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# NASA GRC's Closed Brayton Power Conversion Capabilities


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# Agenda

- Introduction
- Previous Hardware: Power Brayton Systems
  - BRU, Mini-BRU, Dual Capstone
- Previous and On-Going Modeling
  - NPSS, CFD
- Infrastructure for Future Brayton Testing
  - High Power Lab, Alternator Lab
- Conclusion

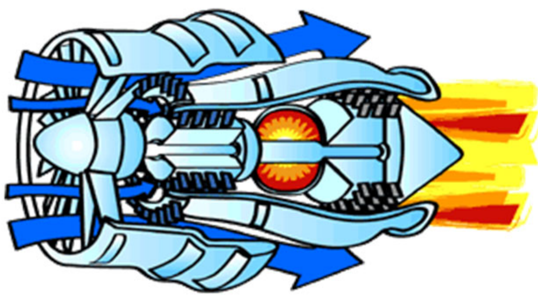
# Introduction – Lab/Brayton History

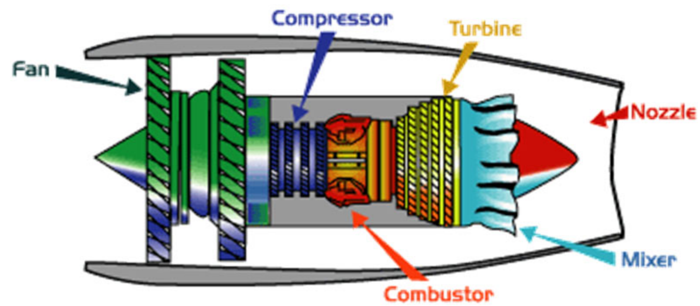
Groundbreaking Ceremony of the Aircraft Engine Research Laboratory (AERL)

- The National Advisory Committee for Aeronautics (NACA) selected 200 acres neighboring Cleveland Airport, Aircraft Engine Research Laboratory (AERL).
- AERL's focus was on propulsion.
- First engine test occurred on May 8, 1942 (US was involved in WWII).
- AERL tested some of the nation's first turbojet and ramjet engines in the Altitude Wind Tunnel at end of WWII.
- After WWII, AERL immersed itself into compressor, turbine, and high temperature material research.
  - Led to much of the current open and closed Brayton technology development.

# Introduction – Open Cycle

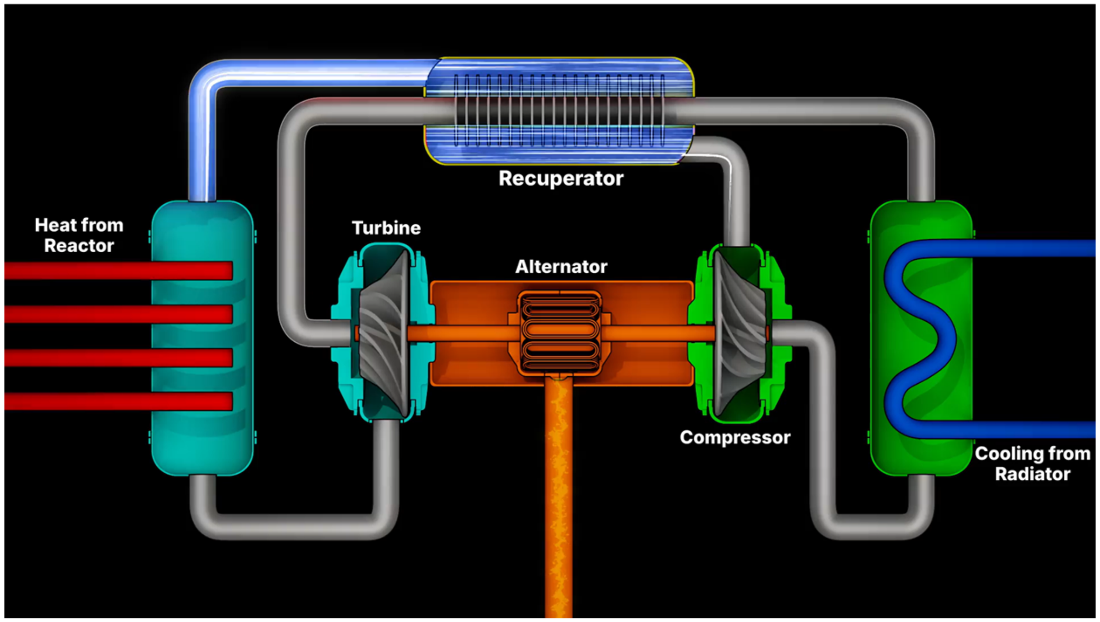
- Air is drawn from the atmosphere and compressed so that it can be mixed with fuel and burned for combustion.
- During combustion, the fluid's temperature, volume, and enthalpy increase to provide the necessary energy to drive the turbine.
- Hot gases are expanded by the turbine and are accelerated to produce thrust.
- Primary heat source is derived from combustion and heat rejection is accomplished via sinking heat into the exhaust stream.





