Design of a Novel Gaseous Hydrogen-Oxygen Rocket Injector Element

REPRINT/IN-20
(C)/NMF / ISS ACT.
086483

Fluent UGM - 26 May 1999

Dennis Glenn / GenCorp Aerojet
P.O. Box 13222
Sacramento, CA 95813-6000

(916) 355 6620

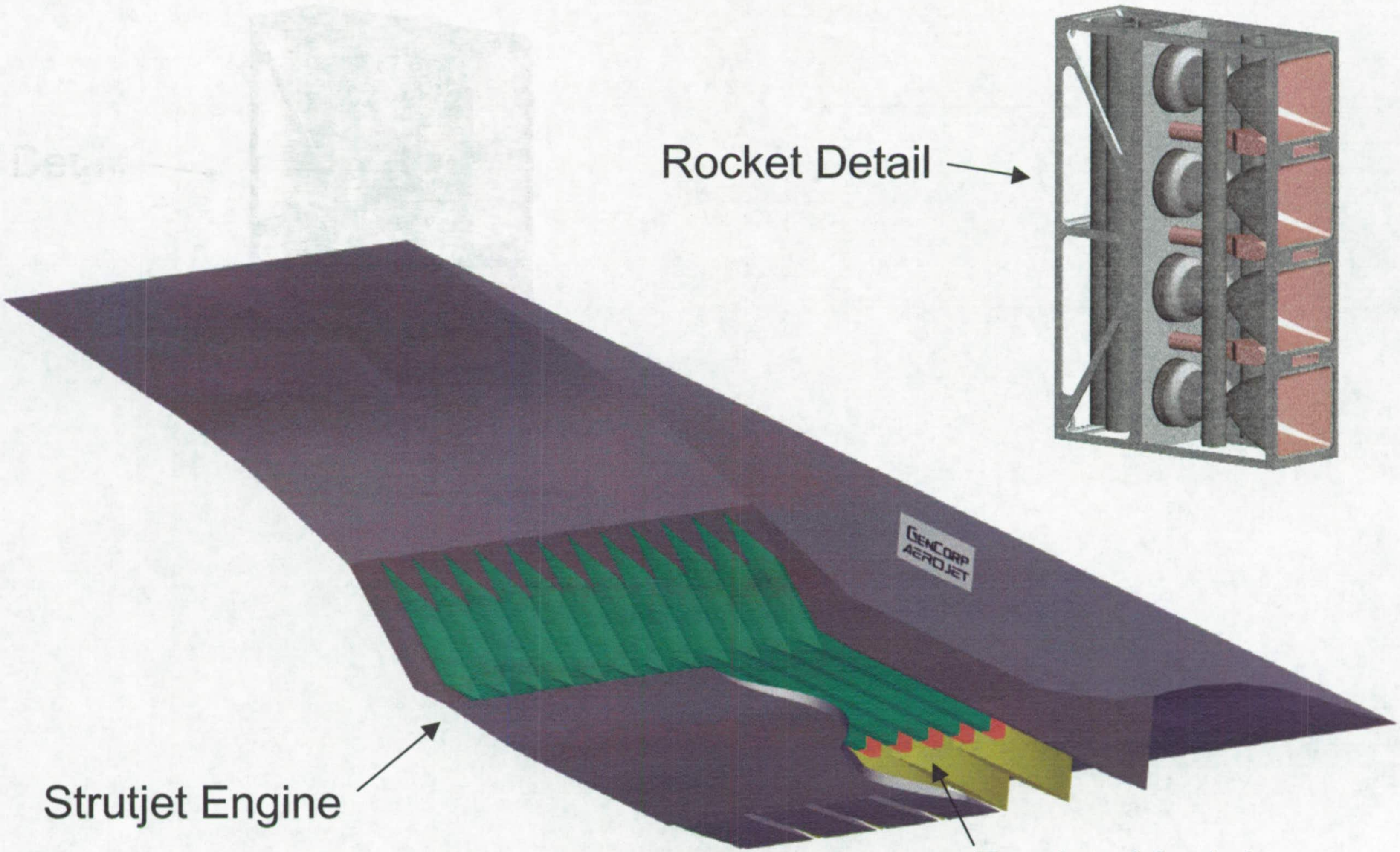
Design of a Novel Gaseous Hydrogen-Oxygen Rocket Injector Element

- PURPOSE: To Find a Viable Design for a Rocket Gas-Gas Injector that Mixes Fuel & Oxidizer Thoroughly and Quickly
- METHOD: Use CFD Analyses with Reacting Flow to Evaluate Design Options for Mixing, Temperature Distribution, and Combustion Efficiency
- RESULT: Found a Design that is an Improvement Over Designs Derived from Liquid Systems and is Far, Far Better than Traditional Shear-Coax

Application

- NASA Advanced Reusable Transport (ART) Program
- Aerojet Rocket-Based Combined Cycle (RBCC) Engine Uses Rockets Combined with Ram and Scram Cycles to Achieve Single-Stage to Orbit
- Many Small Hydrogen-Oxygen Thrusters in Base Area of Engine Struts Provide Initial Thrust to Mach 2+ and Acceleration from Mach 8-10 to Orbit

