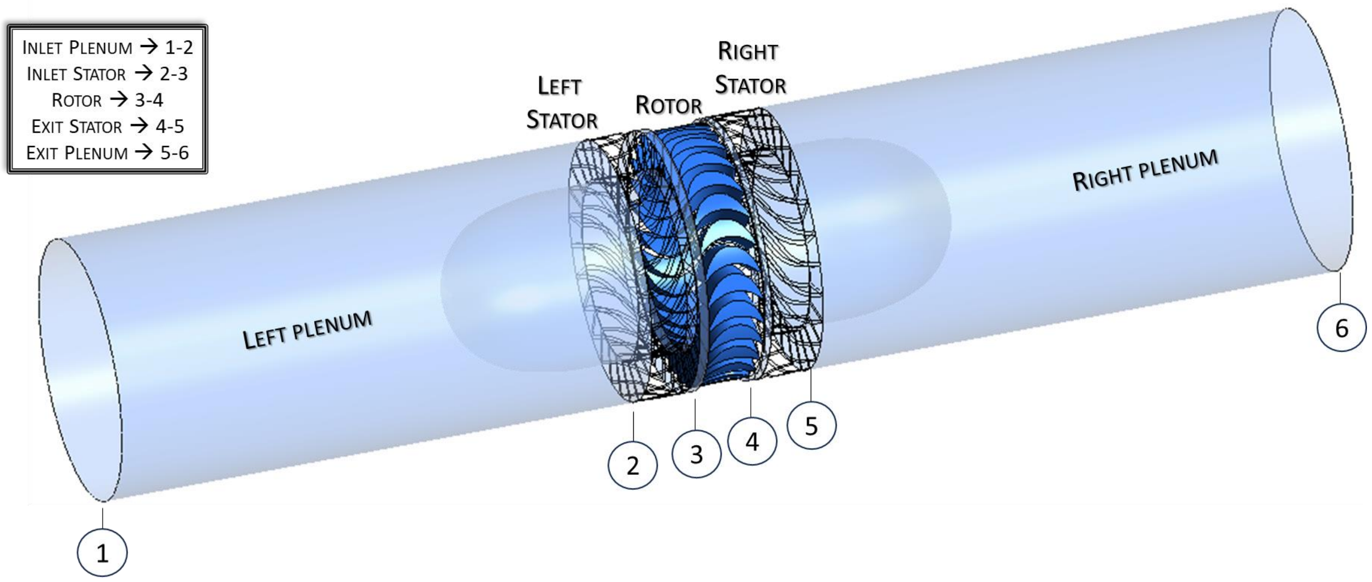
- Mechanical power produced by the turbine can then be converted to electricity by connecting shaft to a generator.

- Goal is to generate 10We!



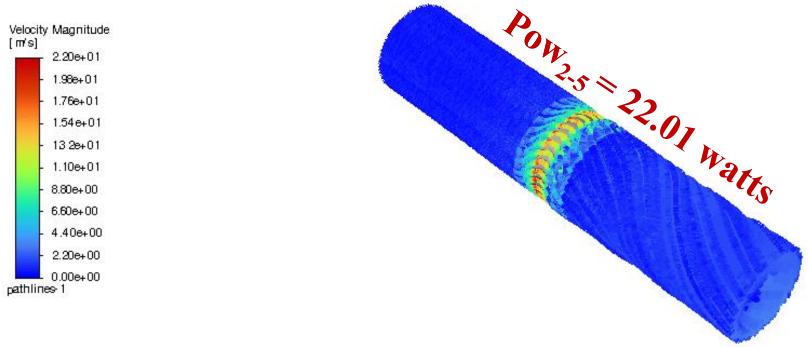
(Timmer, 2020)

Base Turbine CFD Study- Ansys Fluent

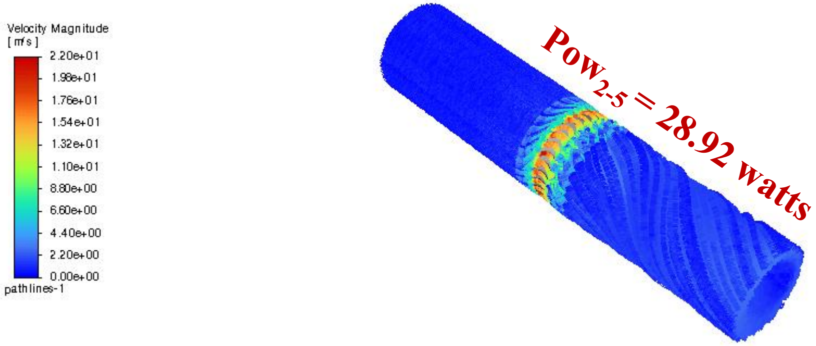


- ✓ **Flow in the model is in a single direction.**
- ✓ **Inlet pressure amplitude for all cases is 1,000 Pa.**
- ✓ **Temperatures are taken at the points in the image above.**

