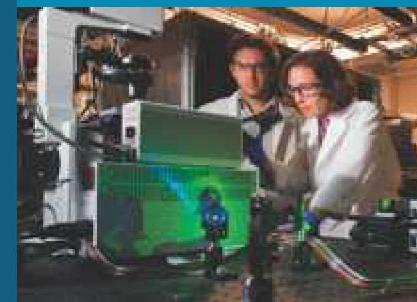
SAND2018-7878PE

Sandia's Aerothermal Arcjet Analysis



PRESENTED BY

Ross Wagnild, Matt Bopp, Justin Smith, Dave Kuntz

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Outline

Problem Setup
- Conditions
- Geometry
- Mesh topology
- Solver
- Inlet condition specification

Nominal Solutions
- Case 1 – Air 0.86 MW/m^2
- Case 18 – Air 5 MW/m^2
- Case 19 – Air 10 MW/m^2

Solver variations
- Viscosity Model
- 3 temperature thermal non-equilibrium
- Frozen flow

Problem Setup

Arcjet conditions: Nominal test conditions

- Chosen to sample a range of heating rates in air
- Fluid runs serve as a preparation for running coupled problems
- Simulation in both L2K and L3K

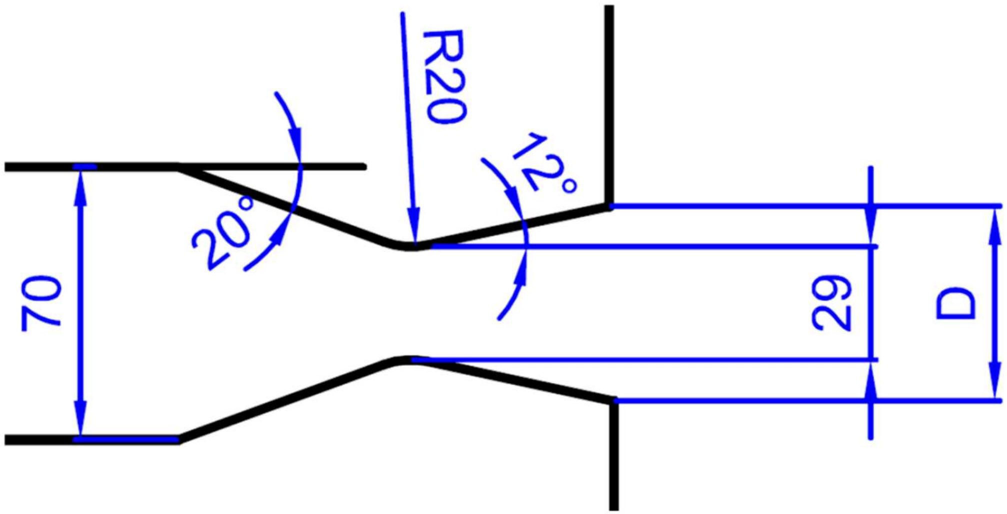
Test	Run #	DSTL Test #	Sample	Facility	Atmosphere	Heat flux rate	Test duration
						[MW/m^2]	[s]
01	110917_02	8	PSG00042899C	L2K	air	0.89	80.3
18	026175L	17	PSG00042899C	L3K	Air	5	60.6
19	027175L	19	PSG00042899B	L3K	Air	10	20.9

Problem Setup

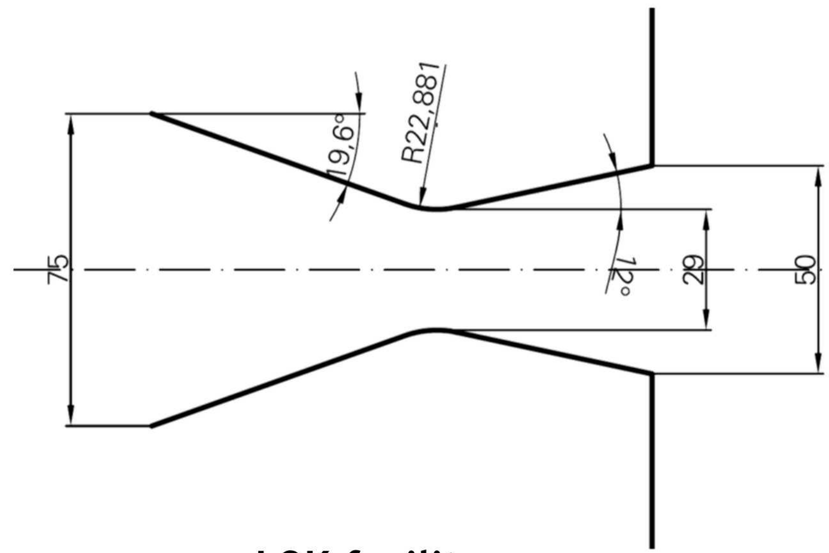
Geometries

- L2K and L3K nozzles have a similar setup, both use exit diameters of 50 mm
- Sample holder set a distance from the nozzle exit to obtain the desired heat flux

Case	Targeted Heat Flux (MW/m²)	Distance from Nozzle (mm)
1	0.89	160
18	5	160
19	10	80



L2K facility



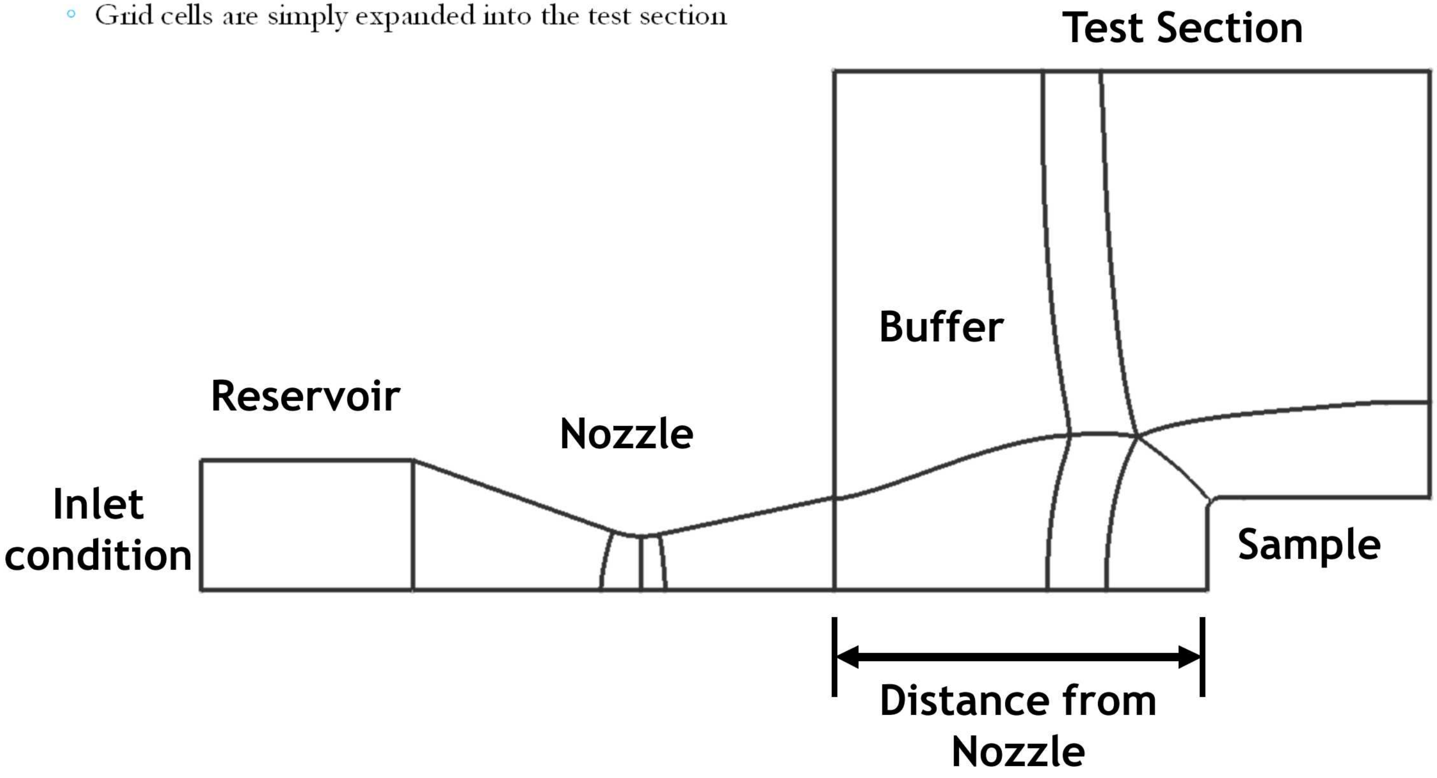
L3K facility

Problem Setup

Case	Targeted Heat Flux (MW/m²)	Distance from Nozzle (mm)	Grid Size (cells)
1	0.89	160	66,240
18	5	160	71,040
19	10	80	67,360

Topology: Multi-block, structured

- Simple wrap of cells around the sample
  - Contains bow shock on the front face
- Clustered to nozzle wall and Sample
  - Smaller clustering for higher heat flux cases
- No wrap of nozzle wall cells into test section
  - Grid cells are simply expanded into the test section