NASA/Aerojet RBCC Engine Concept

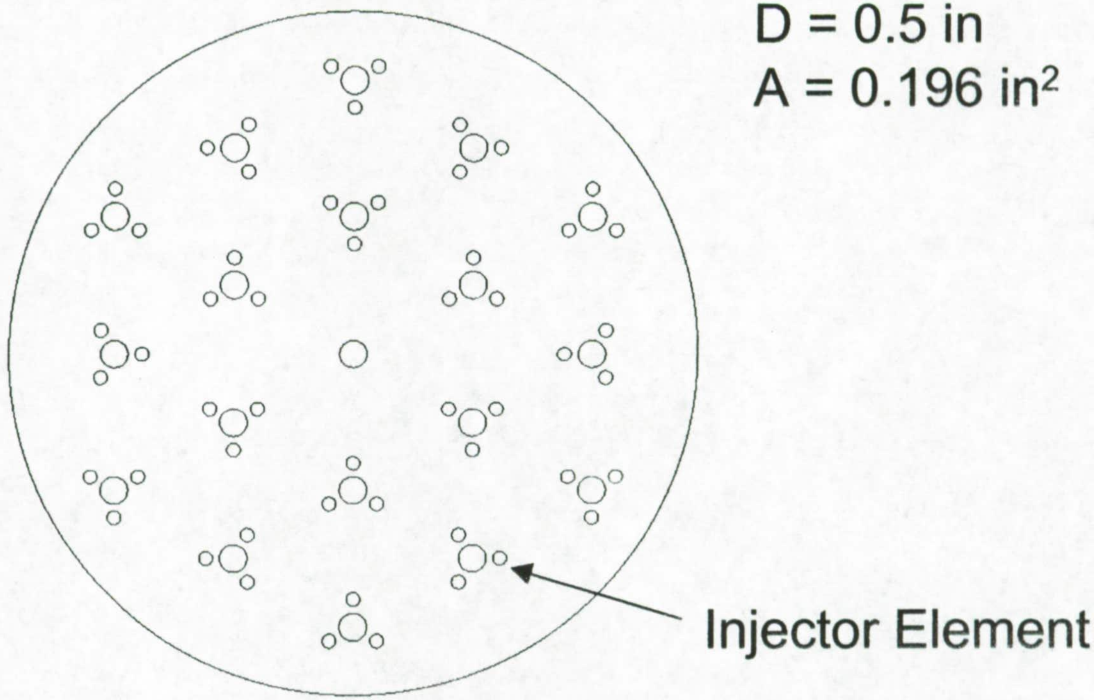


Requirements

- Full-Scale Rocket Provides ~4000 LBF Thrust with 90 Elements
- Sub-Scale Rocket Provides ~140 LBF Thrust with 18 Elements at 40% Scale
- Must Operate at Pc = 2000 PSIA, Mixture Ratio (Oxidizer / Fuel Mass Ratio) = 7
- Mixing and Combustion Should be Completed as Quickly as Possible
- Injector has to Survive Many Duty Cycles, Extended Operation