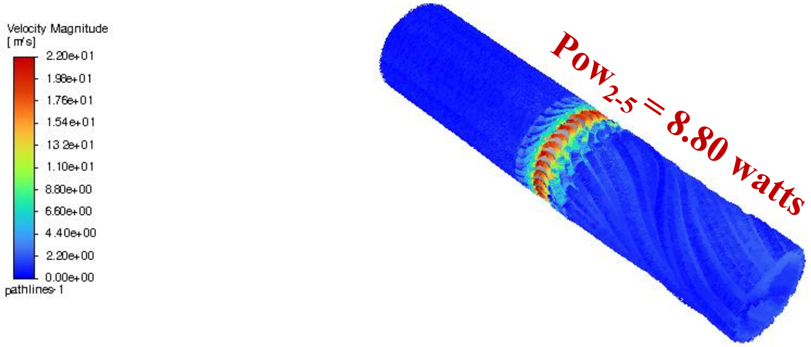
Power and RPM Results



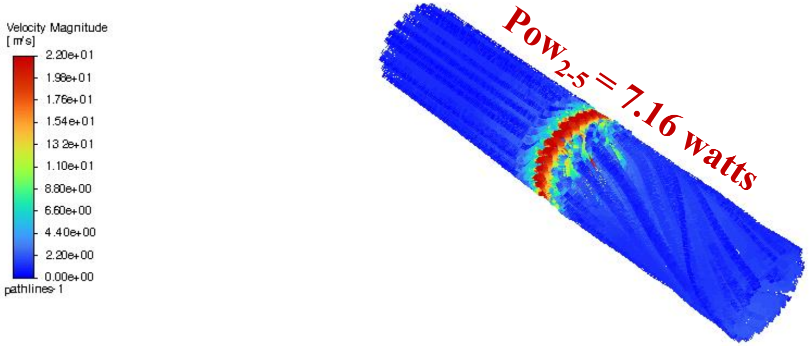
<u>Case 1.5</u> – 21.67 Hz (1,300 RPM)



<u>Case 2</u> – 30 Hz (1,800 RPM)



<u>Case 3</u> – 55 Hz (3,300 RPM)



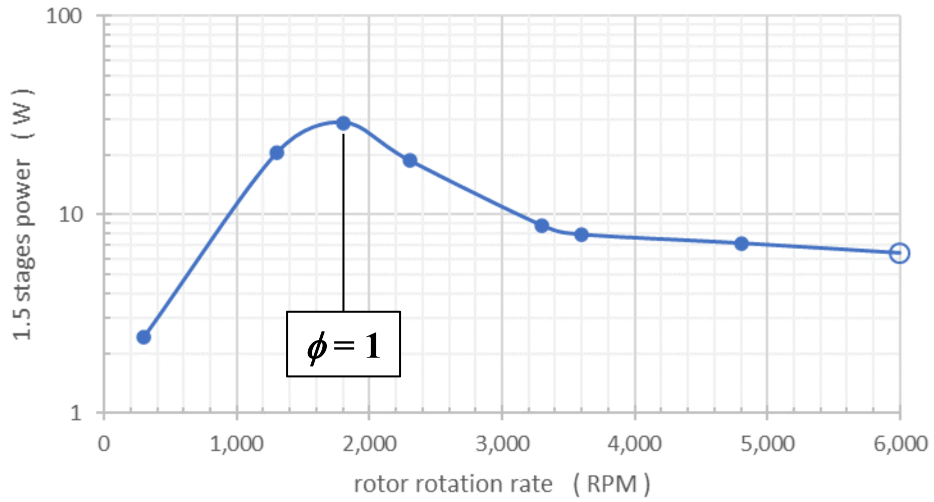
<u>Case 4</u> – 80 Hz (4,800 RPM)

