BANTAM CONTROL SURFACE/TPS SEALS DEVELOPMENT

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BANTAM Control Surface/TPS Seals Development

Objective:

Develop advanced control surface seals and demonstrate using appropriate high temperature test facilities

Approach

- Determine seal requirements
- Select candidate seal concepts/materials
- Perform thermal/structural analyses
- Test seal concepts under representative conditions using ARC Arc-jet heating facility
- Provide seal designs/databases to vehicle programs for successful implementation and flight

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Outline of Activities

Technical Interchanges & Lessons Learned with:

- X-38 at JSC
- X-37 at Boeing,Seal Beach
- NASA Ames Research Center
- Seal/TPS fabricators

Thermal Analysis of Control Surface Gap

- Use X-38 environment and preliminary design
- CFD Analysis with Permeable Seal

Designed and Fabricated Arc-Jet Test Article Mock-Up

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Lessons Learned/Background

Space Shuttle Experience is Valuable ... but

- Vehicles like BANTAM, X-38, X-37 are considerably smaller
- Low temp seals on elevons because Shuttle has sufficient space
- Smaller Vehicles are Looking at Hot seals for elevons or body flaps

X-37 & X-38 are Designing Bulb type seals

Bulb type seals have considerable experience on Shuttle……however

- Ceramic fiber cloth over Inconel woven spring and insulation -- Nextel 312 (2000F multi use)
- Semi-static applications
- Temps only to 1600 F

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Lessons Learned/Background -- continued

X-33 TPS Seals Use Similar Design as Shuttle

Change is Nextel 440 Cover and stiffer, knitted, Inconel Spring.

Very little data on sliding wear behavior of ceramic fiber covered bulb seals

- Steinetz, et. al. Published data on testing all-ceramic braided rope seals
- Anecdotal evidence that harness satin weaves provide better sliding wear than plain weave -- providing that sliding direction is parallel to face fibers
- Current fabricators may not differentiate between warp and fill faces when wrapping fabric

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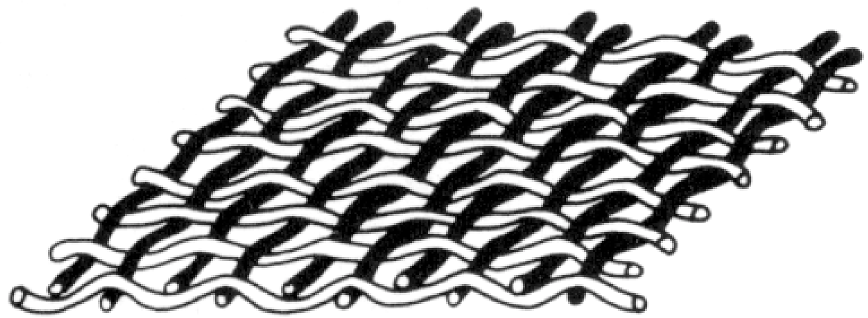
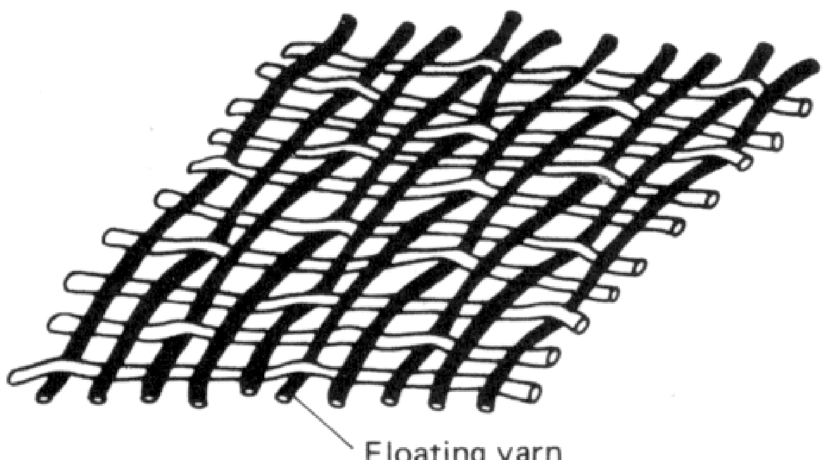