# Introduction – Closed Cycle

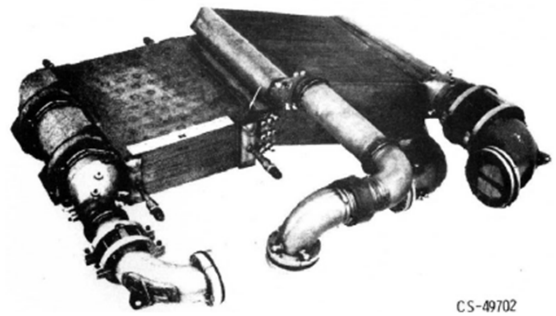
- Inert fluid mixture helium-xenon (HeXe) will recirculate continuously throughout the power system.
- HeXe is compressed by the compressor and expanded by the turbine to drive shaft and alternator.
  - Turbine converts pressure and thermal energy to mechanical energy.
  - Alternator converts mechanical to electrical energy.
- Reactor: provides thermal energy to the Brayton system.
- Recuperator: increases system efficiency by recycling some of the waste heat energy.
- Radiator: rejects the rest of the waste heat to surroundings.



# Previous Brayton Hardware – BRU

- Brayton Rotating Unit (BRU): 1968-1978
  - Aimed at high efficiency power conversion system for Isotope, reactor, and solar concentrator heat sources
  - Designed to operate between 2.25 to 10.5 kWe
  - Efficiency: 32%
  - HeXe molecular weight: 83.8 g/mole
    - Optimal power output due to higher aerodynamic turbine and compressor performance
  - TAC – 36,000 RPM
  - BHXU – Recuperator and Sink HX
    - 95% effectiveness
    - Recuperator - Gas to gas
    - Sink HX - Dow-corning 200 fluid to gas
  - 38,000 hours of operation with no degradation


TAC – 36,000 RPM

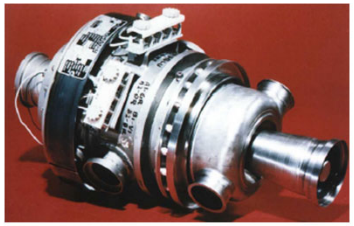
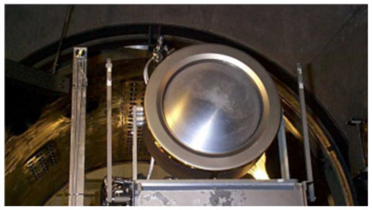
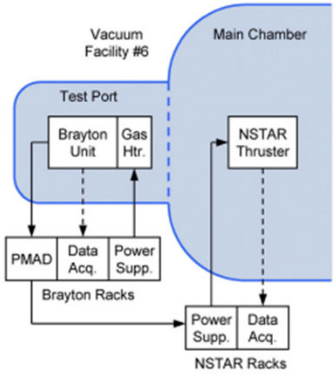



