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Computational Fluid Dynamic (CFD) Analysis of Axisymmetric Plume and Base Flow of a Film/Dump Cooled Rocket Nozzle

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Film/dump cooling a rocket nozzle with fuel rich gas, as in the National Launch System (NLS) Space Transportation Main Engine (STME), adds potential complexities for integrating the engine with the vehicle. The chief concern is that once the film coolant is exhausted from the nozzle, conditions may exist during flight for the fuel-rich film gases to be recirculated to the vehicle base region. The result could be significantly higher base temperatures than would be expected from a regeneratively cooled nozzle.

CFD analyses were conduced to augment classical scaling techniques for vehicle base environments. The FDNS code with finite rate chemistry was used to simulate a single, axisymmetric STME plume and the NLS base area. Parallel calculations were made of the Saturn V S-1C/F1 plume base area flows. The objective was to characterize the plume/freestream shear layer for both vehicles as inputs for scaling the S-C/F1 flight data to NLS/STME conditions. The code was validated on high speed flows with relevant physics. This paper contains the calculations for the NLS/STME plume for the baseline nozzle and a modified nozzle. The modified nozzle was intended to reduce the fuel available for recirculation to the vehicle base region. Plumes for both nozzles were calculated at 10kFT and 50kFT.

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CFD ANALYSIS OF AXISYMMETRIC PLUME & BASE OF A FILM/DUMP COOLED NOZZLE

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NLS/STME Plume and Base Region Results

OVERVIEW

- Objective
- Approach
- Results
  - 10kft/50kft Comparison
  - 50kft Baseline/Modified Comparison
- Status

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NLS/STME Plume and Base Region Results

OBJECTIVES

- **Generate NLS/STME plume/base flows as a function of altitude**
- **Results**
  - -- Comparison of shear layer gradients
    - As a function of altitude
    - As a function of distance donwstream of nozzle
  - -- Comparison of alternate dump schemes
  - -- Comparison to S-1C for scaling Saturn flight data
- **Develop significant in-house capability for**
  - -- Reacting nozzle flows
  - -- Reacting plumes
  - -- Complex base flows

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NLS/STME Plume and Base Region Results

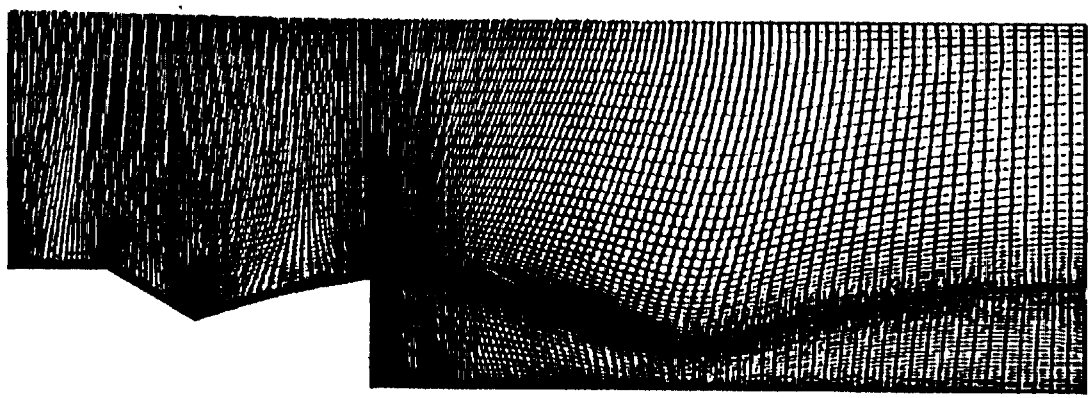
APPROACH

- **Geometry**
  - -- NLS 1.5 Stage Base
  - -- 2-D/axisymmetric model of outer STME
  - -- Nozzle calculations done separately
- **Conditions**
  - -- Baseline nozzle/plume
  - -- Modified nozzle/plume
    - No dump at exit
    - Dump moved to primary injector
- **Altitudes**
  - -- 10kft
  - -- 50kft
- **Freestream**
  - -- Quiescent
  - -- Velocity at trajectory point
- **Chemistry**
  - -- Frozen
  - -- Finite rate (7 species, 9 reactions)

