GE Aerospace

Demonstration of a Gas Turbine-Scale RDC Integrated with Compressor and Turbine Components at 7FA Cycle Conditions

GE Team

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Agenda

— Overview and Status

— Demonstration of Operability and Feasibility along F-Class Cycle

— NCSU : Total Pressure and Temperature Measurements

— CFD : Rig Design and RDC-Turbine Interaction

— UM : Detonation Study for Interaction

— Summary and Next Steps

– Overview and Status

Program Overview

Demonstration of a Gas Turbine-Scale RDC Integrated with Compressor and Turbine Components at 7FA Cycle Conditions (2022 – 2026)

Project Team

GE Research

Deep expertise:
- RDC and gas turbine design
- Gas turbine testing
- Compressor/diffuser aero
- Turbine aero
- Cooling design, heat transfer

Computational Combustion and Aero

UNIVERSITY OF MICHIGAN

Prof. Raman

Measurements and Diagnostics

UCF

Prof. Vasu

Georgia Tech

Prof. Steinberg

NC STATE UNIVERSITY

Prof. Narayanaswamy

Project Deliverables

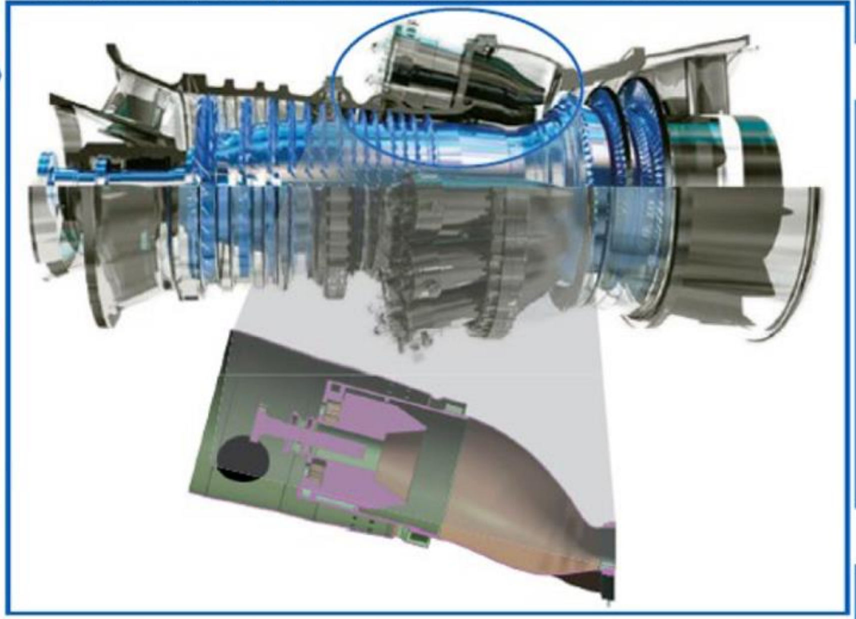
- Low-loss RDC design for turbine integration
- Experimental demos of compressor and turbine integration
- Turbine and compressor component performance estimates in integrated system from detailed test and measurement
- RDC-integrated GT performance estimates

Relevant Prior Work

- Air-cooled RDC demonstration
- RDC operation on natural gas at elevated T,P
- Preliminary gas turbine integration design
- RDC performance estimates
- USAF RDC Program

An 48-month, $8.75M project to develop and demonstrate rotating detonation combustion (RDC) technology in an integrated gas turbine system.

Project Objective(s): Develop low-loss rotating detonation combustor, integrate with upstream and downstream turbomachinery components and verify overall systems performance at F-class turbine conditions.



Technical Approach
- Design air-cooled RDC
- Test with Nat-gas H2 mixtures
- Integrate with compressor and turbine
- Test integrated system
- Verify performance based on high-fidelity data

Technical Challenges
- RDC operation over large P,T range
- Low-loss RDC inlet design
- Fuel flexible operation
- Unsteady flow effects on compressor and turbine performance