BHXU – Recuperator and Sink HX

# Previous Brayton Hardware – Mini-BRU

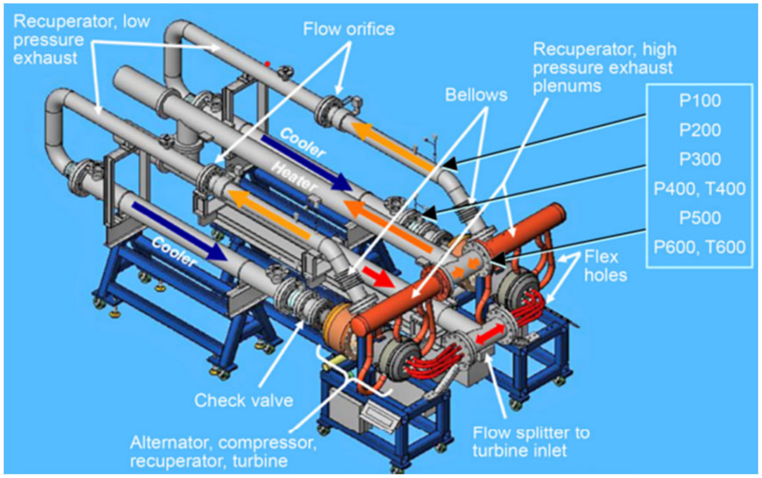
- Mini-BRU: 1974-1978
  - Developed for high cycle efficiency at low power levels
  - Designed to operate between 0.5 to 2.1 kWe
  - Efficiency: 30%
  - HeXe molecular weight: 83.8 g/mole
  - Turbine inlet temperature: 1144 K
  - Compressor inlet temperature: 300 K
  - Max Pressure: 738 kPa
  - TAC: 52,000 RPM
  - Recuperator
    - 97.5% effectiveness
  - Successful integration with a Xenon Ion Thruster (2003)
    - Provided power to thruster
  - Test article is currently at NASA GRC's Neil Armstrong test facility in Sandusky, Ohio
    - Brayton System can be used for further model validation

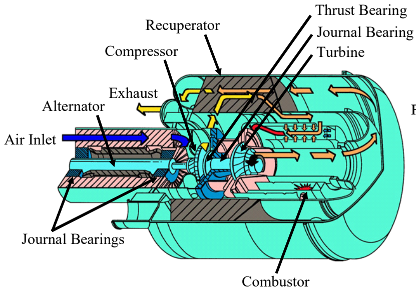


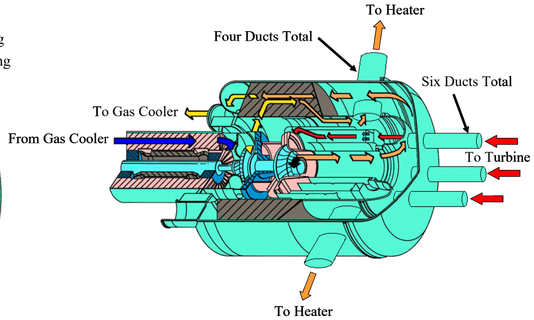




# Previous Brayton Hardware – Dual Capstone

- Dual Capstone Closed Brayton Configuration: 2006-2007
  - Goals:
    - Simulate a gas cooled reactor coupled to two or more CBC converters to provide redundancy
    - Build a dual CBC power conversion system in a relatively short timeframe
  - Open Cycle Desing Point (Atmospheric Intake and Exhaust):
    - 1144 K (Hot End), 294 K (Cold End), 96 kRPM, 30 kWe
  - Modified Closed Cycle Test Point
    - 950 K (Hot End), 294 K (Cold End), 298 kPa (Comp Exit) 90 KRPM, 20 kWe
    - Working Fluid: Nitrogen
  - Testing Type
    - Equal Shaft Speed
    - Variable Shaft Speed
    - Start Scenarios – Constant motoring power, constant shaft speed, dual engine start, and single engine start