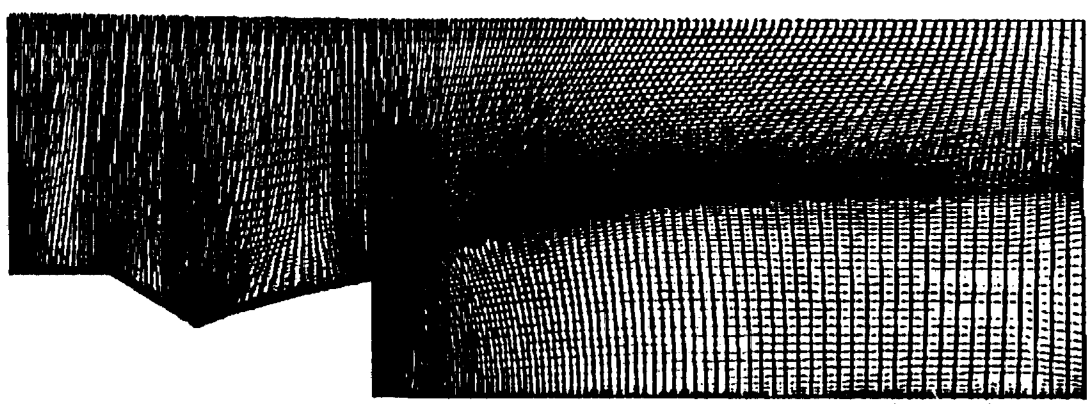
NLS/STME Plume and Base Region Results

RESULTS

10kft Grid

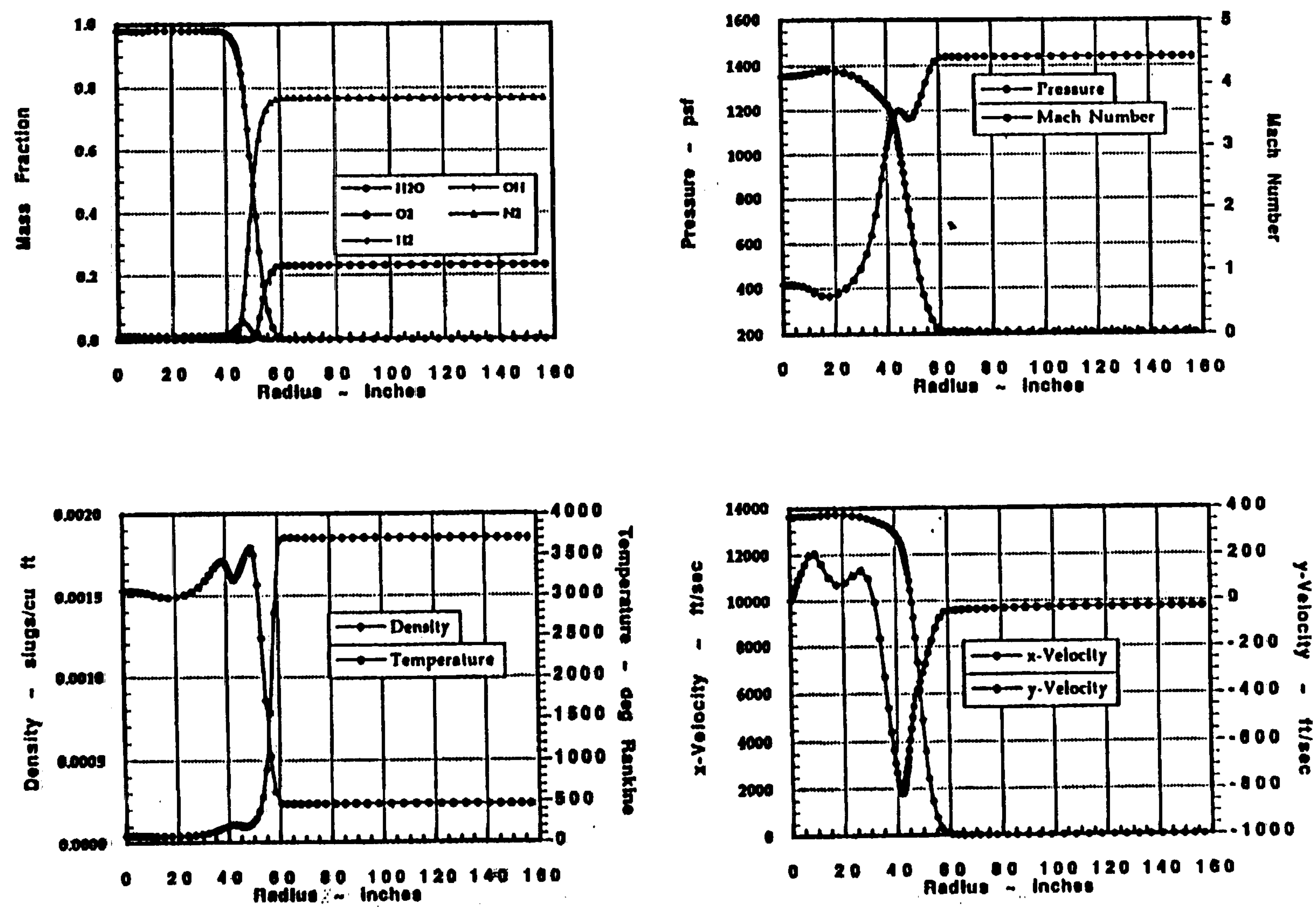


50kft Grid



RESULTS

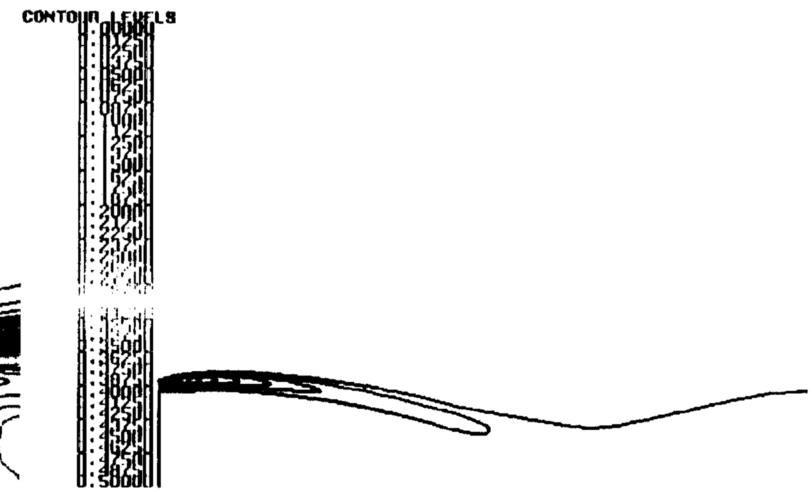
