Computational Optimization of a Rotary Valved Pulse Combustor Concept

Daniel E. Paxson & Hugh D. Perkins
NASA Glenn Research Center
Cleveland, Ohio

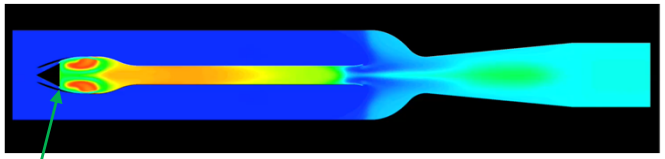
Shaye Yungster
HX5, LLC, NASA Glenn Research Center
Cleveland, Ohio

SciTech 2025
63rd AIAA Aerospace Sciences Meeting
Orlando, FL
January 6-10, 2025

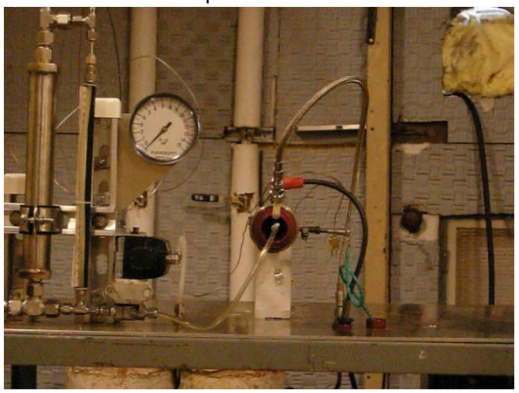
Motivation

- Resonant Pulse Combustors (RPC) represent a promising approach to Pressure Gain Combustion (PGC) for gas turbine application
  - Demonstrated, indisputable pressure gain >50%!
  - Low overall equivalence ratio capability when combined with ejector technology
    - While still yielding demonstrated pressure gains of 3-5%
    - Translates to 2-3% SFC reduction in commercial gas turbines
  - Gaseous or Liquid fuel operation (including kerosene)
  - Low emissions potential
  - Only one moving part
- The air valve is a major technology challenge for RPC
  - State-of-the-art passively actuated reed valves are high-performing, but short-lived due to the harsh environment, high frequency, and slamming motion
  - **Passive actuation ≡ motion induced by internal fluid and mechanical forces**
- Active valves have been peripherally explored
  - Long life attained
  - Performance is poor
  - **Active actuation ≡ motion induced by external mechanical forces**