Plain Weave



5 Harness Satin

Direction of Sliding Contact Relative to Fabric Orientation is Critical

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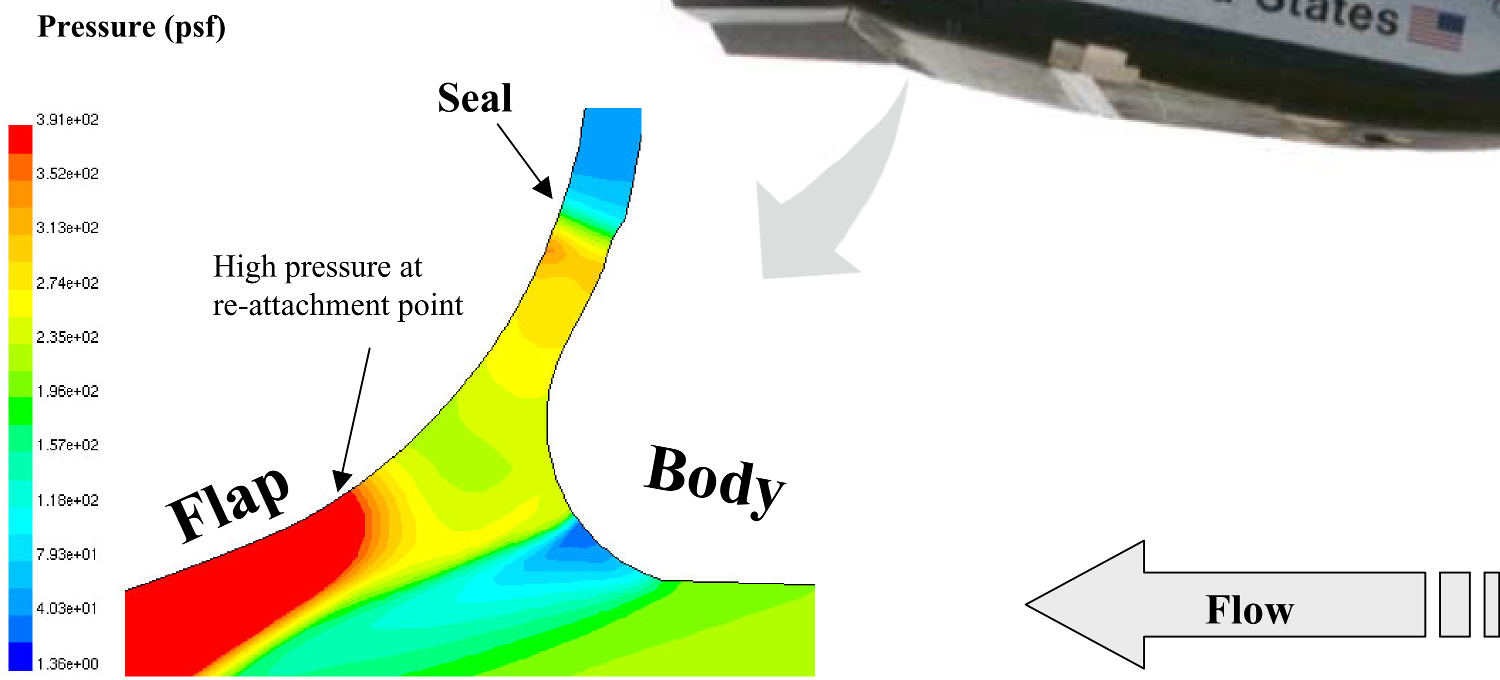

Static Pressure Distribution In Body Flap Gap & Seal Area

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X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Method

- 2-D Navier-Stokes analysis using commercial CFD code FLUENT
- Limited computational domain for faster turn-around
- Evaluate effect of seal permeability
- Use CFD results at key trajectory points to scale simpler methods for entire trajectory
- Apply predicted environments to structural thermal analysis to determine seal temperatures

Current Assumptions

- Boundary layer growth upstream of domain neglected
- Steady 2-D flow
- Turbulent boundary layer
- 20 degree bodyflap deflection angle
- Radiation equilibrium surface condition (ε=0.8, F = 0.144)
- Rectangular shaped seal (to simplify computational grid)

