ANALYSES OF CONTROL SURFACE SEAL TESTED IN THE AMES ARC JET TUNNEL (PANEL TEST FACILITY)

Alton J. Reich and Mahesh Athavale
CFD Research Corporation
Huntsville, Alabama

Patrick H. Dunlap, Jr., and Bruce M. Steinetz
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Daniel P. Breen and Malcolm G. Robbie
Analex Corporation
Brook Park, Ohio

CFD Research Corporation
215 Wynn Dr. , Huntsville, AL 35805 (256) 726-4800 FAX: (256) 726-4806 www.cfdrc.com

Analyses of Control Surface Seal Tested in the AMES Arc Jet Tunnel (PTF)

Presented by:
Alton J. Reich, P.E.
CFD Research Corporation
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Topics

- Rope seal
- Improvements to porous media simulation in CFD-ACE+
- Porous media heat transfer validation case – steady-state and transient flat plate
- Simulation of GRC cold flow seal test fixture
- Simulation of calibration plate in the Panel Test Facility (PTF)
- Simulation of rope seal test in the PTF

Rope Seal

Porous Media Improvements

- CFD-ACE+ had the capability to model porous media via a distributed resistance
  - Difficult to use in practical situations
  - User had to determine linear and quadratic resistance coefficients which have no physical analogue
- Improved porous media model uses physical material properties as inputs
  - Porosity (fraction of volume occupied by the solid)

Porous Media Improvements (con't)

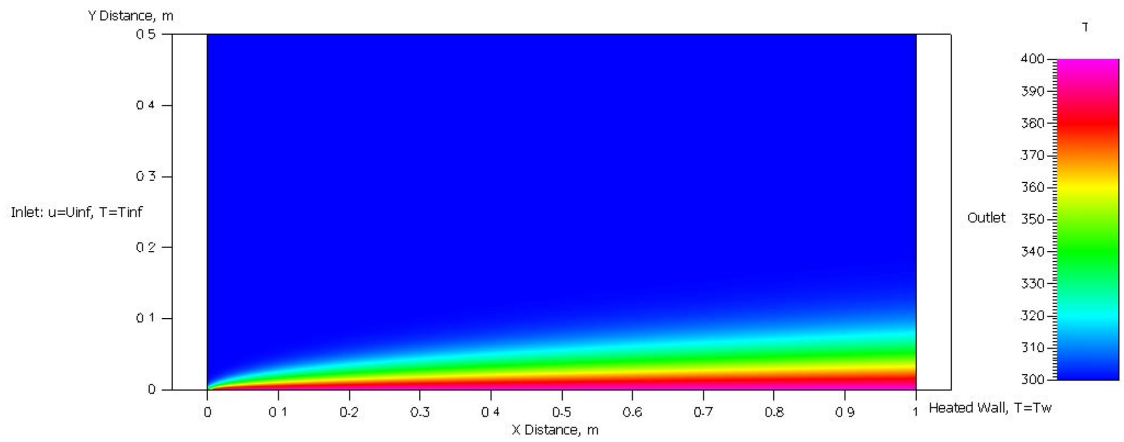
- Permeability (relates to the pressure drop per unit of nominal path length through the media)
  - Several semi-empirical correlations exist for estimating permeability
  - Best obtained from experimental data
- Second order (quadratic) effects may be considered

- Darcy's Law: $\nabla P = -\frac{\mu}{K}\mathrm{v}$

- Forchheimer Drag: $\nabla P = -\frac{\mu}{K}\mathrm{v} - \mathrm{c_F} K^{-1/2} \rho_f |\mathrm{v}| \mathrm{v}$

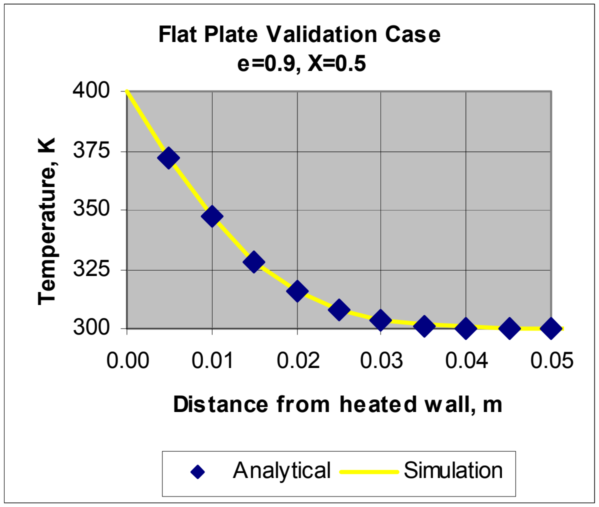
Porous Media Validation

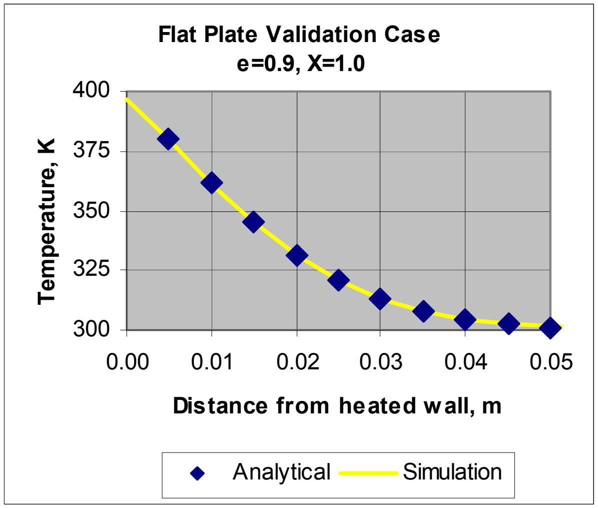
- CFDRC performed a steady-state and transient validation of the improved porous media model with heat transfer
- The geometry is a semi-infinite porous media, bounded by a flat plate
  - Wall temp. is 400K
  - Gas enters at 300K



Porous Media Validation (con't)

