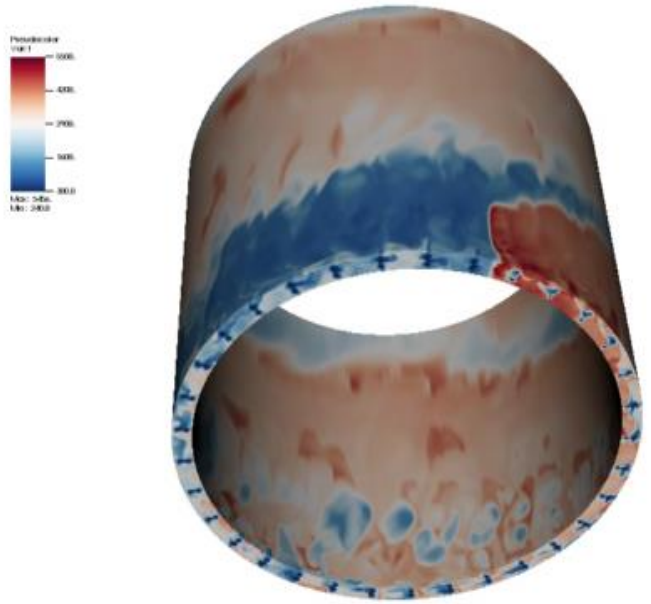


Space Technology Mission Directorate
Game Changing Development Program

Dr. Doug Perkins| Dr. Dan Paxson| FY21 Rotating Detonation Rocket Engine Annual Review Presentation | 09.23.21
NASA Glenn Research Center

Rotating Detonation Rocket Engine (RDRE) Project Overview

- Technology Product Capability
  - Increased specific impulse over conventional rockets – on the order of 10%
    - Options are being explored for even higher performance gain
    - Alternately, combustor feed pressure can be lowered while maintaining equal performance
  - Decreased combustor length - on the order of 50% or more
- Technical Capabilities
  - Conventional design methods and tools are of limited applicability, necessitating the development and validation of unique RDRE numerical tools
  - Advanced designs (injectors, combustor, nozzle) past the original proof-of-concept geometry need to be developed to better take advantage of the performance potential of detonation
  - Computational support is needed for complementary NSTRG ESI grants and STMD Announcement of Collaborative Opportunities (ACO) RDRE experimental activities.
- Exploration & Science Applicability
  - Initial applications are expected to be for in-space propulsion, including upper stages, orbital transfer, and landers. In these applications, the short length of these engines provides significant packaging benefits, in addition to the anticipated performance benefit
  - Long term, RDRE's could be used for any chemical propulsion application



Snapshot of Temperature Contours in Purdue RDRE Combustor Design using O-F-O Triplet Propellant Injectors (GRC Simulation)

Mission Infusion & Partnerships

NASA Centers
- GRC
- MSFC (ACO)

ESI
- U of Alabama
- Purdue University
- UCLA

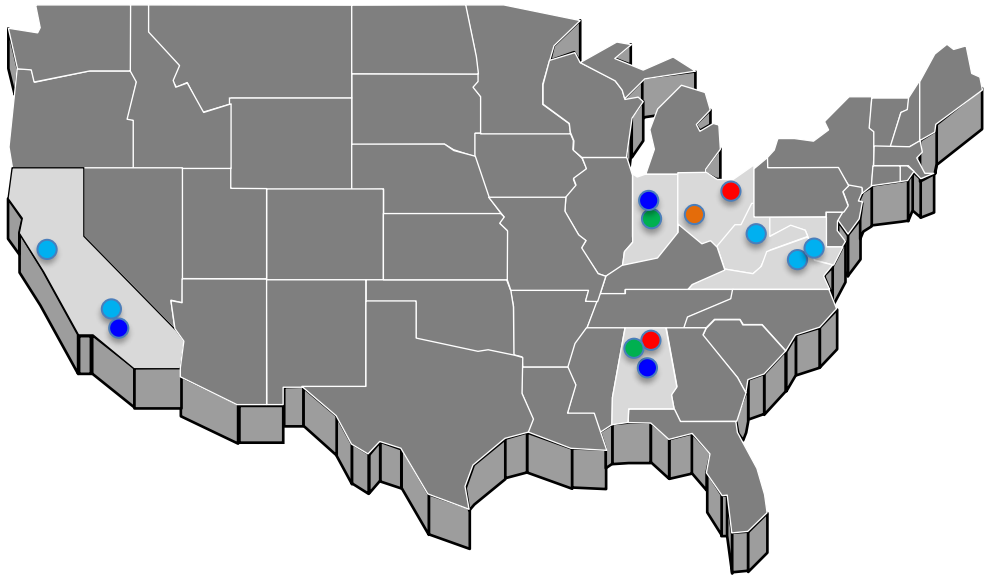
OGA Leveraging
- AFOSR
- AFRL – Edwards
- Navy – NRL, NPGS
- DoE - NETL