CFD Animation of an Ejector Enhanced Resonant Pulse Combustor



Operational Video



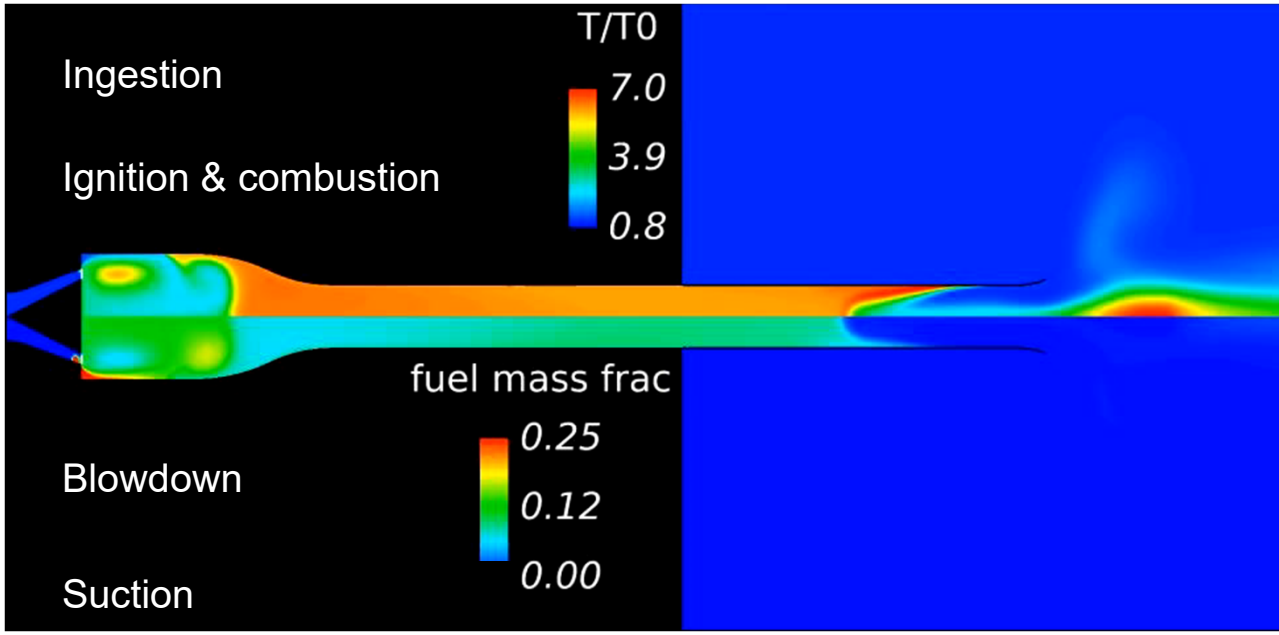
Damaged Reed Valve

This Work Describes a New Active Rotary Disc Valve Concept
Optimized for High Performance Using Computational Fluid Dynamic Simulation

Brief Review of the RPC Cycle
(a controlled thermo-acoustic oscillation)

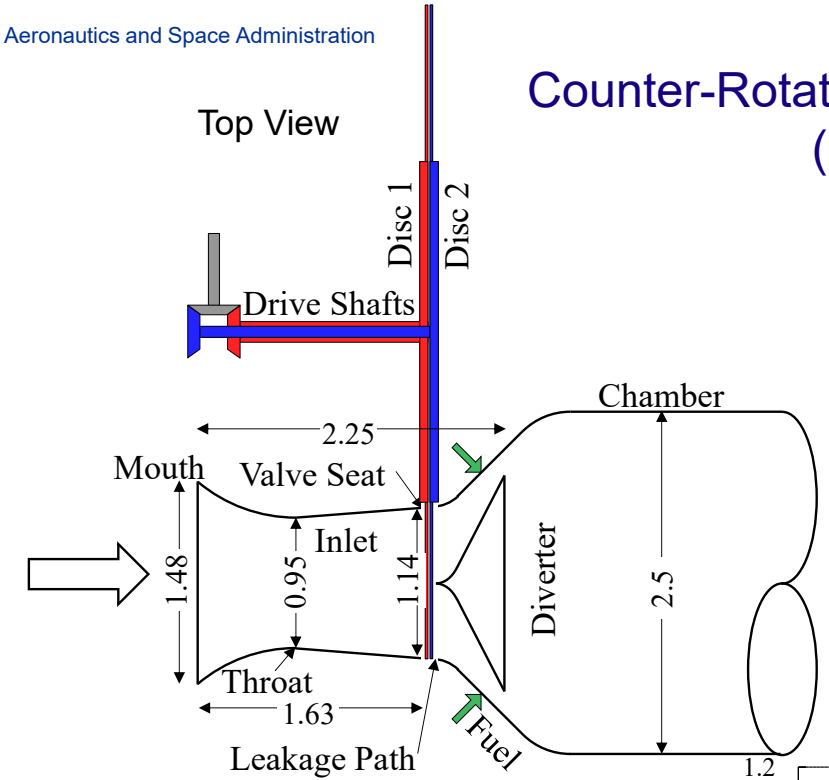
- Ingestion
  - air enters the combustion chamber through the open inlet valve
  - Mixes with fuel
- Ignition & Combustion
  - Residual hot gases cause ignition
  - Valve closes
  - Rapid confined combustion ensues
  - Pressure rises
- Blowdown
  - Compression wave accelerates fluid in tailpipe
  - Exiting fluid causes chamber gas expansion and cooling
- Suction
  - Expansion and fluid momentum reduce chamber pressure below ambient
  - Valve opens to start a new cycle