Problem Setup

Solver: SPARC

- Solves the compressible, reacting Navier-Stokes equations
- Second order MSW inviscid fluxes, viscous flux gradients using weighted least squares method
- Transport models
  - Sutherland, Keyes, VSS, Blottner, **Gupta** viscosity models
  - Prandtl number, Eucken relation, or **Gupta** model for thermal conductivity
  - **Constant Lewis number for diffusivity**
- Thermochemical non-equilibrium
  - **T-Tv** or T-Tr-Tv temperature non-equilibrium
  - Captures effects of finite-rate real gas effects including:
    - **Chemical dissociation, recombination, and exchange**
    - **Surface catalycity**
    - Molecular ionization
- Designed for use on next generation heterogeneous architectures
- Scalability, performance portability

Problem Setup

Initial condition specification

- Follow procedure laid out by Prabhu et al.*
  - Use pressure, enthalpy, gamma=1.2, isentropic relations, and mass conservation to determine reservoir velocity and static conditions
  - Iterate reservoir Mach number until system of equations converges
- Solve for thermochemical equilibrium composition using NASA CEA
  - Determine the temperature that matches the pressure and enthalpy within CEA
- Create supersonic condition for nozzle exit and test section
  - Calculate exit Mach number using isentropic flow and maintain mass fractions

Reservoir Gas State

Case	Total Pressure (hPa)	Total Enthalpy (MJ/kg)	Mass Flux (kg/s)	Total Temperature (K)	Density (kg/m^3)	Temperature (K)	Velocity (m/s)
1	960	7.5	.036	4035	0.0715	4011	133
18,19	3750	15.9	.101	6506	0.1503	6501	167

Reservoir Mass Fractions

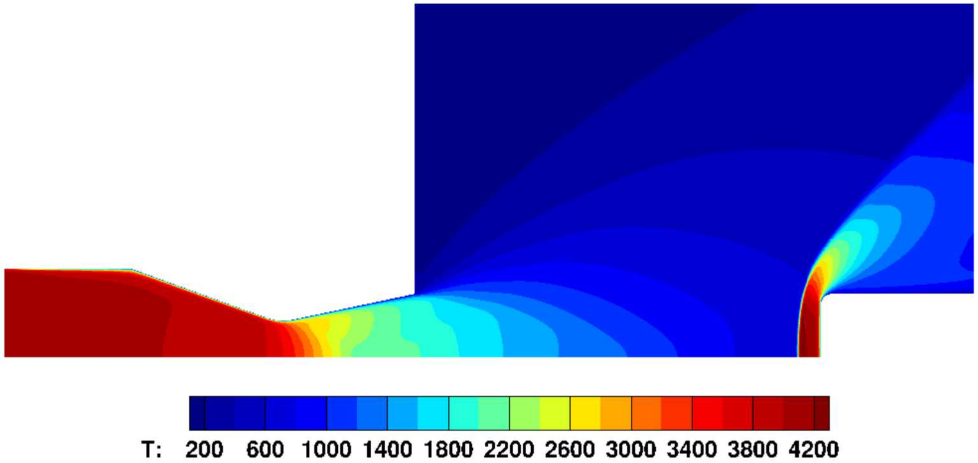
Case	N_2	O_2	NO	N	O
1	0.74337	0.03724	0.04877	0.00086	0.16975
18,19	0.63972	0.00059	0.01565	0.11998	0.224063

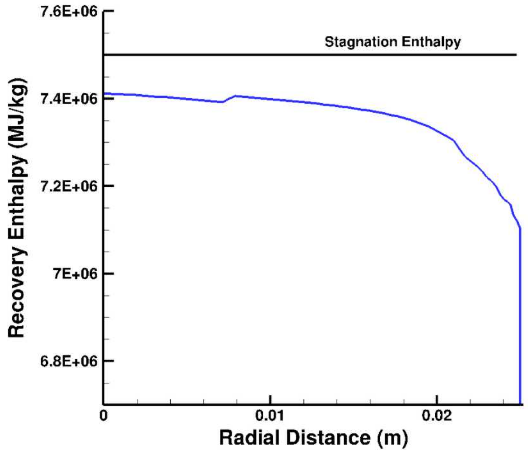
*Prabhu et al. "CFD Analysis Framework for Arc-Heated Flowfields,I: Stagnation Testing in Arc-jets at NASA ARC," AIAA 2009-4080

Nominal Solutions: Case 1 – 0.89 MW/m²

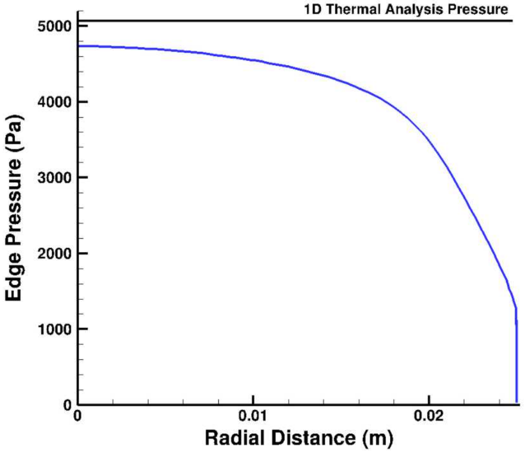
Simulation results

- Reasonable stagnation agreement with ablation properties
- Near constant properties across half the face
- Mach 5 flow at the bow show of the sample
- Post-shock temperature ~4340K

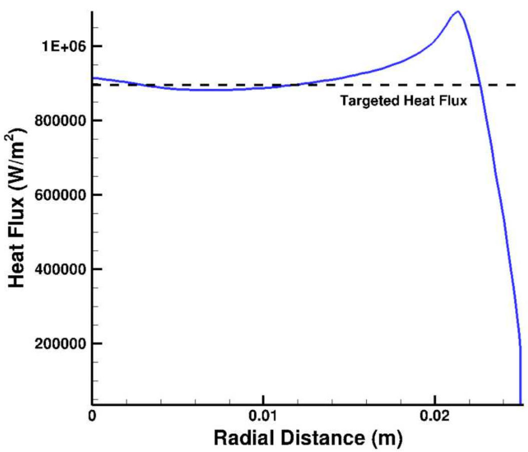




Recovery Enthalpy



Edge Pressure

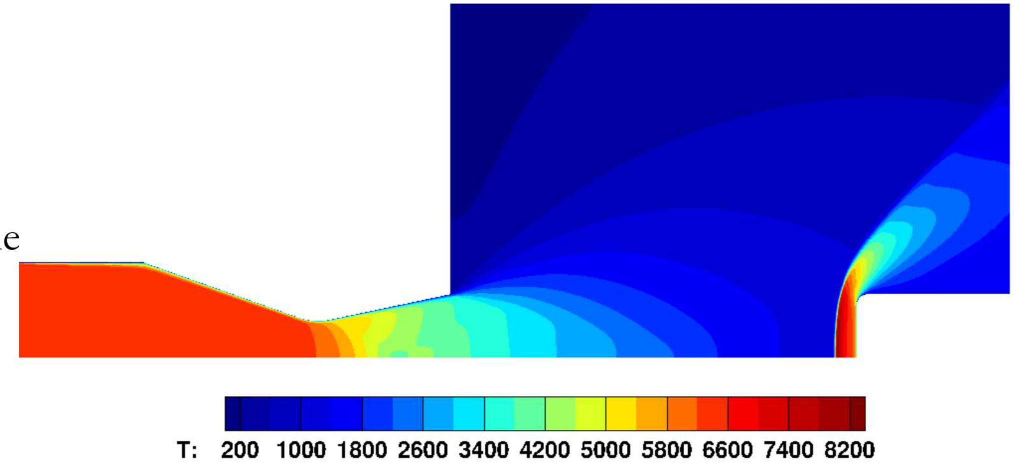


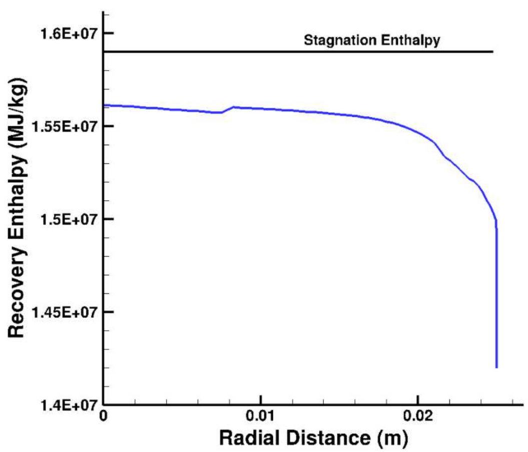
Heat Flux

Nominal Solutions: Case 2 – 5.0 MW/m²

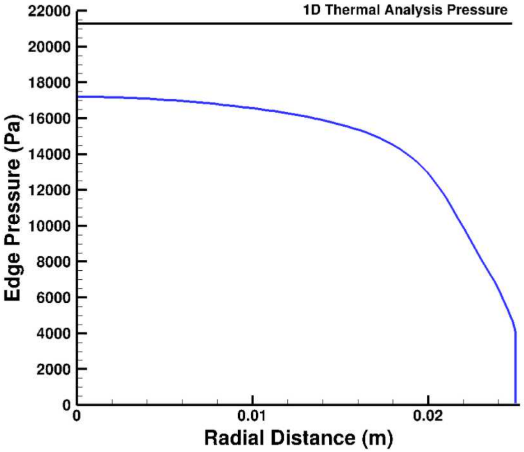
Simulation results

- Reasonable stagnation agreement with ablation properties
- Near constant properties across half the face
- Mach 5 flow at the bow show of the sample
- Post-shock temperature ~8050K