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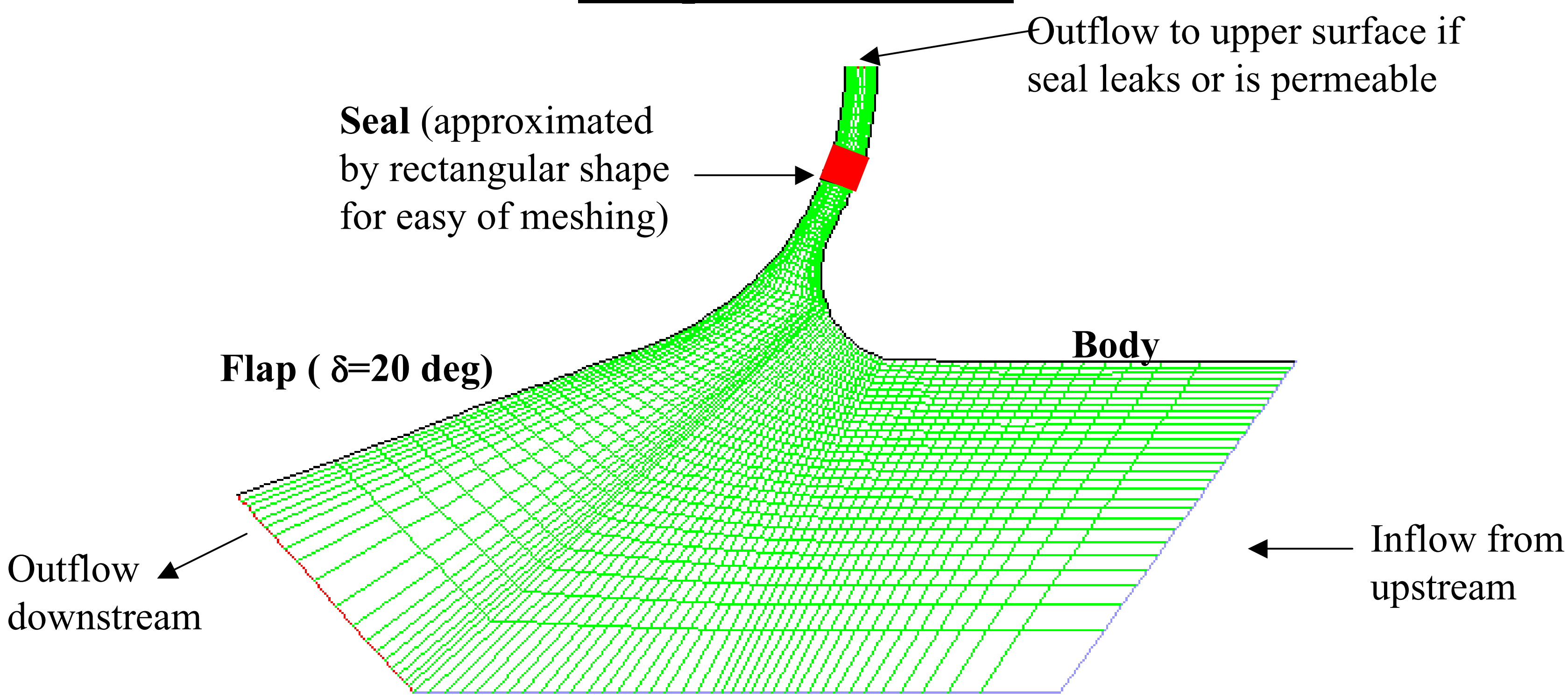
X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Computational Grid



Extent of region modeled kept small to decrease preliminary analysis time

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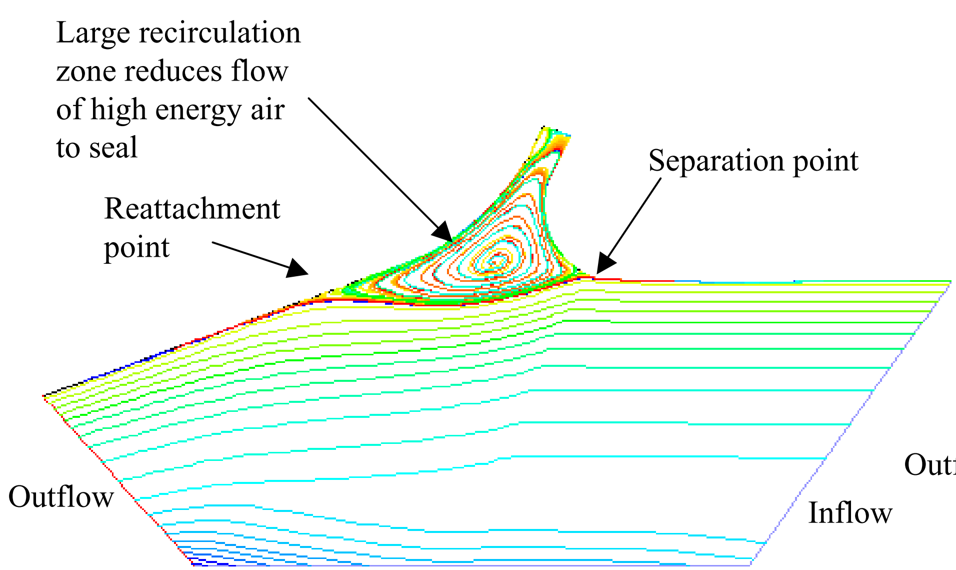
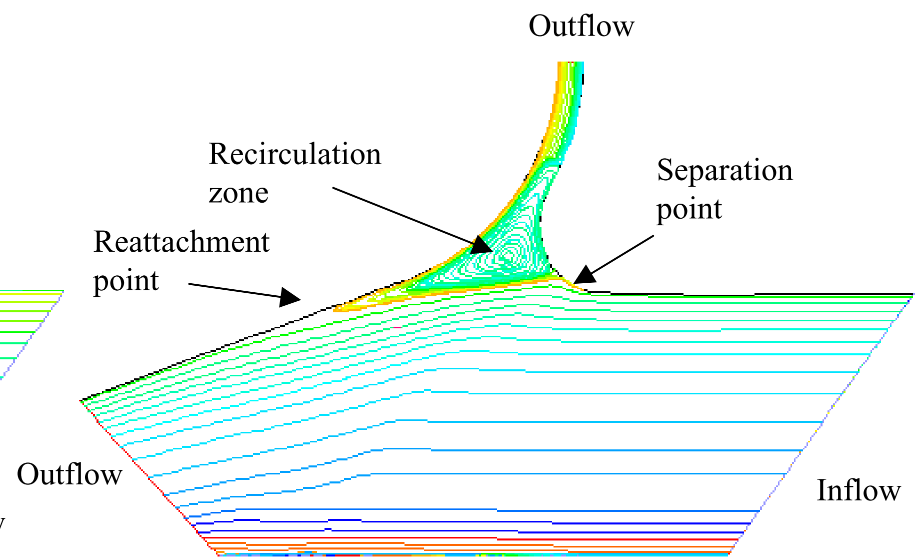
X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Impermeable Seal