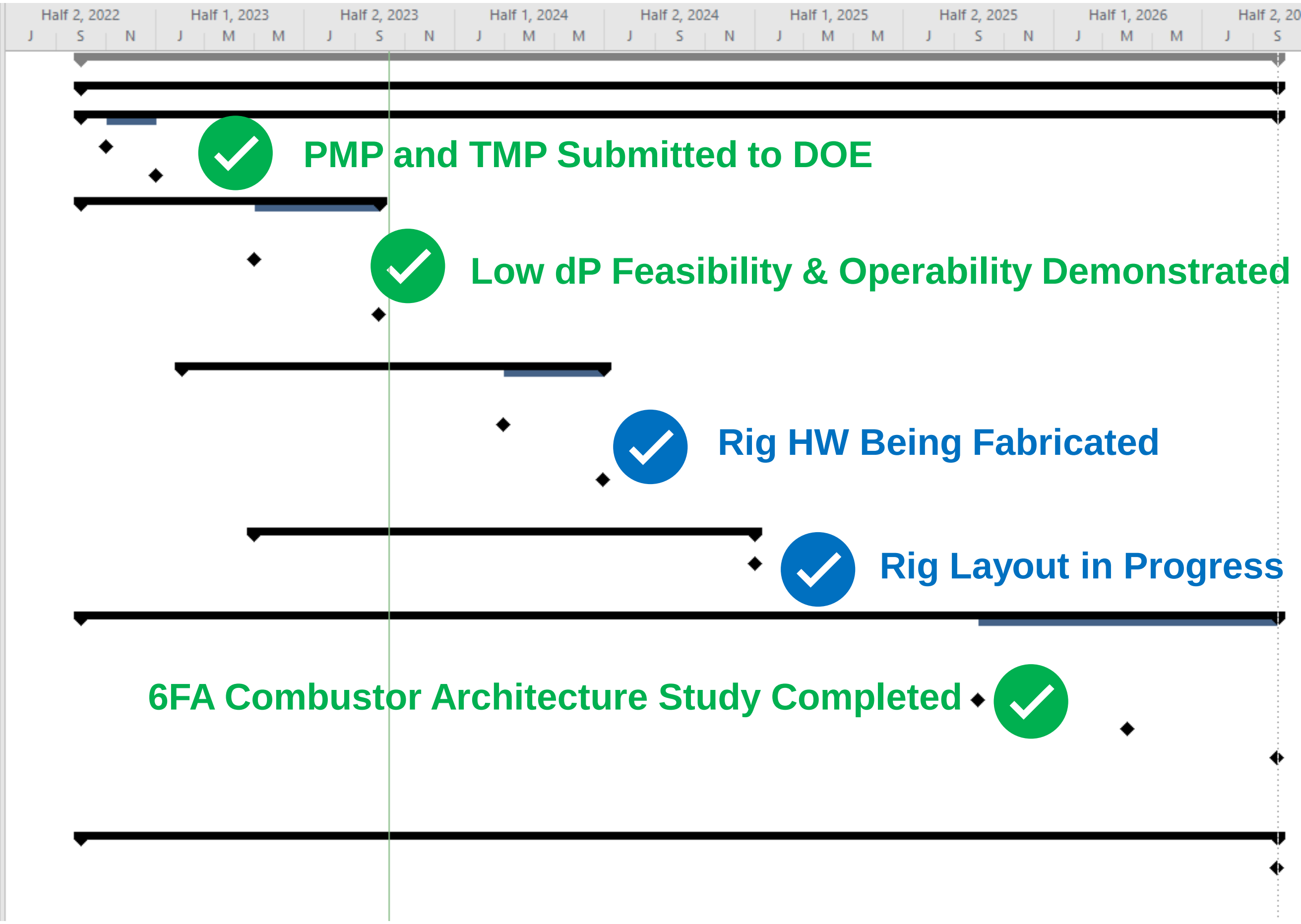
Program Schedule and Status

Complete

In Progress

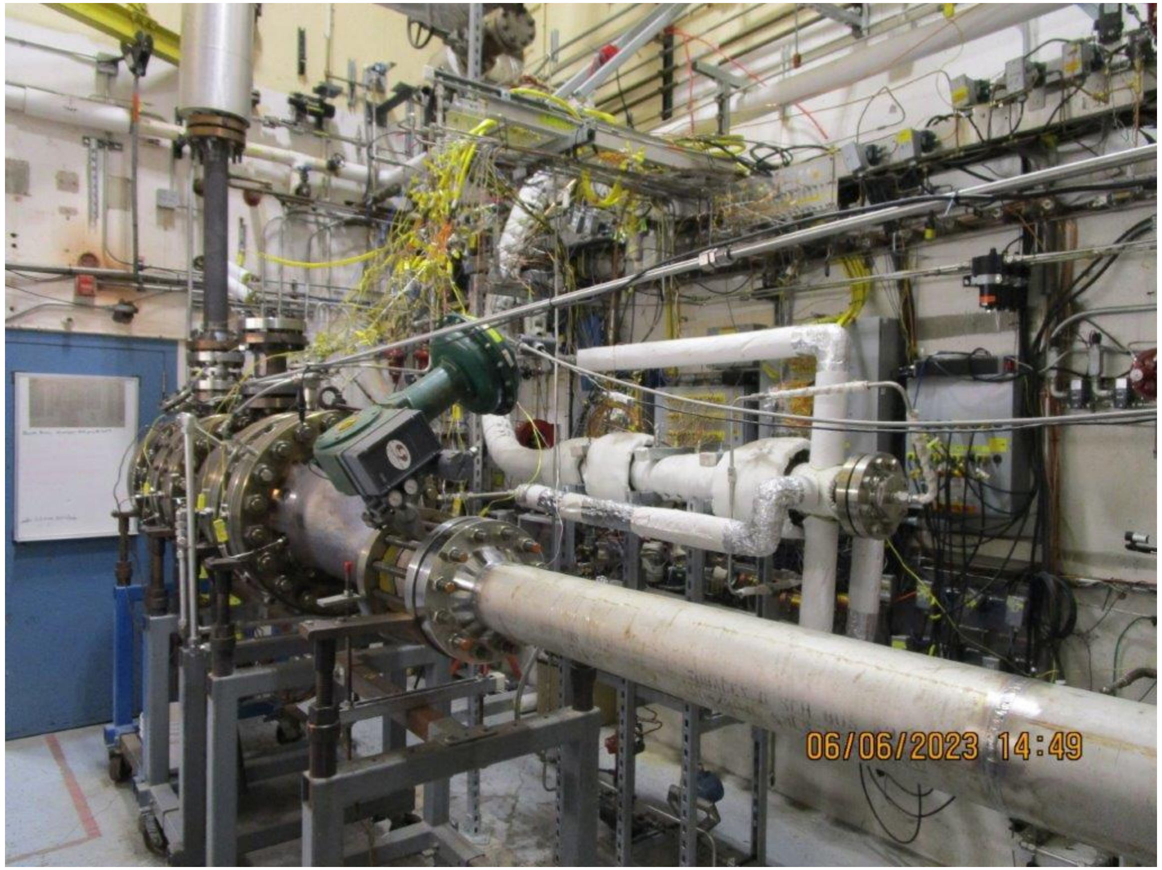
GANTT CHART

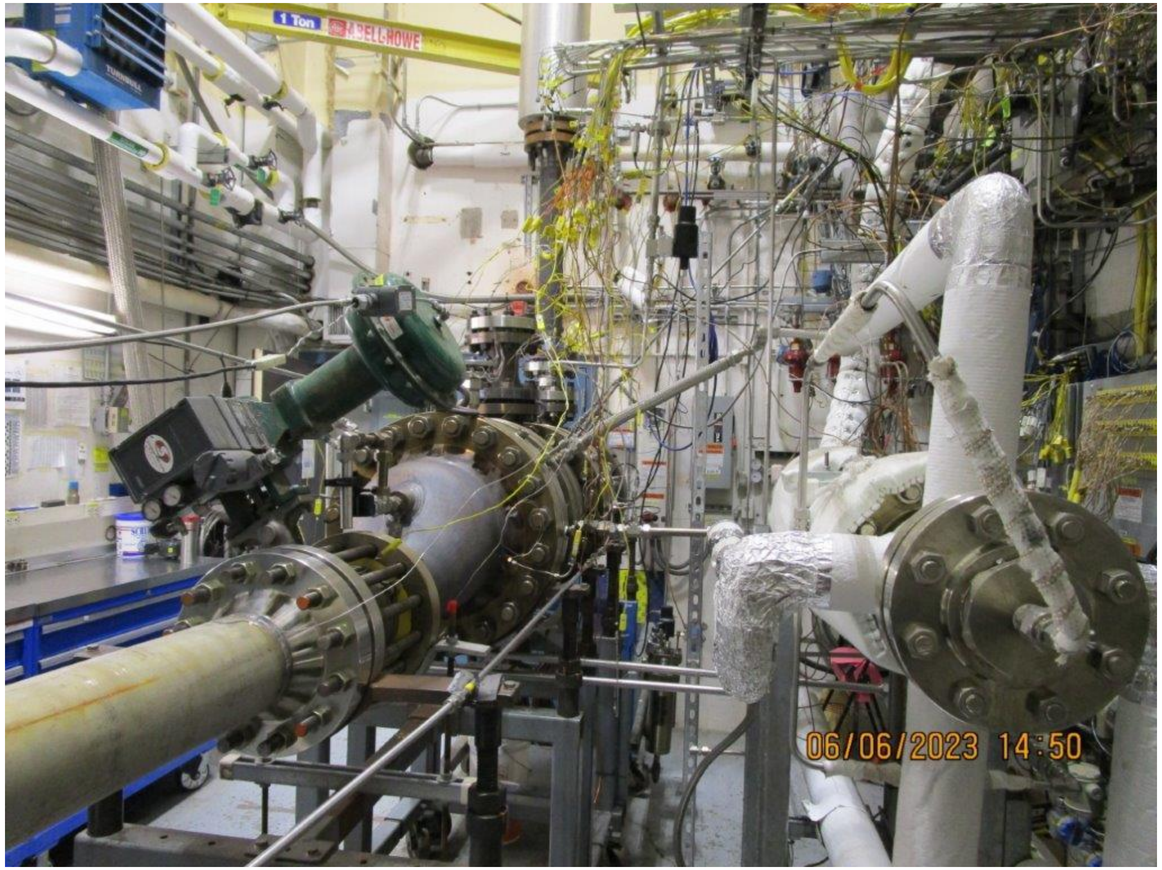
	Text1	% Complete	Task Name	Duration	Start	Finish
0	**Task**	**0%**	**GRC-DOE_RDC**	**1044 days**	**Sat 10/1/22**	**Wed 9/30/26**
1		**0%**	**Appendix L : AOI 12**	**1044 days**	**Sat 10/1/22**	**Wed 9/30/26**
2	**1**	**100%**	**Task 1 : Project Management and Planning**	**1044 days**	**Sat 10/1/22**	**Wed 9/30/26**
3		100%	Submission of Project Management Plan to DOE	0 days	Mon 10/31/22	Mon 10/31/22
4		100%	Submission of Technology Maturation Plan to DOE	0 days	Fri 12/30/22	Fri 12/30/22
5	**2**	**0%**	**Task 2 : Low-Loss RDC Feasibility and Operability along 7FA Op Line**	**262 days**	**Sat 10/1/22**	**Sat 9/30/23**
6		100%	Feasibility and Operability along GT OPLINE Demonstrated	0 days	Sun 4/30/23	Sun 4/30/23
7		50%	Demonstration of Low-Loss RDC Feasibility and Operability along 7FA Op Line	0 days	Sat 9/30/23	Sat 9/30/23
8	**3**	**0%**	**Task 3 : Development of Design Rules, Scaling Laws, and Validated Tools for RDC**	**369 days**	**Wed 2/1/23**	**Sun 6/30/24**
9		30%	First Set of Experiments for Design Rules and Scaling Laws Complete	0 days	Wed 2/28/24	Wed 2/28/24
10		0%	Development of Design Rules, Scaling Laws, and Validated Tools for RDC Complete	0 days	Sun 6/30/24	Sun 6/30/24
11	**4**	**0%**	**Task 4 : Demonstration of Thermal Steady State RDC**	**438 days**	**Mon 5/1/23**	**Tue 12/31/24**
12		20%	Demonstration of Thermal SS RDC Operation along 7FA Op Line	0 days	Tue 12/31/24	Tue 12/31/24
13	**5**	**0%**	**Task 5 : Demonstration of Upstream and Downstream Turbomachinery Boundary Conditions Integrated RDC along 7FA Op Line**	**1045 days**	**Sat 10/1/22**	**Wed 9/30/26**
14		75%	Preliminary Assessment of BC Intergrated RDC Complete	0 days	Tue 9/30/25	Tue 9/30/25
15		0%	Performance Evaluation of BC Integrated RDC Complete	0 days	Tue 3/31/26	Tue 3/31/26
16		0%	Demonstration of Upstream and Downstream Turbomachinery Boundary Conditions Integrated RDC along 7FA Op Line	0 days	Wed 9/30/26	Wed 9/30/26
17	**6**	**0%**	**Task 6 : System Integration and Component Performance**	**1045 days**	**Sat 10/1/22**	**Wed 9/30/26**
18		0%	Report on System Integration and Component Performance	0 days	Wed 9/30/26	Wed 9/30/26