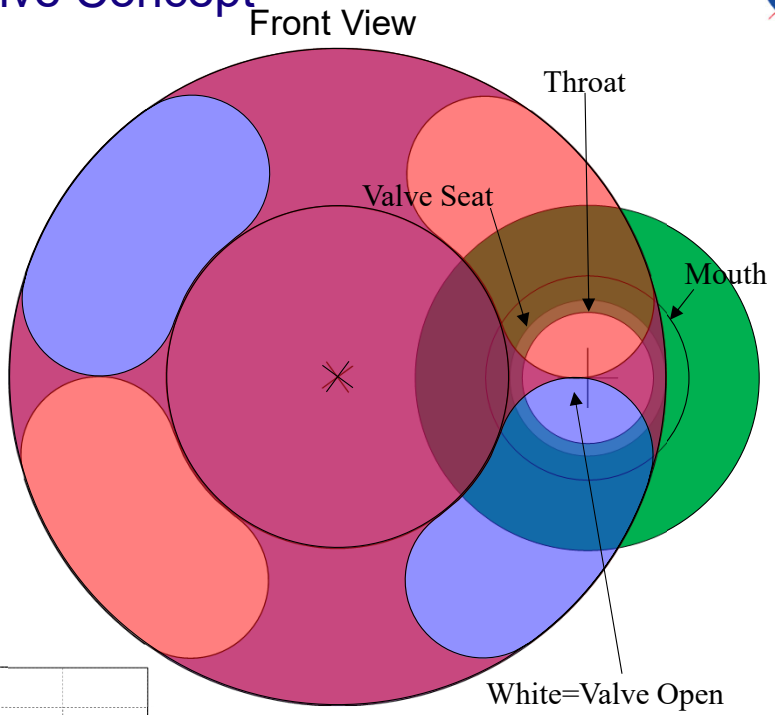
CFD Animation of a Laboratory Scale Resonant Pulse Combustor With Reed Valves Operated at NASA Glenn

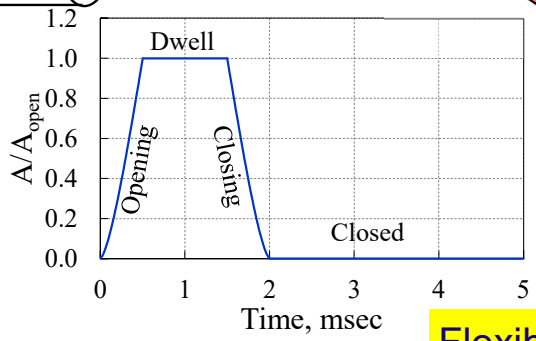


Cycle is Self-Sustaining at ≈ 200 Hz. on Laboratory RPC for Which Investigation is Aimed

Counter-Rotating Disc Valve Concept (*animated*)