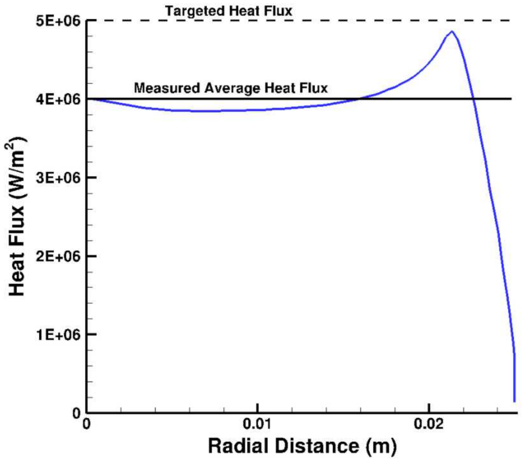




Recovery Enthalpy



Edge Pressure

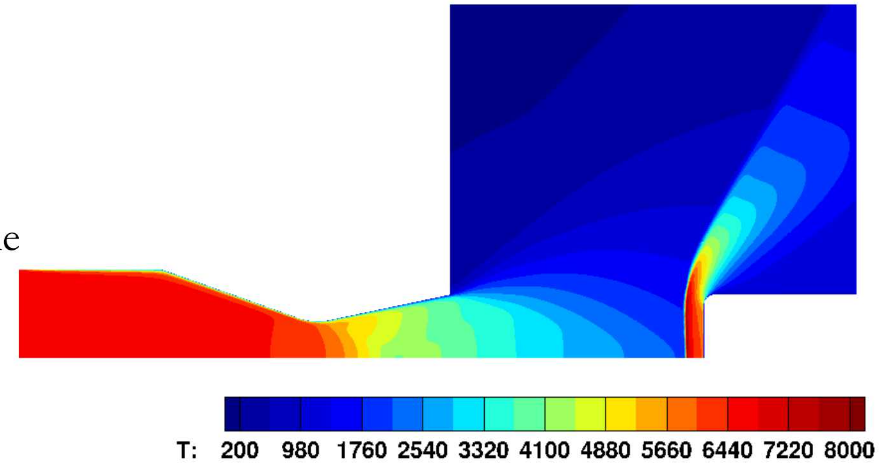


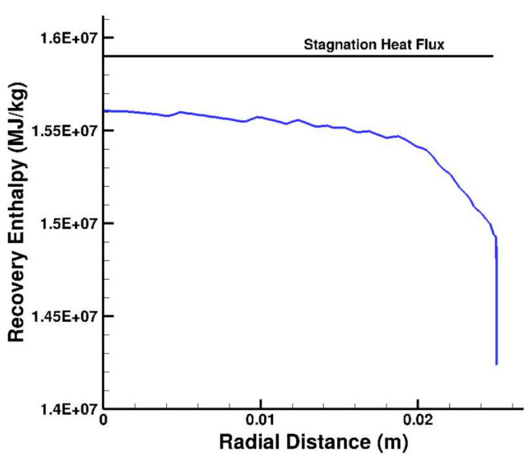
Heat Flux

Nominal Solutions: Case 3 – 10.0 MW/m^2

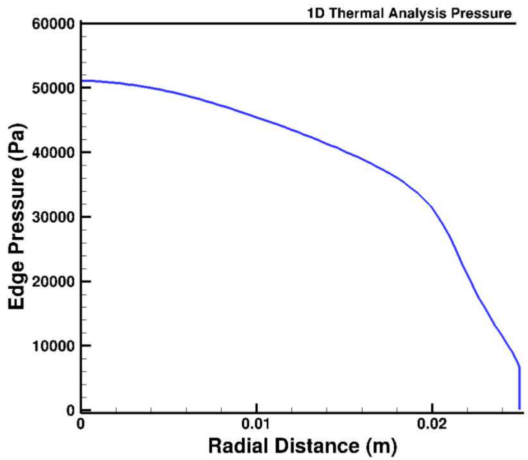
Simulation results

- Reasonable stagnation agreement with ablation properties
- Near constant properties across half the face
- Mach 3.7 flow at the bow show of the sample
- Post-shock temperature ~7590K

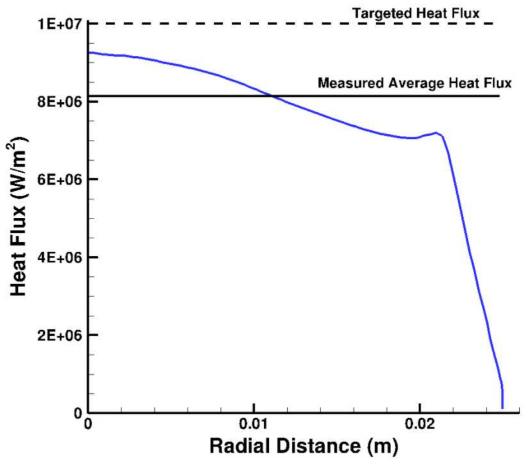




Recovery Enthalpy



Edge Pressure

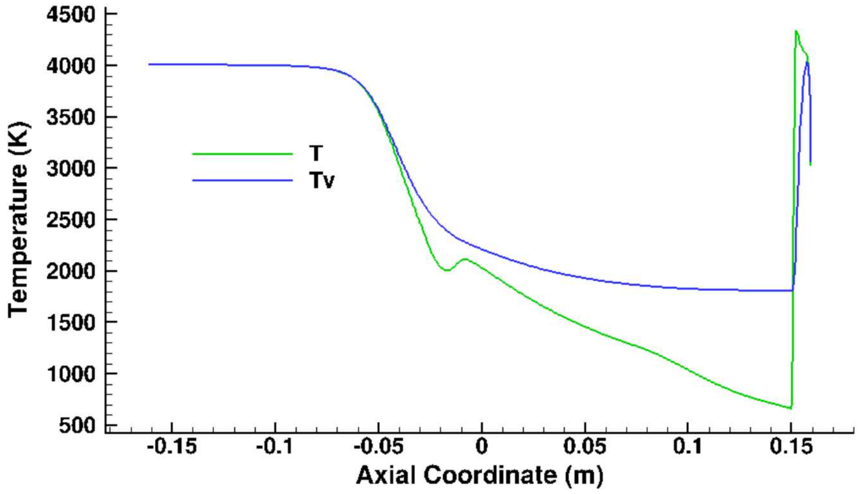


Heat Flux

Nominal Solutions: Non-equilibrium

Thermal non-equilibrium

- Vibrational temperature freezes out for samples 160 mm from nozzle
- 160 mm sample location has a greater degree of non-equilibrium due to lower pressure and increased shock strength
- Similar features and magnitudes of non-equilibrium over the nozzle



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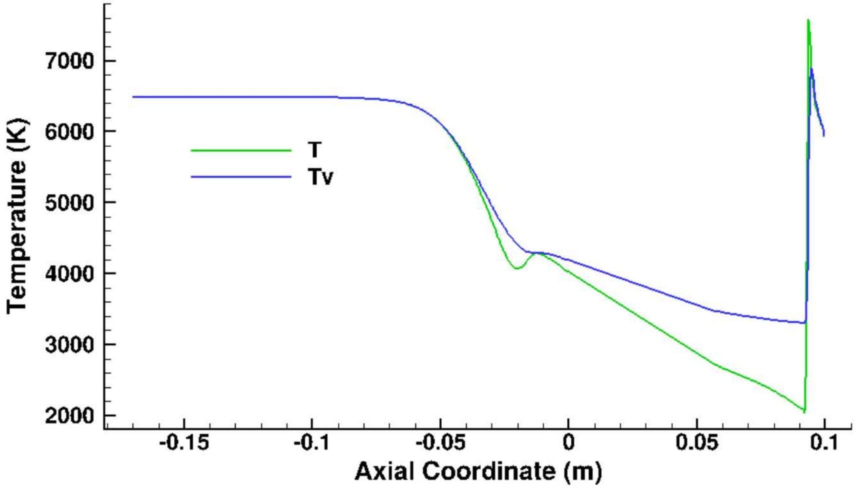
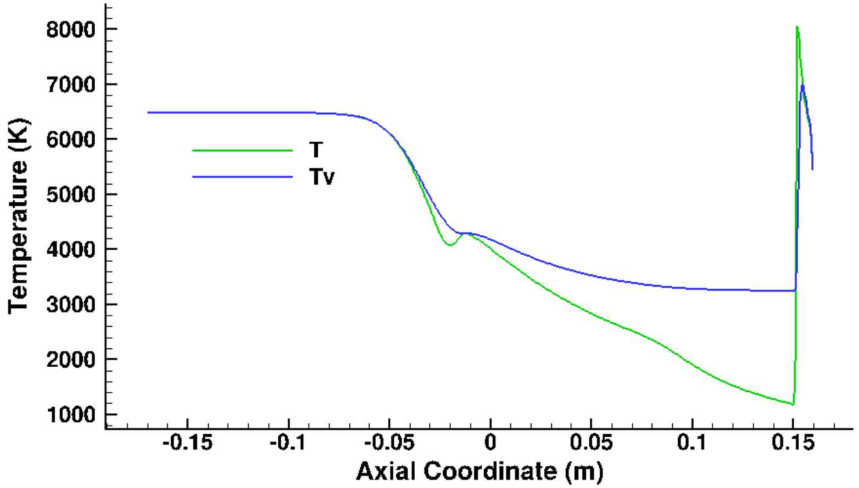