Typical Sub-Scale Injector Face

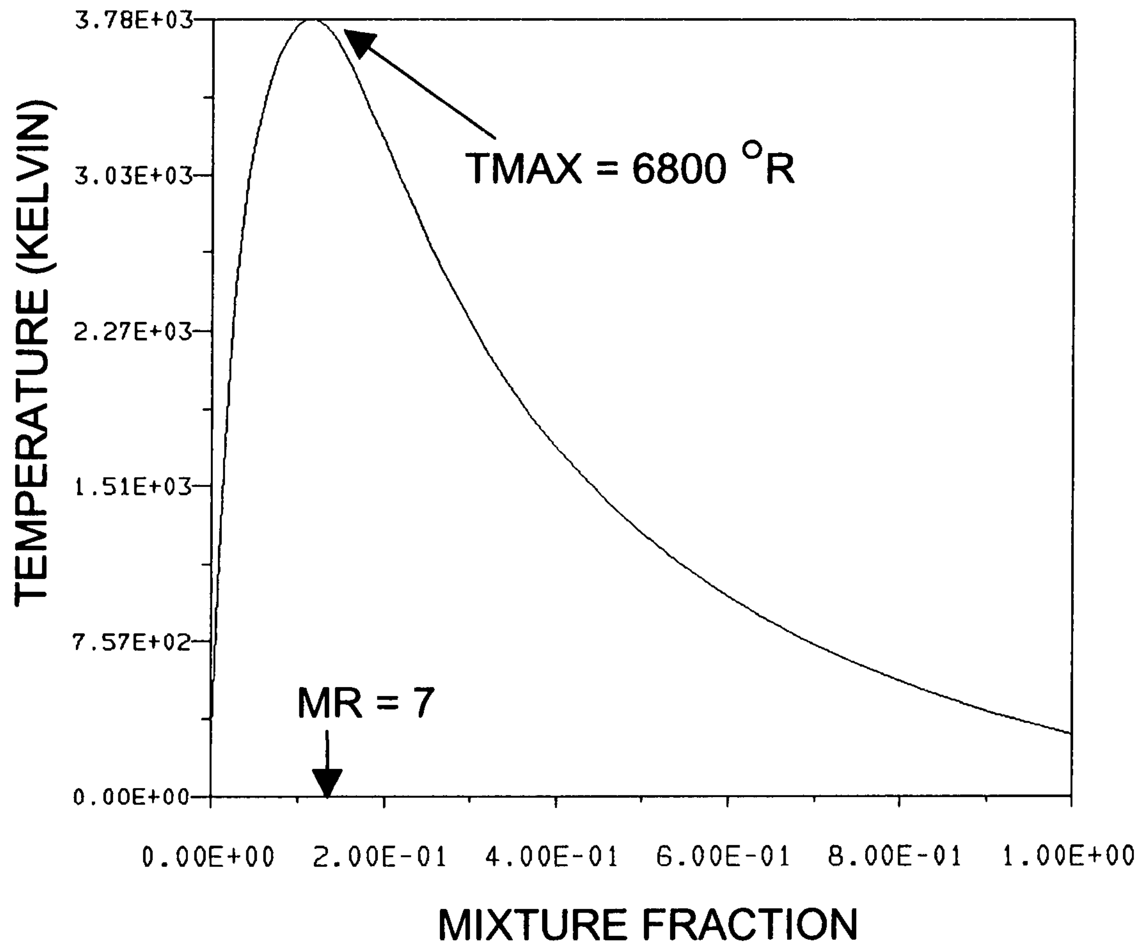
$D = 0.5$ in
$A = 0.196$ in^2



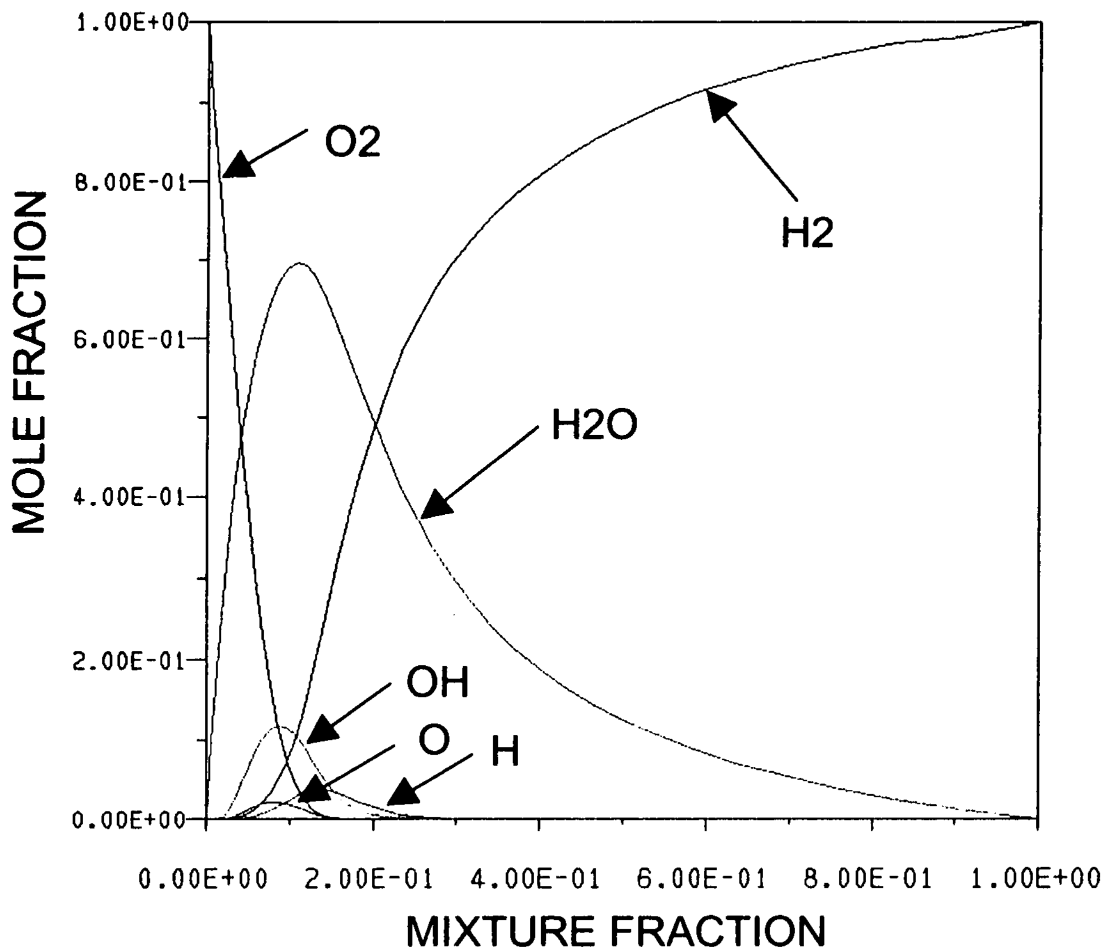
Major Features of Investigation

- 3D Simulations with Fluent/UNS 4.1 and 4.2
- Standard k-epsilon Turbulence Model (initially walls were not an important consideration)
- Chemistry Modeled Using PDF (Probability Density Function) Approach
- 8 Different Geometries with Gas-only Simulations
- 1 Model of Solid Injector Face with Propellant Manifolds and Conjugate Heat Transfer

PDF Temperatures vs. Mixture Fraction



PDF Species vs Mixture Fraction



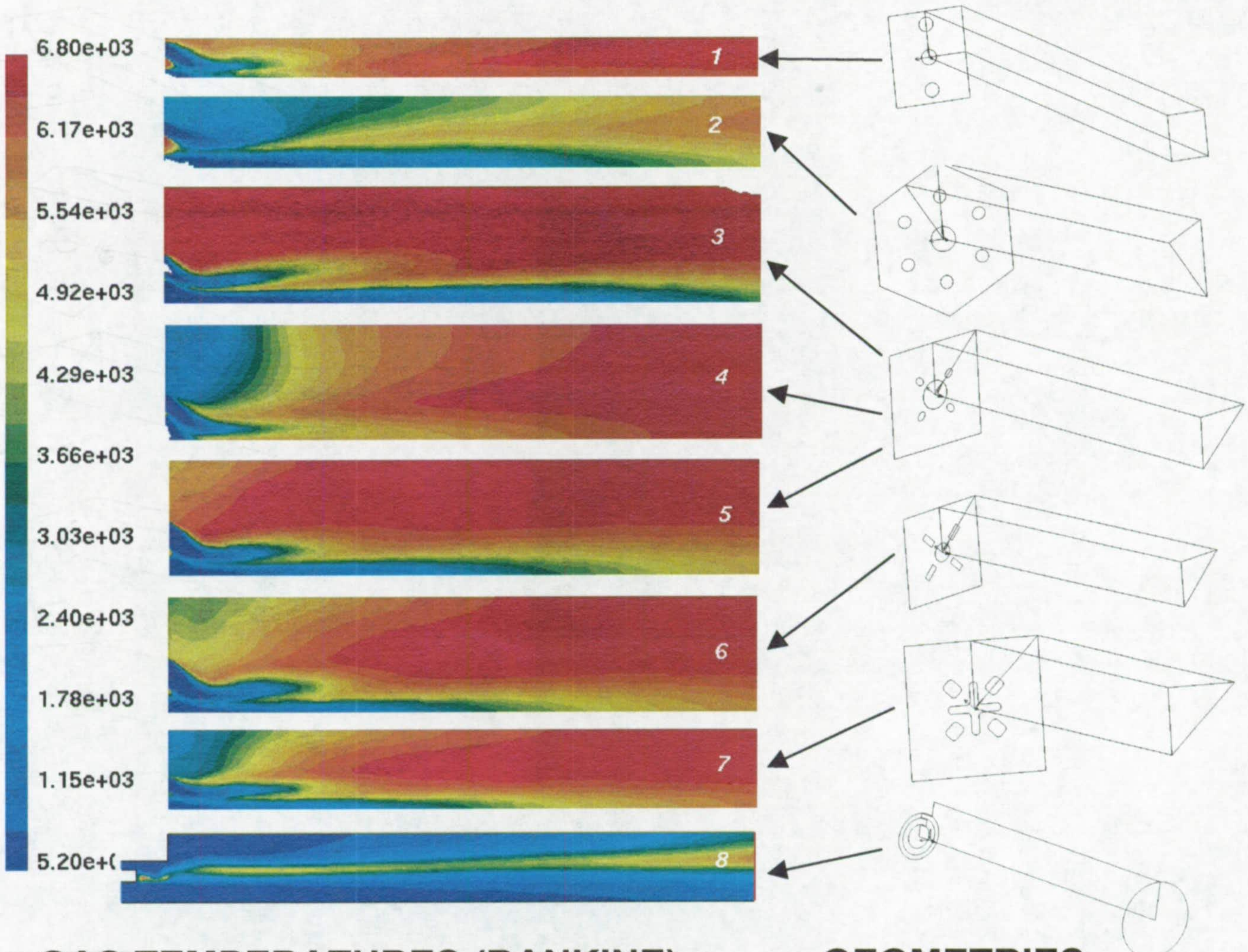
Gas-only Results

- Generally, Combustion is 95-98% Complete Within 1/2 Inch of Injector Face (Except for Coax Design)
- Coax Simulation was 2D, both Steady-State and Time-Dependent
- Combustion Results Similar for Steady-State and Time-Dependent Solutions
- Model #7 Selected for Further Analysis Based on Combustion Efficiency and Gas Temperatures Near Face

Description of Models

- MR = 7, 0.02 lbm/sec/injector O_2, .00287 lbm/sec/injector H_2
- Varied Injector Orifice Sizes, Impingement Angles, Geometries
- Generally, Modeled Small Part of One Injector Element as Allowed by Symmetry for Distance of 0.5 inch Downstream of Face
- Used Unstructured Tetrahedral Meshes with Pyramid Cells at Wall Boundaries to Resolve Boundary Layers