– Demonstration of Operability and Feasibility along F-Class Cycle

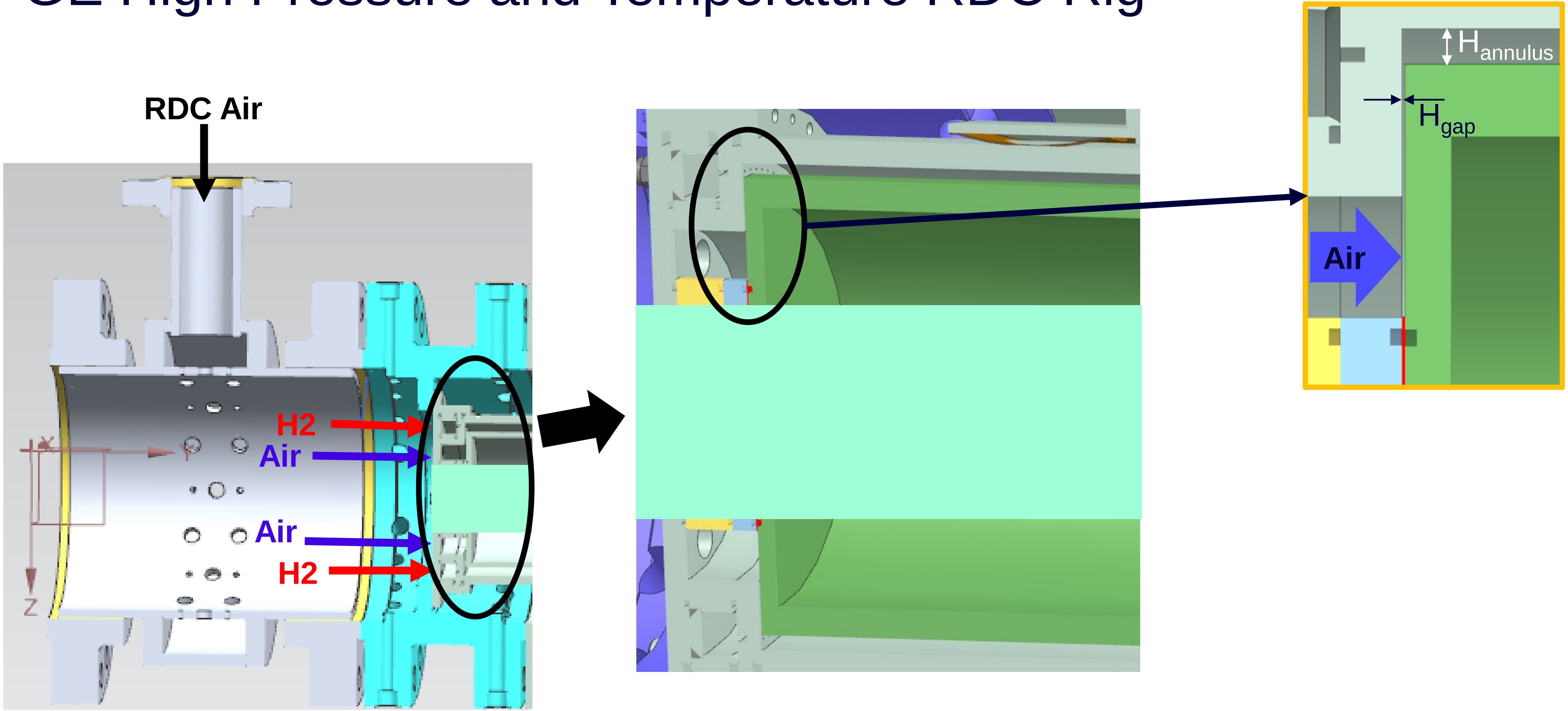
GE High Pressure and Temperature RDC Rig