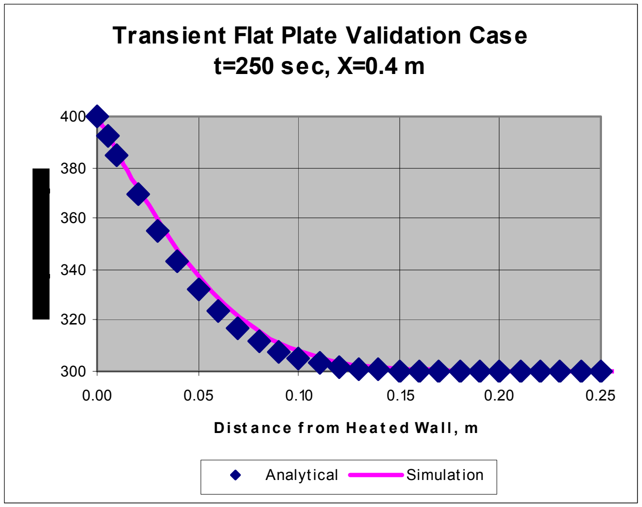
- Both steady-state and transient cases have an analytical solution
- CFDRC compared simulation results to the analytical solutions

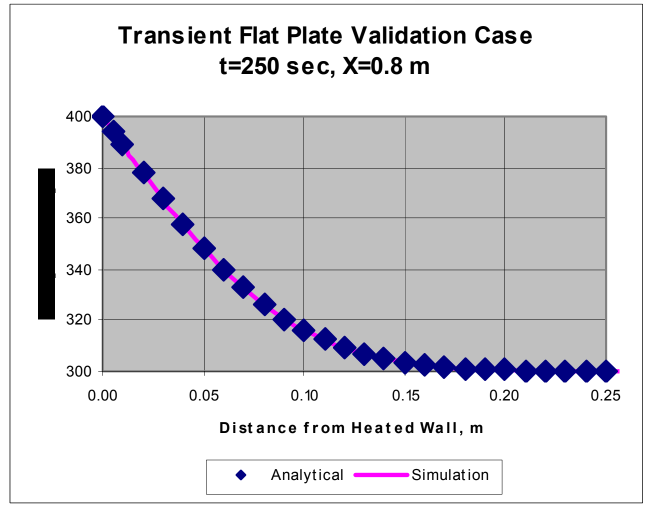




Steady-State Comparison

Porous Media Validation (con’t)



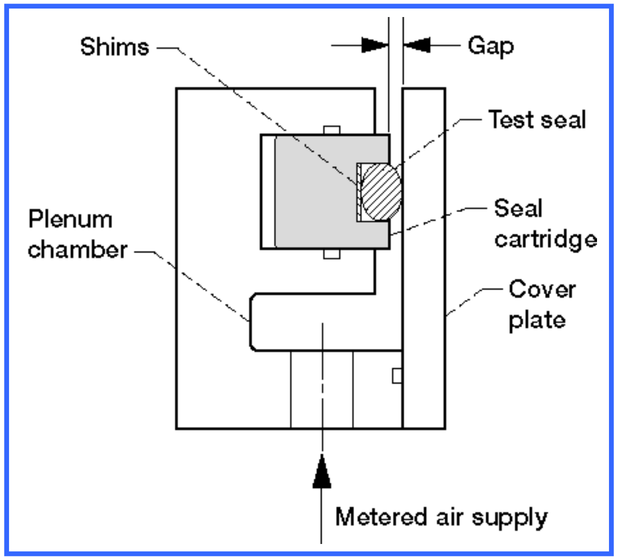


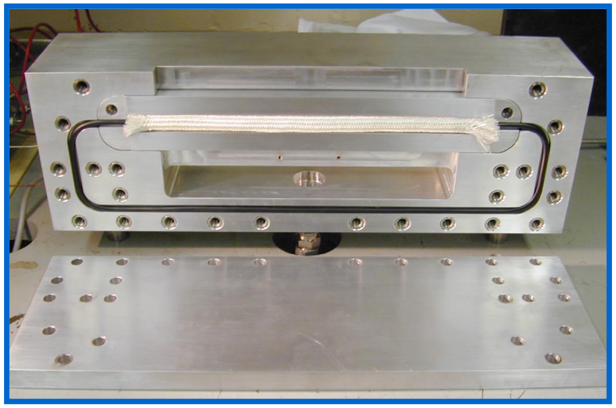
Transient Comparison

- Simulation results compare well with the analytical solutions

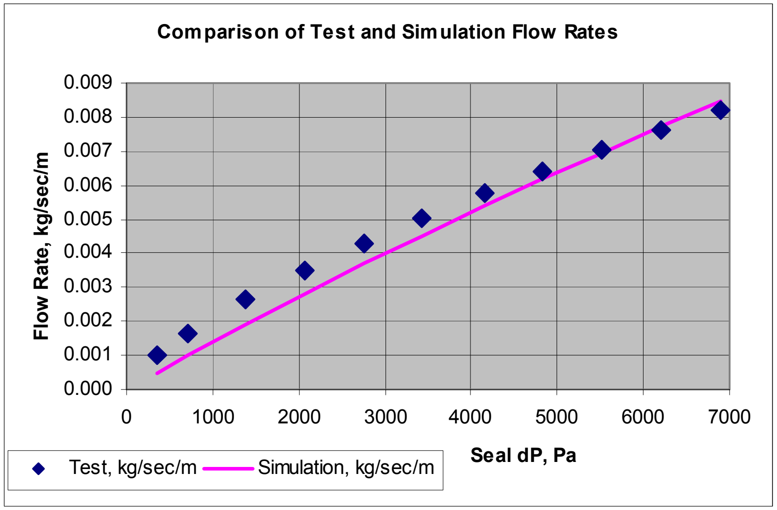
GRC Cold Flow Seal Test

- GRC measured the flow rate through a compressed seal
- CFDRC was provided mass flow rate vs. dP data
- A set of simulations were performed and results were compared using:
  - Porosity = 0.85
  - Permeability = 3.7E-11 m^2