CFD Gas-only Models & Results

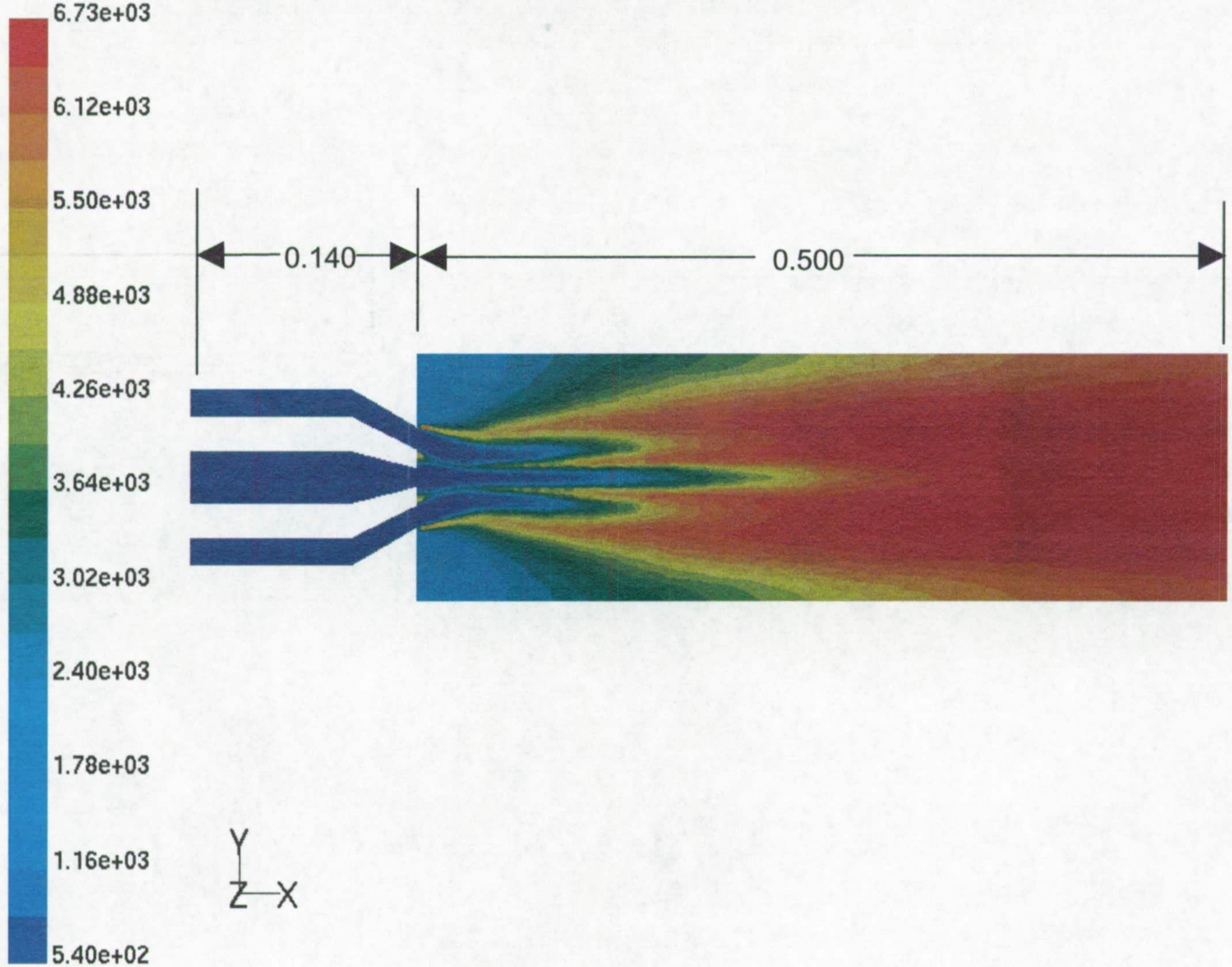


GAS TEMPERATURES (RANKINE) **GEOMETRIES**

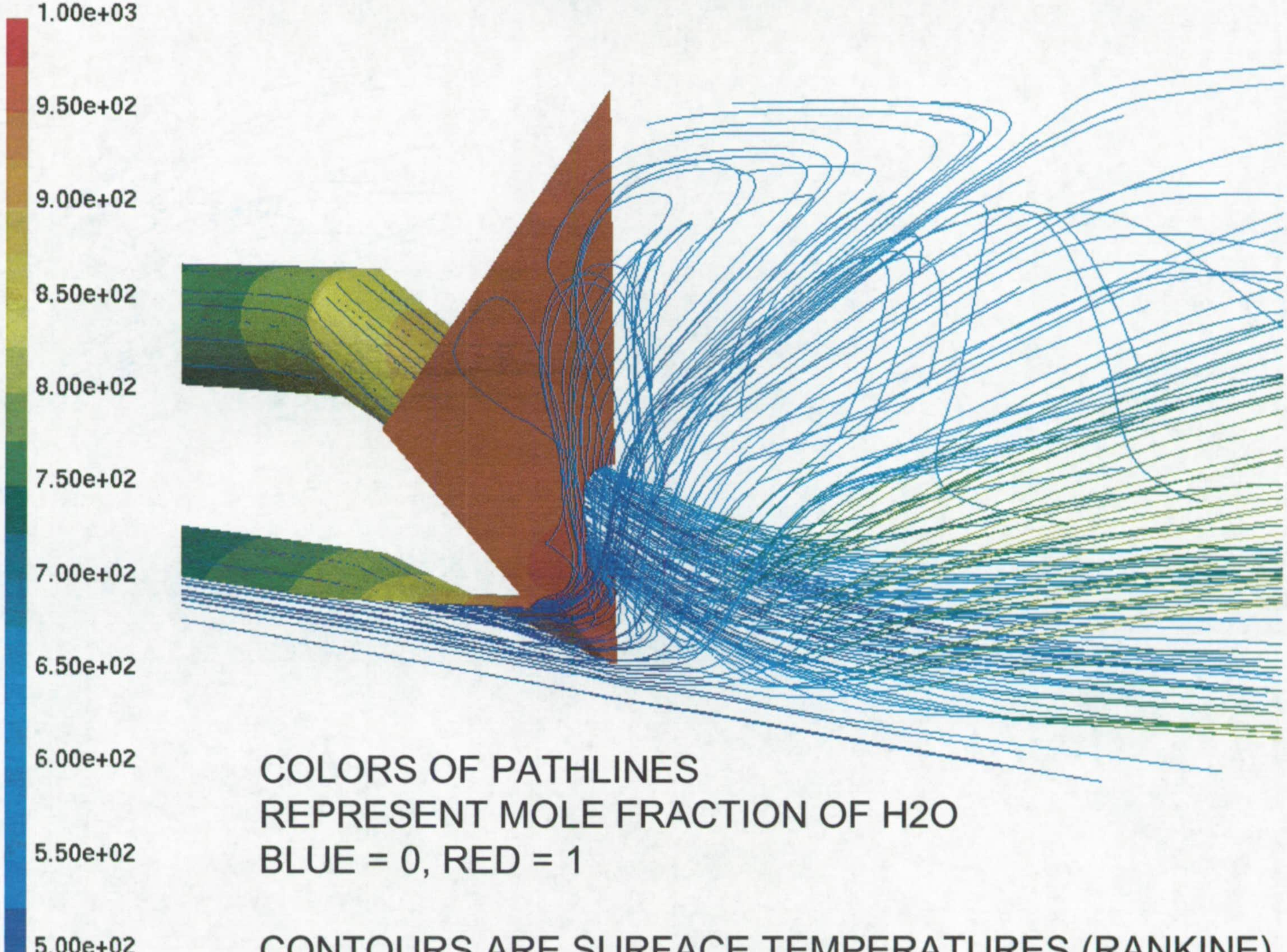
Needed to Predict Face Temperatures of Selected Design (#7, Pentad)