SBIR/STTR
- Spectral Energies, LLC

NSTRG Fellowships
- Purdue (4)
- U of Alabama, Huntsville

Infusion/Transition Plan

- Improved specific impulse will benefit any mission application by lowering vehicle mass, or extending duration.
- Decreased length will decrease overall launch vehicle length, decreasing launch vehicle weight and propellant use for upper stage and in-space payload applications.
- Commercial launch companies have expressed interest and explored technology develop partnerships on current efforts.
- Immediate technology development path includes MSFC-led ACO effort with IN-Space/Purdue (testing at MSFC late this calendar year into the following year) followed by potential GCD funded demonstration engine.



Collaborative partnerships to leverage fiscal resources, facilities, knowledge & expertise.

Rotating Detonation Rocket Engine Technology Goals & Project Objectives



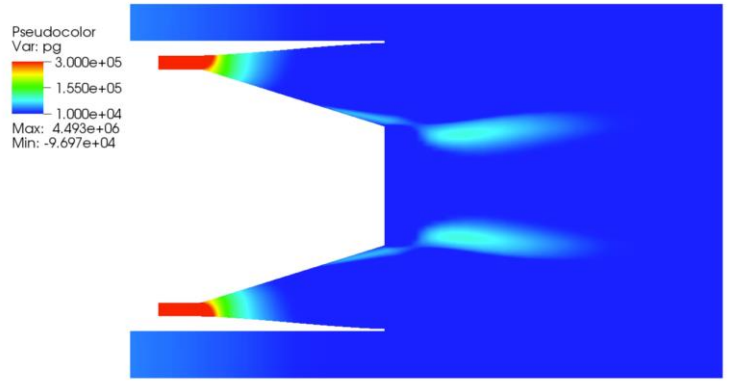
Technology Goals	
Goal #1	Develop RDRE cycle code with all relevant propellants, propellant density effects, and radial RDRE performance estimation capability
Goal #2	Modify existing 3-D CFD codes and develop validated modeling techniques for RDRE's to allow simulations to be performed in one week or less on a workstation cluster.
Goal #3	Demonstrate and refine RDRE nozzle design methodology. Validate approach using experimental data when such data becomes available.
Goal #4	Provide design and analysis support to other NASA and grantee RDRE projects

Project Objectives	
Objective #1	Add MMH, MON-25 and N2O4 propellants to RDRE cycle code. Develop User's Guide and prepare code for initial release to RDRE community.
Objective #2	Modify NASA National Combustor Code (NCC) for liquid fueled RDRE CFD studies. Demonstrate applicability of CONVERGE commercial CFD code.
Objective #3	Validate CFD codes against experimental data from ACO, STTR and ESI grant projects.
Objective #4	Perform nozzle design for MSFC-led ACO RDRE design and validate design methodology with experimental data.