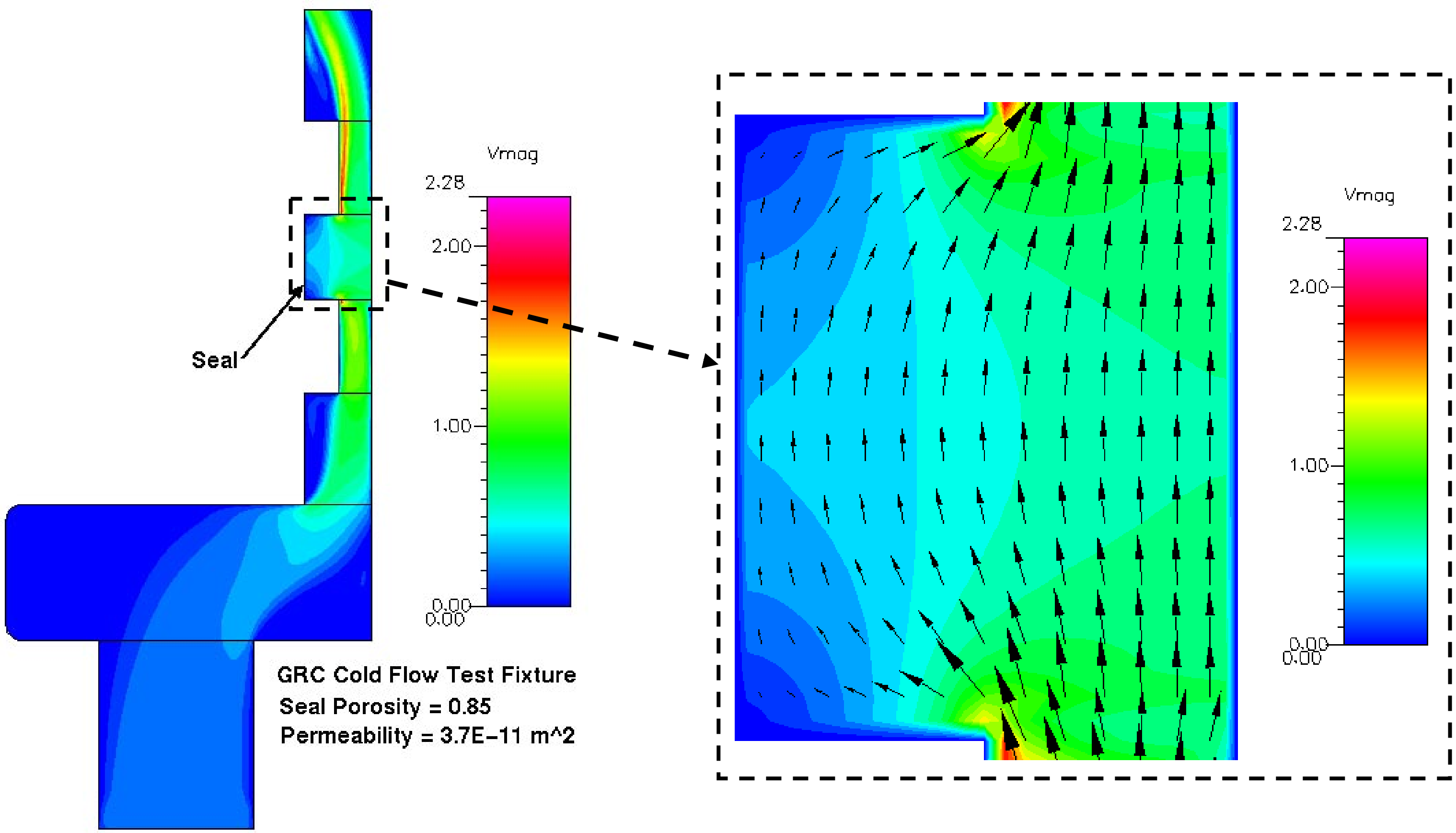


GRC Cold Flow Seal Test (con't)



- The simulation and test results compare well
- Lessons learned:
  - Semi-empirical equations predicted a permeability that was ~2 OOM too low (~1E-13 m^2)
  - When using test data to compute permeability, the cross sectional area of the seal should be considered, not the flow area upstream

GRC Cold Flow Seal Test (con't)