Permeable Seal (k = 1.0e-7)



Flow Pathlines

A permeable seal does not significantly influence flow field structure

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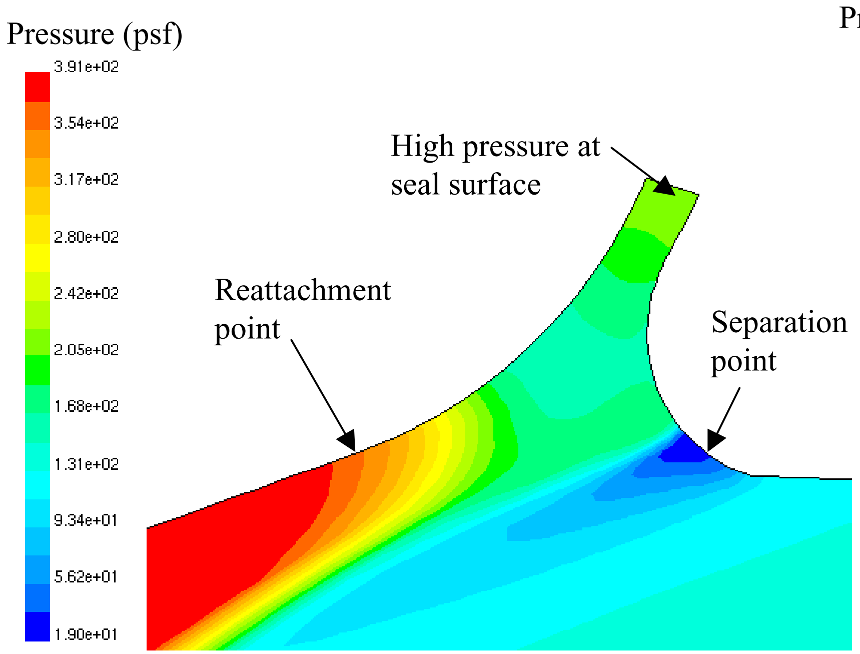
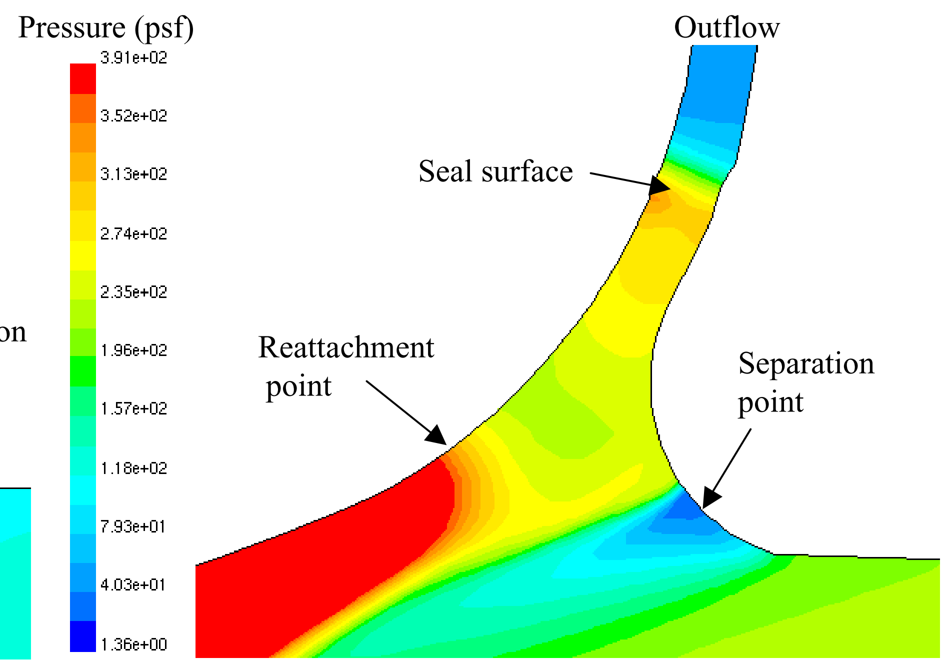
X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Impermeable Seal



Permeable Seal (k = 1.0e-7)



Static Pressure Distribution

Flow through permeable seal does not significantly affect pressure at the seal surface