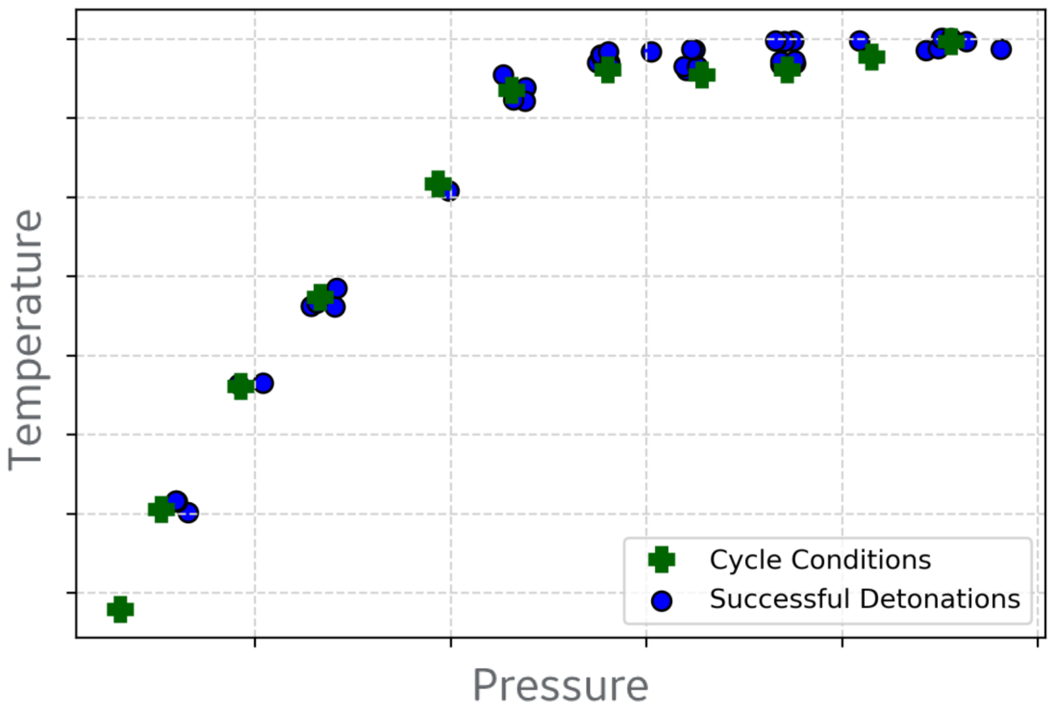
Facility can reach all operating conditions for 7FA Cycle
Max 7F Cycle Operating Conditions : 800 F, 250 psi

GE High Pressure and Temperature RDC Rig



Radial Airflow Design

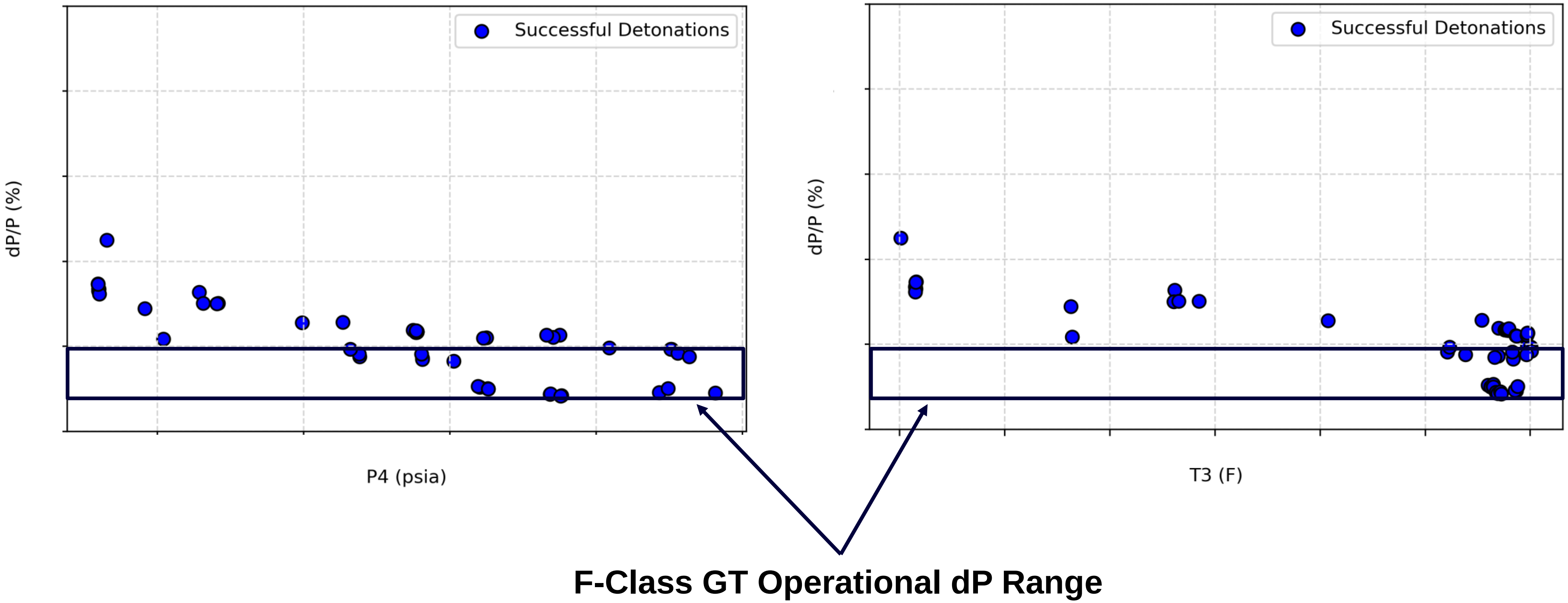
Demonstrated Detonation along 7FA Cycle



- Test durations are typically 2-4 seconds
- 2 different hardware configurations
- Various equivalence ratios
- “Detonation” includes sustained detonation only
- Sustained detonation demonstrated over full range of cycle

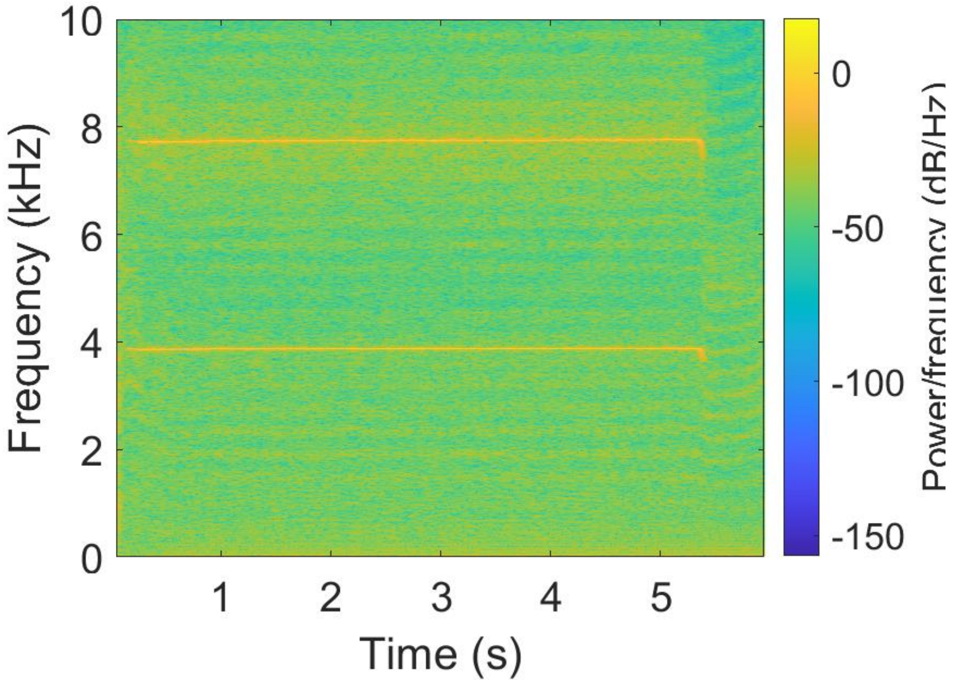
Demonstrated Successful Detonation Along F-Class Cycle