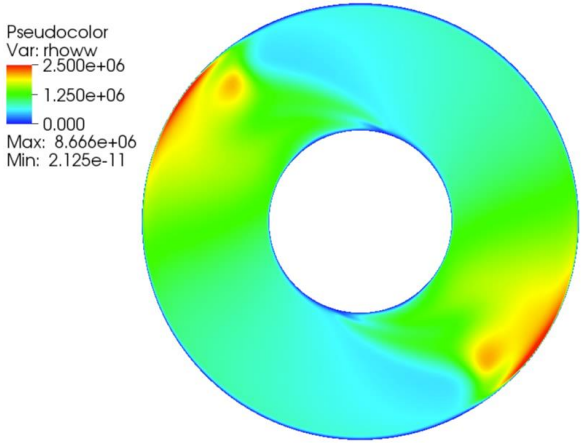
Goals and Objectives are from DRAFT Project Plan

RDRE Technical Accomplishments

- ACO nozzle design study
  - Performed a series of 9 quasi-2D/3-D coupled simulations of RDRE combustor/nozzle sets to determine optimum nozzle configuration given design constraints of additive manufacturing techniques to be employed for nozzle fabrication
  - Identified key differences between single wave designs and designs anticipating multiple detonation waves in the combustor
  - Optimum nozzle calculated performance was only 6% below performance of ideal nozzle operating under equivalent steady flow conditions
  - Optimized design balances nozzle base drag caused by shallow central cone angle against improved shock wave expansion achieved with flared cowl.