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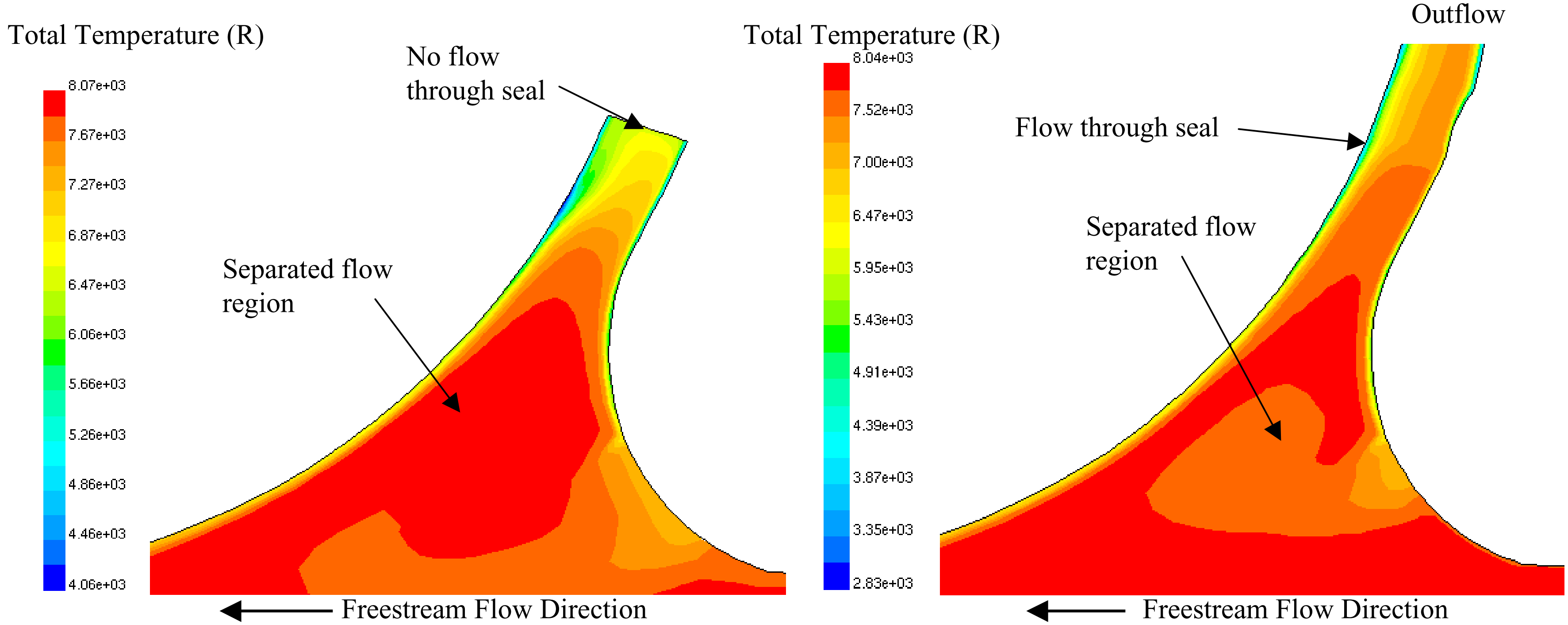
X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Impermeable Seal

Permeable Seal (k = 1.0e-7)



Total Temperature Distribution

Permeable seal allows hotter flow to seal surface

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Seal Surface Condition (20° flap δ)	**Impermeable**	**Permeable**
Radiation Equilibrium Heat Flux (Btu/sq ft-hr)	7000 to 9000	15000 to 30000

Seal permeablility significantly increases seal heating
Note: Heat flux from the flow into the seal is defined as a negative value in FLUENT.

Radiation Equilibrium Temperatures (°F)	2000 to 2200	2500 to 3000

High seal permeablility significantly increases seal temperatures
Note: These radiation equilibrium temperatures are only a rough estimate of actual material temperatures. A transient structural thermal analysis is required to accurately predict seal temperatures.