Case 19



Case 18

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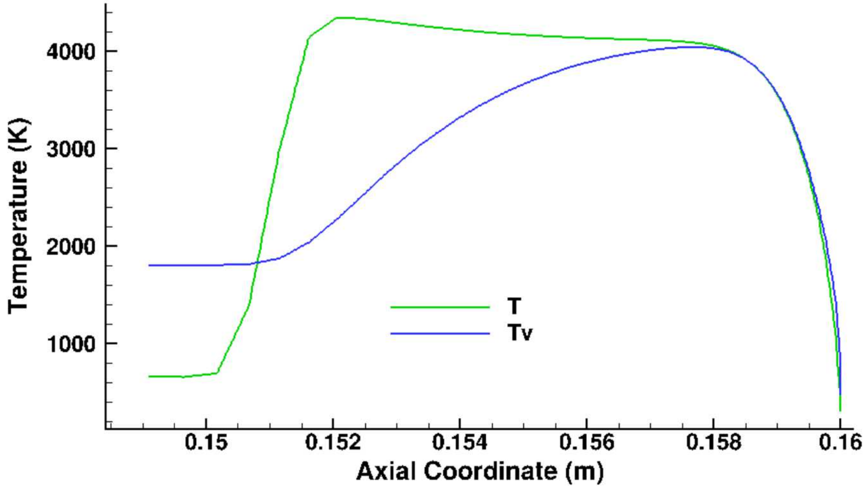

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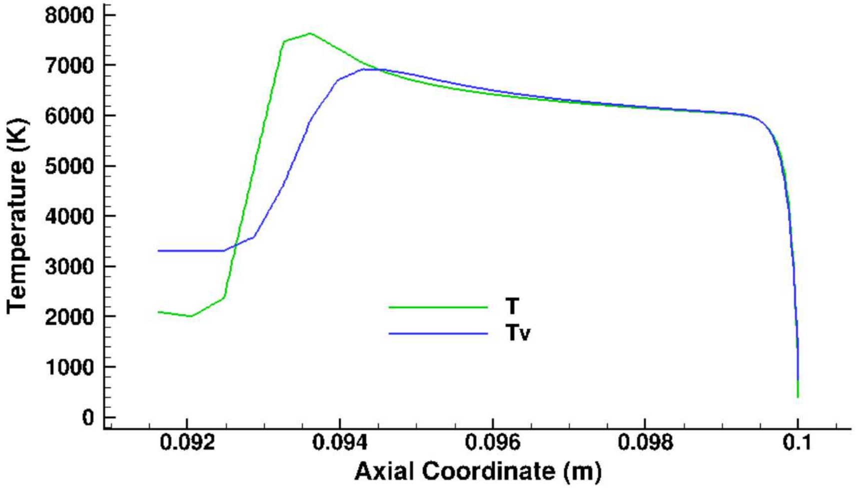

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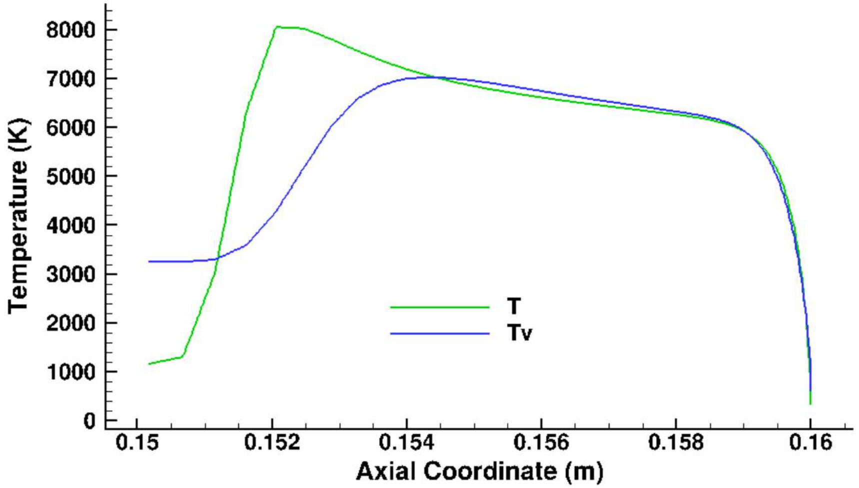

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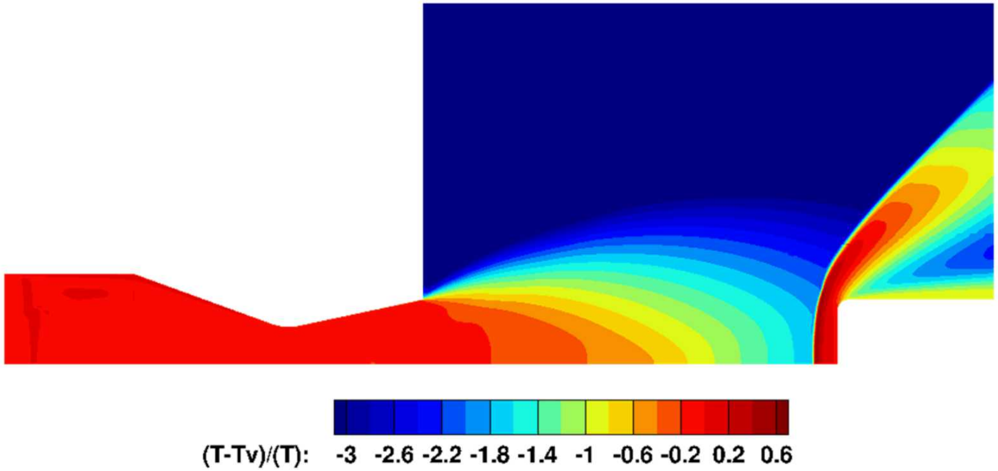

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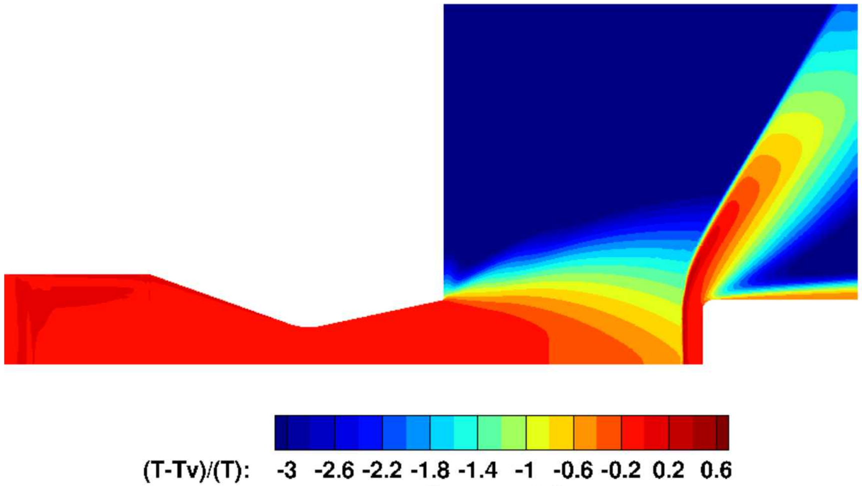

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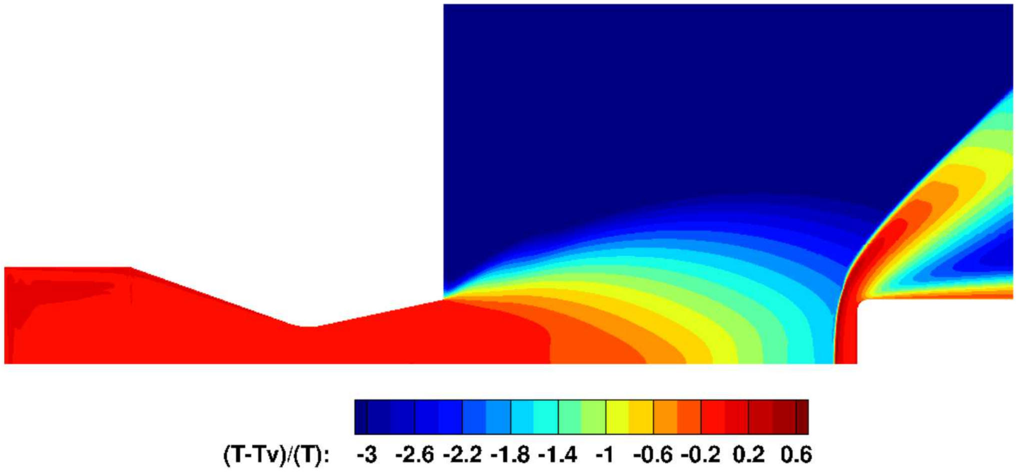
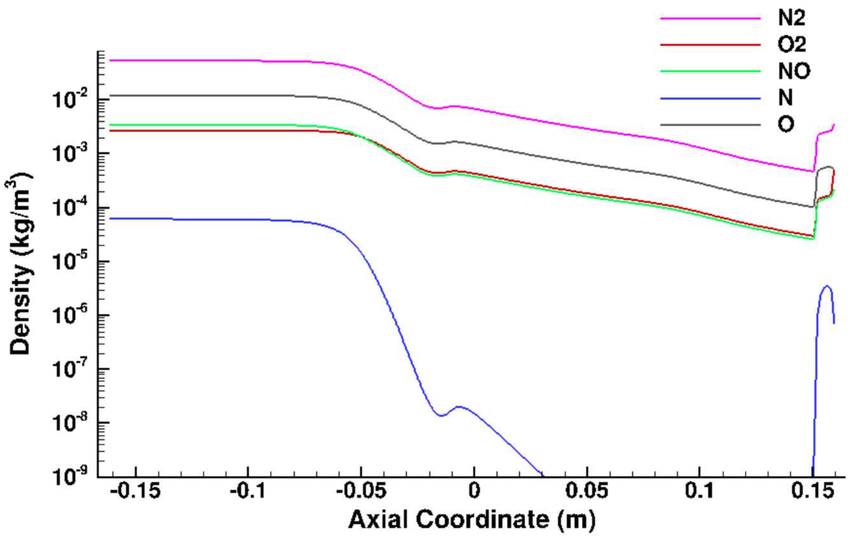