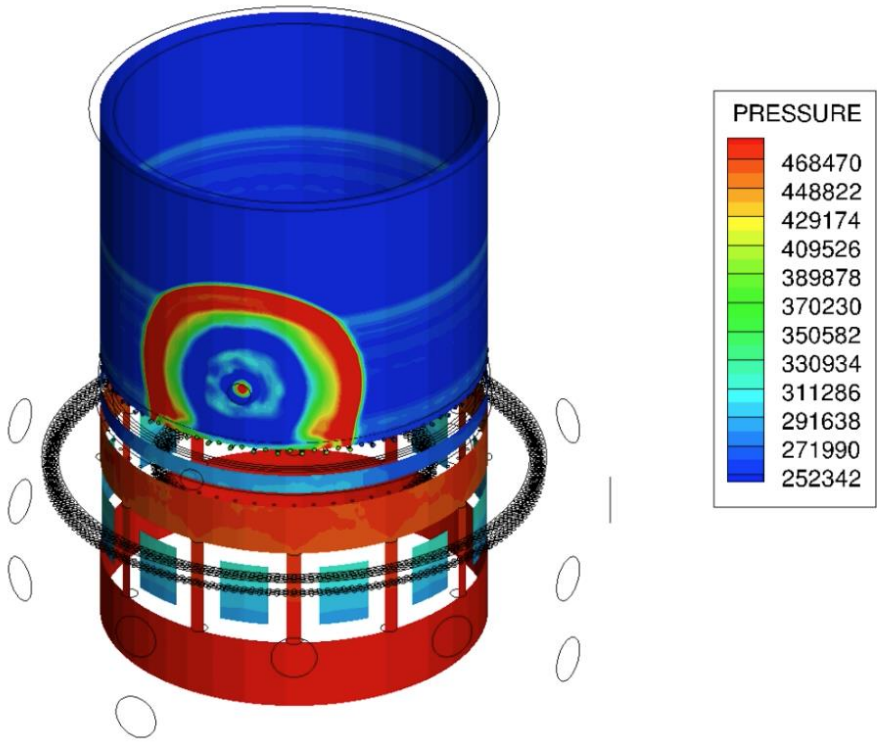
Optimized RDRE Nozzle
Cut Section View



Optimized RDRE Nozzle
End View Looking Upstream

RDRE Technical Accomplishments

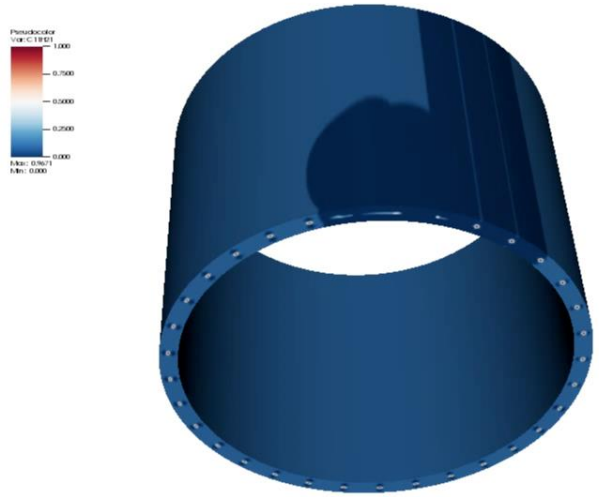
- Capability assessment of CONVERGE 3-D CFD software against Naval Post-Graduate School (NPGS) experimental data
  - Code proposed for RDRE modeling because of advanced techniques in Adaptive Mesh Refinement (AMR), which may be able to reduce total number of grid points required in a simulation.
  - Developed detailed model of complex experimental hardware
  - Worked with code developer to solve significant “bugs” in current version of software
  - Currently running full multi-cycle simulation for final validation



Detonation Wave Expansion During RDE Ignition from External Detonation Tube Using CONVERGE CFD Software