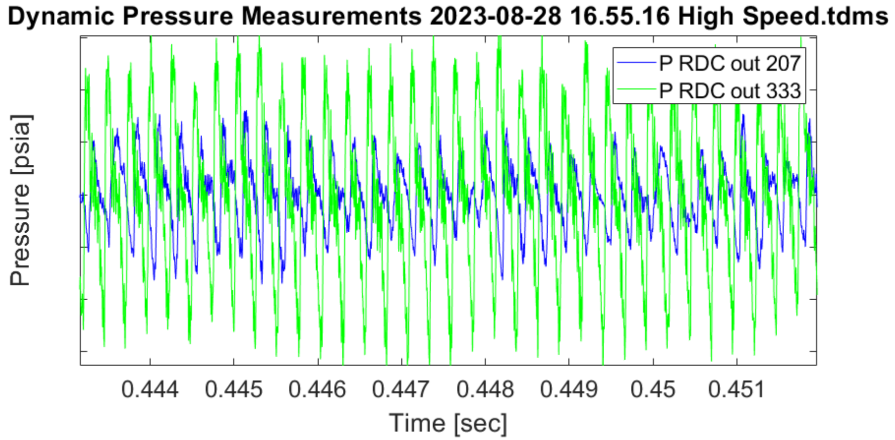
GE RDC Rig Air Injector Pressure Drop

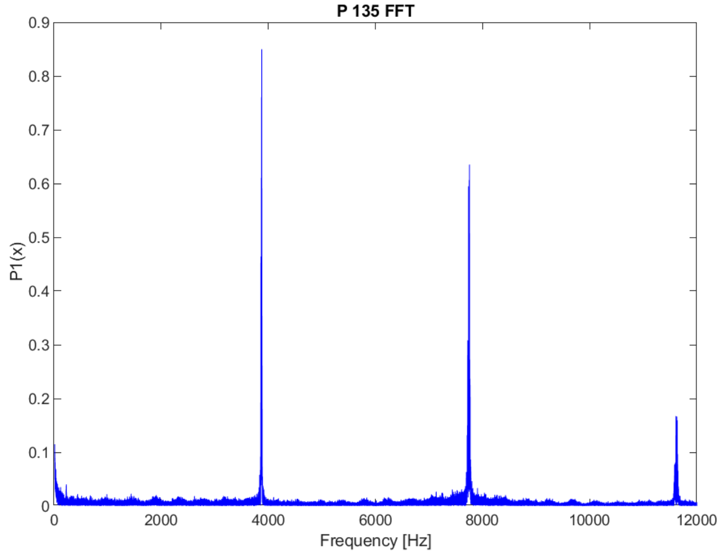


Successful Detonation at Actual Gas Turbine dP/P

Representative H_2-Detonation Pressure Signature



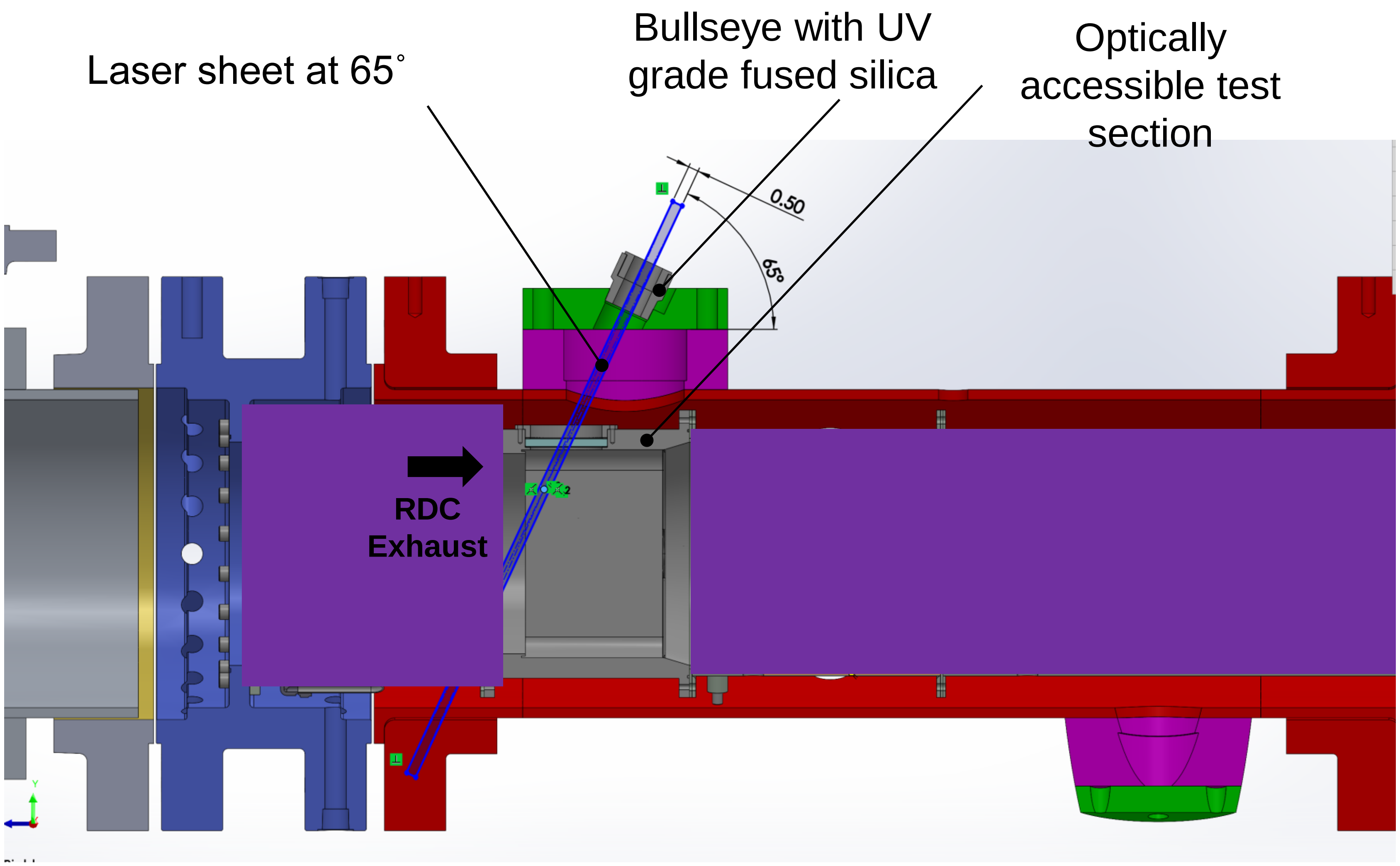


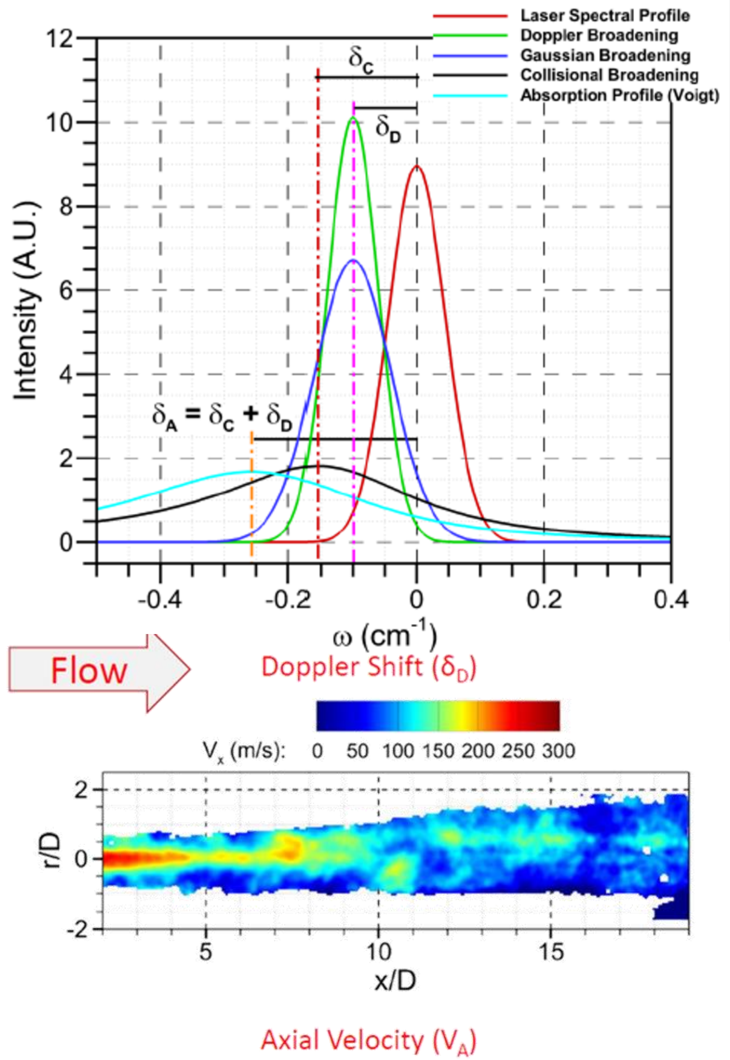


> 80% of CJ speed demonstrated

– NCSU : Total Pressure and Total Temperature Measurements

GE Optical Access Rig for NCSU Measurements





– CFD : Rig Design & RDC-Turbine Integration

CFD for Unmixedness Studies over Design Parameter Range

To determine **unmixedness**:

- Generate axial planes.
