Overview of CFD Analyses Supporting the Reusable Solid Rocket Motor (RSRM) Program at MSFC

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During the past year, various CFD analyses were performed at MSFC to support the RSRM program. The successful completion of these analyses was realized through the cooperation of ESI, ERC, and The Computational Fluid Dynamics Branch (ED32) at MSFC and involved application of the CFD codes FDNS and CELMINT. The topics addressed by the analyses were; 1. the design and prediction of slag accumulation within the five inch test motor, 2. prediction of slag pool behavior and its response to lateral accelerations, 3. the clogging of potential insulation debonds within the nozzle by slag accumulation, 4. the behavior of jets within small voids inside nozzle joint gaps, 5. the effect of increased inhibitor stiffness on motor acoustics, and 6. the effect of a nozzle defect on particle impingement enhanced erosion. Topics 1, 2, and 5 will be discussed in some detail by other speakers at the conference and are only mentioned here for the sake of completeness. Thus, the emphasis of this presentation will be to further discuss the work involved in topics 3, 4, and 6.

Eric Stewart

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Overview

- Overview of RSRM CFD analyses at MSFC
- Insulation Debond Analysis
- Potential RTV Flaw Analysis
- Nose Inlet Assembly Wetline Investigation
- Future efforts

Overview of RSRM CFD Analyses at MSFC

- **Slag (Al_2O_3) behavior and accumulation**
  - 5 inch spin motor design and analysis
  - Accumulation within RSRM at 67 seconds
  - Response of slag pool to lateral accelerations using VOF methodology

- **Increase in Nitrile Butadiene Rubber (NBR) stiffness**
  - Aerodynamic torque on nozzle
  - Potential effect on internal acoustics/pressure oscillations
    - Change in inhibitor deflections
    - Vortex shedding by the inhibitors

- **Code validation for the 8-percent ASRM cold flow model**

- **Insulation debond analysis**
- **Potential RTV flaw analysis**
- **Nose inlet assembly wetline Investigation**

RSRM CFD Analyses
at MSFC

Insulation Debond Analysis

Issues
- Prediction of flow/clogging through potential insulation defect flow paths during motor operation

Approach
- Use two-phase flow and condensation models to predict propensity for pore clogging during motor operation
    - prescribed thermal boundary conditions

Results
- Small (0.01″) pores probably clog quickly (.05 sec) under severe thermal gradients
- Lower probability of clogging during start pressurization transient

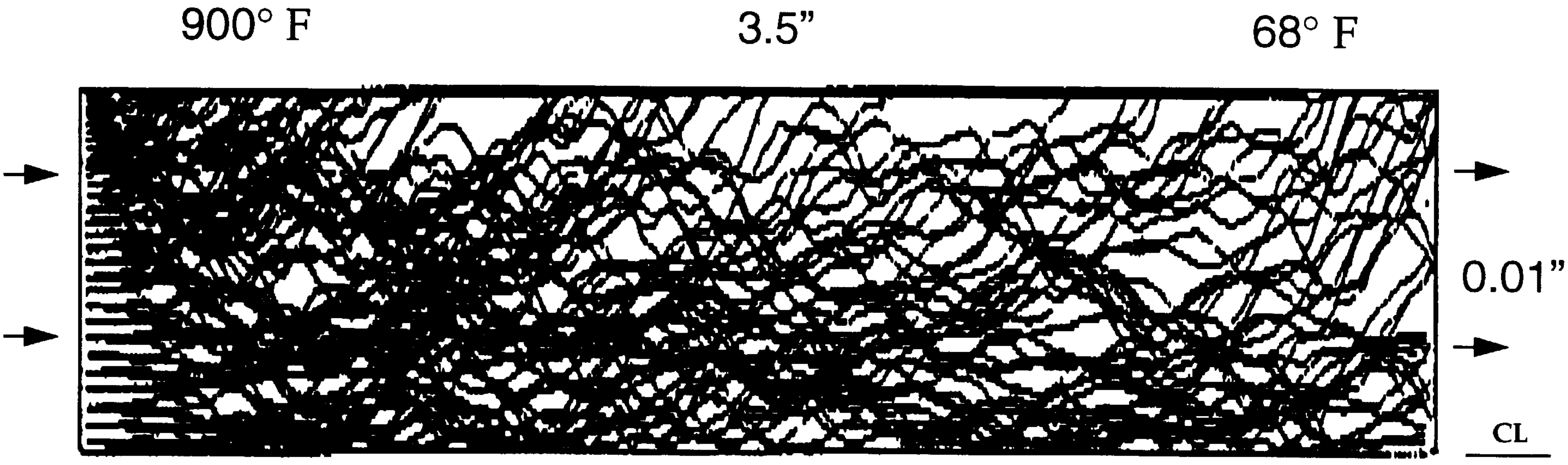
Impact
- Joint gap clogging prediction methodology is available to support potential anomalies