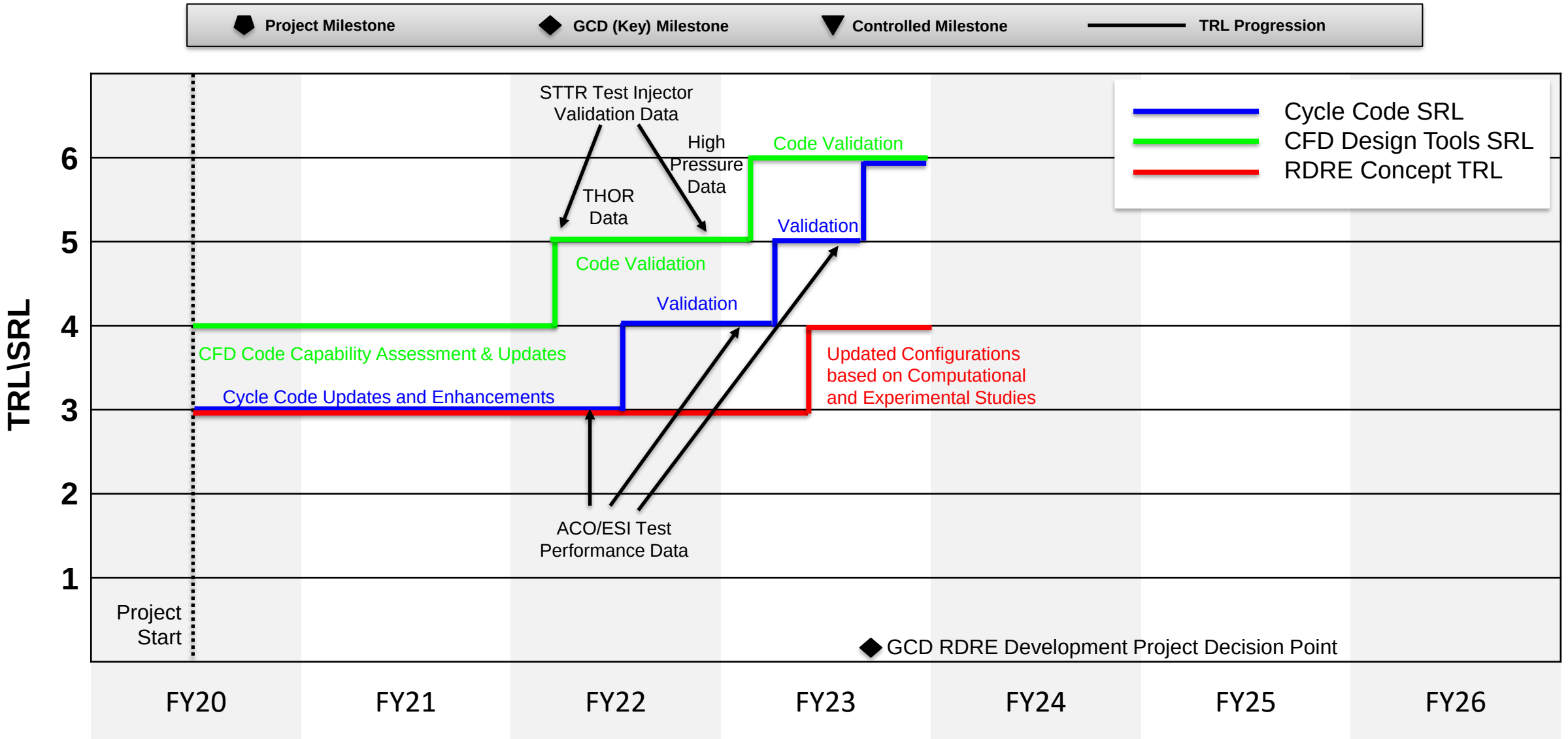
RDRE Technical Accomplishments

- Development of Purdue ESI rig model
  - Modeled kerosene/O2 operation with NCC Code
  - Achieved cyclic detonative operation in simulation
  - Mixing/combustion efficiency issues identified
- Completion of droplet model in NCC and initial validation runs in NCC
  - Shock/droplet interaction model added to NCC code
  - Initial detonation tube simulations completed for first step in validation
- RDRE cycle code User's Guide written and in review
  - Working toward release of first version of code this fall
  - Validation still ongoing as data becomes available
  - Development version of code used for design of MSFC ACO engine



Fuel Concentration Contours of Purdue RDRE Geometry with 33 sets of Discrete Injectors Modeled Using NCC code – Initial Combustor Startup (Non-Optimal Operation)

Rotating Detonation Rocket Engine



Technical Assessment

Technical Elements	TRL				AD[2]	
	Entry	Current[1]	Exit	Verification	Entry	Current
Element 1				Milestone		
Element 2						
Element 3						

Technical Elements					AD[2]	
					Entry	Current
Element 1						
Element 2				ID#		
Element 3				Milestone ID#		

Technical Elements	MRL				AD[2]	
	Entry	Current[1]	Exit	Verification	Entry	Current
Element 1				Milestone ID#		
Element 2				Milestone ID#		
Element 3				Milestone ID#		

No Technical Assessments have been performed as yet for this project.

Date of last Technical Assessment was XYZ

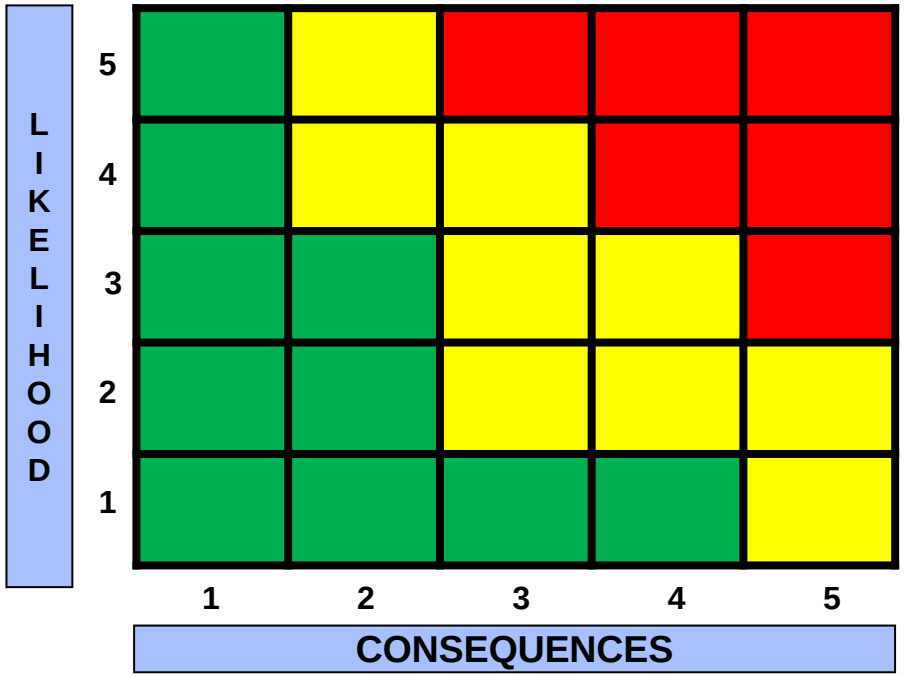
RDRE Key Performance Parameter (KPP) Status