10kft Baseline Reacting Flow - Quiescent Freestream (x/R = 1)



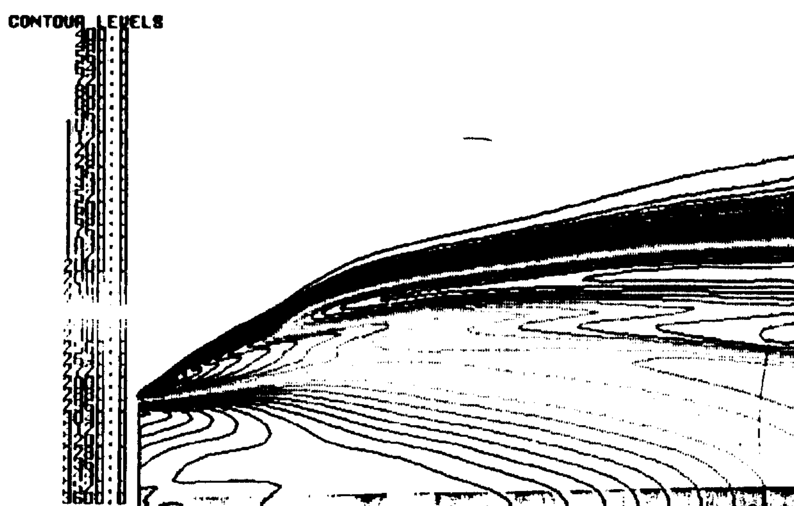
NLS/STME Plume and Base Region Results

Temperature (deg R)
NLS Baseline - 10kft
Reacting Flow (Quiescent)