RSRM CFD Analyses at MSFC

- **Results (Problem 1, debond vent to ambient)**

gap width	time to clog
0.010″	0.05 sec.
0.005″	0.02 sec.
0.002″	0.006 sec.

- **Results (Problem 2, start-up transient through debond)**
  - clogging of debond predicted in 0.61 sec. after initiation of particle flow
  - lower mass flow rate (4X less) due to cavity fill results in fewer particles to condense on pore wall



Joint Gap Clogging Prediction

Potential RTV Flaw Analysis

Issues
- Hot gas jet impingement environments on O-rings within RSRM nozzle due to potential RTV flaws
- Predict jet spreading within irregularly shaped cavities

Approach
- Predict 3-D Jet Spreading for potential joint gap/cavity flows for input into thermal models

Results
- Hot gas jet spreading within joint cavities is smaller than that used in previous non-CFD analyses

Impact
- Jet spread width used in thermal models should be 0.7″ (rather than 1.25″)
- Jet spreading predictions are available to support potential anomalies

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RSRM CFD Analyses at MSFC

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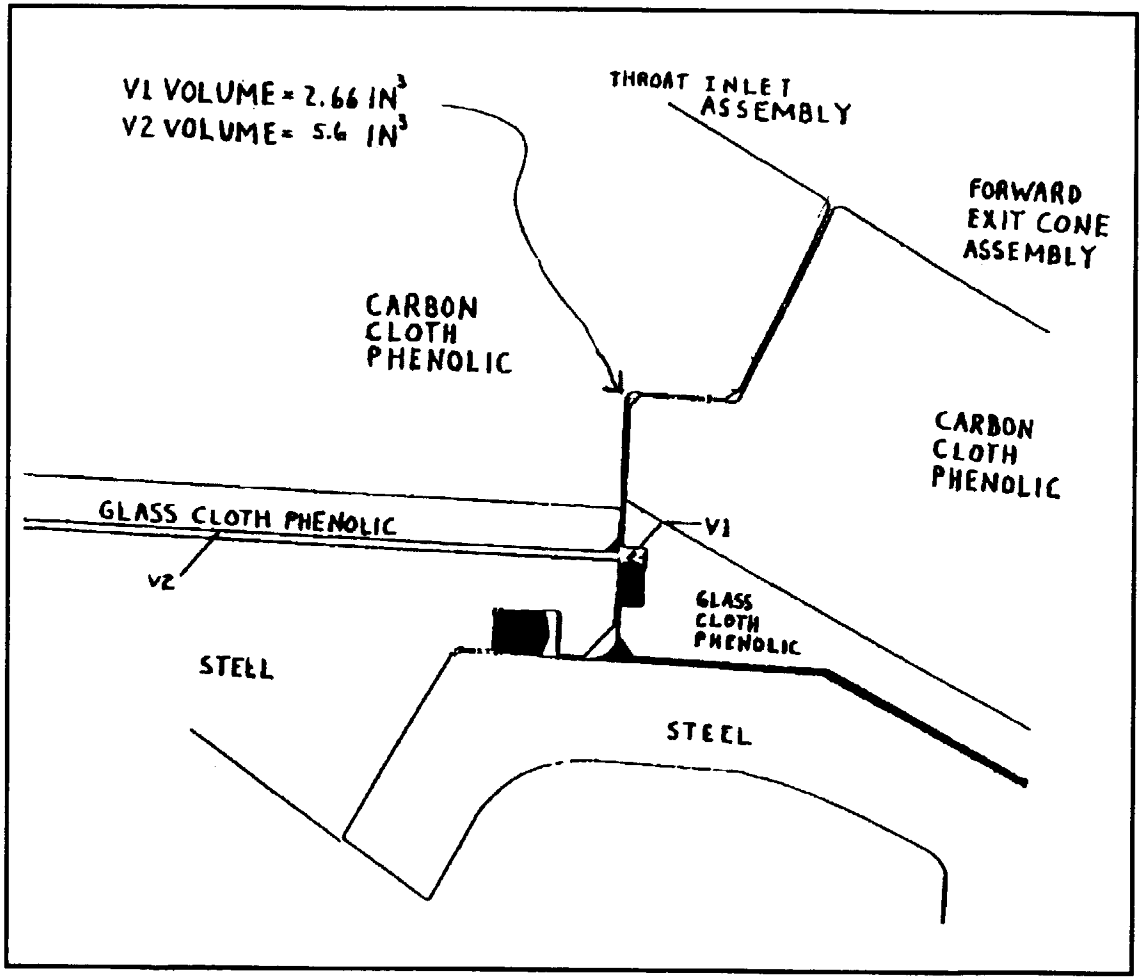
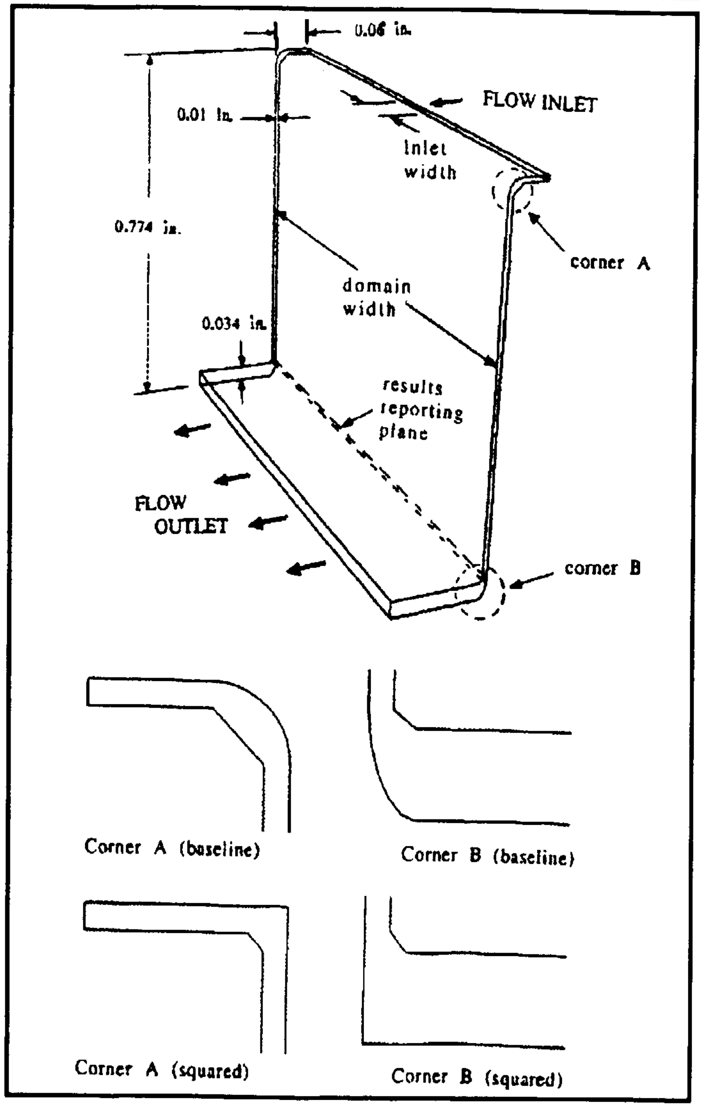