Key Performance Parameters								
Parameter	**Units**	**State of the Art (SOA)**	**Threshold Value**	**Project Goal**	**Current Value To Date**	**TBoE for the provided Current Value**	**Expected Exit Value**	**TBoE for the provided Expected Exit Value**
3-D Simulation Run Time	Days	30+	7	5	15	Estimate[1]	5	Estimate[2]

Notes:
Technical Basis of Estimate (TBoE)
(1) Combustor and nozzle simulated in ~10 days by GCD RDRE team – full engine model including injection system and manifolds in process
(2) SME estimate

KPPs are not yet in an approved state.

Risk Summary



Criticality
- High
- Med
- Low

L x C Trend
- Decreasing (Improving)
- Increasing (Worsening)
- Unchanged
- New Since Last Period

Approach
- M - Mitigate
- W - Watch
- A - Accept
- R - Research

Affinity: **T**-Technical **C**-Cost **Sc**-Schedule **Sa**-Safety

Risk ID	Affinity/ Approach	Description/Status	Trend
ID#			

Provide ALL Yellow and Red Risks

No formally recognized project risks have been identified
- Outyear staffing of PhD level CFD support is an ongoing concern (FY22 and FY23)

Project Assessment Summary

Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – Cost – Schedule – Simulation of Purdue liquid/gas injection scheme proved more challenging than expected Programmatic -
Annual					Technical – Cost – Schedule – Liquid/gas injection simulation required date slipped due to hardware issue in supported project (Purdue ESI) Programmatic -

EPO Update

- No public outreach activities planned in FY22
  - Have consulted with outreach staff, but technology deemed too low TRL for available opportunities

- Conferences
  - Currently in discussion with AFRL regarding appropriate export control measures for publications. Likely that most results will have to presented in export controlled forum (JANNAF). Next JANNAF LPS Subcommittee meeting not until December 2022.

RDRE Plans Forward and Infusion Plan

- The purpose of this project (multi-year seedling task) is to develop required tools for RDRE design and determine viability of RDRE for future larger scale investment by GCD. The code development, code validation, and concept development done under this task, when combined with experimental projects funded under NSTRG ESI projects, MSFC ACO project and STTR project should provide an adequate basis for determining viability of RDRE for further investment at the end of FY23.

Summary

- Accomplishments for the Year
  - ACO Nozzle Design completed
  - Shock/droplet interaction model coded and partially validated in NCC code
  - Model developed in CONVERGE software of NPGS RDE engine and validation underway
  - Purdue ESI test rig modeled and design issues identified
  - Cycle code User's Guide written and in review. Preparing for initial release of code to partners.

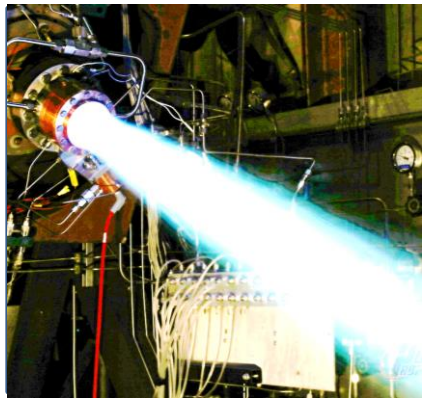
- Summarize the TechMat Capability End State for the Scope of the Project
  - Validated RDRE cycle code capable of providing basic RDRE geometry, operating conditions and performance for propellant combinations of interest
  - CFD-based design codes available for rapid (1 week or less) turnaround assessment of engine flowpath designs
  - Candidate next-generation RDRE design(s) developed and computationally evaluated