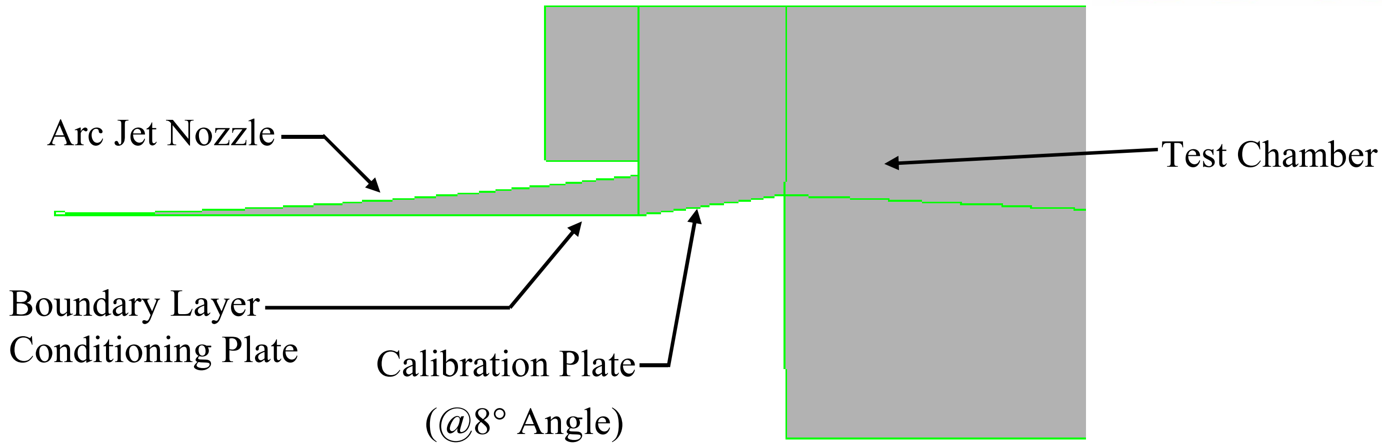


Velocity Magnitude Within the Seal

Simulation of Calibration Plate

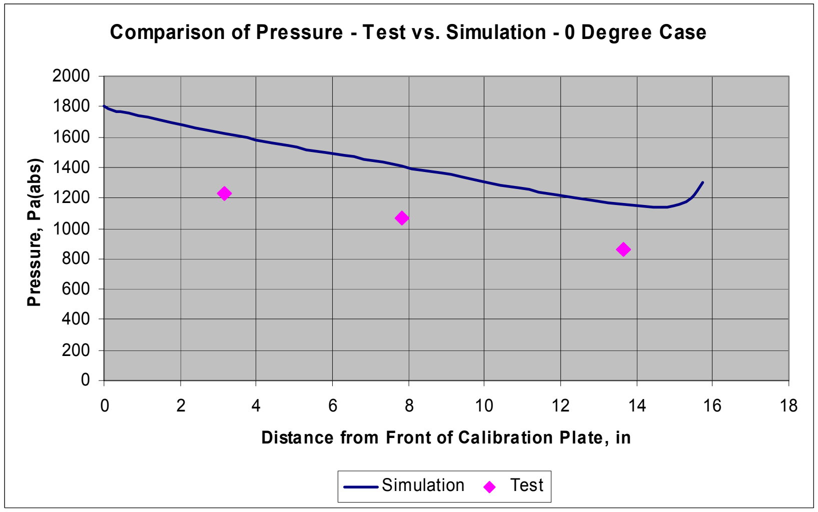
- The Panel Test Facility (PTF) uses an instrumented calibration plate to measure arc heater enthalpy and chamber pressure
- GRC provided CFDRC with a data set from recent PTF runs with the calibration plate installed
- CFDRC developed a 2D model of the PTF nozzle section and the calibration plate installed in the test chamber

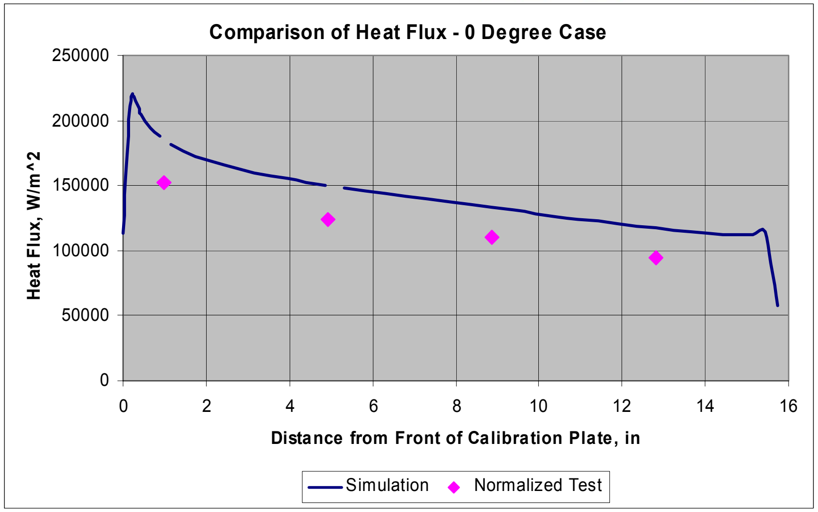
Calibration Plate Model

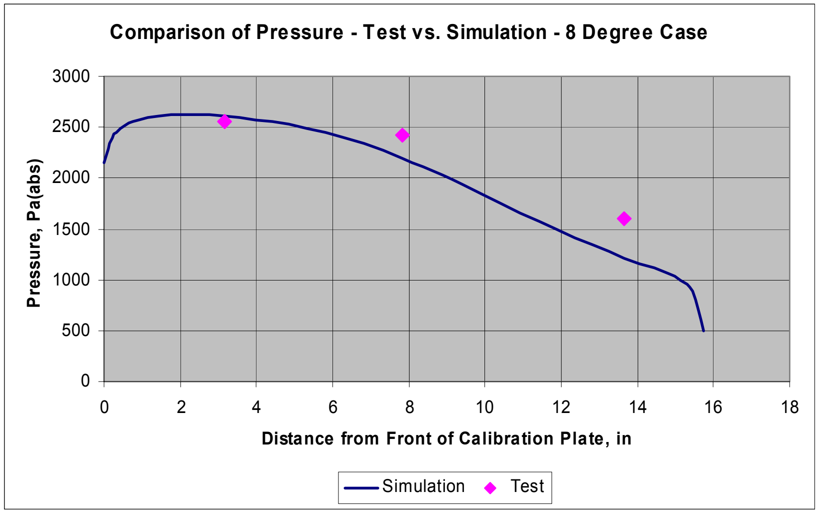


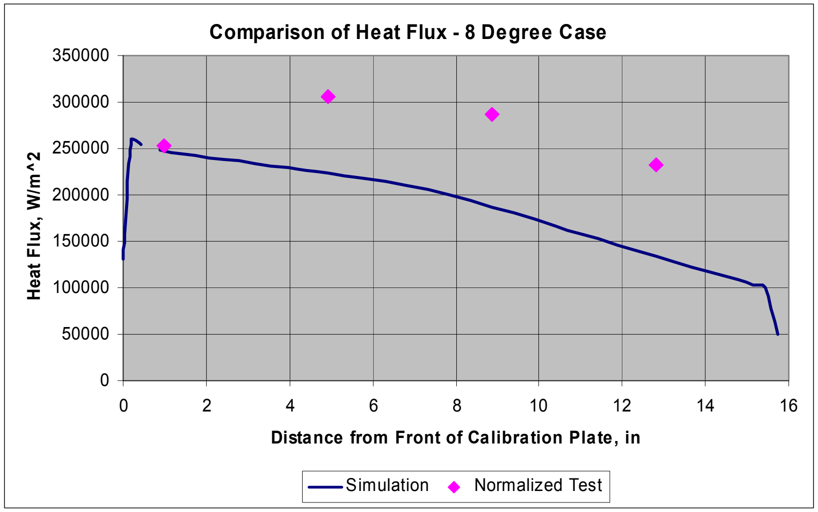
- Model Size: ~16,000 Cells
- Inlet: Air / Argon mixture, Oxygen fully dissociated
- Outlet: Low pressure, ~300Pa (abs)
- Nozzle Walls: Cooled to 600K
- Calibration Plate: Cooled to 300K