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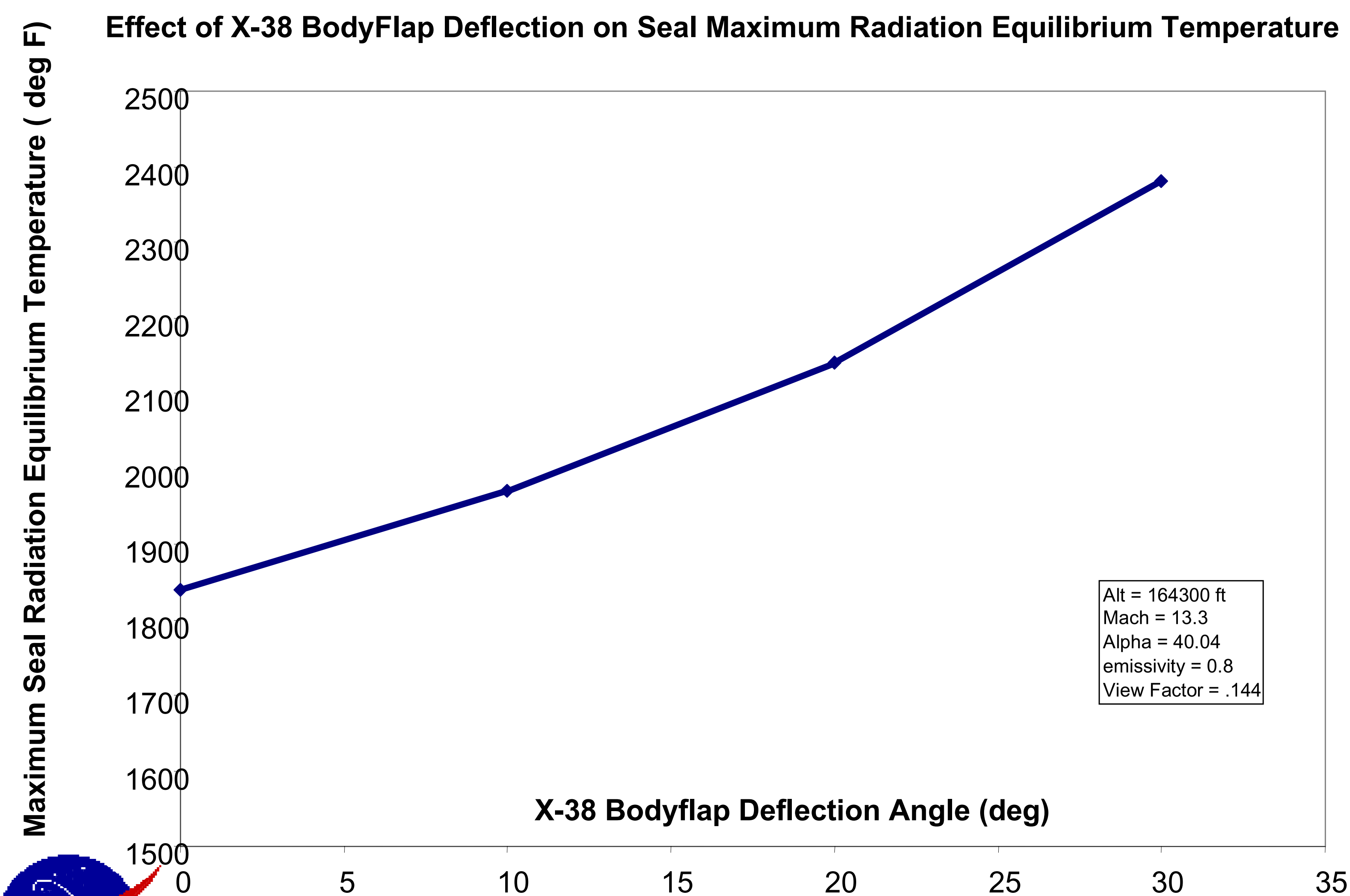

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X-38 Bodyflap Seal Preliminary Aerothermal Analysis

Conclusions

- Preliminary CFD analysis indicates that handbook cavity correlations slightly underpredict the aerothermal environment for deflected flaps.
- High seal permeability results in slightly increased aero-heating to the seal.
- Maximum seal surface temperatures are expected to be in the neighborhood of 2300°F for a 20 deg flap deflection.
- Seal temperatures increase as bodyflap deflection angle increases

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Arc-Jet test Fixture for Seals

Features of test article will include:

- Control surface hinge-line seal cavity with replaceable cartridge to quickly and easily change-out candidate seals and seal materials
- Actuated trailing flap to deflect the control surface and assess effects of potential flow ingestion into the control surface hinge-line seal cavity
- Cavity will be well instrumented with probes to measure upstream and downstream pressures and temperatures.
- Test results will be used to validate control surface seal design (ref. Task 6) and aero-thermal analyses (ref. Task 3.)

We Have completed a Mock-Up Article and Evaluated Design in AMES Arc-Jet Facility (PTF)

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Mock-Up for Arc-Jet test Fixture for Seals

