



Space Technology Mission Directorate Game Changing Development Program

Dr. Doug Perkins| Dr. Dan Paxson| FY22 Rotating Detonation Rocket Engine Annual Review Presentation | 09.12.22

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Project Overview



➤ Technology Product Capability

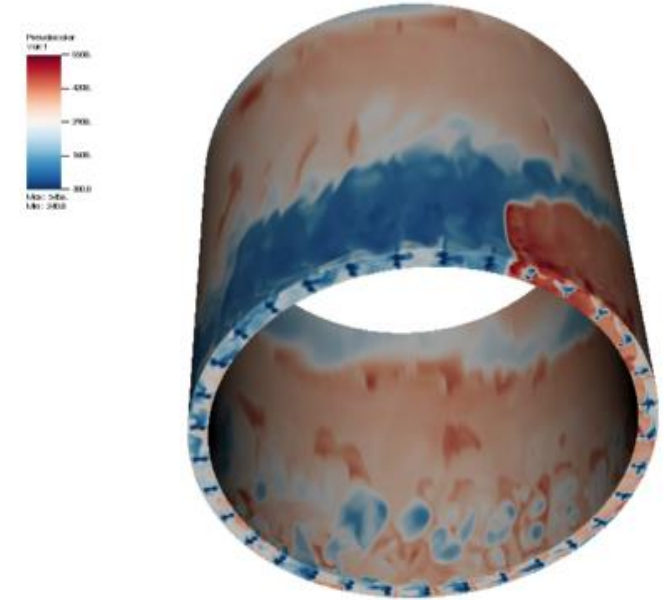
- Increased specific impulse over conventional rockets – on the order of 10%
 - Options are being explored for even higher performance gain
 - Alternately, combustor feed pressure can be lowered while maintaining equal performance
- Decreased combustor length - on the order of 50% or more

➤ 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

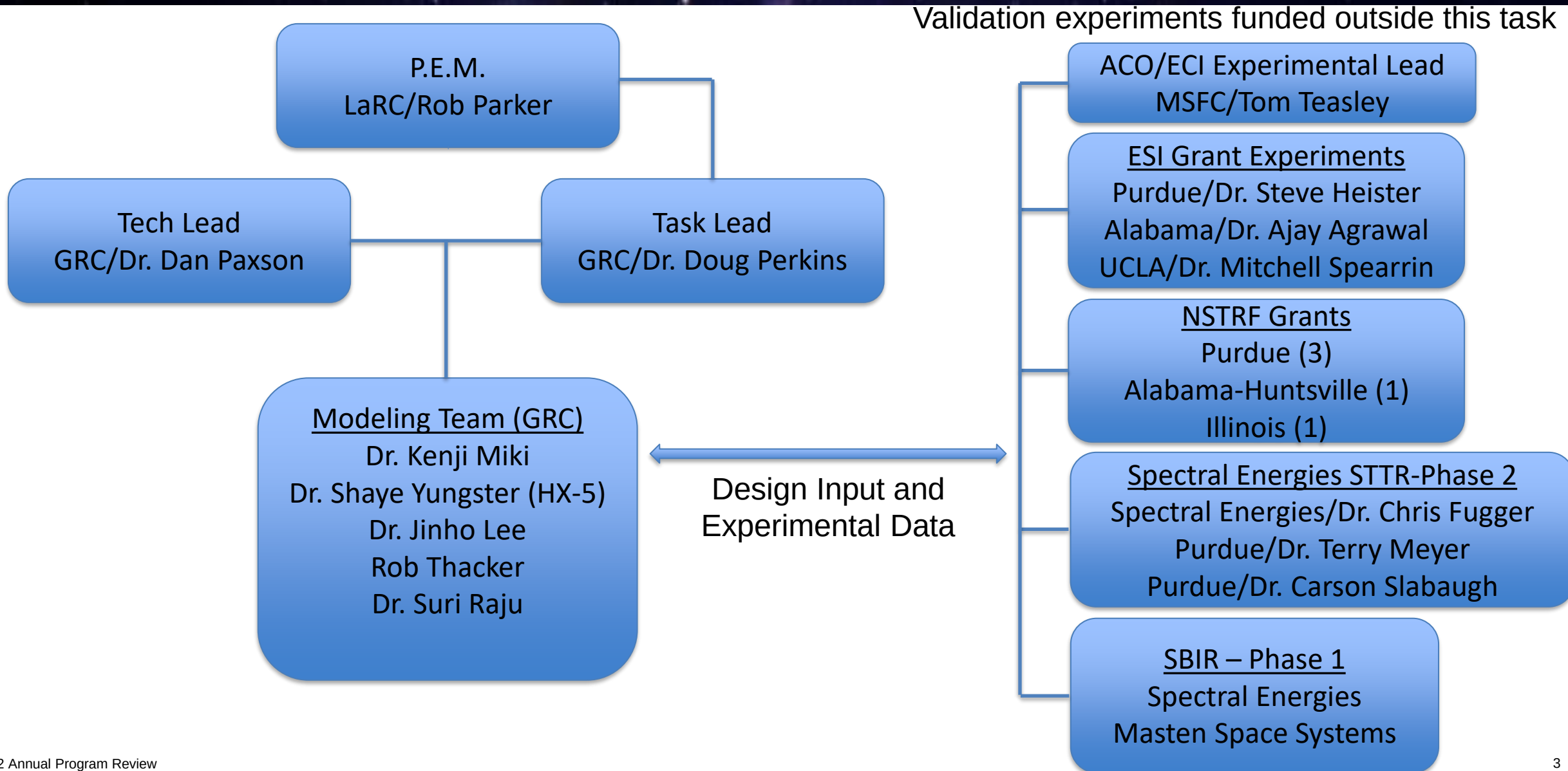
- Initial applications are expected to be for in-space propulsion, including upper stages, orbital transfer, and landers. In these applications, the short length of these engines provides significant packaging benefits, in addition to the anticipated performance benefit
- Long term, RDRE's could be used for any chemical propulsion application