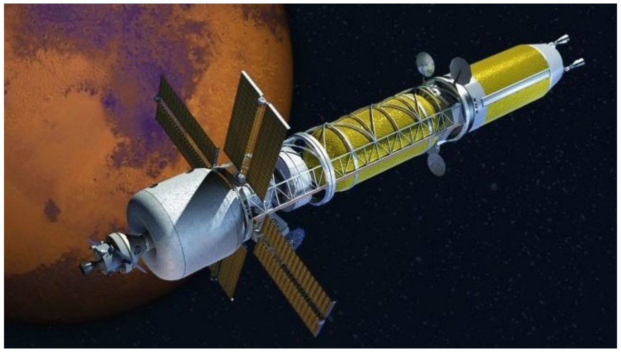
# Previous and On-Going Modeling - NPSS

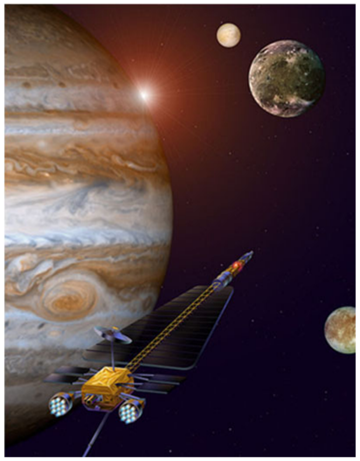
- CCEP – Closed Cycle Engine Program
  - Fortran code
  - https://ntrs.nasa.gov/api/citations/20050217204/downloads/20050217204.pdf
    - Paul Johnson
  - Grew out of NNEP (NASA Navy Engine Program)
    - NNEP -> NEPP (NASA Engine Performance Program)
      - NASA's previous analysis code before NPSS
    - Added components
      - Recuperator, Radiator, Waste Heat Exchanger, Alternator
    - Components included sizing and design calculations
      - Efficiencies
      - Sizes and weights

- Conversion to Numerical Propulsion System Simulation (NPSS) done in mid 2000s
  - Wrote a code to convert Fortran routines directly into .int files
  - Worked, but the components were never broken down and built back up
  - CCEP based elements are still available for use

# Previous and On-Going Modeling - NPSS

- JIMO (Jupiter Icy Moon Orbiter)
  - 2000’s plan to send a probe to Jovian System: Callisto, Ganymede, and Europa
  - Reactor would allow for many high-powered instruments
    - Radars measure subsurface water and nature of magnetosphere-moon interactions
- Power System for Nuclear Thermal Rocket System
  - Reactor would be set at a low level to provide power for spacecraft
  - Ph.D. on this work done by Josh Clough
  - https://www.semanticscholar.org/paper/Integrated-propulsion-and-power-Modeling-for-Clough/78aa72fe43bd3316ec80d4e991c6ad857ad49c7d





# Previous and On-Going Modeling – NPSS

TABLE 2

BRU PREDICTED PERFORMANCE

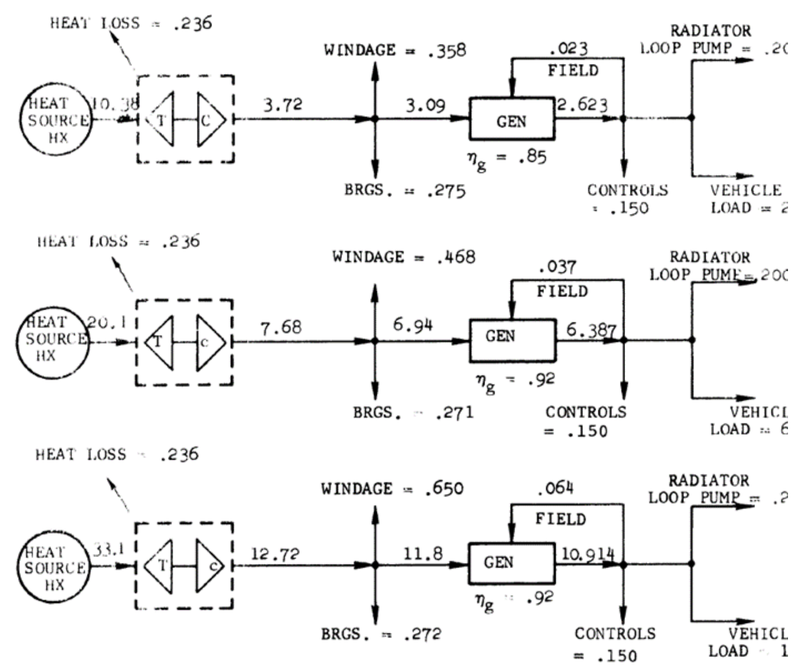
| NET GENERATOR OUTPUT, KW | 2.25 | 6.0 | 10.5 |
|---|---|---|---|
| Gross generator output, kw (1200 Hz | 2.623 | 6.387 | 10.914 |
| Working fluid, Xe-He, mw | 83.8 | 83.8 | 83.8 |
| Shaft speed, rpm | 36,000 | 36,000 | 36,000 |
| Recuperator effectiveness | 0.95 | 0.95 | 0.95 |
| β, 1- (ΔP/P) TOTAL SYSTEM | 0.92 | 0.92 | 0.92 |
| Compressor corrected mass flow rate, lb/sec | 0.825 | 0.841 | 0.835 |
| Compressor bleed flow, % | 2 | 2 | 2 |
| Compressor inlet temperature, °R | 540 | 540 | 540 |
| Compressor inlet pressure, psia | 7.6 | 14.2 | 23.7 |
| Compressor diameter, in. | 4.25 | 4.25 | 4.25 |
| Compressor pressure ratio | 1.88 | 1.9 | 1.9 |
| Compressor efficiency | 0.79 | 0.80 | 0.80 |
| Compressor specific speed | 0.11 | 0.11 | 0.11 |
| Turbine inlet temperature, °R | 2060 | 2060 | 2060 |
| Turbine inlet pressure, psia | 13.7 | 25.8 | 43.2 |
| Turbine diamter, in. | 4.97 | 4.97 | 4.97 |
| Turbine pressure ratio | 1.73 | 1.75 | 1.75 |
| Turbine efficiency | 0.85 | 0.87 | 0.87 |
| Turbine specific speed | 0.093 | 0.092 | 0.092 |
| Rice Generator | | | |
| Generator diameter, in. | 3.3 | 3.3 | 3.3 |
| Generator efficiency | 0.85 | 0.92 | 0.92 |
| Generator windage loss, kw | 0.358 | 0.468 | 0.650 |
| BRU Thermal losses, kw | 0.236 | 0.236 | 0.236 |
| Bearing friction loss, kw | 0.275 | 0.271 | 0.272 |
| Electrical Losses | | | |
| Field excitation, kw | 0.023 | 0.037 | 0.064 |
| Speed control, kw | 0.100 | 0.100 | 0.100 |
| VRE, kw | 0.050 | 0.050 | 0.050 |
| Radiator loop pump, kw | 0.200 | 0.200 | 0.200 |
| Cycle efficiency, $\eta_{cy} = \frac{\text{NET OUTPUT}}{\text{Q in}}$ | 0.217 | 0.30 | 0.32 |