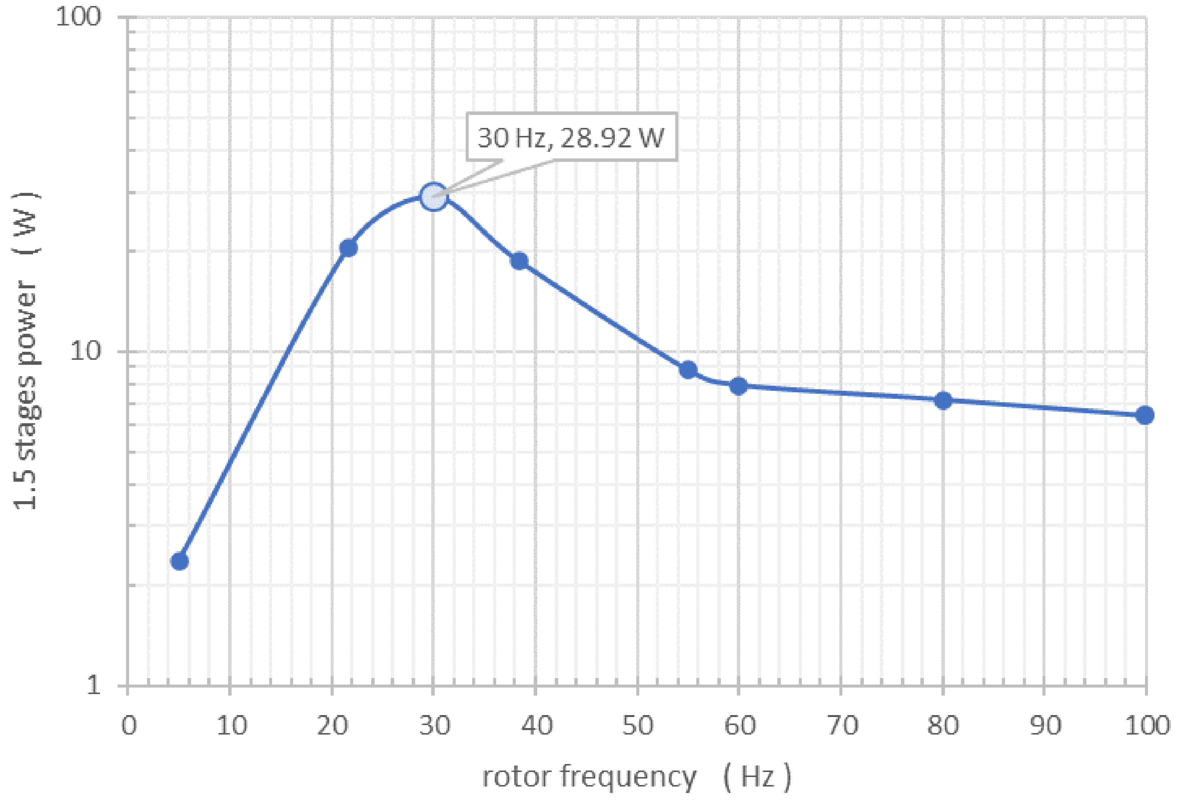
Additional Power and RPM Results

Power was calculated for each case run.

$$Power = \dot{m}C_p(T_{T2} - T_{T5})$$

For the device being assembled, power output is critical. In this instance, book-keeping includes the inlet stator (2), through the rotor, to the exit stator (5).