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



Team Members



Collaborations & Partnerships

NASA Centers

- GRC
- MSFC (ACO/ECI)

ESI

- U of Alabama
- Purdue University
- UCLA

OGA Leveraging

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

SBIR/STTR

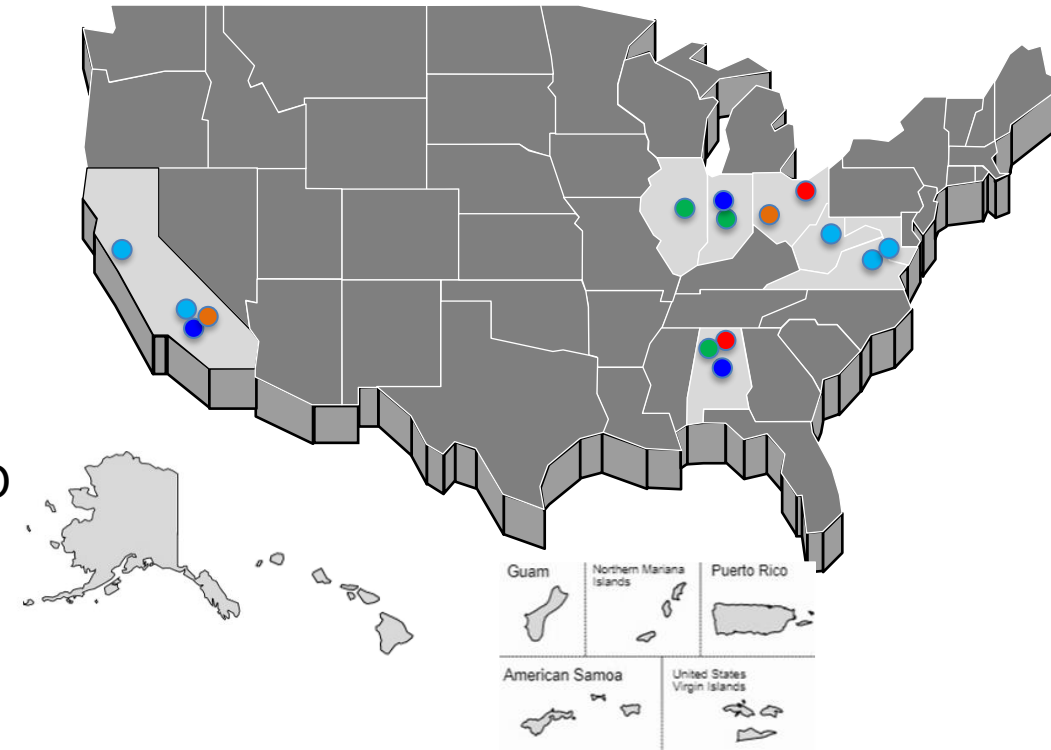
- Spectral Energies, LLC
- Masten Space Systems