Geometry of Internal Nozzle, Joint #4



Computational Geometry

RSRM CFD Analyses at MSFC

- **Analysis matrix and results**

case	flowrate (lbm/s)	domain width (in)	corners	inlet width (in)	jet spread width (in)
1	0.0001	8.0	rounded	0.1	1.5
2	0.0002	8.0	rounded	0.1	1.1
3	0.0005	8.0	rounded	0.1	0.6
4	0.001	8.0	rounded	0.1	0.5
5	0.00155	8.0	rounded	0.1	0.5
6	0.00155	16.0	rounded	0.1	0.5
7	0.00155	8.0	square	0.1	0.75
8	0.00155	8.0	rounded	0.2	0.75

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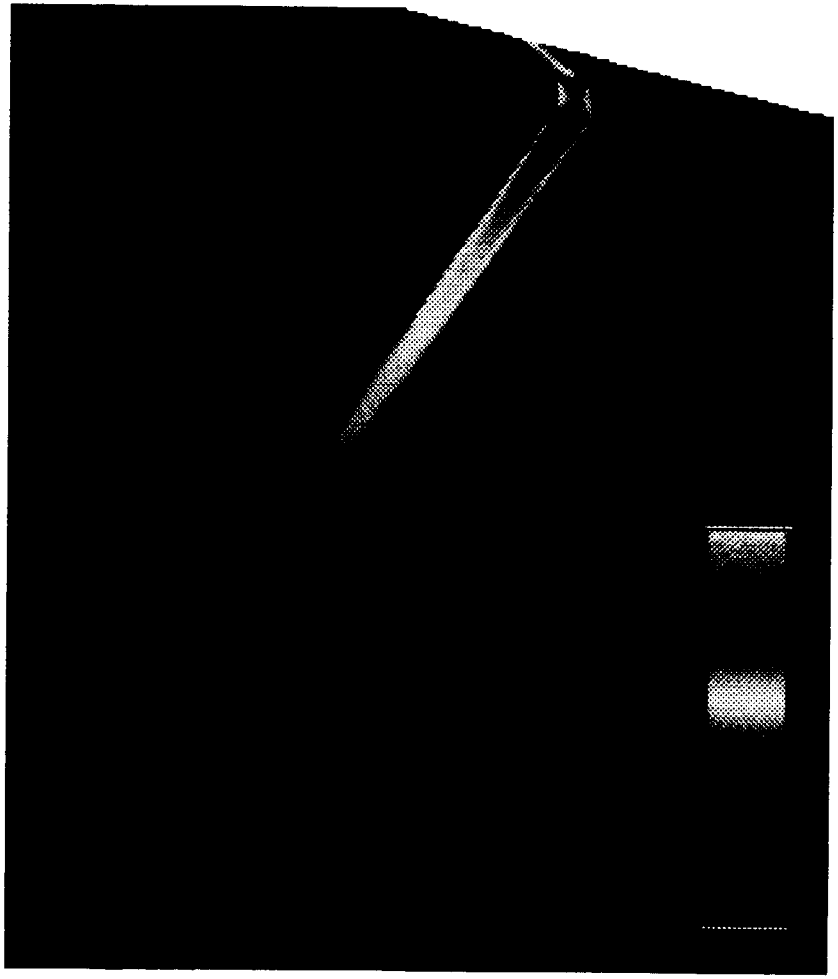
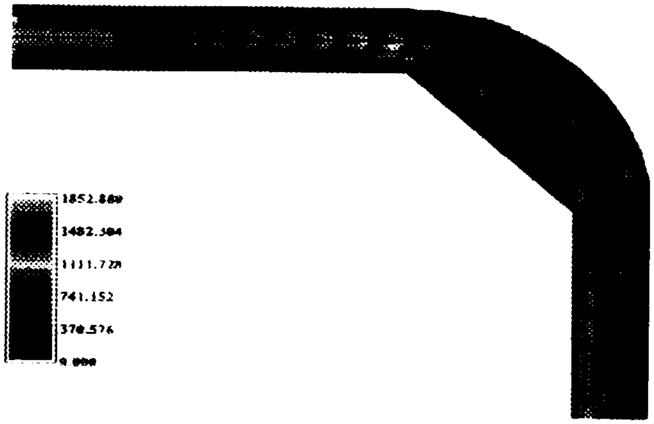
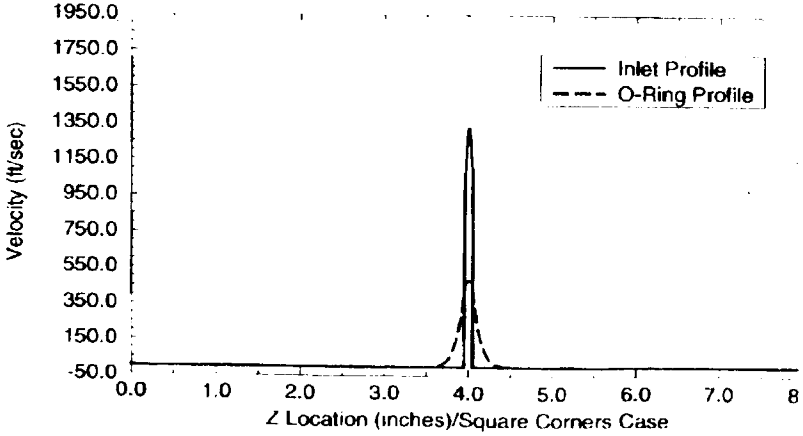