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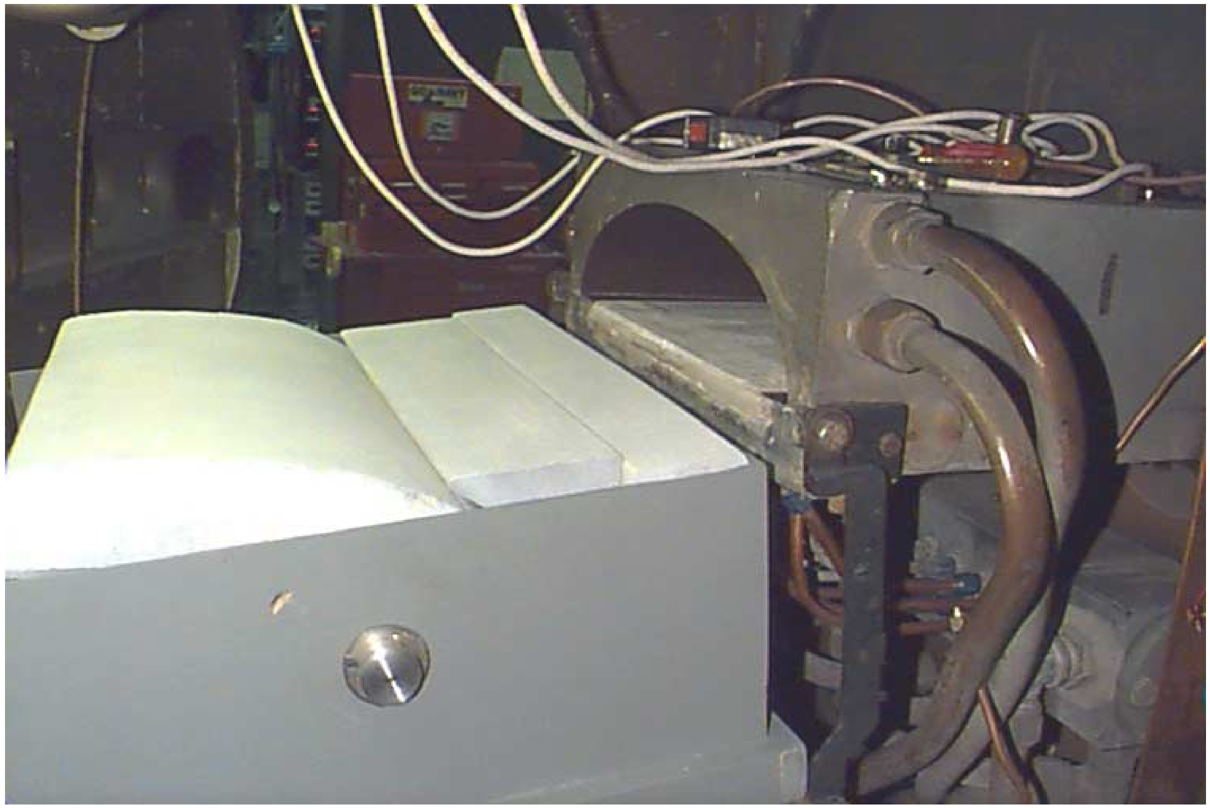

Test Article Mock-Up In Ames PTF

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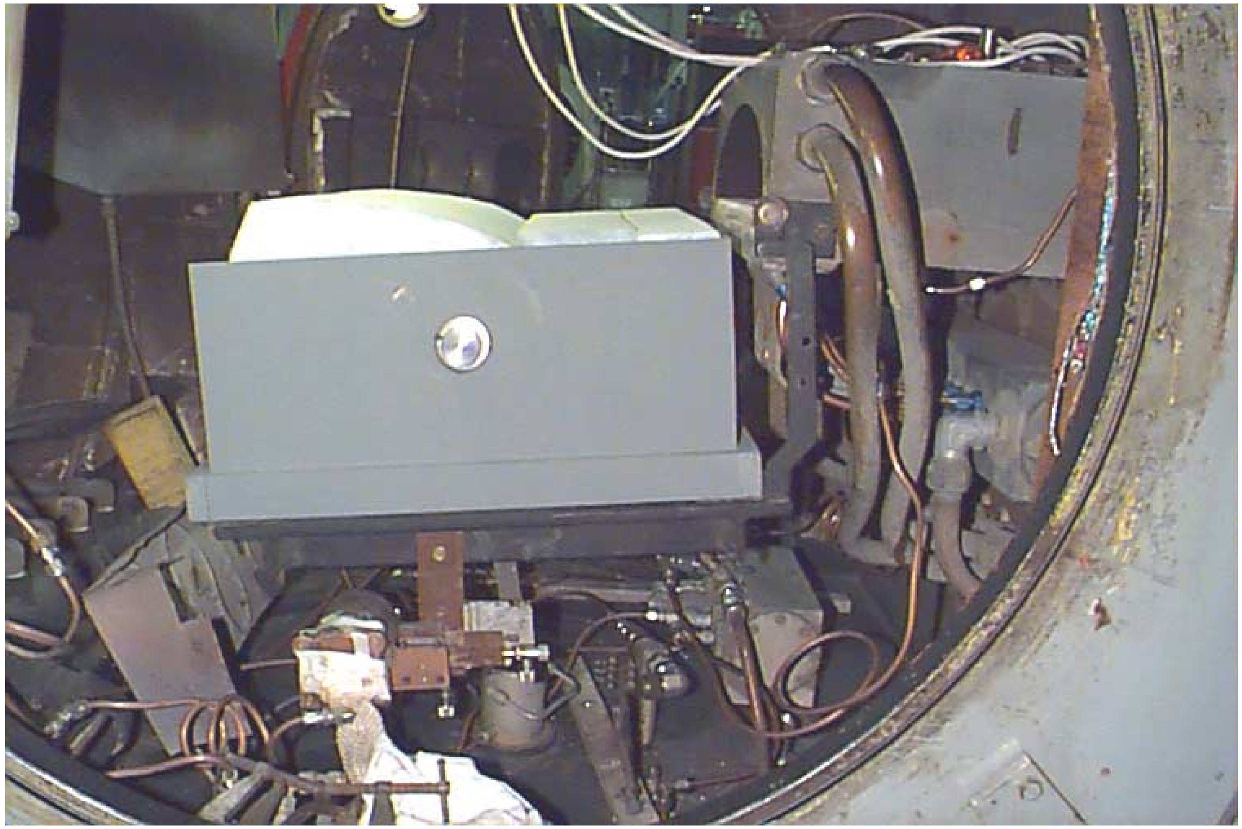