- Calculate Bilger mixture fraction* β, variance, average of mixture fraction, and average of variance squared on planes.

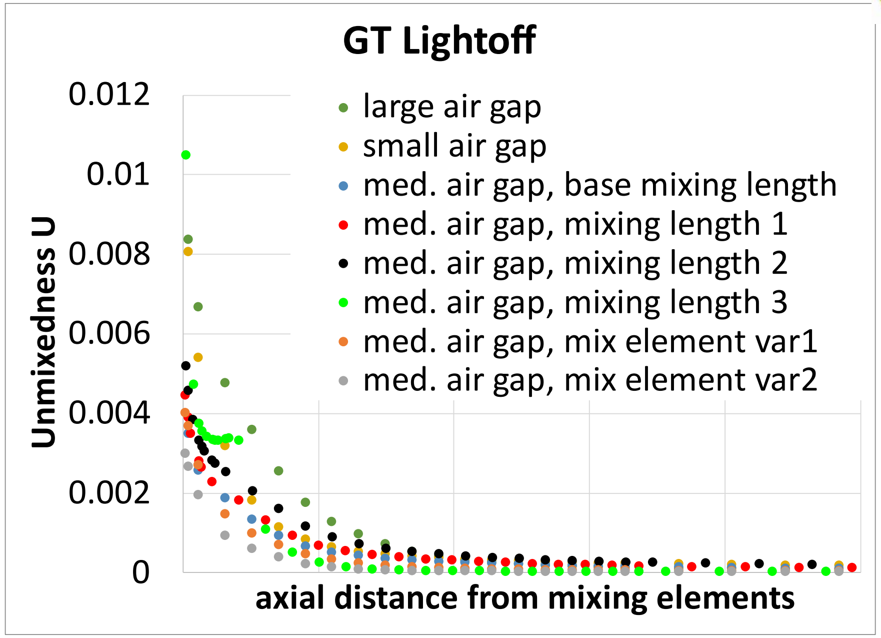
$$\beta = \sum_{l=1}^{N_e} \gamma_l Z_l = \sum_{l=1}^{N_e} \gamma_l \sum_{i=1}^{N_s} \frac{\alpha_{l,i} W_l Y_i}{W_i} \qquad U = \frac{\overline{\beta''^2}}{\bar{\beta}(1-\bar{\beta})}$$

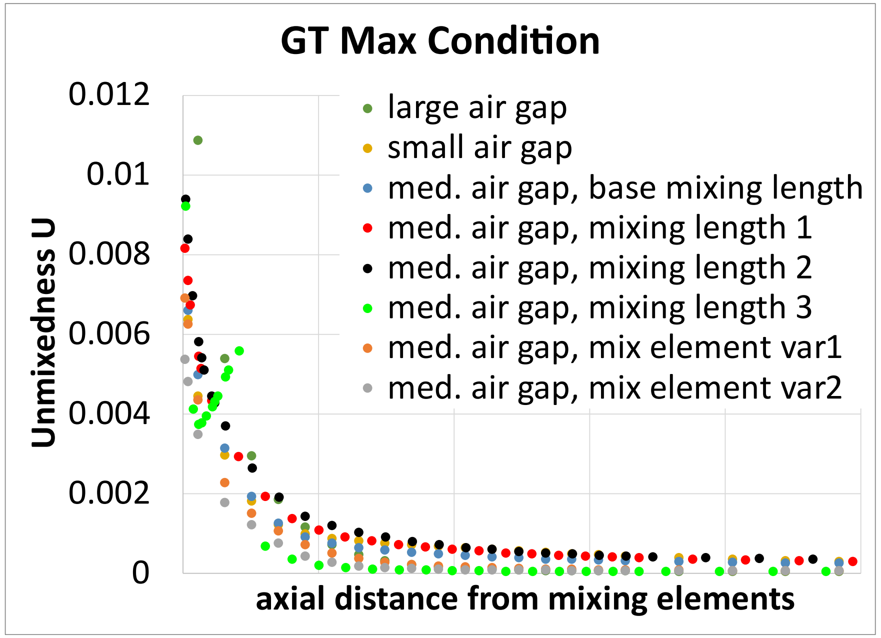
Bilger mixture fraction:

- γ_l = weighting factors for individual elements
- $\alpha_{l,i}$ = number of element *l* in species *i*
- W_l = atomic weight of element *l* in species *i*
- W_i = atomic weight of species *l*
- Y_i = mass fraction of species *i*