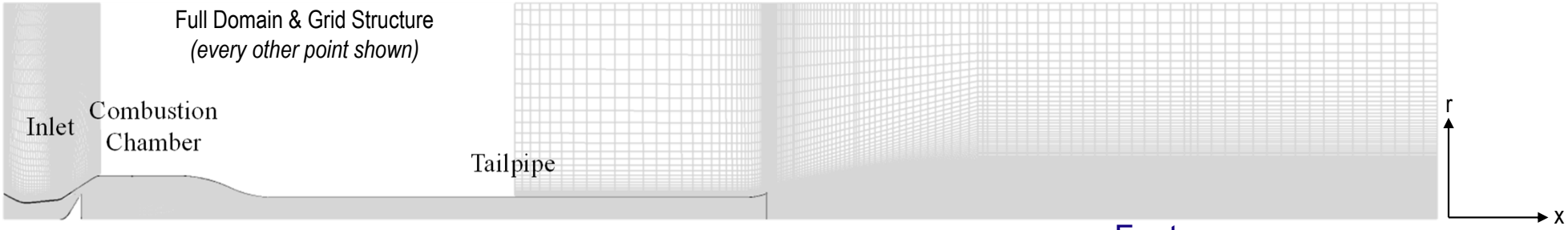


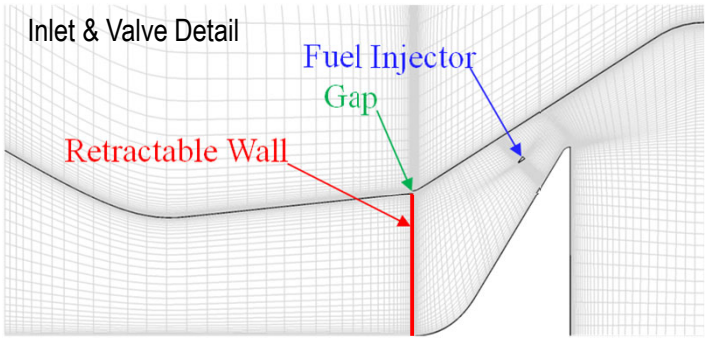


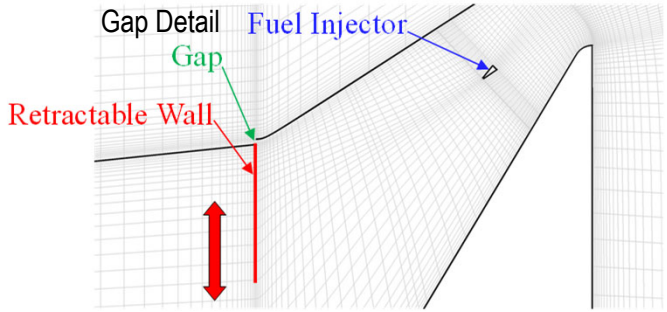
- Concept allows variation in:
  - Overall frequency
  - Opening and closing rate
  - Dwell period in fully open position
  - Fully closed period
- ≈ 6000 rpm per disc for present experiment
- Unavoidable leakage must be assessed

Flexible Cycle Parameters With No Slamming

Computational Fluid Dynamic Optimization Simulation







Features

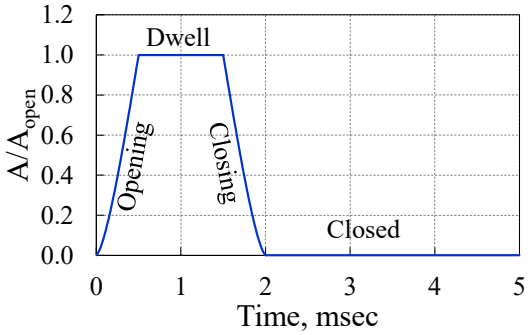
- In house code
  - Axisymmetric, URANS, w/ Turbulence
  - Thermally perfect, multi-species mixture of reacting gases
  - Fuel is gaseous Propane, pressure driven-injection
  - 160,000 grid-points
  - 10 species, 10 reaction kinetics model
  - Domain includes RPC and beyond
- Validated with experimental RPC measurements
- Valve modeled using a retractable wall
  - Feedback mode opens each cycle when chamber pressure < atmospheric
  - Fixed mode opens each cycle via a regular period
- Leakage gap % open can be adjusted
- Simulation runs to limit cycle operation
  - Typically 12-14 cycles

Goal: Determine Parameters That Maximize Performance

Results

Parameters Examined:

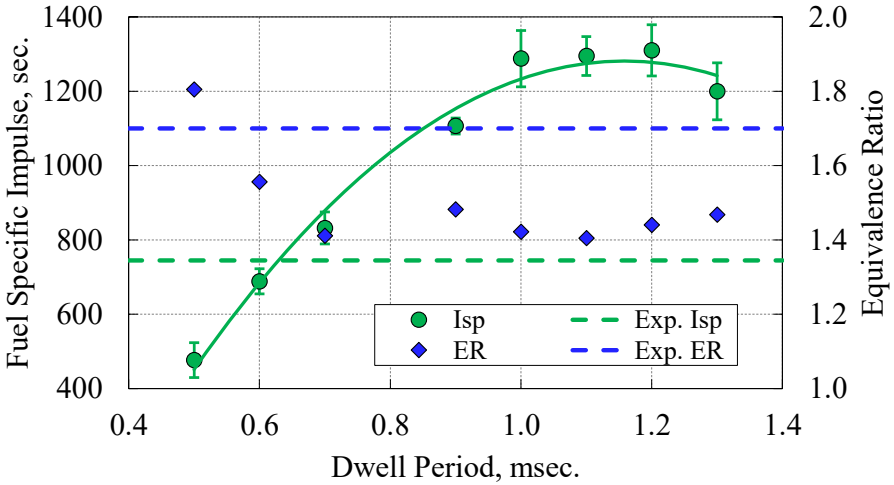
- Dwell period ⟸
- Closed period ⟸ *Only discussing these today*
- Leakage (cursory only) ⟸
- Equivalence Ratio (cursory only)
- Fuel injector location
- Feedback vs. Fixed operation