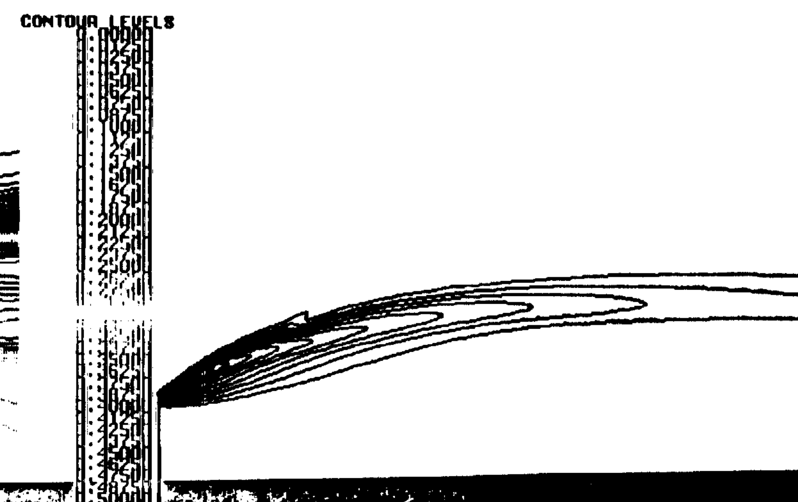
H2 Mass Fraction
NLS Baseline - 10kft
Reacting Flow (Quiescent)



Temperature (deg R)
NLS Baseline - 50kft
Reacting Flow (Quiescent)



H2 Mass Fraction
NLS Baseline - 50kft
Reacting Flow (Quiescent)