- Injector Face Fabricated Using Aerojet Platelet Technology from Zirconium-Copper Alloy
- Begins to Lose Mechanical Strength at 1300 °R
- Melts at 2436 °R (Liquidus Temperature)
- Solidifies at 2256 °R (Solidus Temperature)
- Density, Heat Capacity, and Conductivity Taken from Fluent/UNS Database for Pure Copper
- Customer Expressed Strong Misgivings About Survival of Injector Face - Predicted Face Temperatures of 1940 to 2140 °R

Pentad Gas Temperatures (°R)



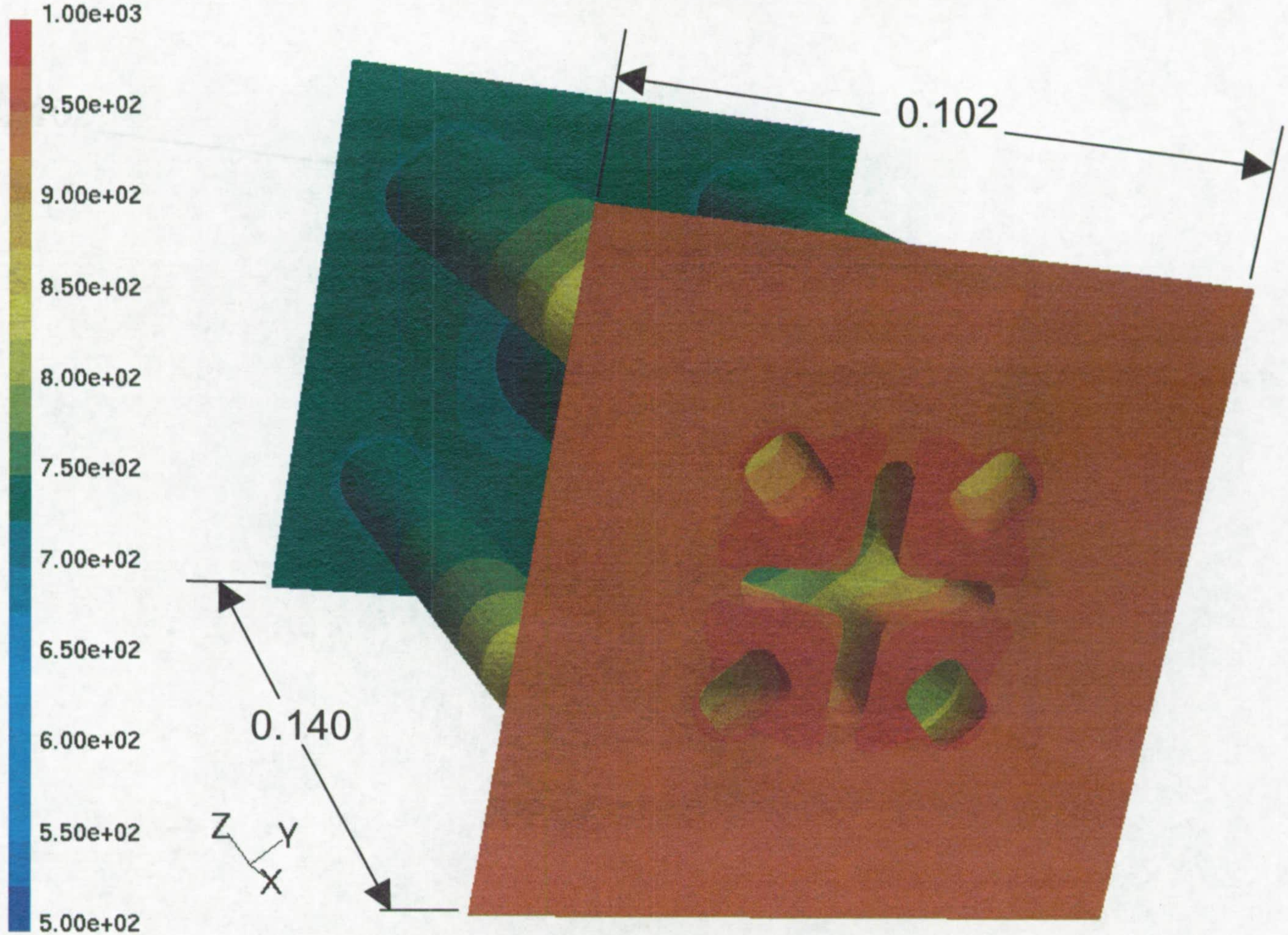
Pentad Propellant Pathlines



COLORS OF PATHLINES
REPRESENT MOLE FRACTION OF H2O
BLUE = 0, RED = 1

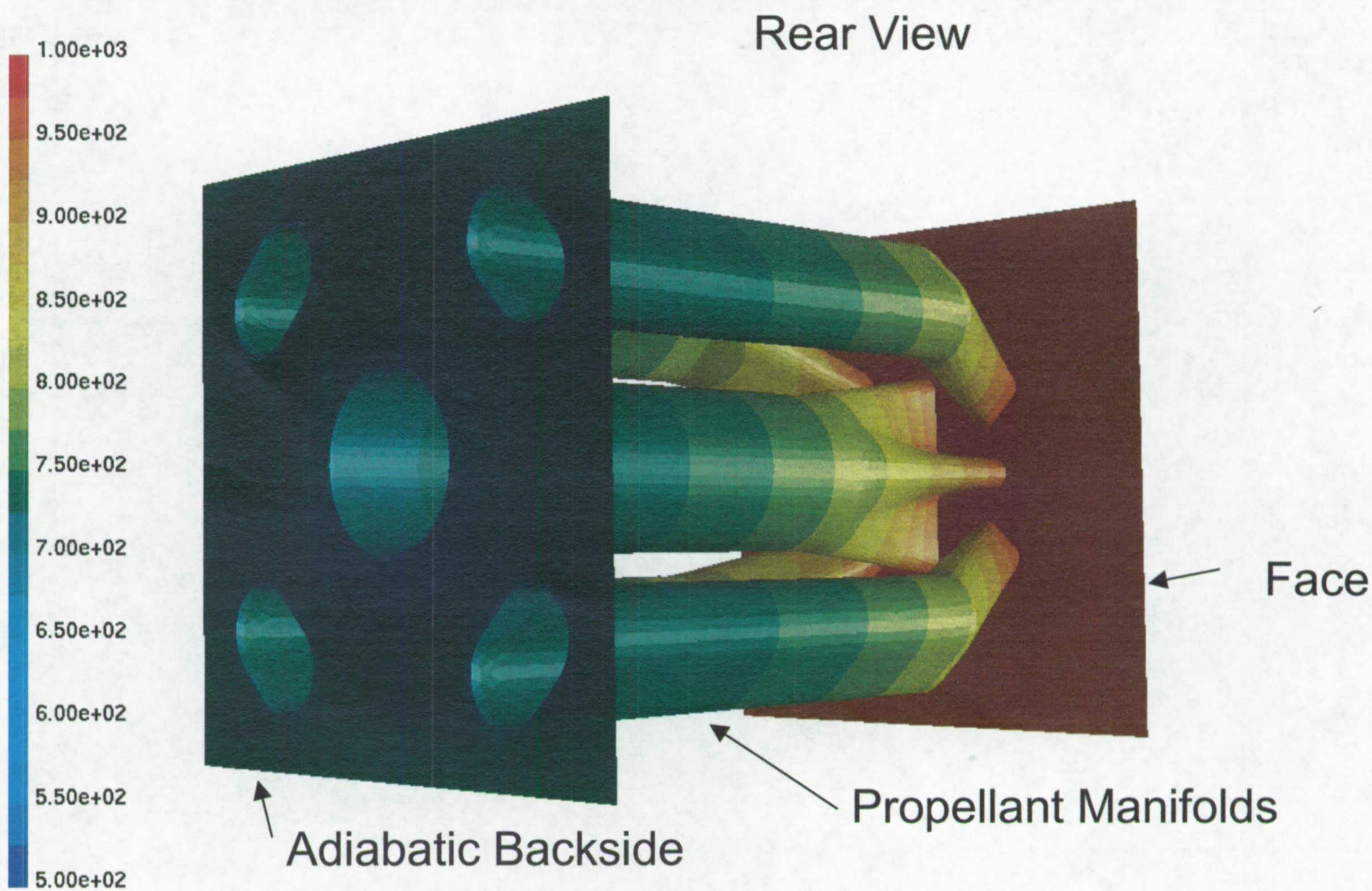
CONTOURS ARE SURFACE TEMPERATURES (RANKINE)