Velocity Magnitudes



Center Line Velocity Profile Through Corner A



Average Velocity Magnitudes

RSRM CFD Analyses at MSFC

Nose Inlet Assembly Wetline Investigation

Issues

- Enhancement of nozzle erosion due to presence of defect
- Effect of defect on slag particle impingement

Approach

- Assume wedge shaped nozzle defect
- Use two-phase flow results to assess flow environment near defect
- Use current data/experience base to assess potential flow deviations

Results

- Size of defect relative to local boundary layer is not sufficient to significantly alter flow external to boundary layer
- Main source of particle impingement is external to boundary layer
- Erosion enhancement due to particle impingement is not significantly altered by presence of defect

Impact

- Recommend nozzle in question for flight

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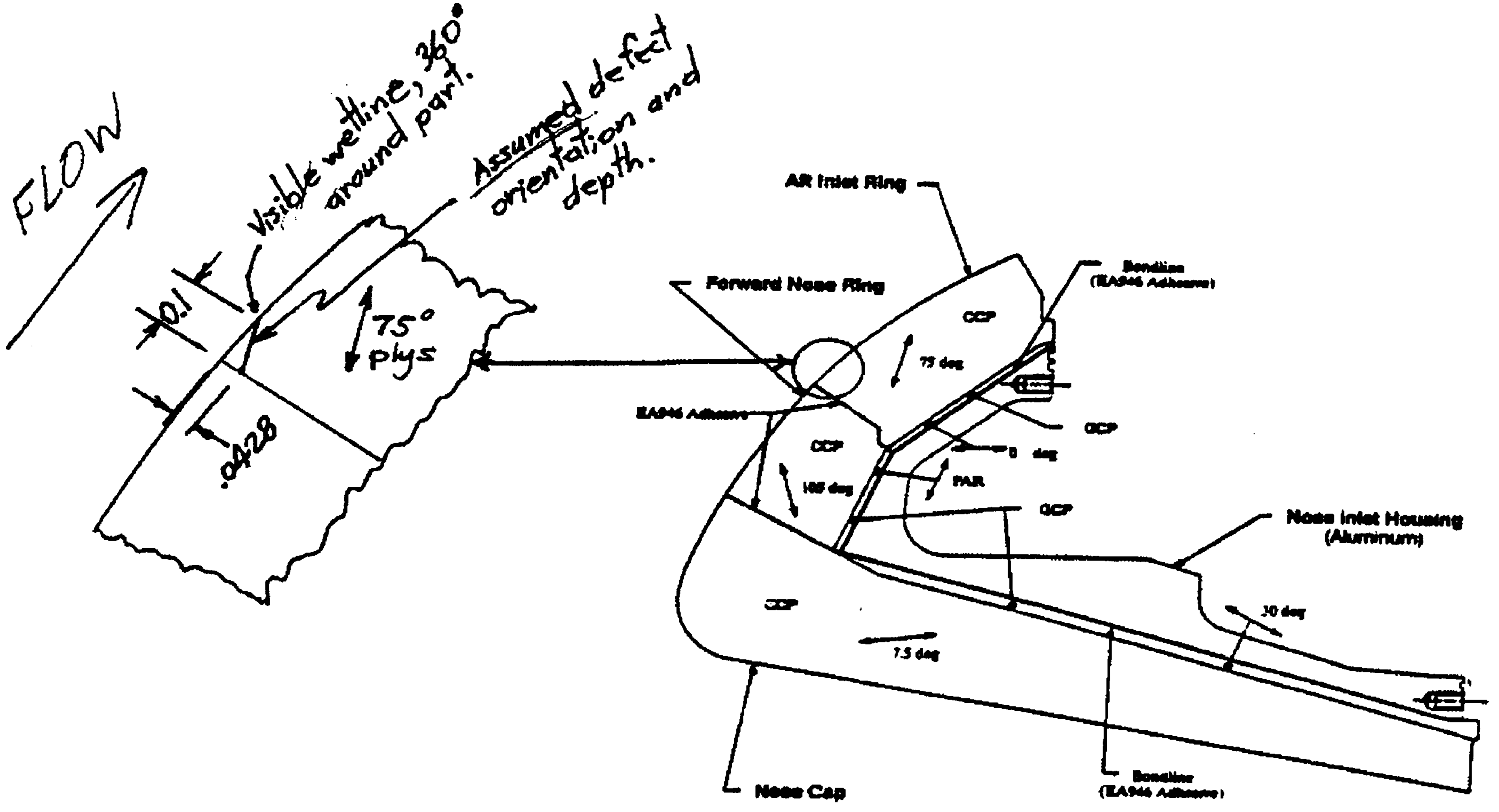