Opening=0.5 msec.
Closing=0.5 msec.
Dwell=variable, prescribed
Closed=variable based on $P_{cc} < P_{in}$ feedback

Static Operating Conditions:

- P_{in}=14.7 psia, T_{in}=540 R
- P_{amb}=14.7 psia



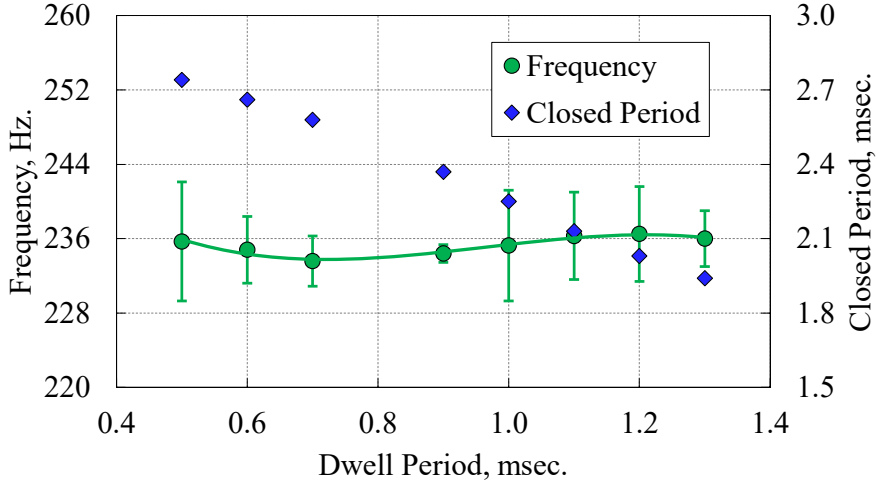


Figure of Merit:

- Fuel specific impulse
  - Directly related to pressure gain
  - Easily measurable in a lab

Disc Valve Shows Significant Improvement Over Reed Valve*
Performance Peaks Near Dwell Period=1.1 msec