NSTRG Fellowships

- Purdue (4)
- U of Alabama, Huntsville
- U of Illinois

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 and ECI projects, supported by configuration and component development grants/contracts and computational design studies. A mission-focused development program would follow these activities.



Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise.

Project Goals & Project Objectives



Technology Goals

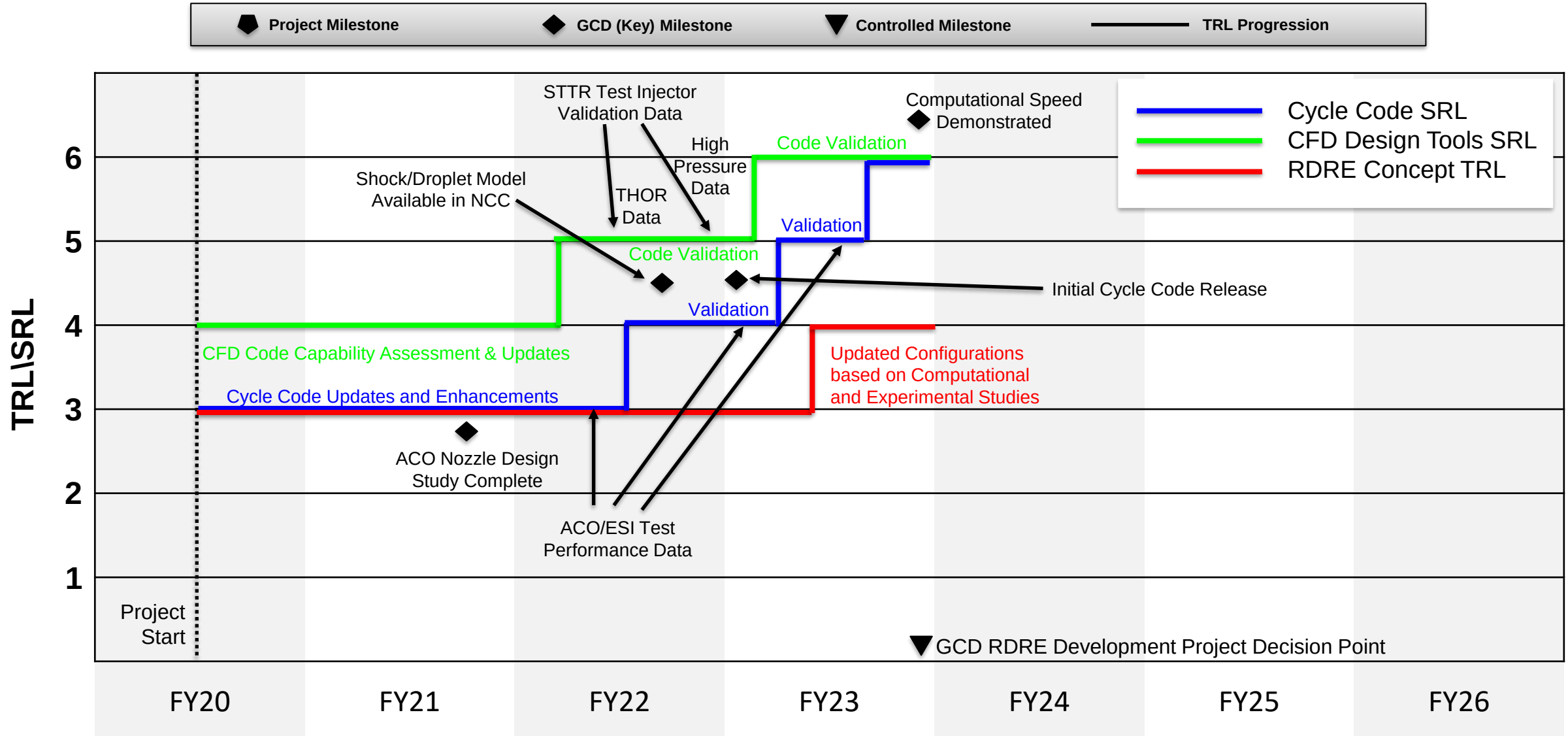
Goal #1	Develop RDRE cycle code with all relevant propellants, propellant density effects, and radial RDRE performance estimation capability
Goal #2	Modify existing 3-D CFD codes and develop validated modeling techniques for RDRE's to allow simulations to be performed in one week or less on a workstation 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 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