Specific speed = $\frac{NQ^{1/2}}{(gH)^{3/4}}$

N = rev/sec
q = ft/sec$^2$
Q = ft$^3$/sec
H = ft

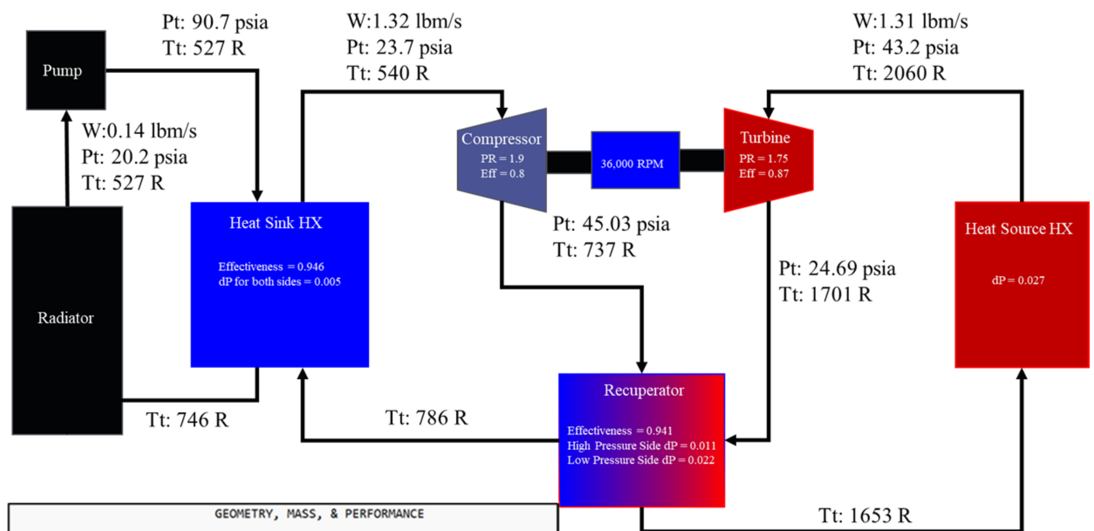
BRU SYSTEMS
ENERGY BALANCES

(All values in kilowatts)