Calibration Plate Results









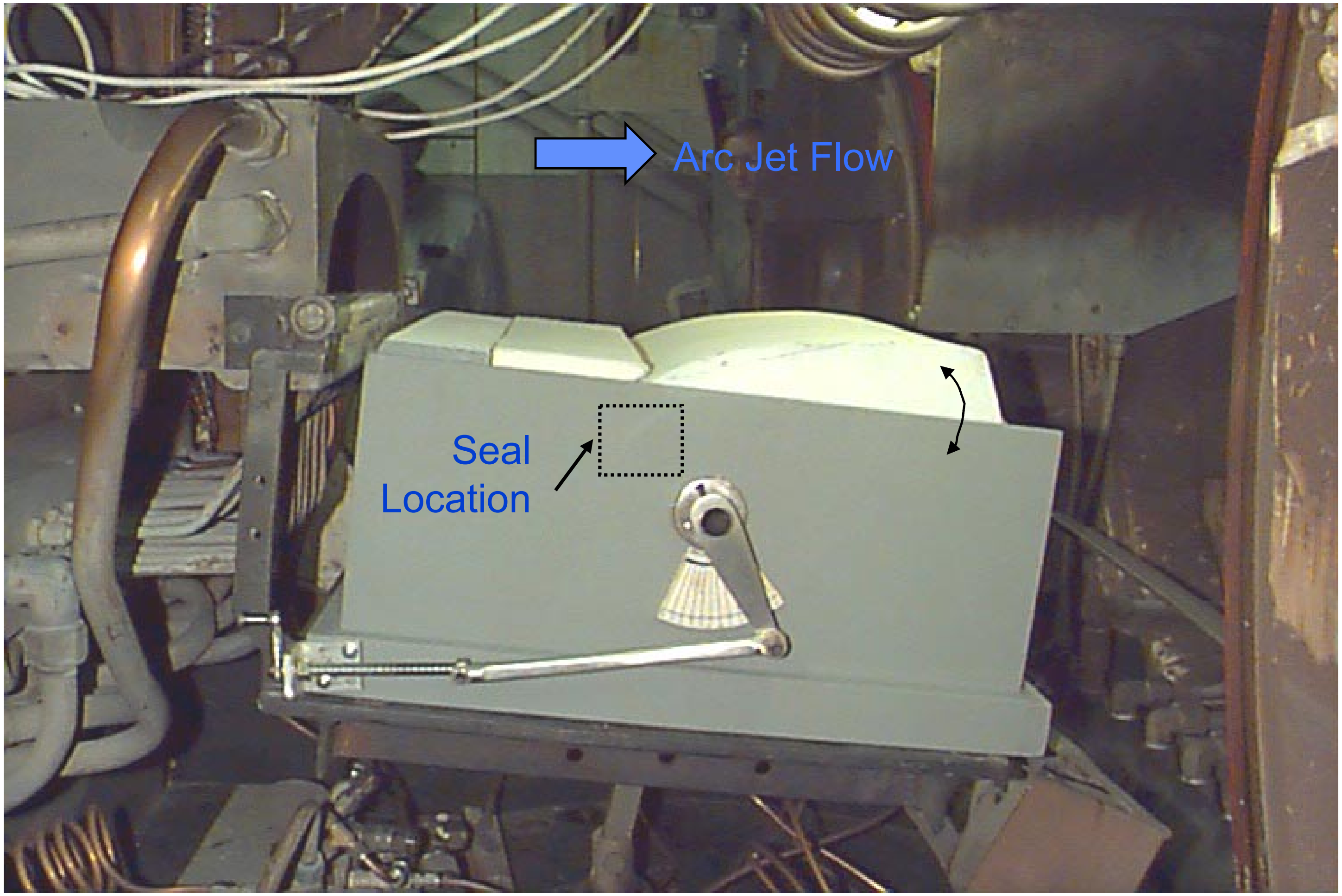
Calibration Plate Result Comments

- Pressure results show fairly good agreement in both shape and magnitude
  - CFD-ACE+ simulation over predicts the surface pressure at 0° angle of attack
- Wall heat flux is under predicted by ~40% at both 0° and 8° angles of attack
  - CFDRC is still investigating this discrepancy