Rotating Detonation Rocket Engine



RDRE Technical Accomplishments



ACO-funded RDRE successfully run at MSFC summer of FY22

- Engine sized using RDRE cycle code developed by GRC – performance calculation validation ongoing
- Water calorimetry performed to validate heat transfer models
- Optimized nozzle could not be tested due to fabrication issue, so nozzle validation is limited
- Shaped combustor/nozzle configuration tested for future simulation and validation

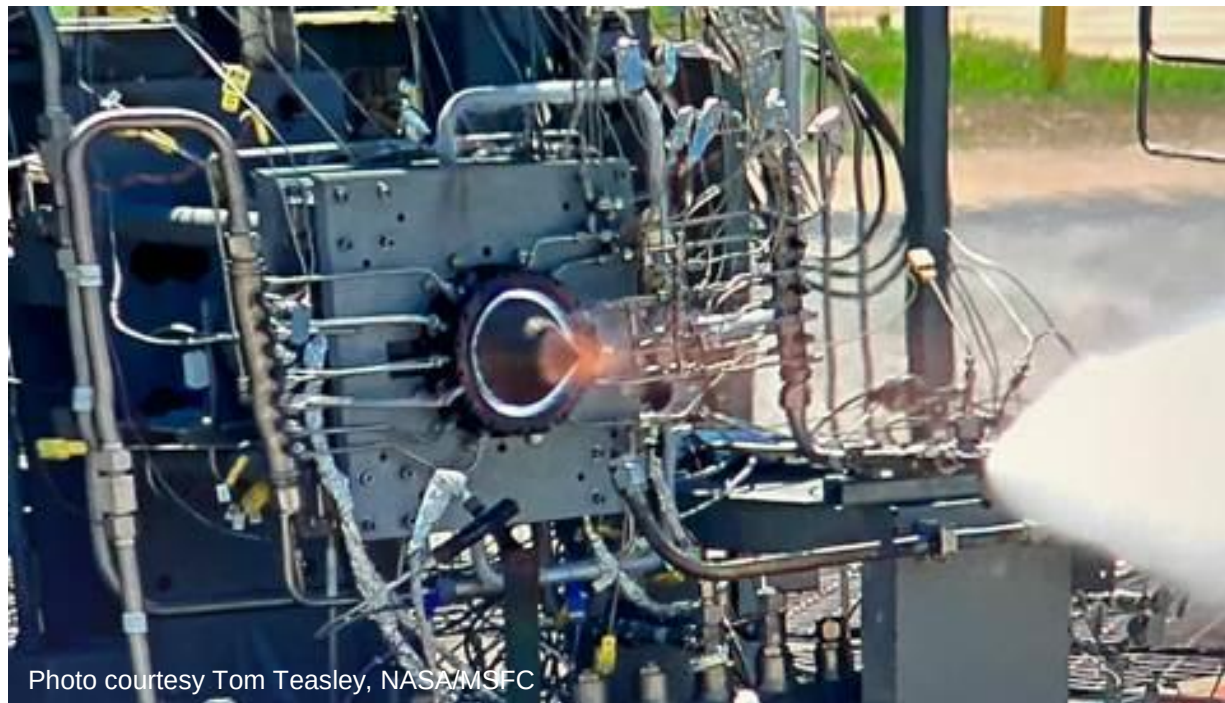
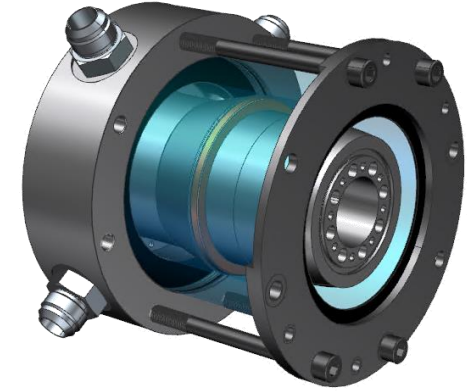