# Previous and On-Going Modeling – NPSS

- Initial thermodynamic cycle of model has converged
- Object oriented turbomachinery analysis code (OTAC) has been integrated
  - Mean line turbomachinery calculations
- Evaluating size and weight calculations of each component
- Integrating heat exchanger elements
  - Developing new in-house code for HX elements (Finite Volume Elements)
- Reactor
  - Point heat source
  - MCMP implementation (transients)



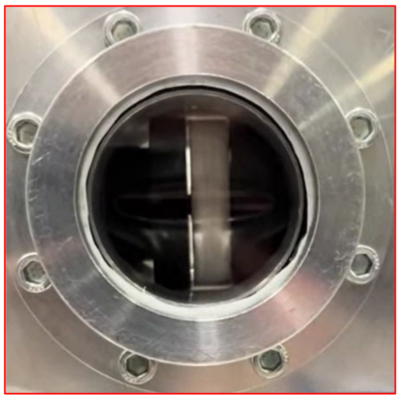

GEOMETRY, MASS, & PERFORMANCE

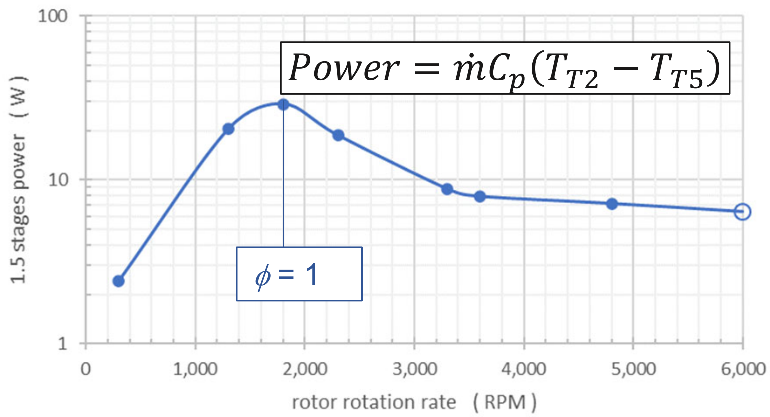
| | |
|---|---|
| ASPECT RATIO, W/H | 2.244 |
| NO. OF HOT SANDWICHES | 49 |
| NO. OF ACTIVE COLD SANDWICHES | 50 |
| NO. OF COLD PASSES | 1 |

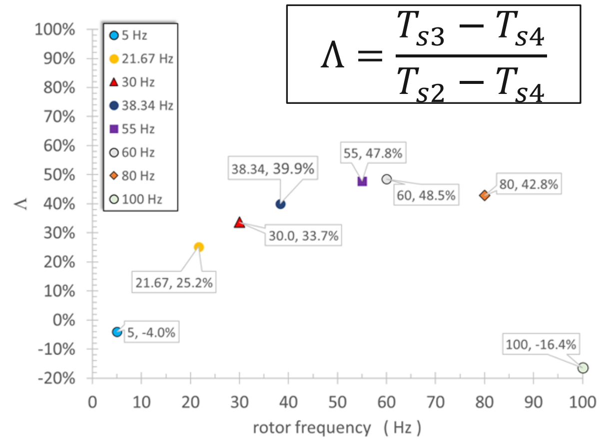
| DIMENSIONS (IN) | |
|---|---|
| TOTAL DEPTH | 13.13 |
| TOTAL WIDTH | 20.00 |
| TOTAL HEIGHT | 8.91 |

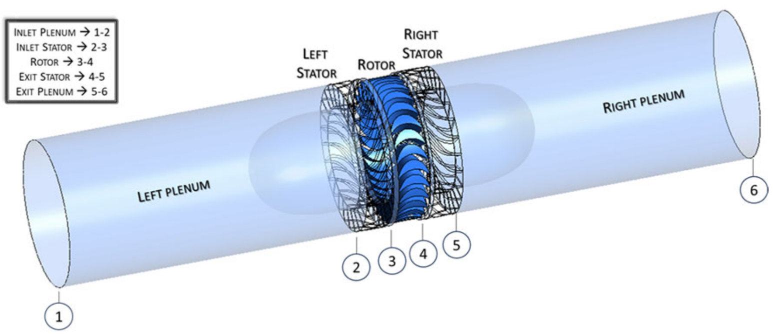
| MASSES (LB) | |
|---|---|
| PLATES | 59.40 |
| WALLS | 26.79 |
| FINS | 96.58 |
| BAFFLE PLATES | 0.00 |
| BRAZE MATERIAL | 18.23 |
| FLUID | 23.52 |
| TOTAL MASS | 224.53 |