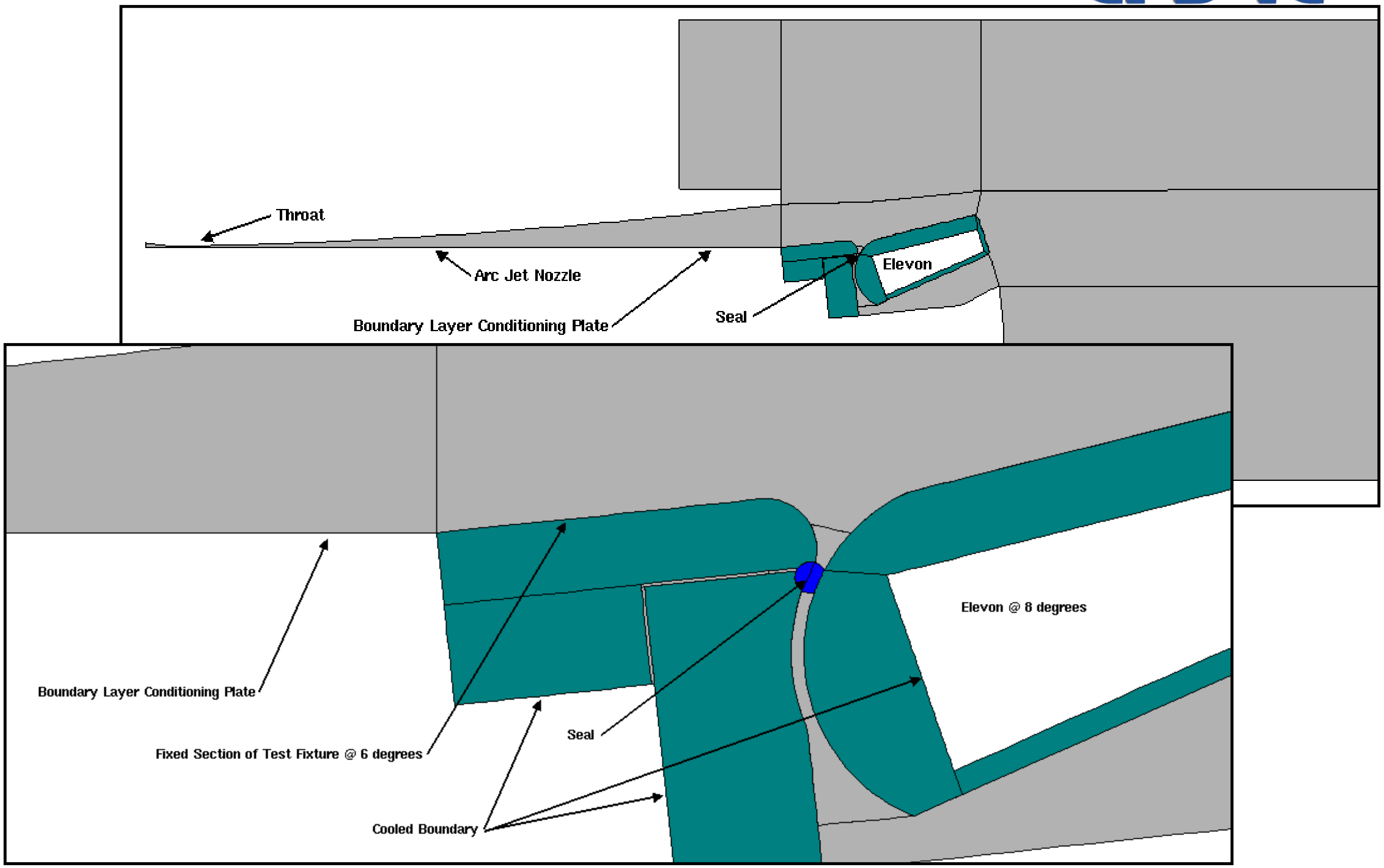
Simulation of Arc Jet Test

- Performed to show that simulation could predict the steady state temperature of the rope seal
- Data for comparison is from a test performed at the Panel Test Facility (PTF) at ARC
- CFDRC developed a 2D model of the arc jet nozzle, test chamber and test fixture
- Inlet species composition and nozzle wall temperature was the same as for the calibration plate