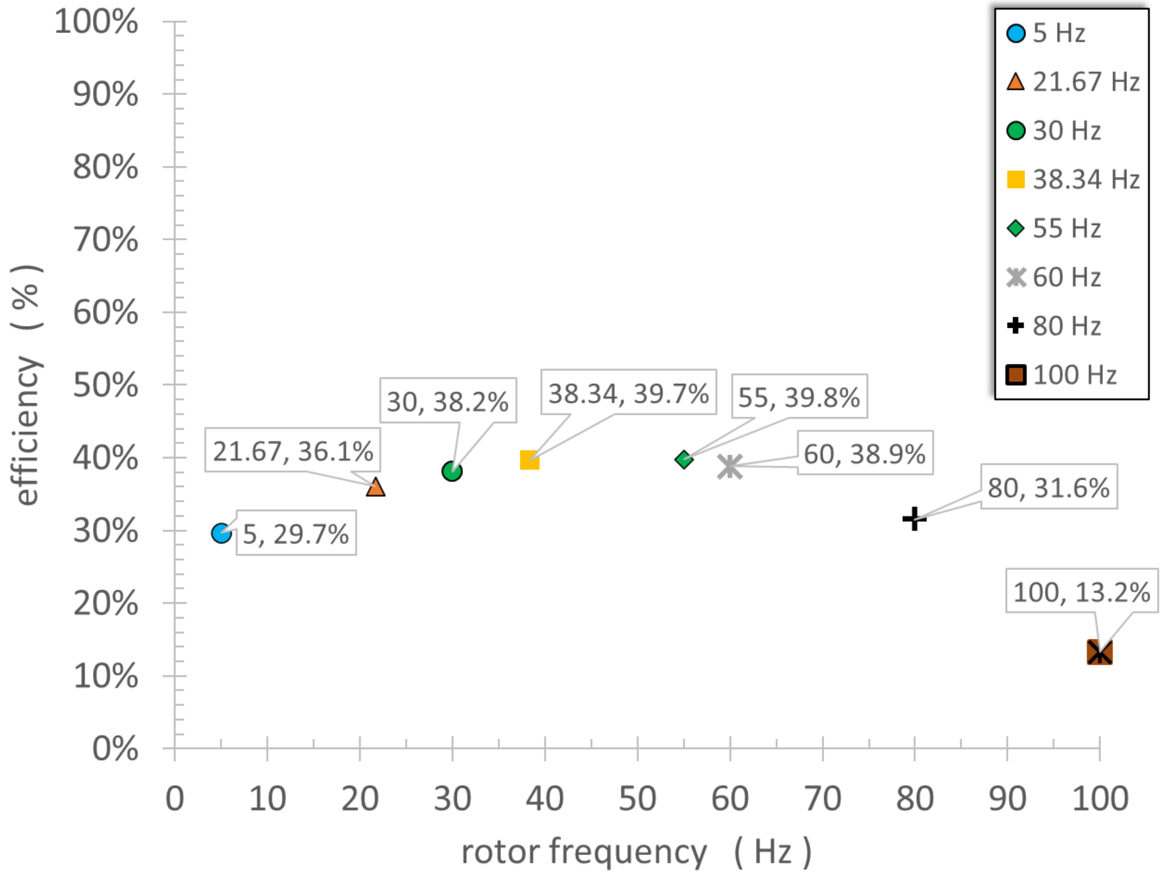
Turbine Efficiency

Efficiency is usually defined as

desired output/required input.

The higher the efficiency is, the more bang for your buck you are getting regarding supplied input. Using the total-to-total efficiency equation from the textbook **Gas Turbine Theory** (*H. Cohen, G.F.C Rogers, and H.I.H. Saravanamuttoo, 1991*).

$$\eta_T = \frac{T_{02} - T_{04}}{T_{02}\left[1 - \frac{1}{\left(\frac{P_{02}}{P_{04}}\right)}\right]^{\frac{\gamma-1}{\gamma}}}$$