Case 18

Nominal Solutions: Non-equilibrium

Chemical non-equilibrium

- Chemical composition approximately constant through reservoir and between nozzle exit and the sample
- Similar composition profiles for L3K cases with the exception of a thinner boundary layer



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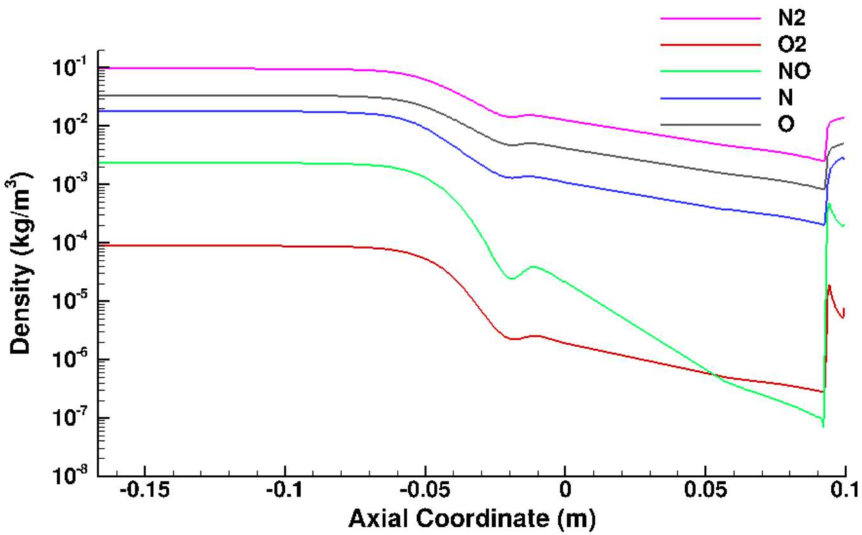

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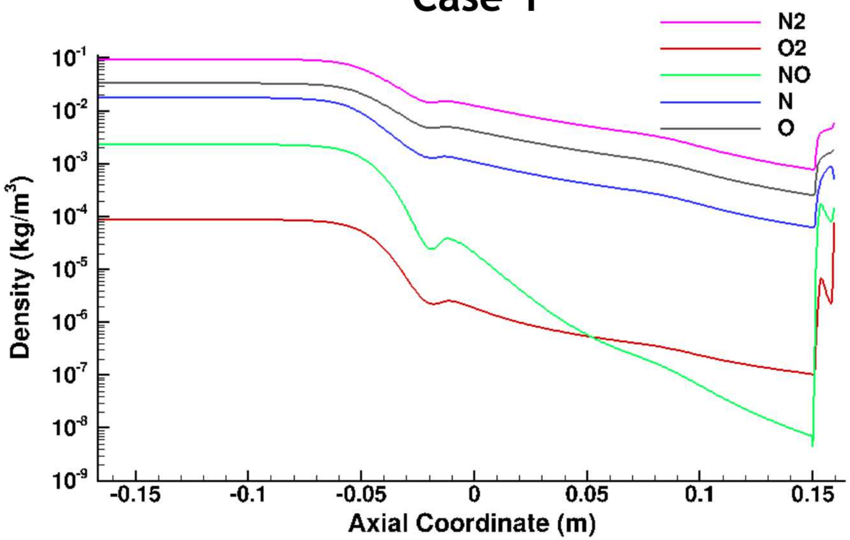

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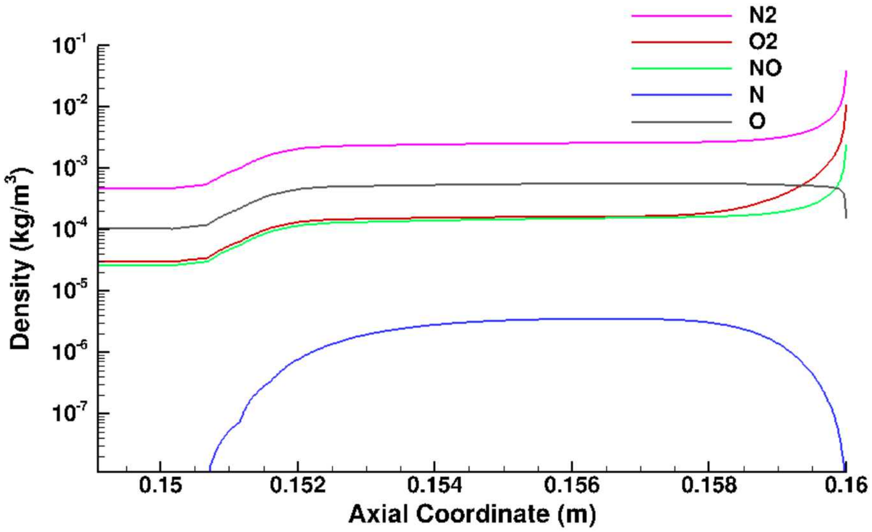

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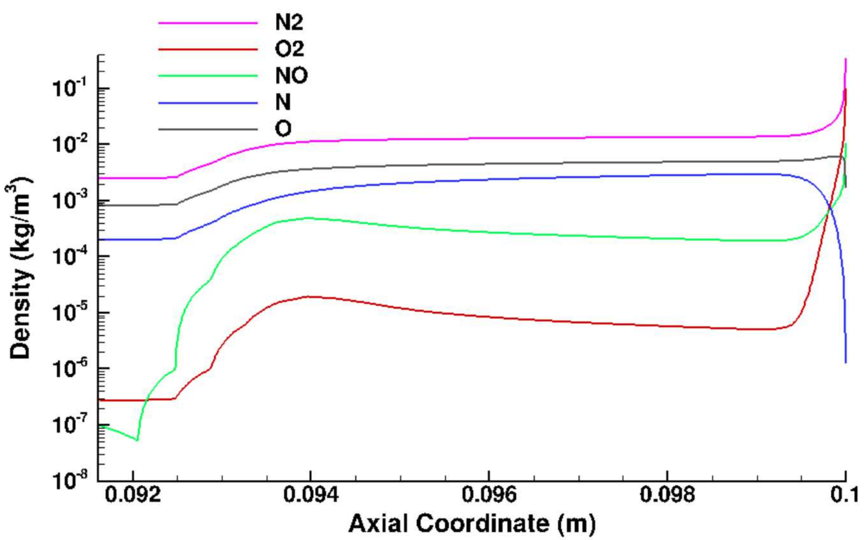

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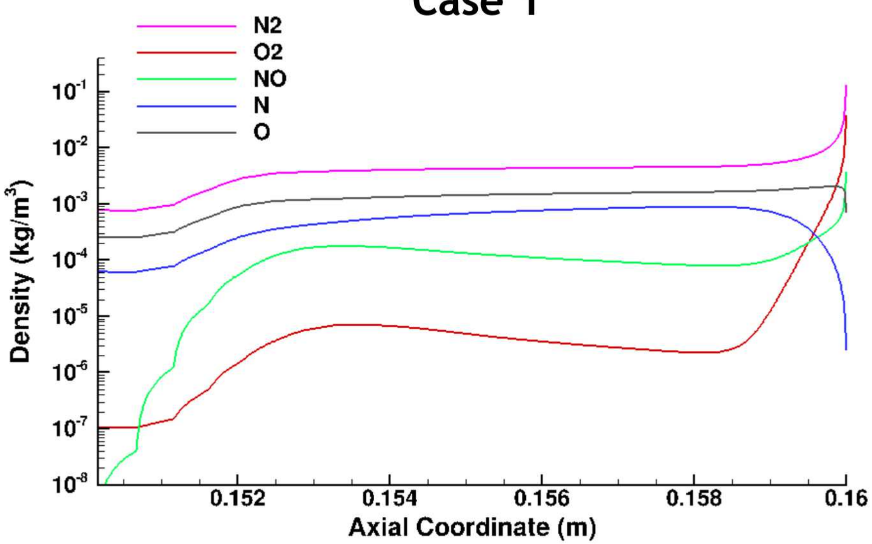
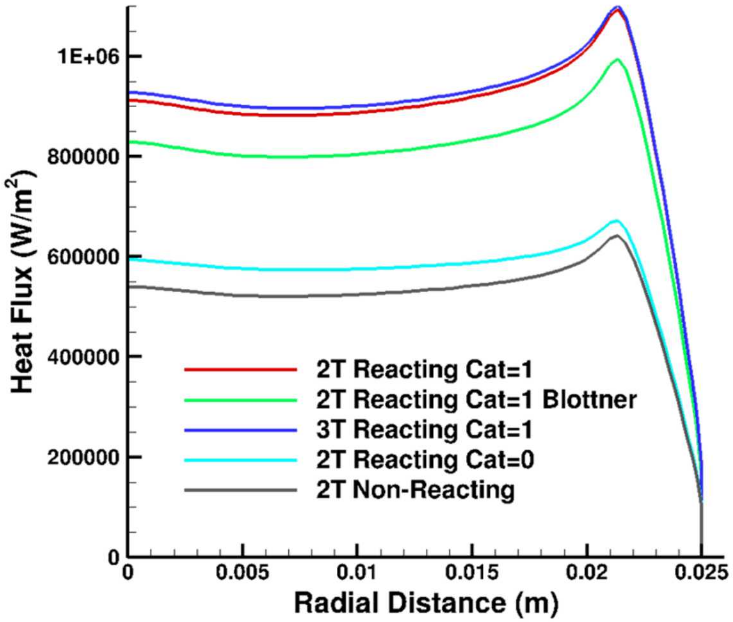