Pentad Solid Temperatures (°R)



Manifold Surface Temperatures (°R)

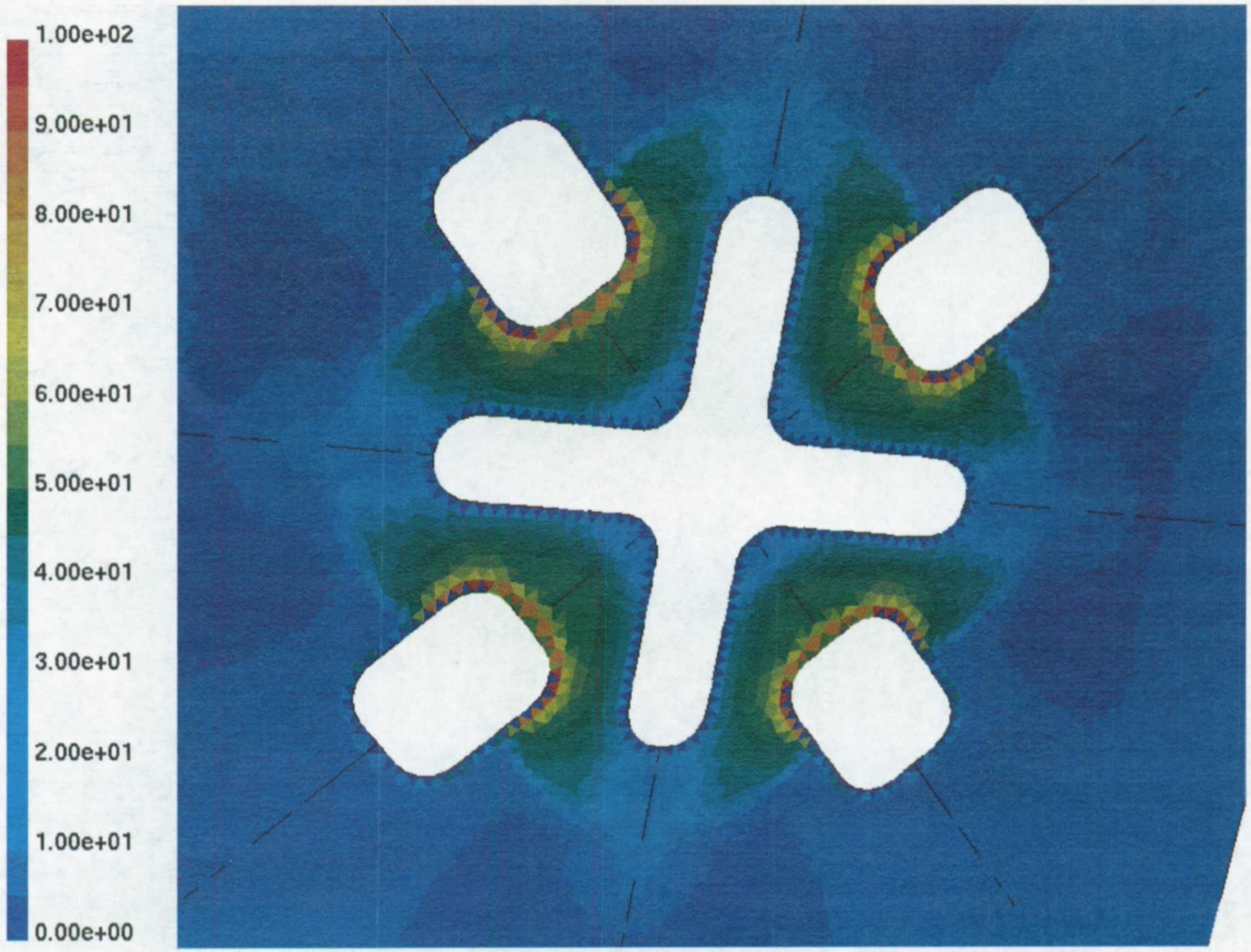
Pentad Surface Temperatures (°R)