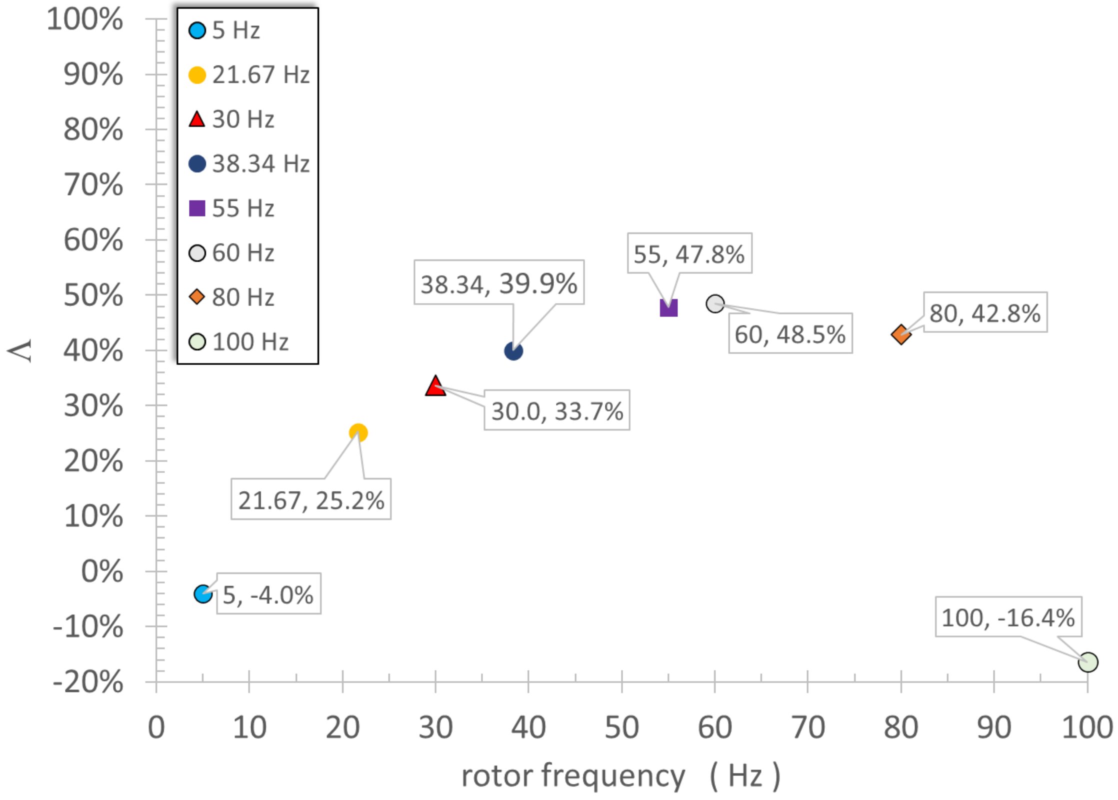
Degree of Reaction

The Reaction (L) is defined as the ratio of the enthalpy drop across the rotor versus the enthalpy drop over the stage. This can be rephrased as the fraction of expansion across a stage that occurs in the rotor. In this case, the stage is defined as the stator and the rotor (not including the second stator). Since the specific heat is being held constant, the ratio is defined using static temperatures.

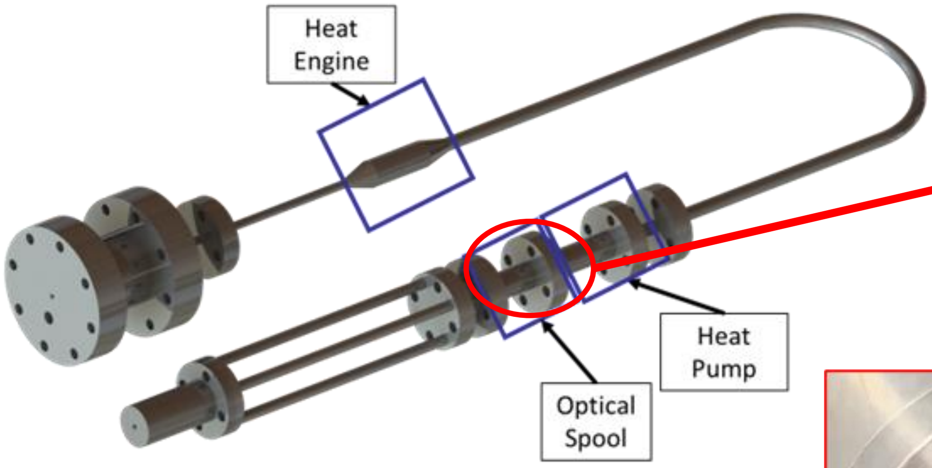
Stages having 50% of expansion occurring in the rotor is typically desired. If the rate of expansion is equally shared between the stator and the rotor rows, this can reduce the tendency of boundary layer separation from the blade surface, which will help avoiding large stagnation pressure losses.

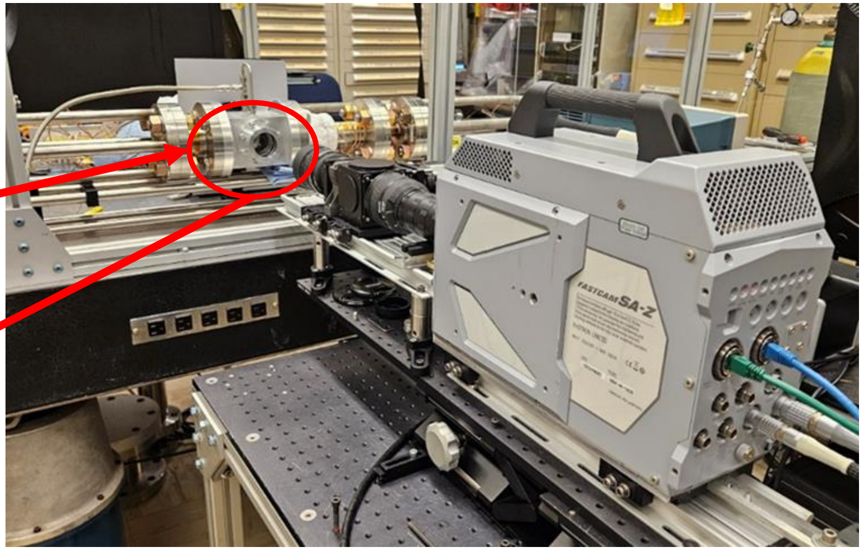
$$\Lambda = \frac{T_{s3} - T_{s4}}{T_{s2} - T_{s4}}$$