Photo courtesy Tom Teasley, NASA/MSFC

RDRE Technical Accomplishments

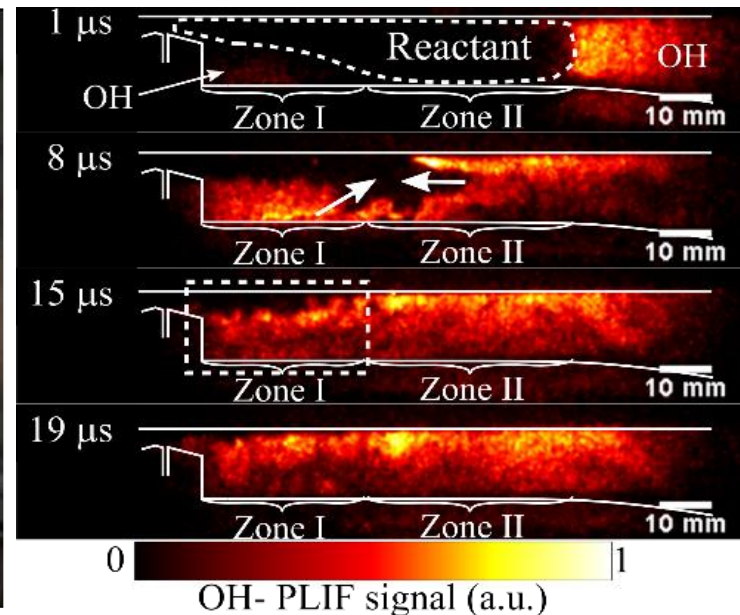
- Validation of NCC code for gaseous and liquid injection
 - Full 3-D model of “THOR” rig, including feed manifolds, created in NCC 3-D code
 - Currently validating overall operation of rig in NCC in H₂/Air
 - Experiment included single liquid fuel jet (diesel) which will be modeled to examine behavior of liquid injectors subjected to passing detonations



Purdue “THOR” Optically Accessible RDE



“THOR” Rig in Operation



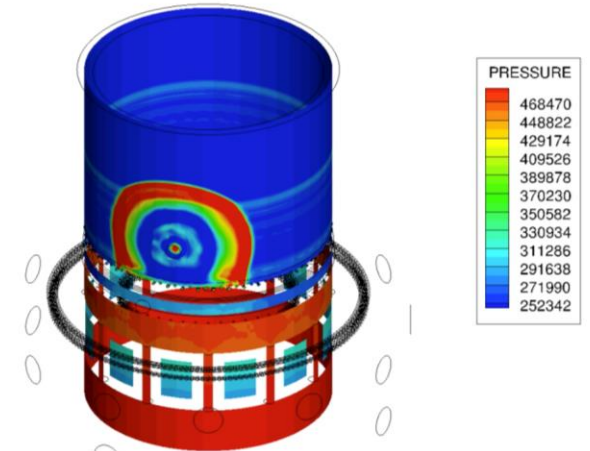
OH-PLIF of “THOR” rig
(2-D slice of combustor)
showing reactant penetration
And combustion products