Case 18

Solver Variations

Variations in heat flux

- Blottner/Eucken model reduces heat flux ~10 %
- 3 Temperature non-eq. has a small effect
- Wall catalysis varies depending on condition
- Non-reacting reduces heat flux by half



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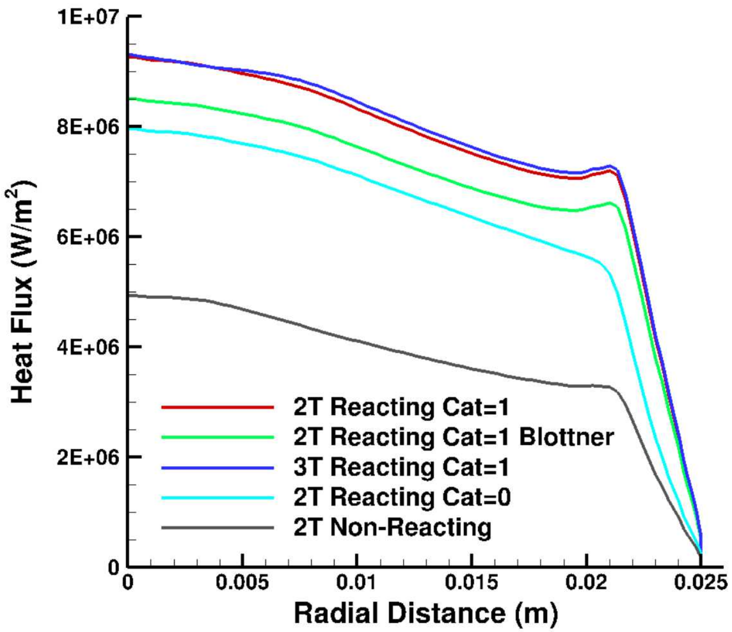

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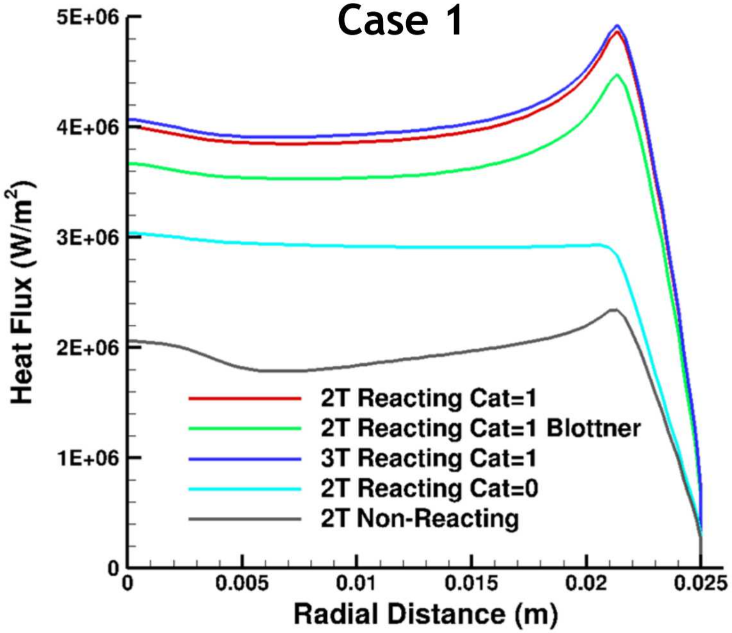

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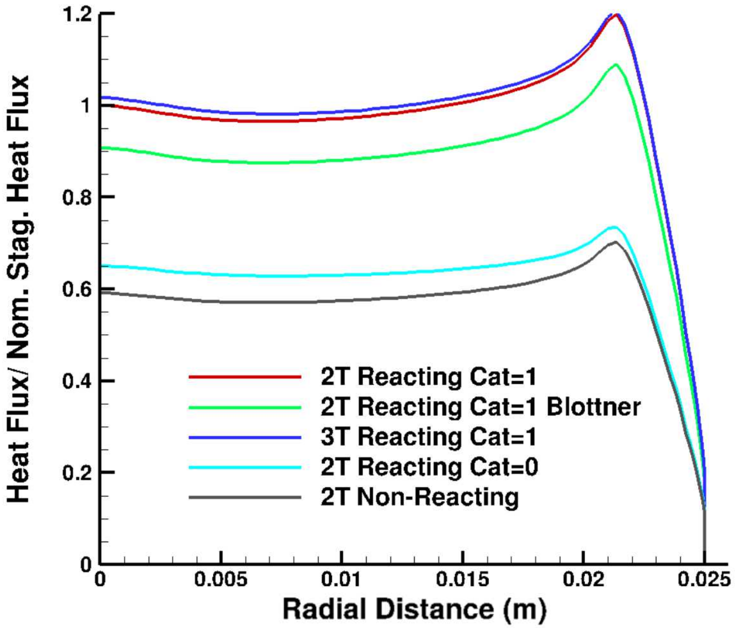

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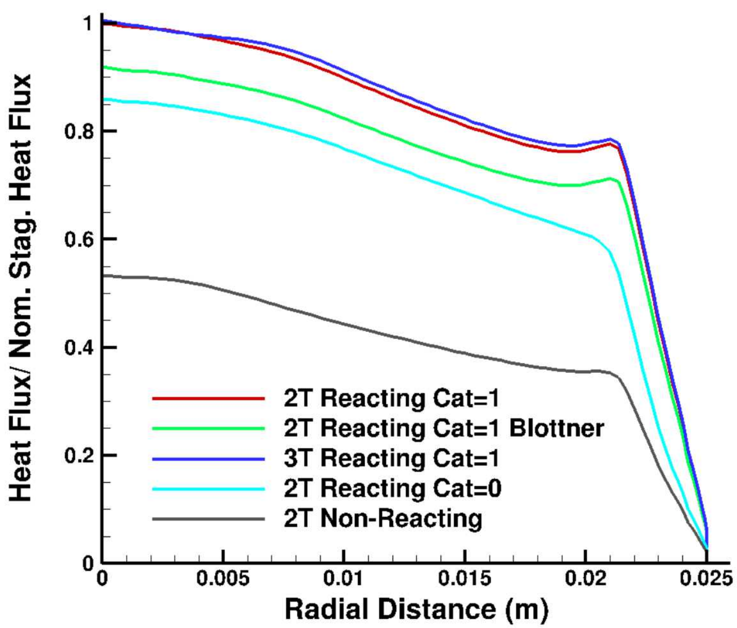

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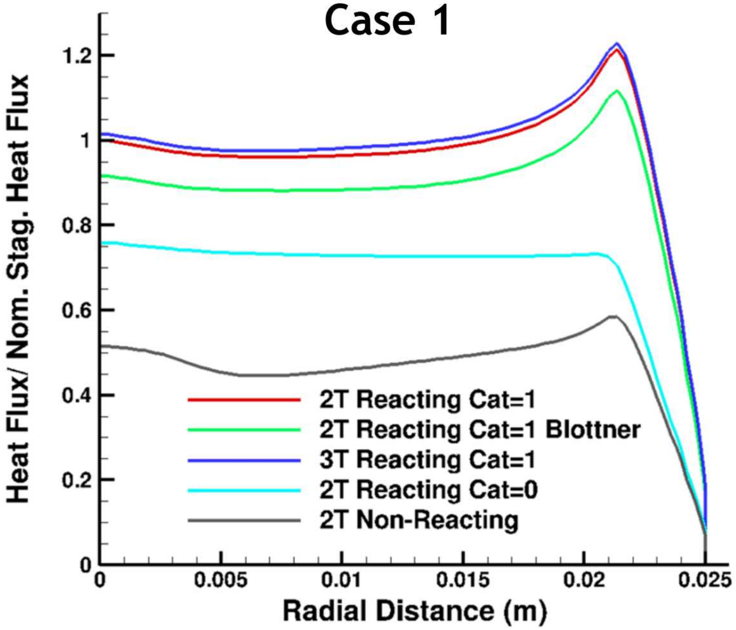