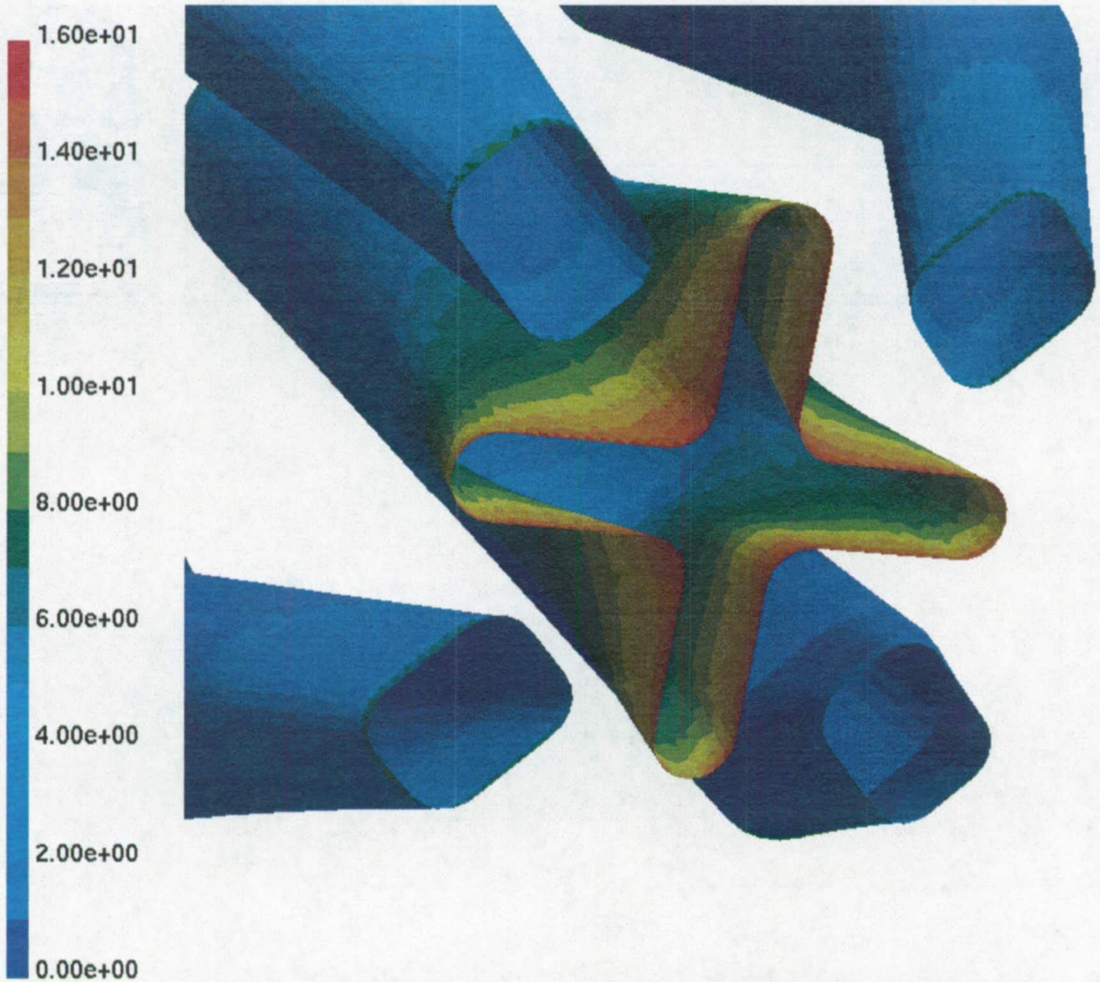
Fluent/UNS Predicts Survival

- 1 BTU/sec = 1055 Watts
- One Element Absorbs ~0.15 BTU/sec
- Peak Heat Flux into Face is ~90 BTU/sec-in^2, Average is ~15 BTU/sec-in^2
- Peak Heat Flux into Propellants is ~15 BTU/sec-in^2, Average is ~3 BTU/sec-in^2
- Predicted Face Temperatures of 900-950 °R

Pentad Heat Flux (BTU/sec-in2)



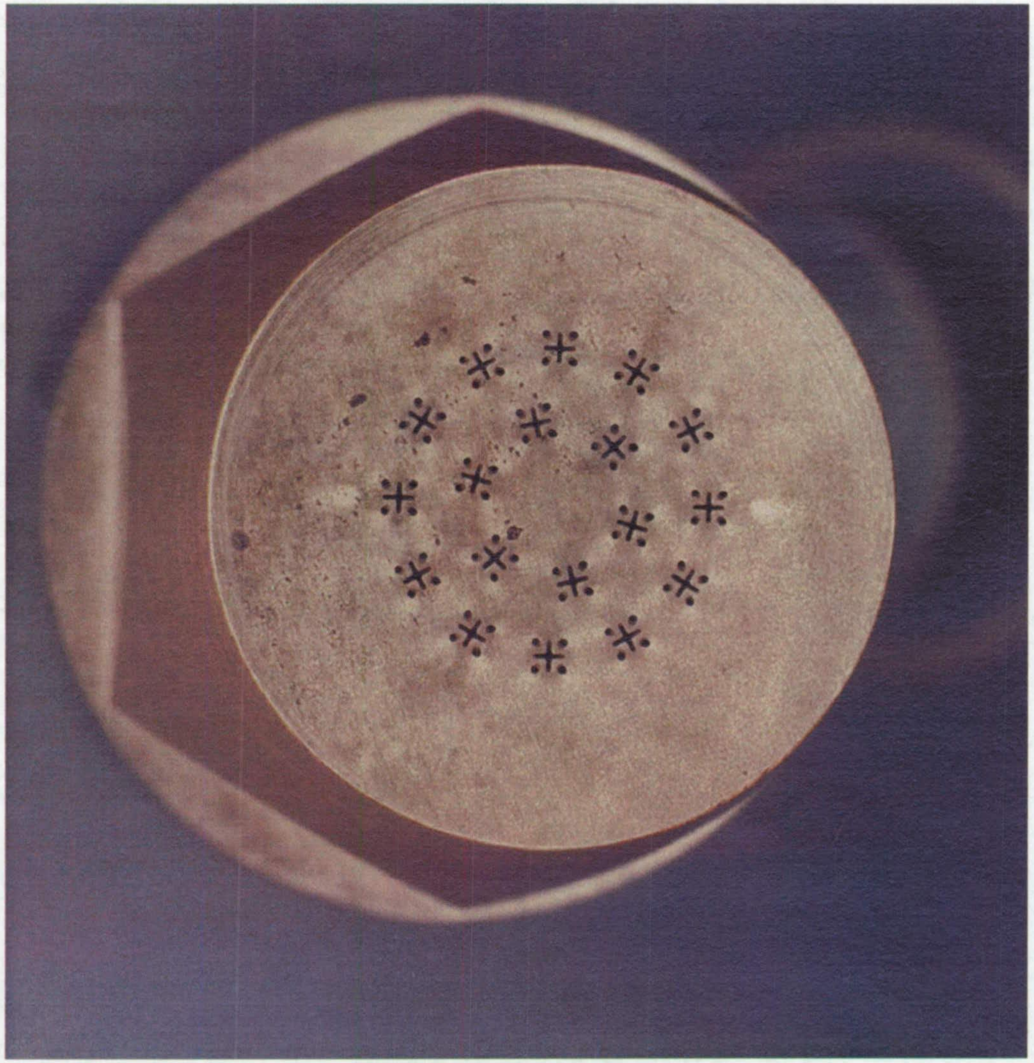
Heat Flux to Propellants (BTU/sec-in2)