Reaction rates less than 50% suggests that expansion rate is not equally shared between the rotor and the stage. It suggests that higher rates of expansion are occurring in the stator. If reaction rates are low at mid span, they will be even lower near the hub. Reaction rates < 0 suggests recompression in the rotor, which is undesirable and would contribute to aerodynamic losses.

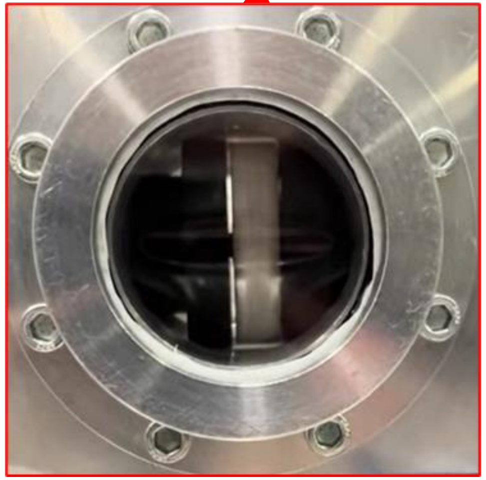


In-House Testing





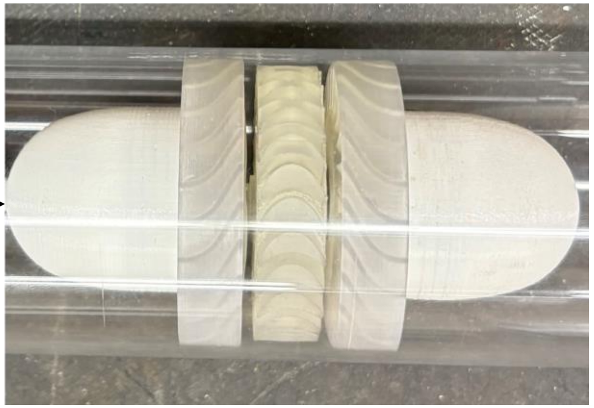
Self Aligned Focusing Schlieren System



Experimental Test (Sans Motor)

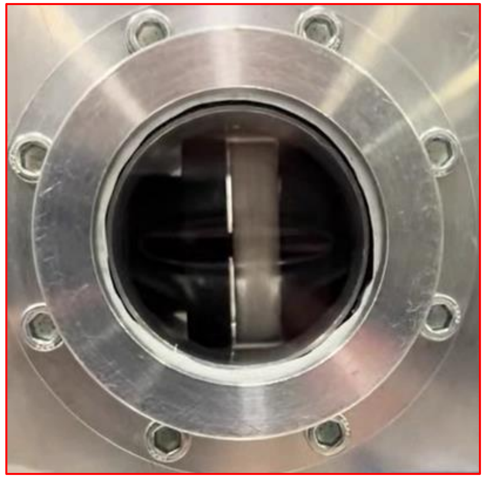
Turbine Prototypes and Results

Optimized Design



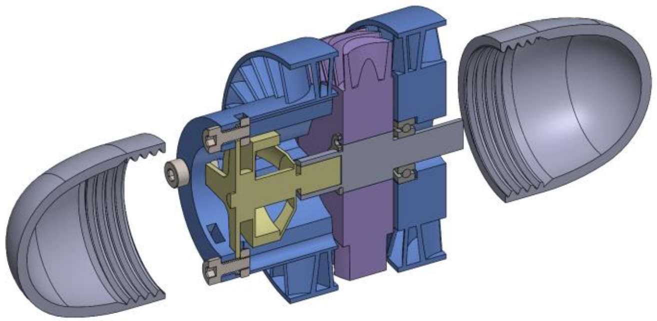
Printer: Ultimaker 3
Material: PLA
(1296 RPM)

Printer: Formlabs Form 3L
Material: Clear Resin V4
(2117 RPM)



Summary

- Preliminary CFD analysis used to define baseline bi-directional turbine geometry.
- Demonstrated rotating bi-directional turbine and increased RPM.
- Next steps are to attach rotating generator to produce ~10We.



Turbine CAD with Motor

Questions

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