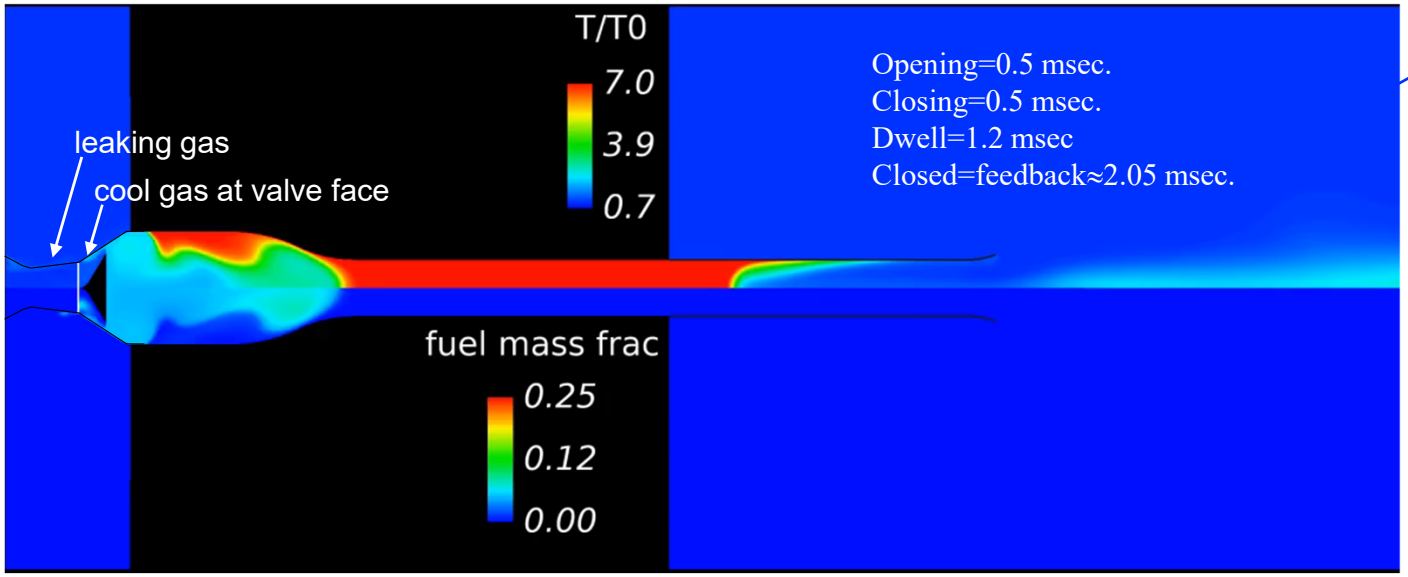
*Reed valve results are experimental and use gasoline

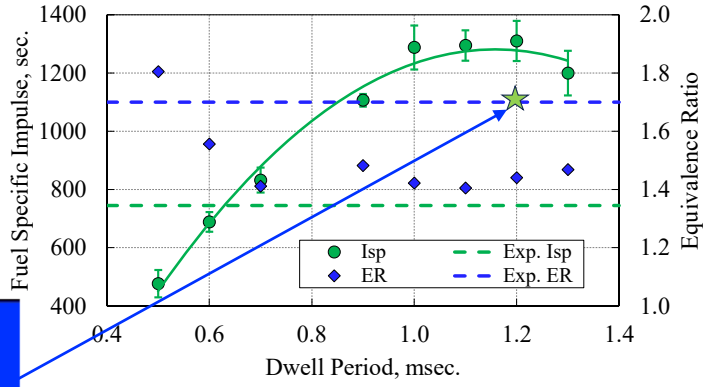
Results

Leakage Impact:

- Gap imposed is larger than expected from current engineering design
- Simulation utilized feedback for closed period
- **Specific Impulse Reduced Just 9%**
- What does leak out is not hot!

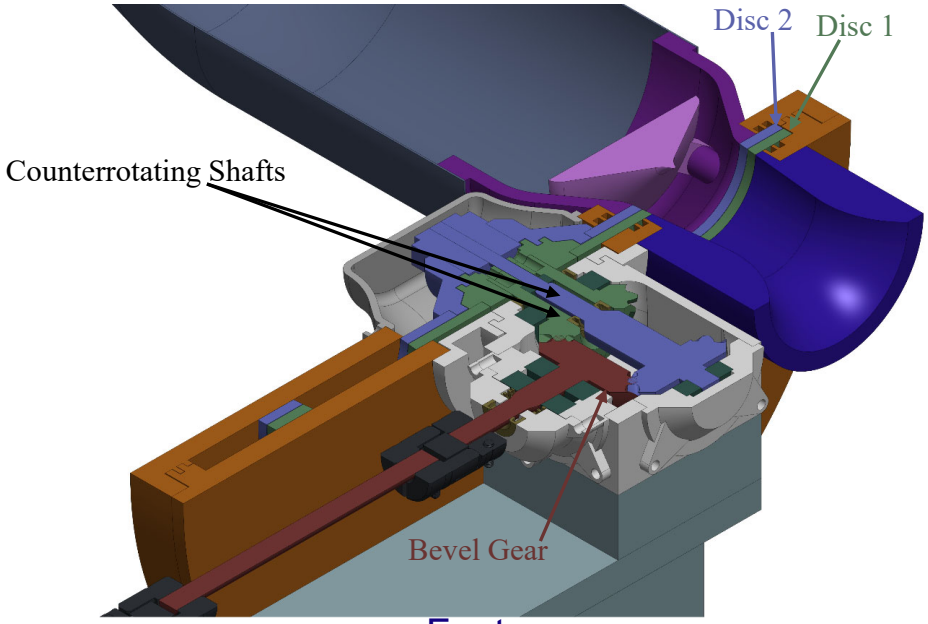
CFD Animation of RPC with Optimized Rotary Disk Valve