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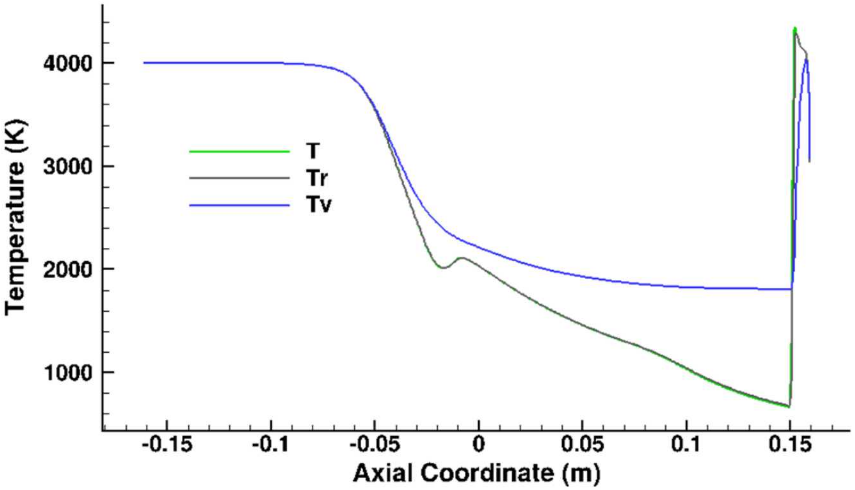
Solver Variations

Effect of third temperature

- Rotational temperature remains in near equilibrium from the reservoir to the bow shock, ~ 10 K difference
- Shock layer has thin layer of 3 temperature non-equilibrium



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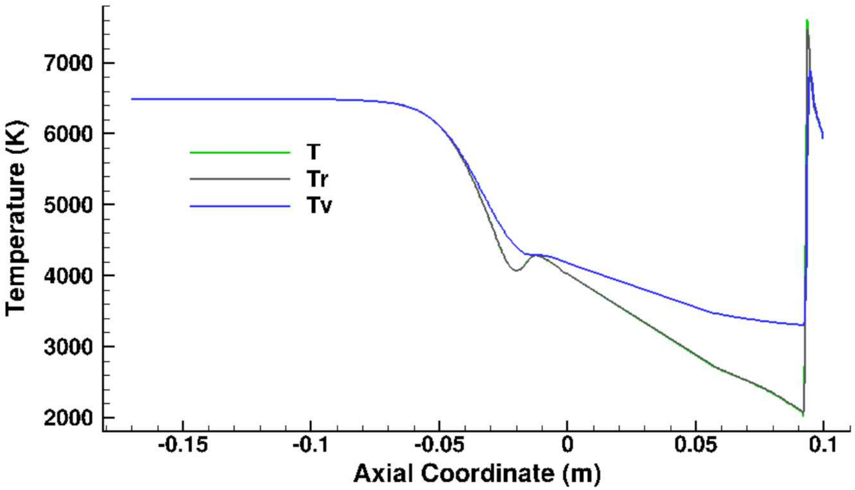

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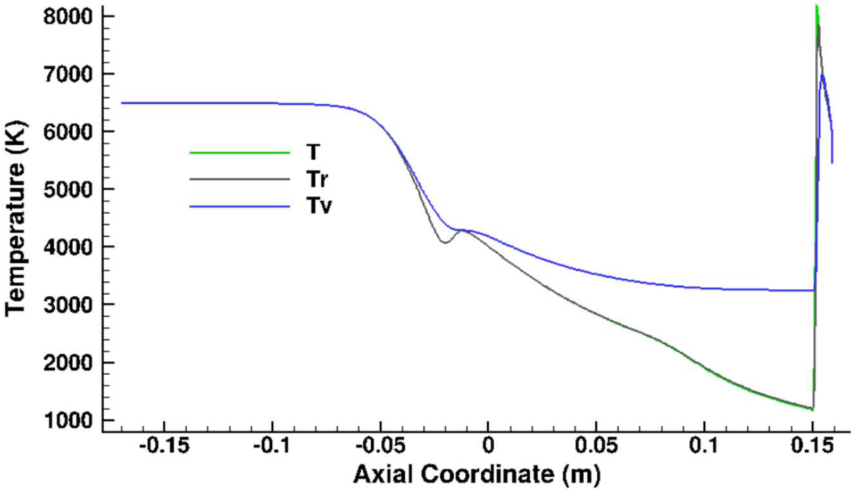

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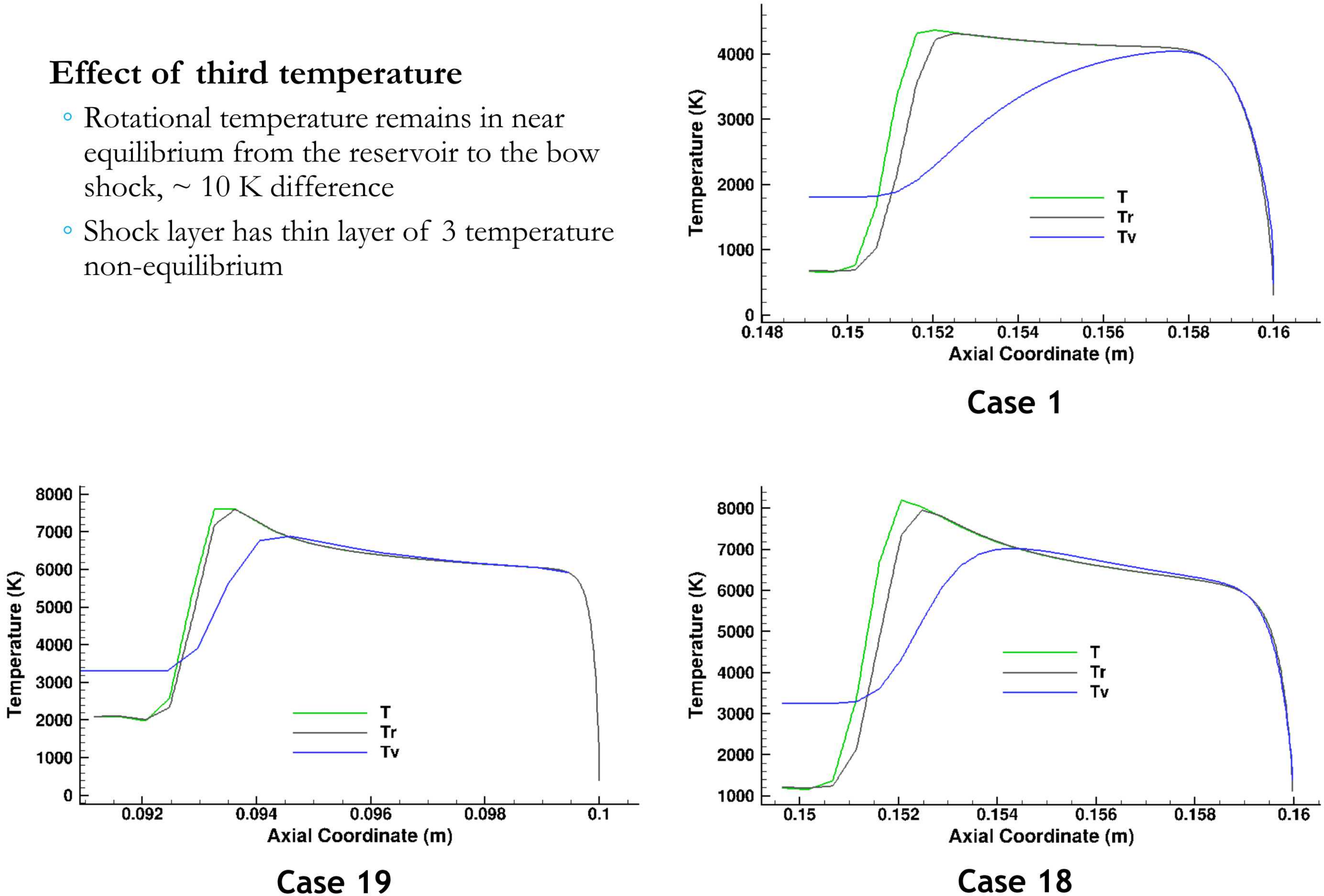


Summary

Reasonable agreement with expected heat flux for nominal solver options

- Simulation setup ready for couple flow simulations
- Need to bring in more data to anchor flow simulations
- Currently working on verifying fully coupled method in SPARC

Variations in solver options

- Flow chemistry/wall catalycity has a strong impact on calculated heat flux
- Need to better quantify sensitivities in heat flux to chemical reactions and transport model parameters