Test Article Mock-Up In Ames PTF

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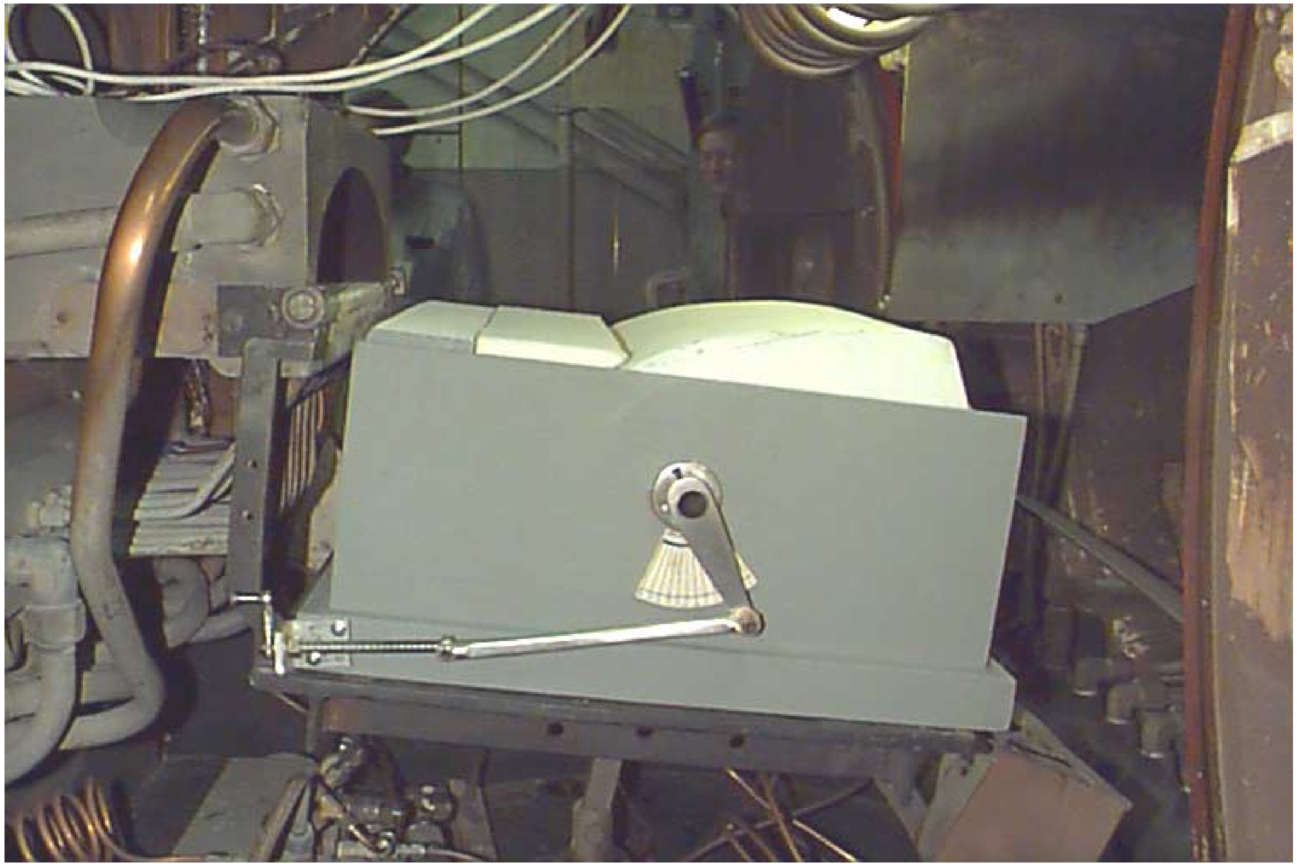

Test Article Mock-Up In Ames PTF

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PLANNED CONTINUING ACTIVITIES

Fabricate the Test Article

Design/Fabricate Seals and TPS Components

Complete Thermal/Structural Analysis

Perform Arc-Jet Testing of Seal Designs