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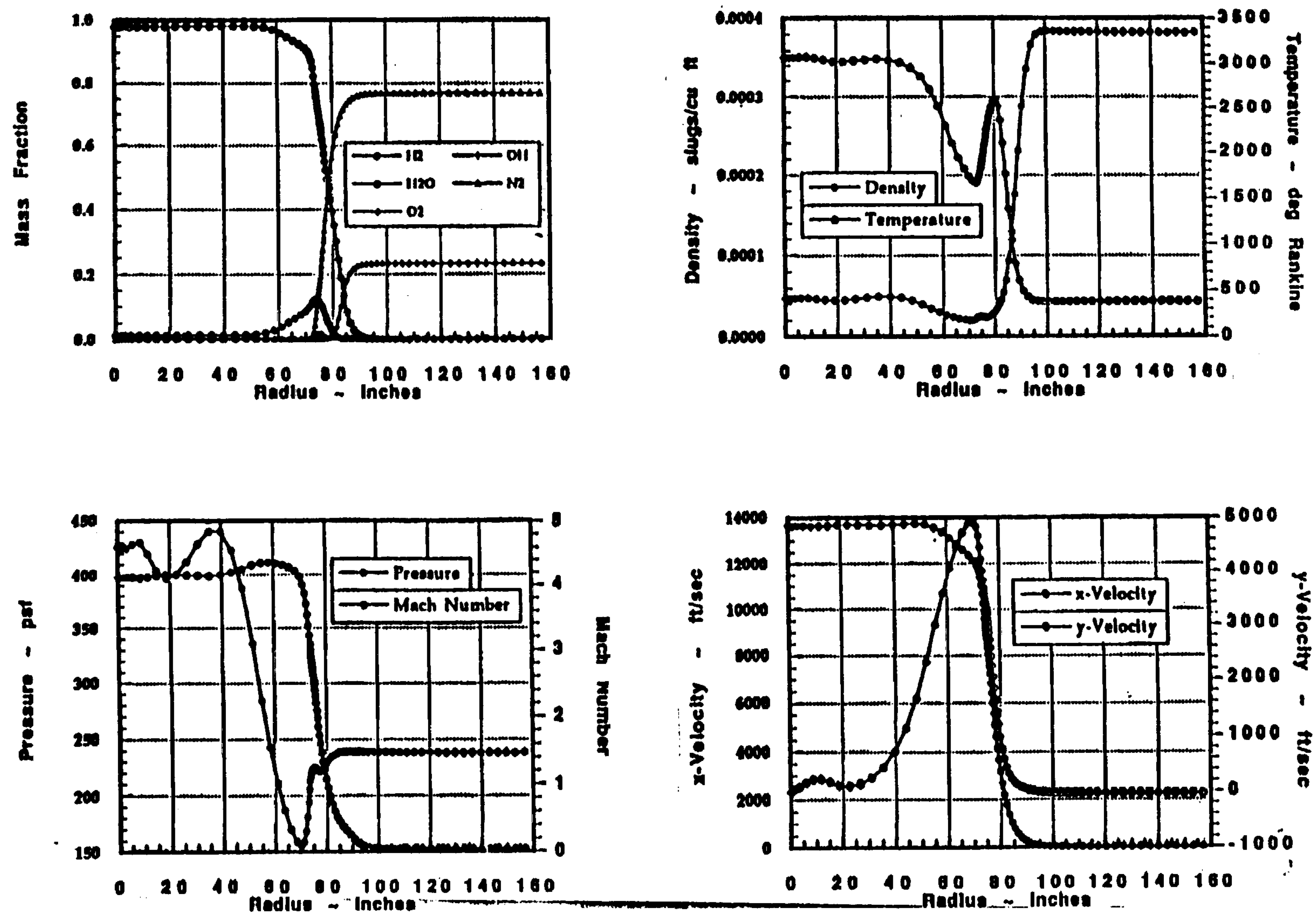
NLS/STME Plume and Base Region Results

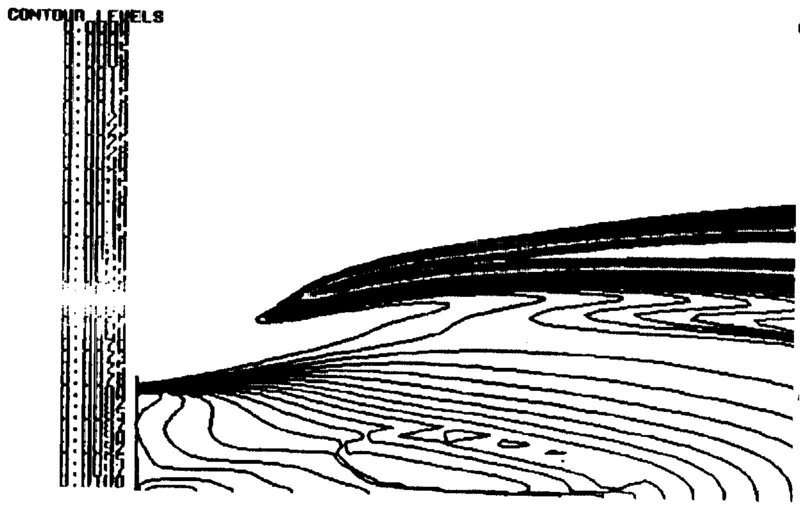
RESULTS

50kft Modified Reacting Flow - Quiescent Freestream (x/R = 1)