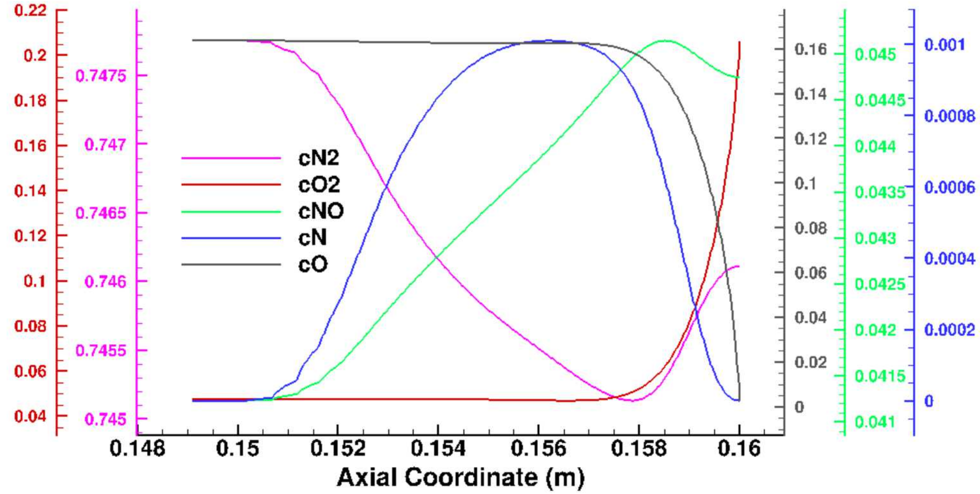
Backup slides

Solver Variations

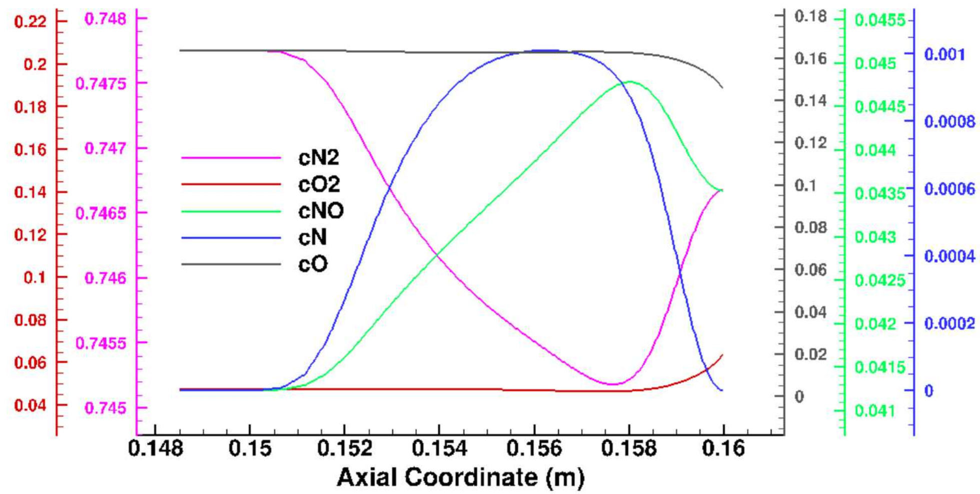
Catalytic Efficiency

- Catalytic wall drives changes throughout the boundary layer

Case 1



Fully Catalytic



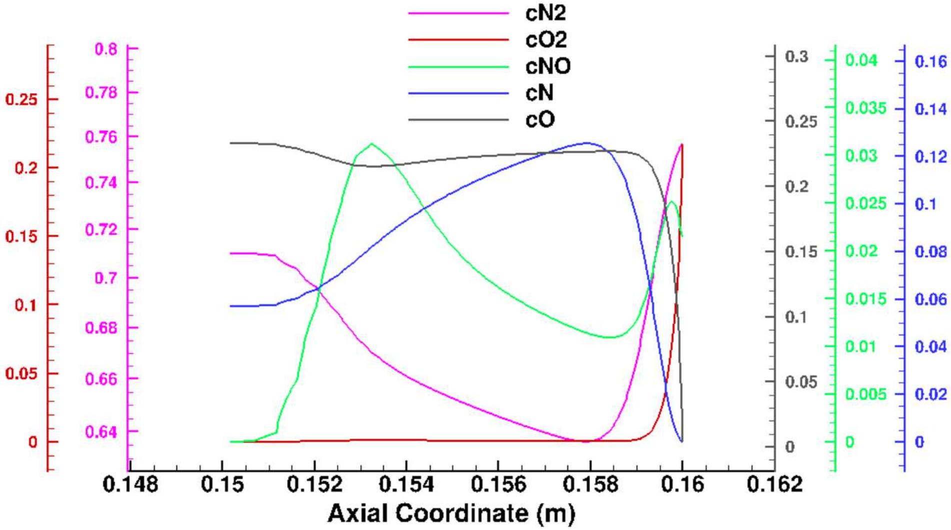
Non Catalytic

Solver Variations

Catalytic Efficiency

- Catalytic wall drives changes throughout the boundary layer

Case 18



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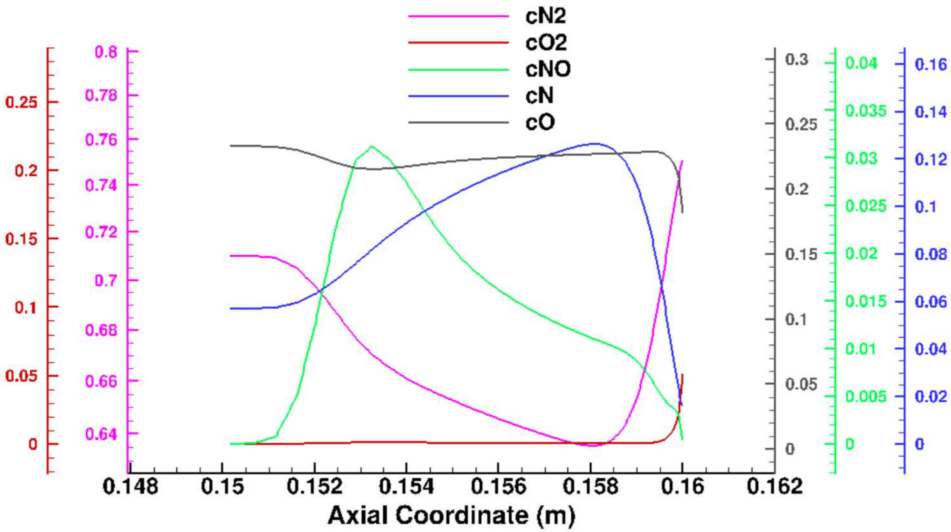


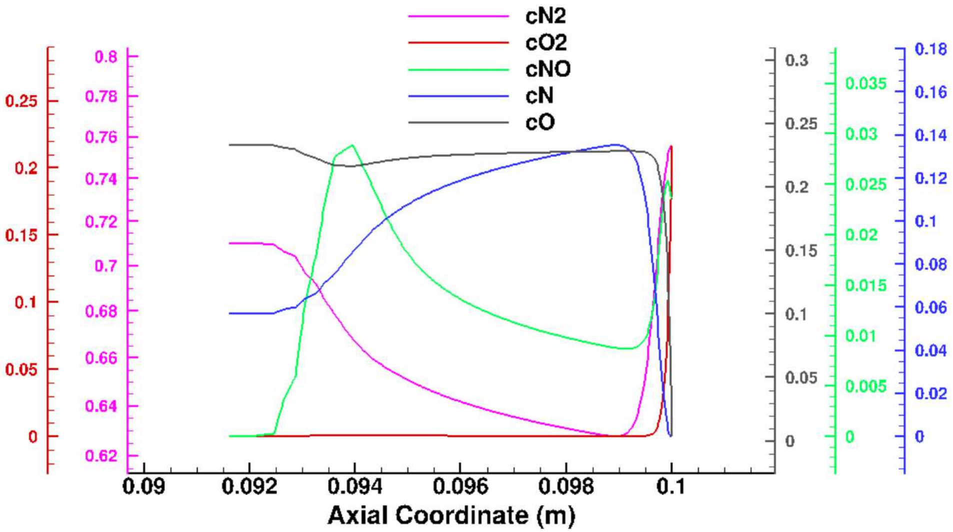
Non Catalytic

Solver Variations

Catalytic Efficiency

- Boundary condition working as expected
- Catalytic wall drives changes throughout the boundary layer

Case 18



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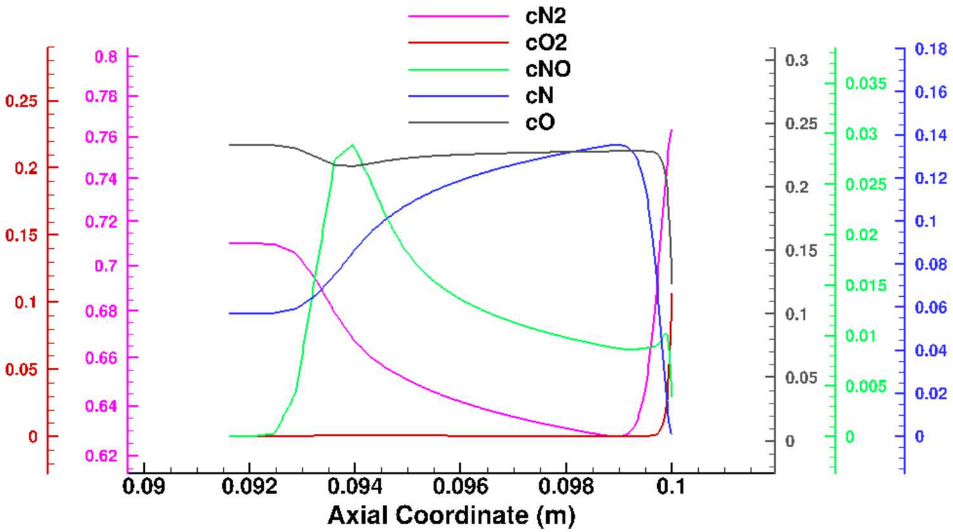

Non Catalytic