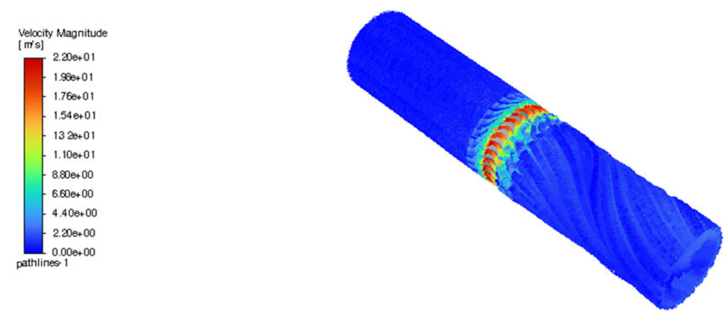
# Previous and On-Going Modeling - CFD





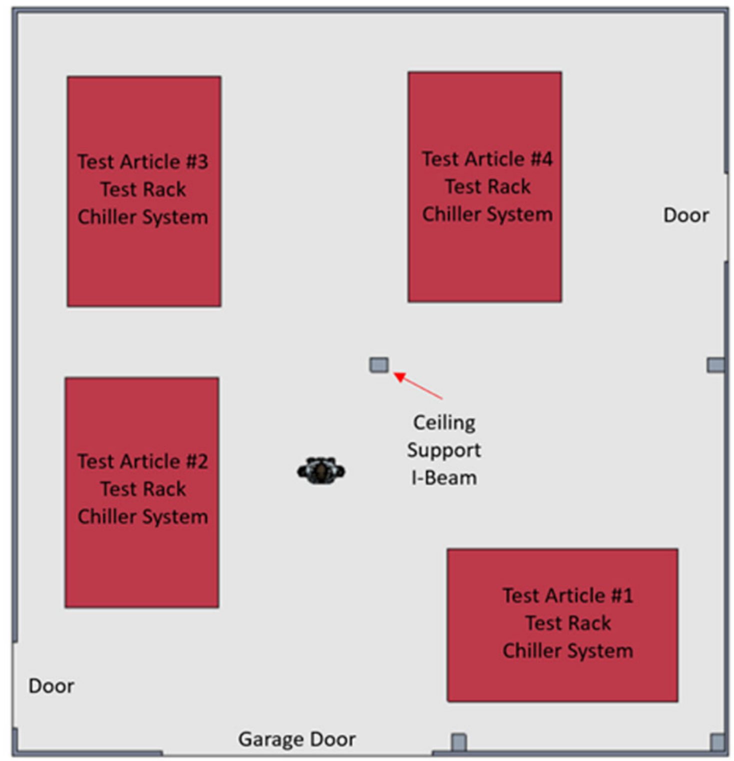



# Infrastructure for Future Brayton Testing

- High Power Lab – Test high power Brayton or Stirling power systems
  - Allows 4 independent test articles to be tested or a single higher power article
  - Lab space built with scalability and modularity in mind
    - Lab space volume – 28x28x15 ft
    - Power Input – 500 kW
    - Cooling – 400 kW
  - Long term duration testing
  - Brayon Power System – Model Verification and Validation
    - TAC Tests– evaluating Turbine, Alternator, Compressor components simultaneously
    - HX Tests – Recuperator, Heat Sink, and Heat Source




- Alternator Test Lab
  - Lab was used to test flywheel rotors in a metal pit
  - Used an air driven turbine to spin up a rotor at 60 kRPM
  - Concrete reinforced walls
  - Instrumentation and controls are located in separate room
  - Reading Lab to test a 10 kW alternator

# Conclusion

- NASA GRC’s long term investment in closed Brayton cycle technology has brought to life a strong ecosystem of advanced hardware prototypes, verified system models, and continuous infrastructure development.
- This synergy of hardware, modeling, and infrastructure development not only demonstrates the maturity of space power conversion systems, but also provides a pathway for thorough technology readiness assessments and mission planning.
- As development continues, GRC’s work positions closed Brayton systems as a cornerstone for future exploration, enabling reliable, efficient power for lunar and Mars bases, and deep-space propulsion.

# ¿Questions?

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