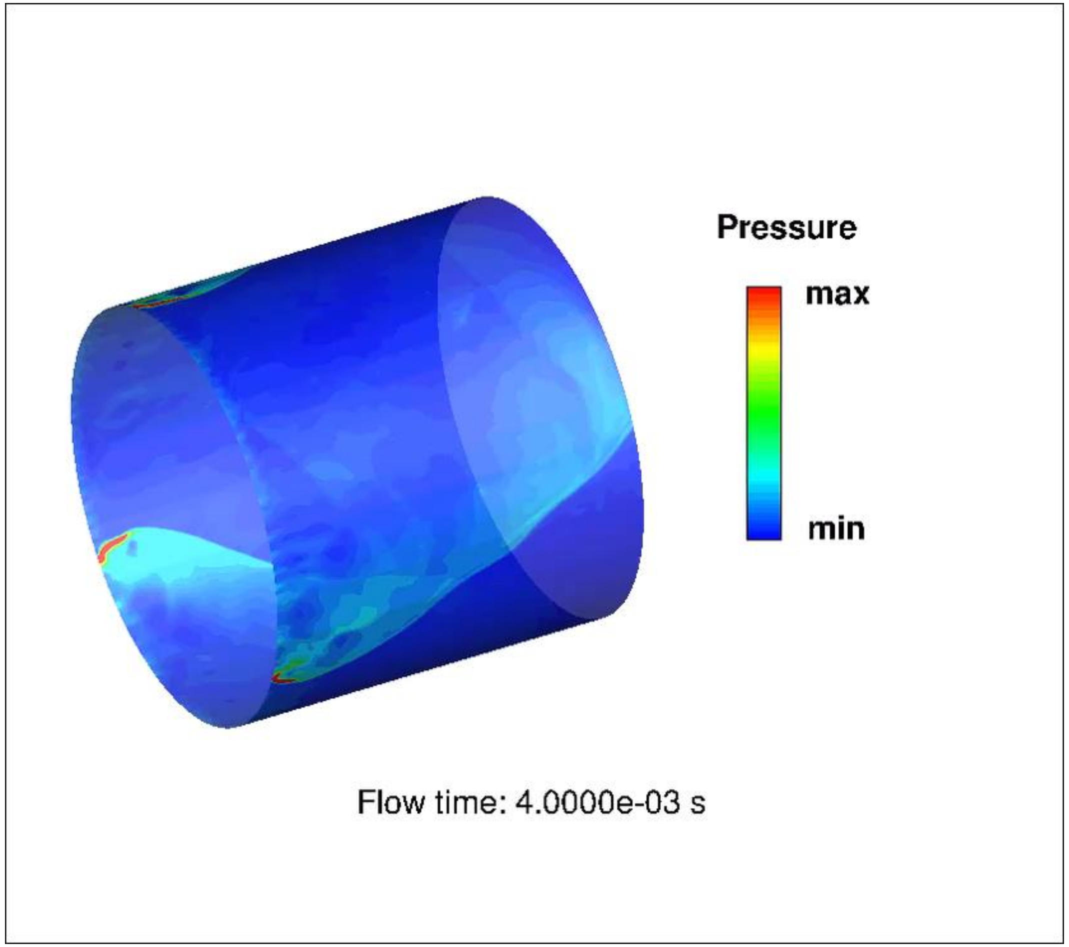
— The lower the U value, the better the fuel-air mixing.
— Assess impact of different features & enable design down-selection.

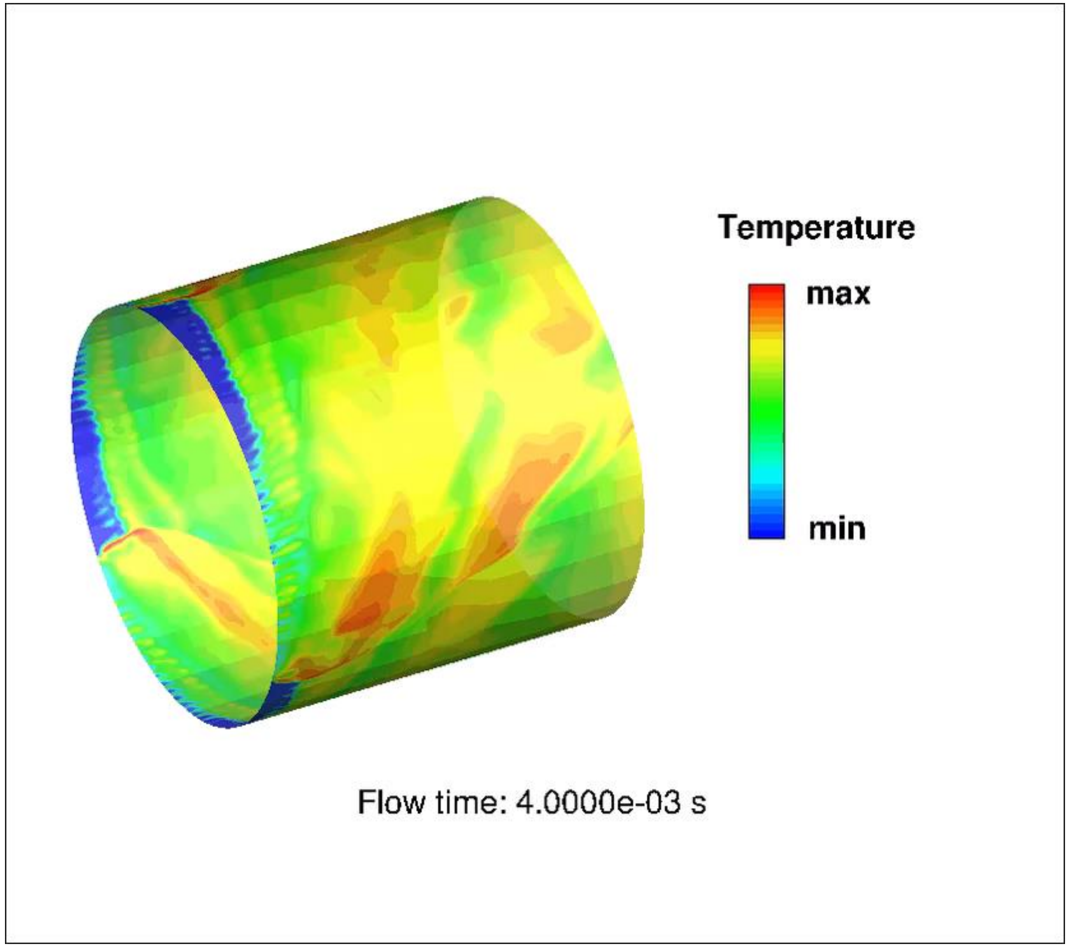
*Bilger, R. W., and Starner, S. H., and Kee, R. J., On reduced mechanisms for methane air combustion in nonpremixed flames, Combustion and Flame, 80, 2, 135–149, 1990.