Geometry of Nozzle Nose Region

RSRM CFD Analyses
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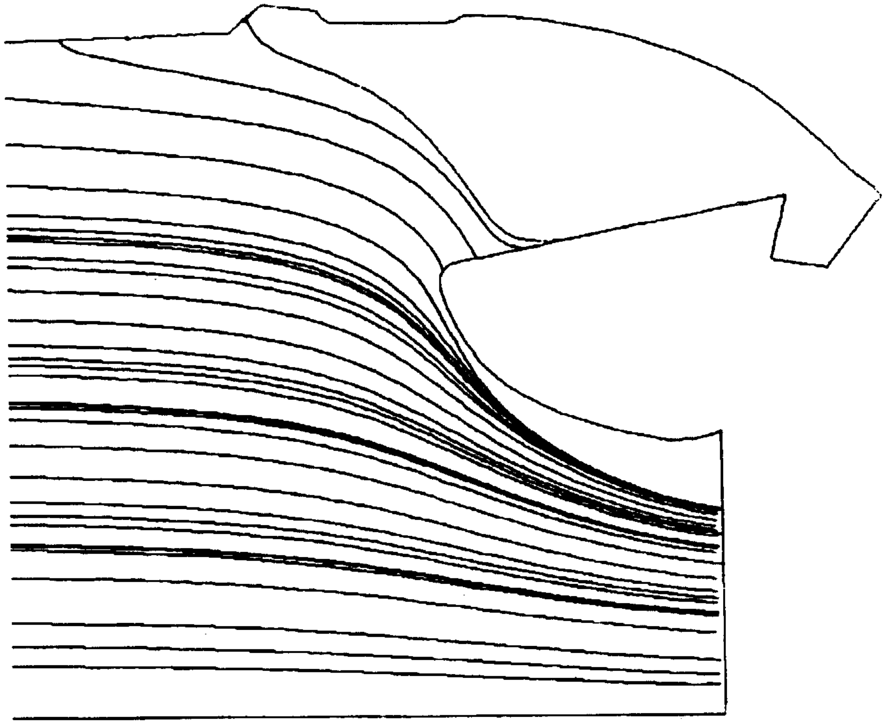
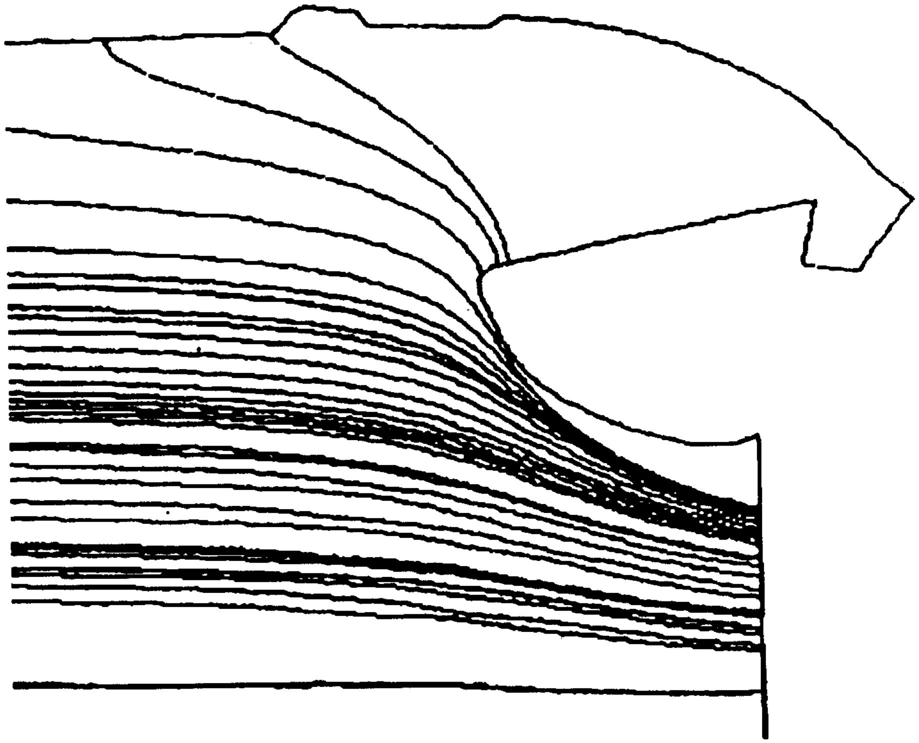
RSRM 67 Sec. Burn Time, 150 Micron Particle Trajectories



ED32 Results



ERC Results

RSRM CFD Analyses
at MSFC

Future Effort

- Continue code validation

- Continue to enhance modeling capabilities
  - two-phase flow
  - combustion
  - turbulence
  - slag accumulation
  - unsteady flow

- Improve readiness to address potential anomalies
  - Perform similar analyses at additional burn times