Seal Test Fixture



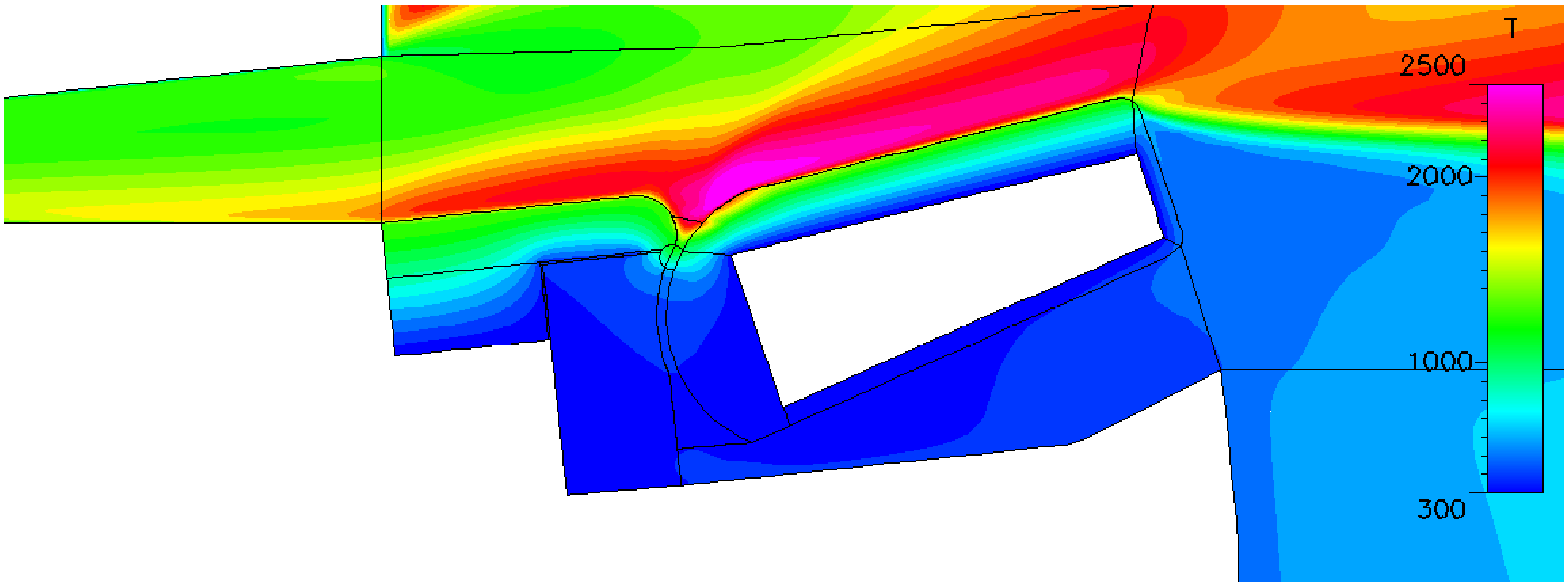
Seal Simulation Model Geometry



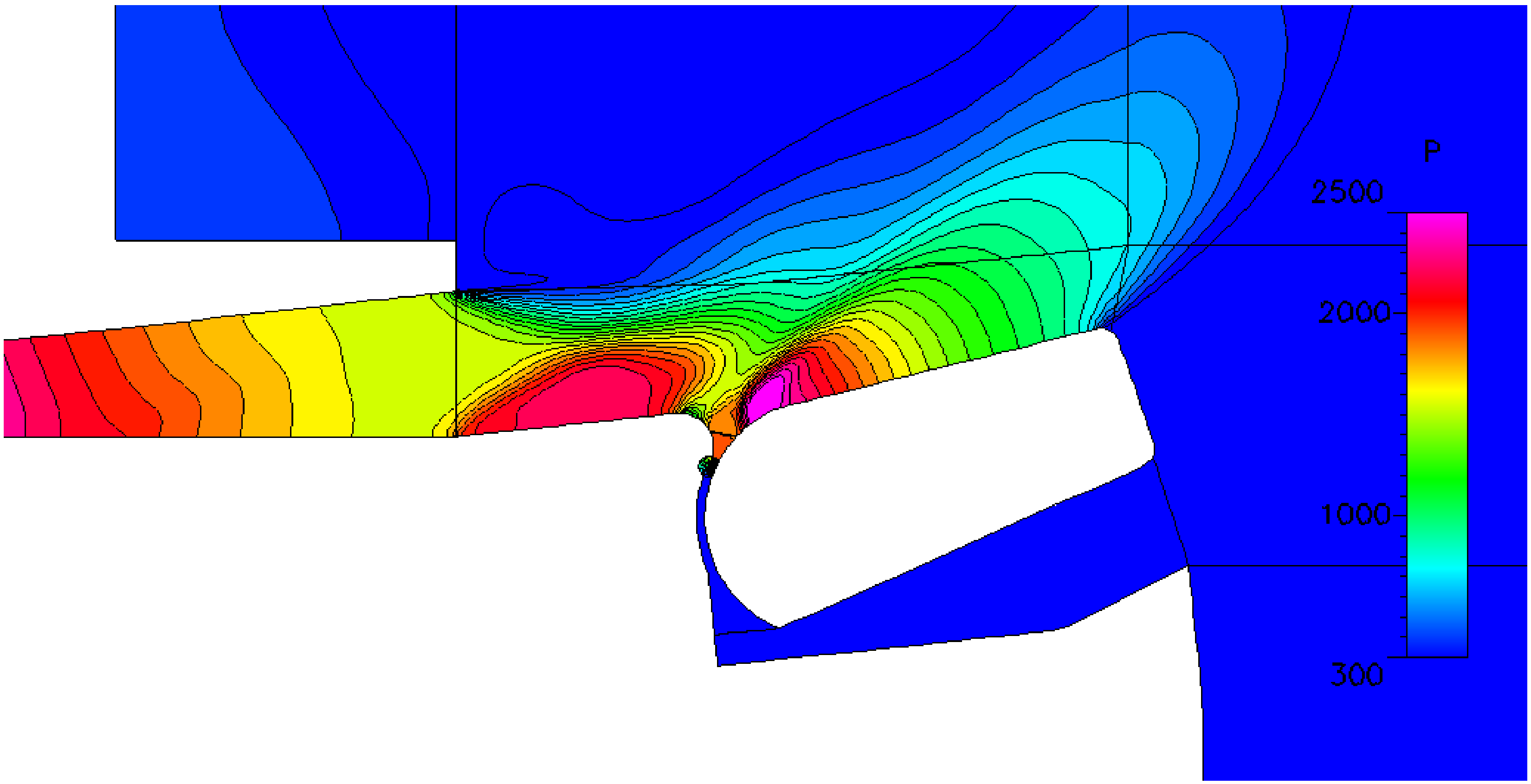
Seal Simulation Challenges

- Test data provides ample time-dependent information about the areas of interest (i.e.: temperature on hot surfaces of test fixture)
- Data is lacking for specification of CFD analysis boundary conditions
  - Nozzle wall temperature
  - Fixture cold side cooling water temperature
- Inlet temperature is inferred from calibration plate test data