Example of Reacting Flow CFD for H_2 RDC

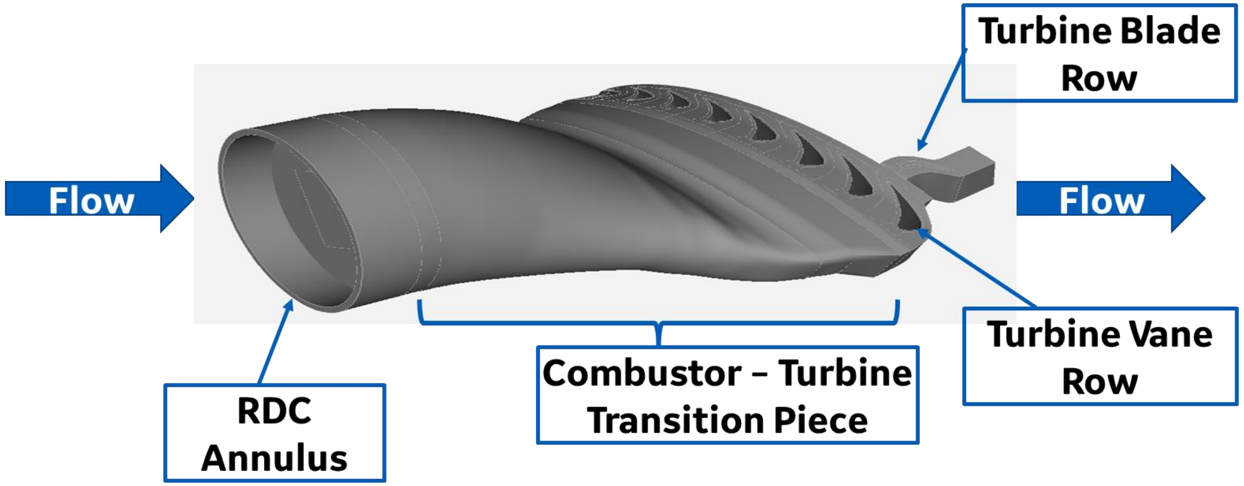


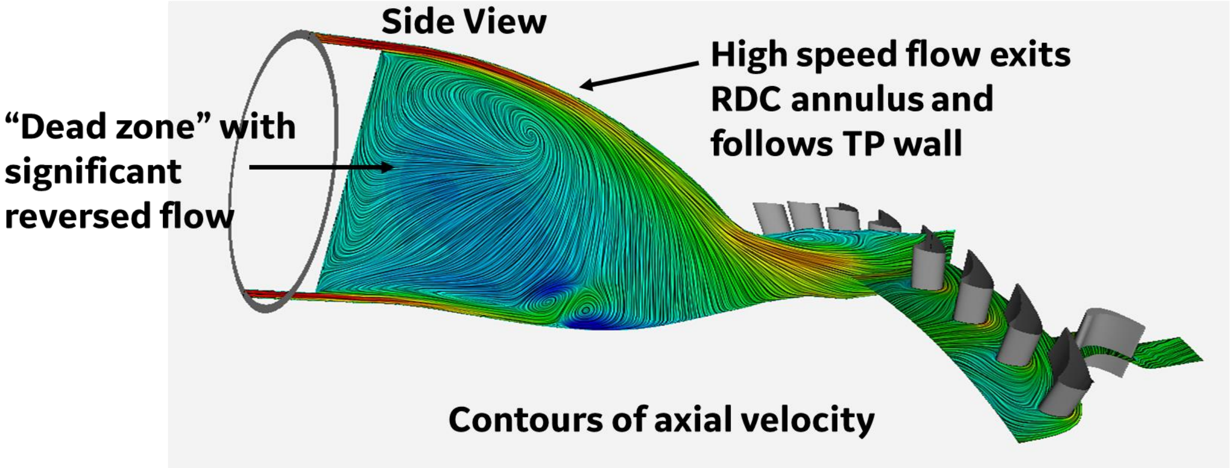


— CFD provides insights into what geometric or operating parameters can be examined for detonation feasibility.
— RDC CFD yields boundary conditions for modeling flow path downstream of RDC toward turbomachinery.

Aero Modeling for Downstream Flowpath

- Identify major aero performance concerns in downstream flowpath
- Steady-state screening CFD calculations performed to assess aero performance in the combustor-turbine transition piece





Architecture design choices will require careful attention to avoid significant aerodynamic losses in the transition piece.

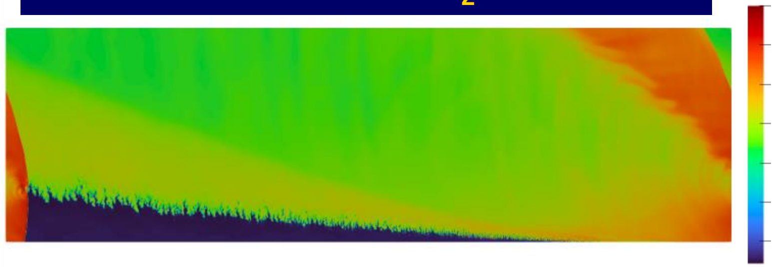
– UM : Detonation Study for Interaction

UM : CFD for RDC-Turbine Integration

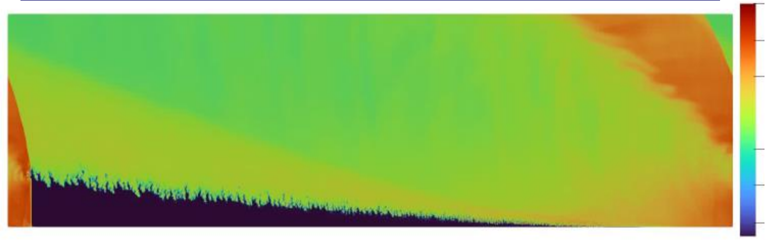
Detonation fitting approach:

- Capture induced properties without needing to resolve detonation
- Properly model oblique shock resulting from detonation wave

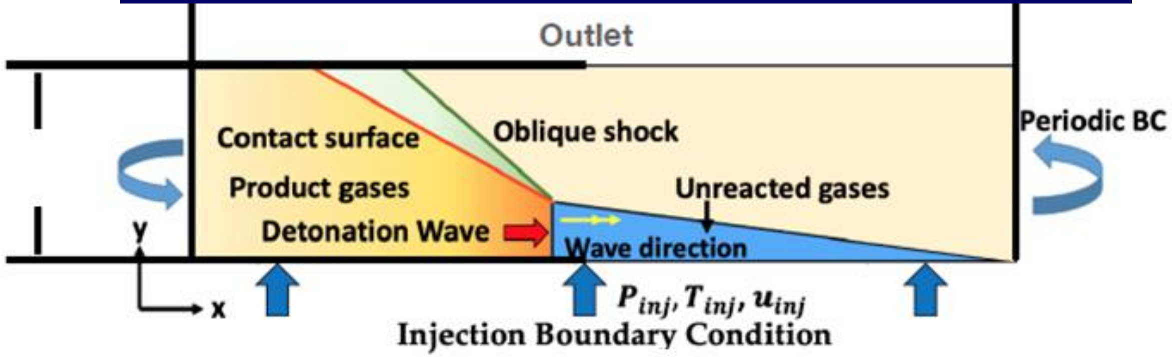
2D RDE with General Chemistry, Stoichiometric H_2 + Air



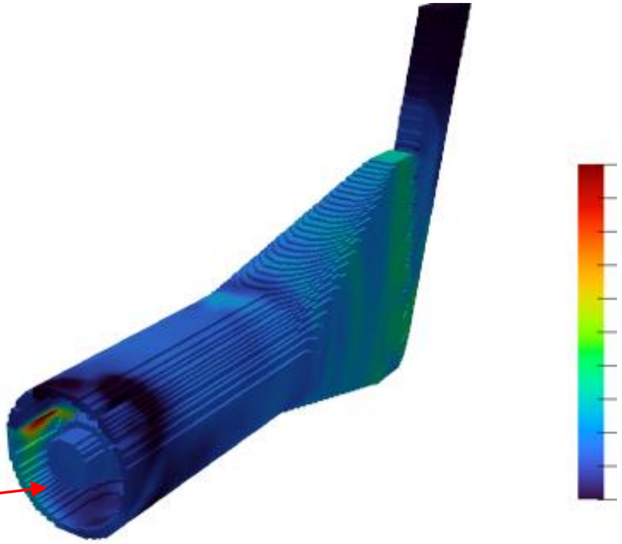
2D RDE with Detonation Fitting, Stoichiometric H_2 + Air



2D RDE Domain and Boundary Conditions



- Domain is initialized with stoichiometric premixed H2 Air at 1 atm



— Detonation fitting approach predicts same temperature field as general chemistry approach.
— Detonation fitting solution applied at RDC for downstream flow domain BC.

– Summary and Next Steps

Summary And Next Steps

- Task 1 : PMP and TMP submitted
- Task 2 : Radial low dP (GT Cycle) feasibility and operability along 7FA GT OPLINE Demonstrated. Axial next.
- Task 3 : Scaling rig design finalized. First set of hardware released for fabrication.
- Task 4 : Thermal steady state rig layout in progress.
- Task 5 : Combustor Architecture study completed. RDC-Turbine interaction and integration studies in progress.

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