RDRE Technical Accomplishments

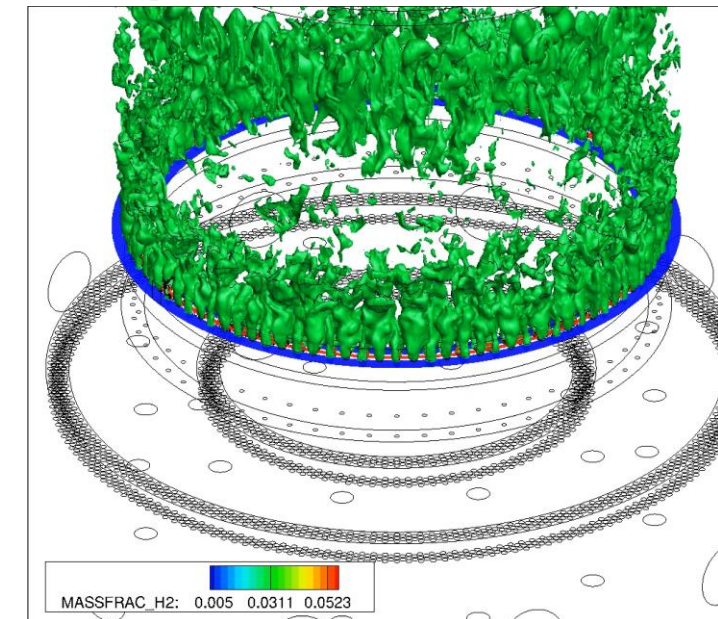
➤ Capability assessment of CONVERGE 3-D CFD software against Naval Post-Graduate School (NPGS) experimental data

- 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 validation

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



Animation of fuel
mass fraction during
propagation of
detonation wave for
one pass around the
combustor



RDRE Technical Accomplishments

- Development and analysis of advanced gaseous injector concepts
 - Geometric details of injectors are export controlled
 - Mass-averaged pressure gain of up to 13% achieved in simulations (first time pressure gain demonstrated for RDE)
- Validation of Liquid Spray Model for Detonation Applications
 - Shock/droplet interaction model added to NCC code
 - Detonation tube simulations completed for first step in validation
 - Begun simulations with droplets in 3-D
 - Implemented liquid propellant injector CFD capability in Q2D code for injector studies
- 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

RDRE Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – Cost – Schedule – Lost 3 months computational time due to NAS hardware failure Programmatic – Budget reduction of 29% in FY22 required re-baselining of effort
Annual					Technical – Cost – Schedule – Programmatic –

Note: Budget reduced 53% in FY23 compared to original plan, requiring additional re-baselining

Plans Forward and Transition / Infusion Plan



- Complete code validation and code performance demonstration by end of FY23
- Perform initial studies on advanced RDRE configuration based on results of current configuration and component studies
- Provide computational and design support to RDRE ECI project starting October 2022
- Transition to mission-focused development effort in FY24

Education/Public Outreach

EPO Involvement

- NASA presented Rotating Detonation projects summary at National RDE Council Technical Interchange Meeting in Monterrey, CA the week of July 17, 2022.
- NASA ACO RDRE testing completed – August 2022. Achieved multiple 100+ second test firing with regenerative cooling – first time demonstrated in an RDRE
- JANNAF RDRE panel sponsoring 3 RDRE sessions at December JANNAF LPS meeting.

EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead

JANNAF LPS Meeting, Huntsville, AL	December 6-8

Summary



- Accomplishments for the Year
 - ACO RDRE tested including design input from GCD developed tools
 - Validation of computational tools against experimental data well under way
 - Gaseous injectors computationally demonstrated that provide high pressure gain
- A Couple of Significant Challenges were Encountered which Reduced Progress
 - NAS hardware failure last August led to zero computational capability for ~3 months, and reduced capability for another ~3 months beyond that, significantly reducing computational output
 - Rescope of level of effort on tasks to accommodate budget reduction at mid-year
 - 29% of annual budget, but had to be absorbed in 6 months, right when we were getting the NAS back at full (and improved!) capability.
- 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