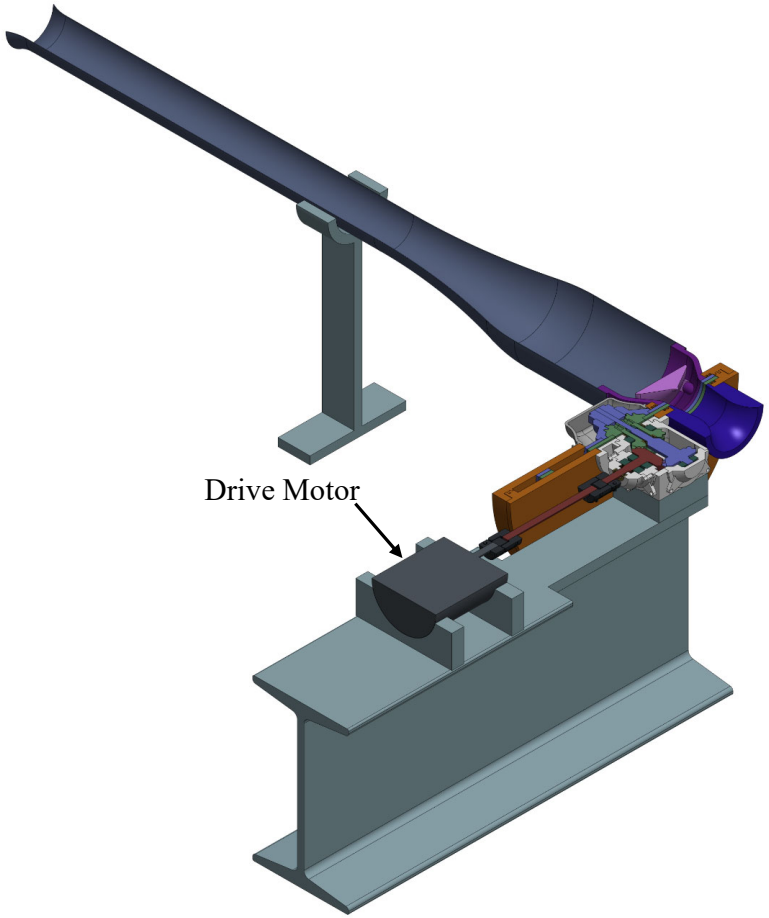




Unavoidable Leakage Performance Impact is Very Modest

Preliminary Mechanical Design





Features

- Bevel gear counterrotating shaft system
- Compact
- Labyrinth seals on discs
- Discs encased in housing
  - Reduces leakage to/from outside

No Significant Fabrication or Structural Issues Identified

Summary

- An active counterrotating dual disc valve concept for a Resonant Pulse Combustor (RPC) was introduced with the goals of:
  - Improved performance (over reed valves)
  - Long life
- Parametric optimization was performed using a validated CFD simulation
  - Dwell period, closed period, equivalence ratio, fuel injector location, and leakage investigated
- Optimization produced a 60% specific impulse improvement of state-of-the-art reed valve
  - Without the life-limiting slamming or high temperature!
- Preliminary mechanical design of the valve shows feasibility with ordinary fabrication techniques

Prototype Fabrication and Testing Are Justified

Acknowledgements

This work was supported by the NASA Transformational Tools and Technologies project under the Transformative Aeronautics Concepts Program.

We are grateful to Shawn Dellinger of HX5 for his excellent mechanical design work on the rotary valve concept presented here

Thank You for Viewing