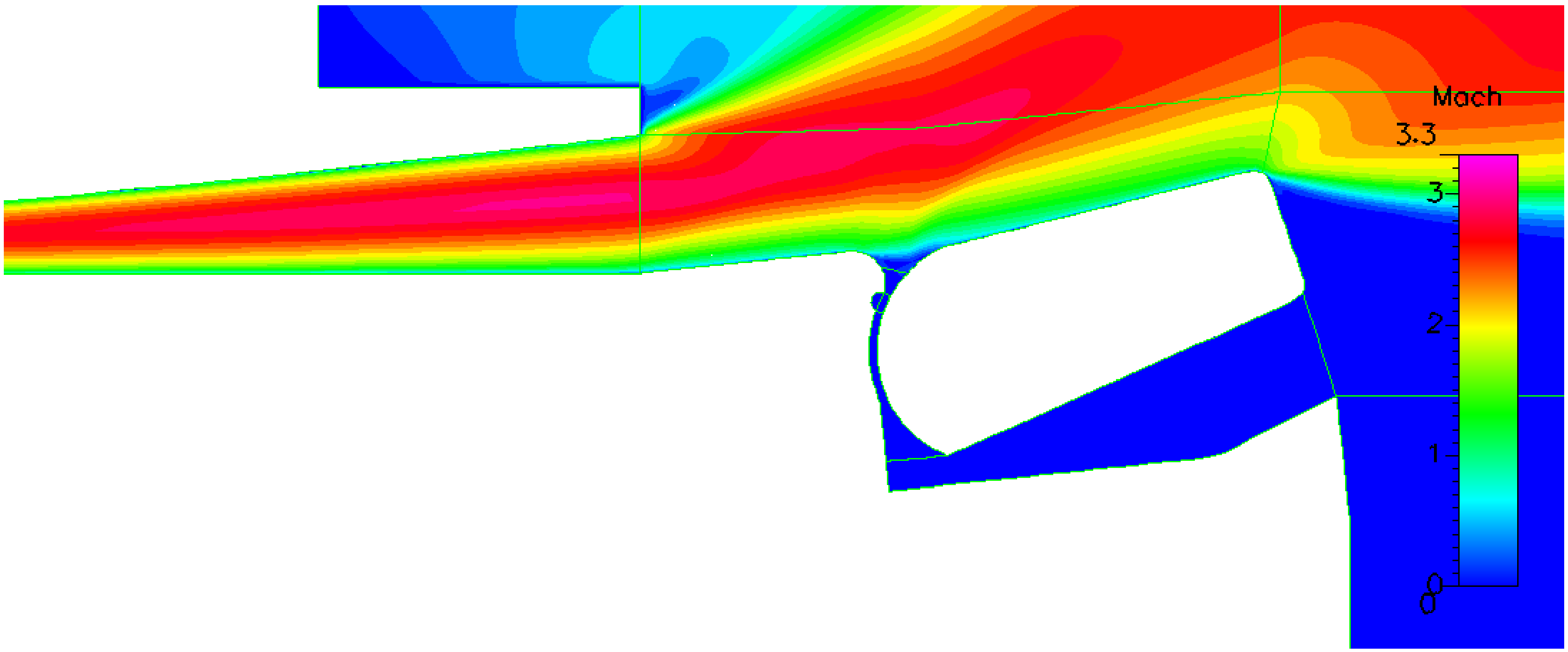
Simulation Results - Temperature



Simulation Results - Pressure



Simulation Results – Mach



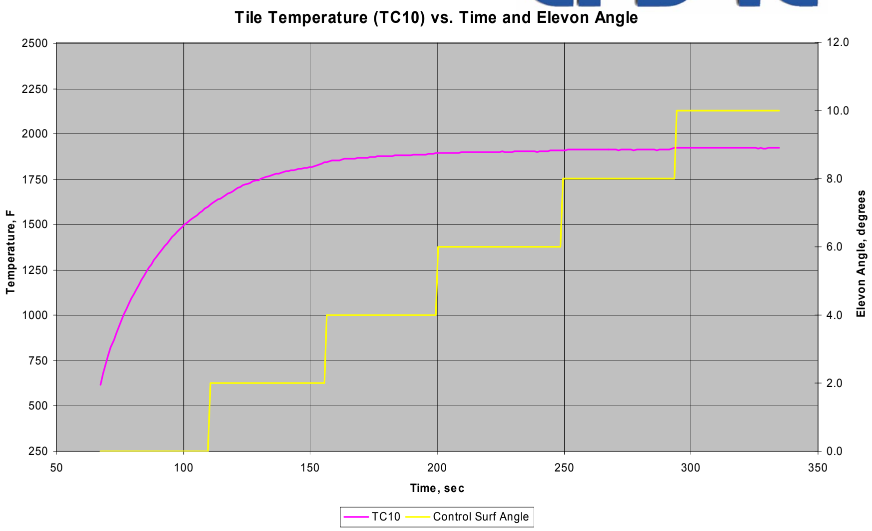
Seal Simulation – Temperatures

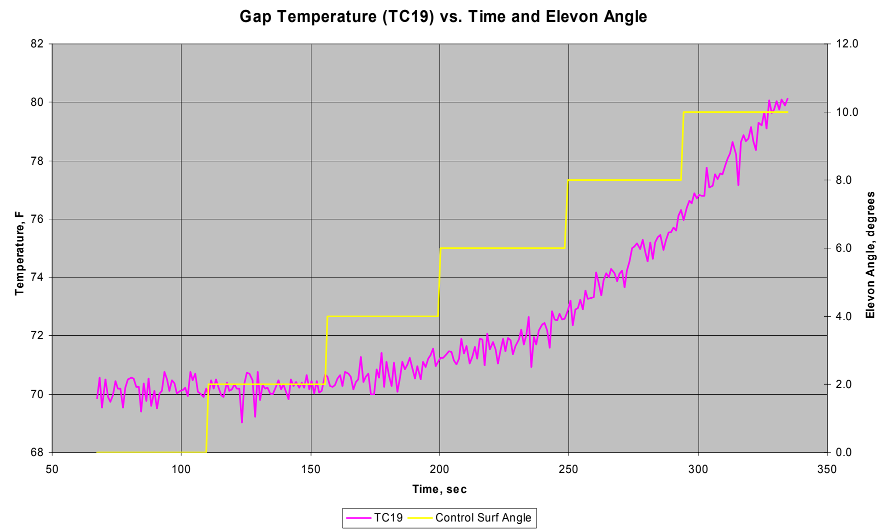
Arc Jet Test vs. Simulation Result Comparison						
Fixture Angle:	6 deg					
Elevon Angle:	8 deg					
Thermocouple						
Location #	Test T, F	Test T, K	ACE T, K	X, m	Y, m	Location Notes
4	2227	1493	1621	0.164	0.017	"Fixed" surface, 6.5" from nozzle lip
10	1916	1320	1582	0.192	-0.002	Cove entrance surface, 0.5" above seal
16	158	343	529	0.181	-0.041	Cove gap surface, 0.5" below seal
19	76	298	444	0.179	-0.067	Cove gap surface, 1.5" below seal
20	157	343	388	0.195	-0.167	Cove gap surface, 5.5" below seal
23	930	772	1123	0.198	-0.015	Elevon nose surface, 45 deg above 0
28	107	315	517	0.187	-0.044	Elevon nose surface, 25 deg above 0

- Simulation predicts temperatures greater than measured during test
  - Does the model provide enough cooling downstream of the seal?
  - Are the test temperatures really steady state?

Test Data – Temperature vs. Time

- Test data indicates:
  - Temperature of tile on fixed surface has reached steady state at 8° elevon angle
  - Temperature below seal has NOT reached steady state during test





Seal Simulations – Future Steps

- Wrap up runs
- Write report on this phase of project
- Planned follow-on work:
  - 3D simulations of control surface seals with X-38 boundary layer flow
  - Simulations of ceramic ram jet ramp seals
  - Explore active cooling of seals by gap-side gas injection