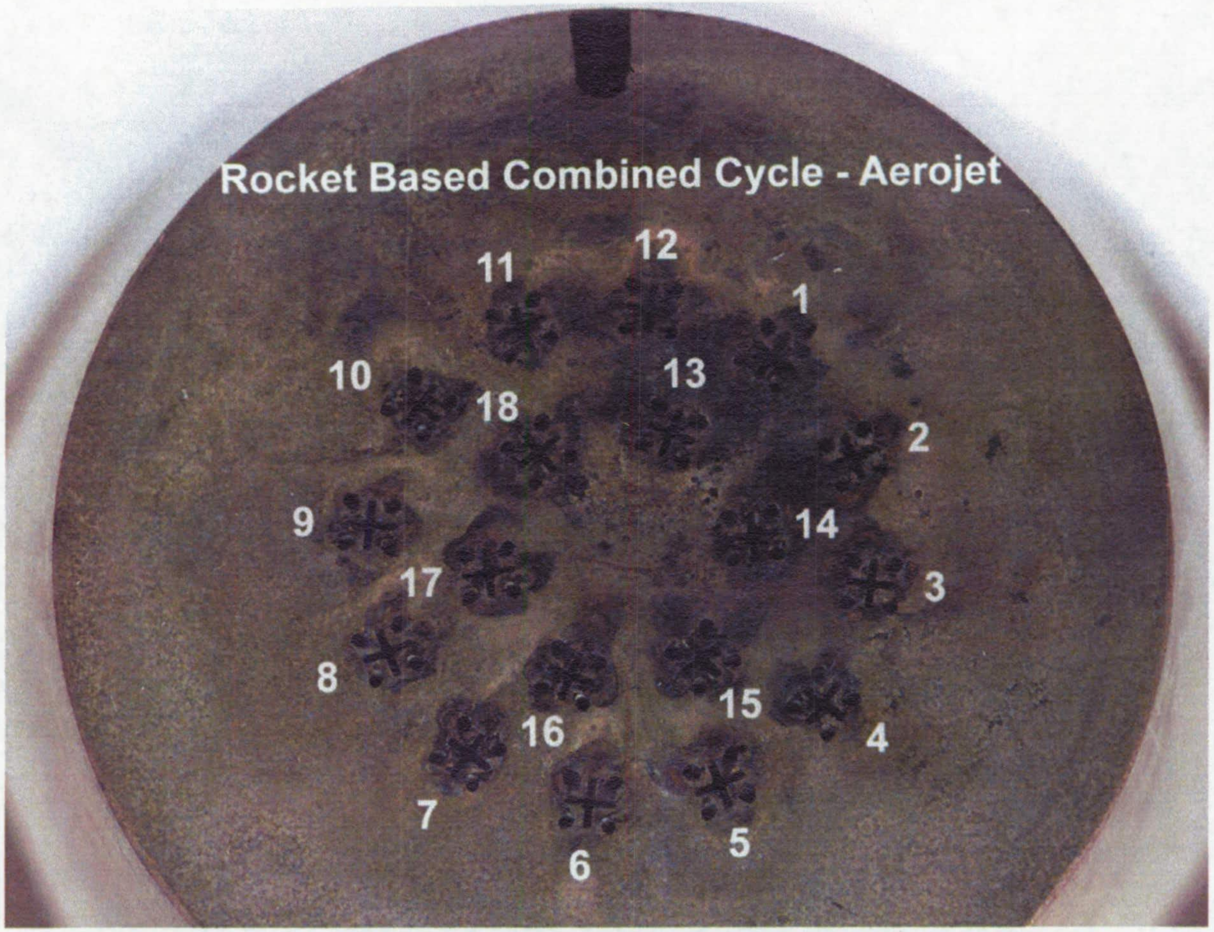
Testing Confirms Survival of Element

- Element Was Fabricated
- Tested at Aerojet for ~5 Seconds at Approximately 1500 PSIA
- Tested at NASA for ~60 Seconds at Varying Pressures and MR's
- Size of Element Made Detailed Measurements of Temperatures and Fluxes Impossible
- Deposits on Face Determined to be Stainless Steel (probably from O_2 supply)
- Edges Are Sharp, No Measurable Erosion

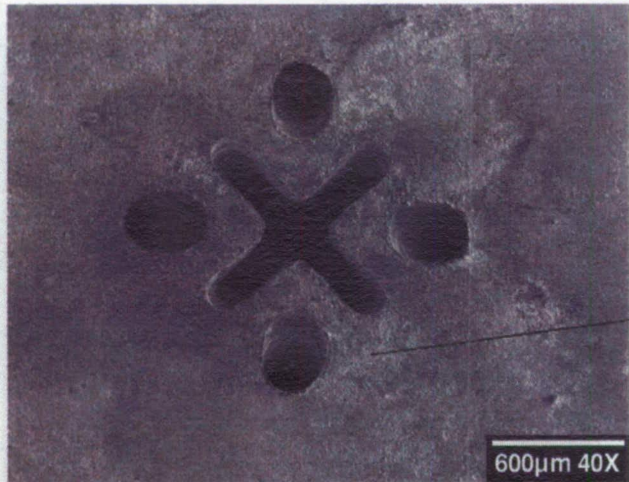
Pentad Uni-Element (pre-test)



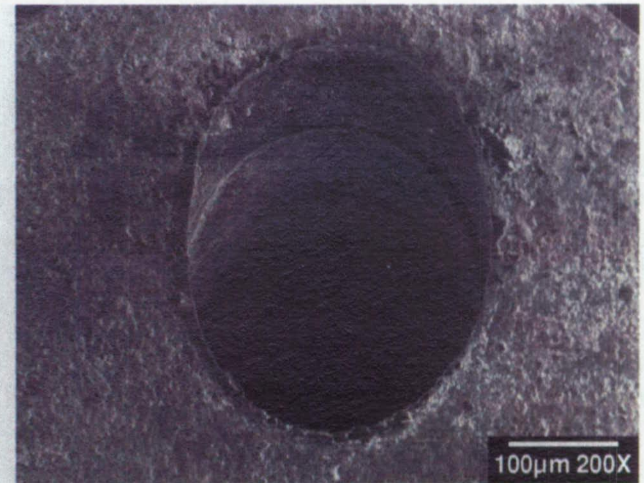
Pentad Uni-Element (post-test)



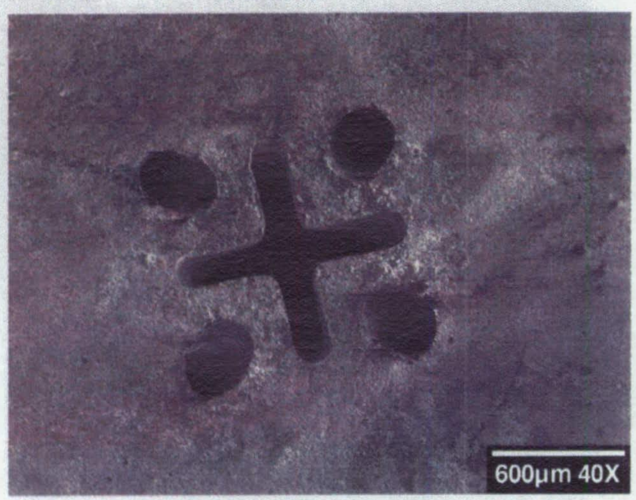
SEM Images of Pentad (post-test)



C2146 40 Position #1



C2147 200 Position #1



C2148 40 Position #2

C2149 40 Position #3

5/16/97

Conclusions

- CFD Analyses Were an Essential Part of the Design Process
- CFD Provided Database for Understanding Mixing and Combustion Phenomenology of H_2/O_2 System at High Pressure
- CFD with Conjugate Heat Transfer Predicted Survival of Injector Face
- Element Has Been Incorporated into Working Sub-Scale Thrusters and RBCC Engine
- Six Thrusters Have Accumulated About 800 Starts and 3900 Seconds of Operation Without Failure