BACKUP

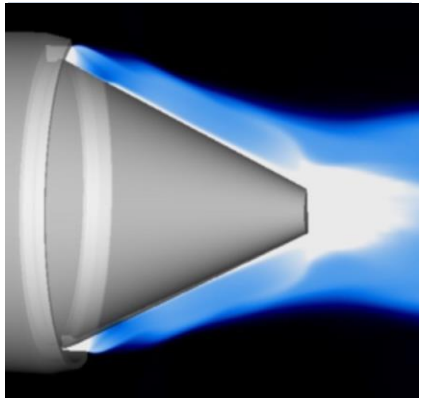
Rotating Detonation Rocket Engine – Annotated Cover Pictures

Annotated Cover Slide Images

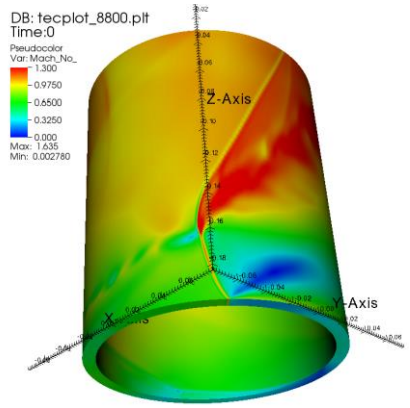
Note: Images from external sources are from STMD ESI grantees and NASA STTR contractor



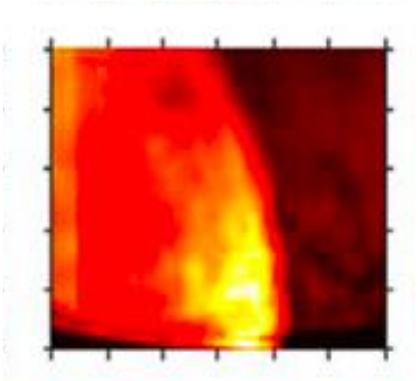
RDRE Hot Fire
(Courtesy of Purdue University)



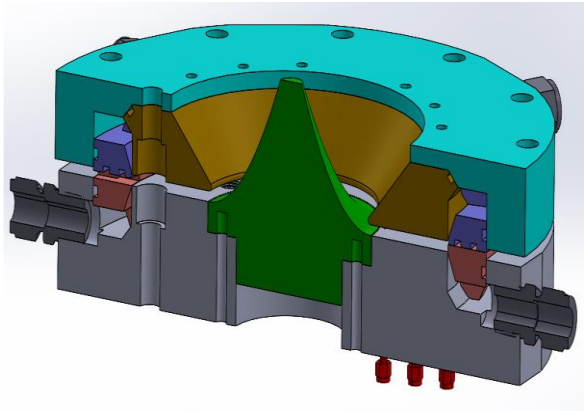
RDRE Nozzle Flow Simulation
(NASA GRC)



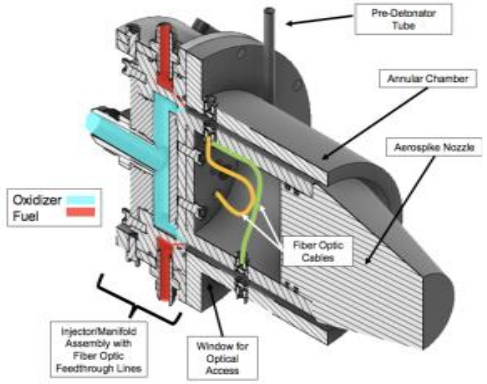
RDRE Simulation with Idealized Injection
(*NASA* GRC)



IR Image of Detonation Wave Propagating in an RDE
(Courtesy of Spectral Energies)



Disk RDRE Design Concept
(Courtesy of University of Alabama)



Annular RDRE Design Concept
(Courtesy of UCLA)