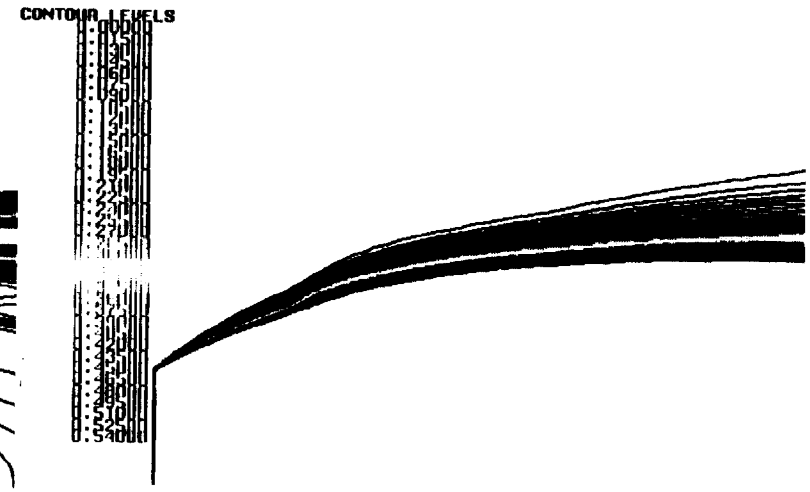


NLS/STME Plume and Base Region Results

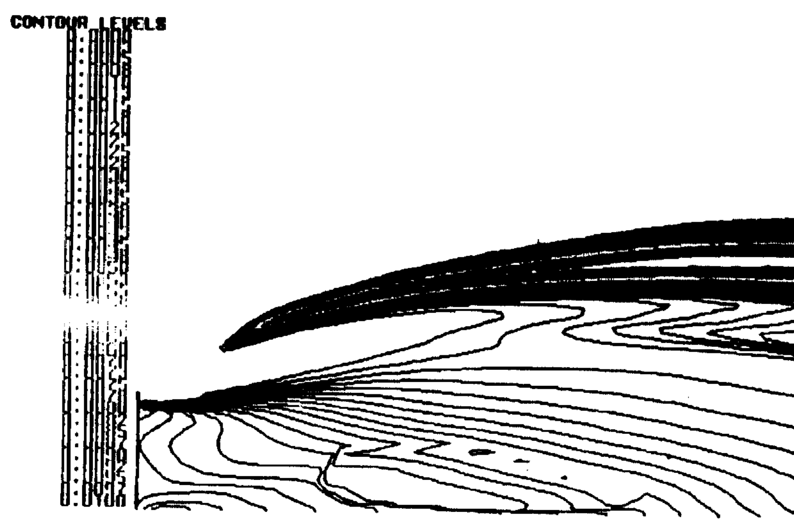
OH Mass Fraction
NLS Baseline - 50kft
Reacting Flow (Quiescent)



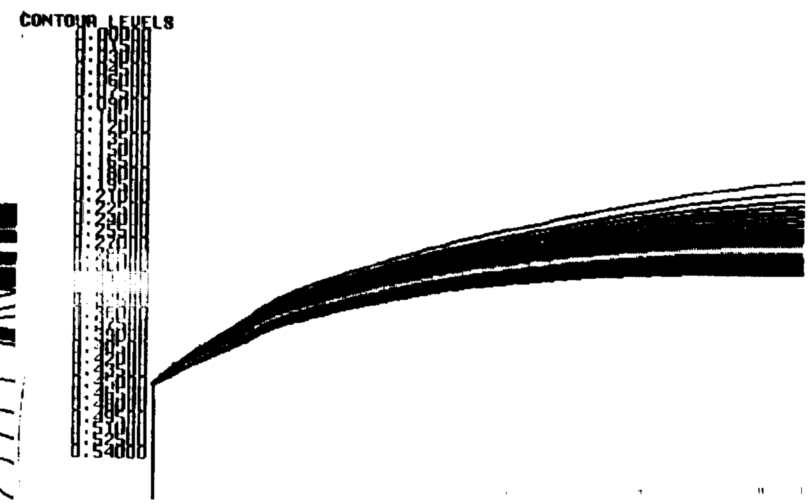
H2O Mass Fraction
NLS Baseline - 50kft
Reacting Flow (Quiescent)



OH Mass Fraction
NLS Modified - 50kft
Reacting Flow (Quiescent)



H2O Mass Fraction
NLS Modified - 50kft
Reacting Flow (Quiescent)



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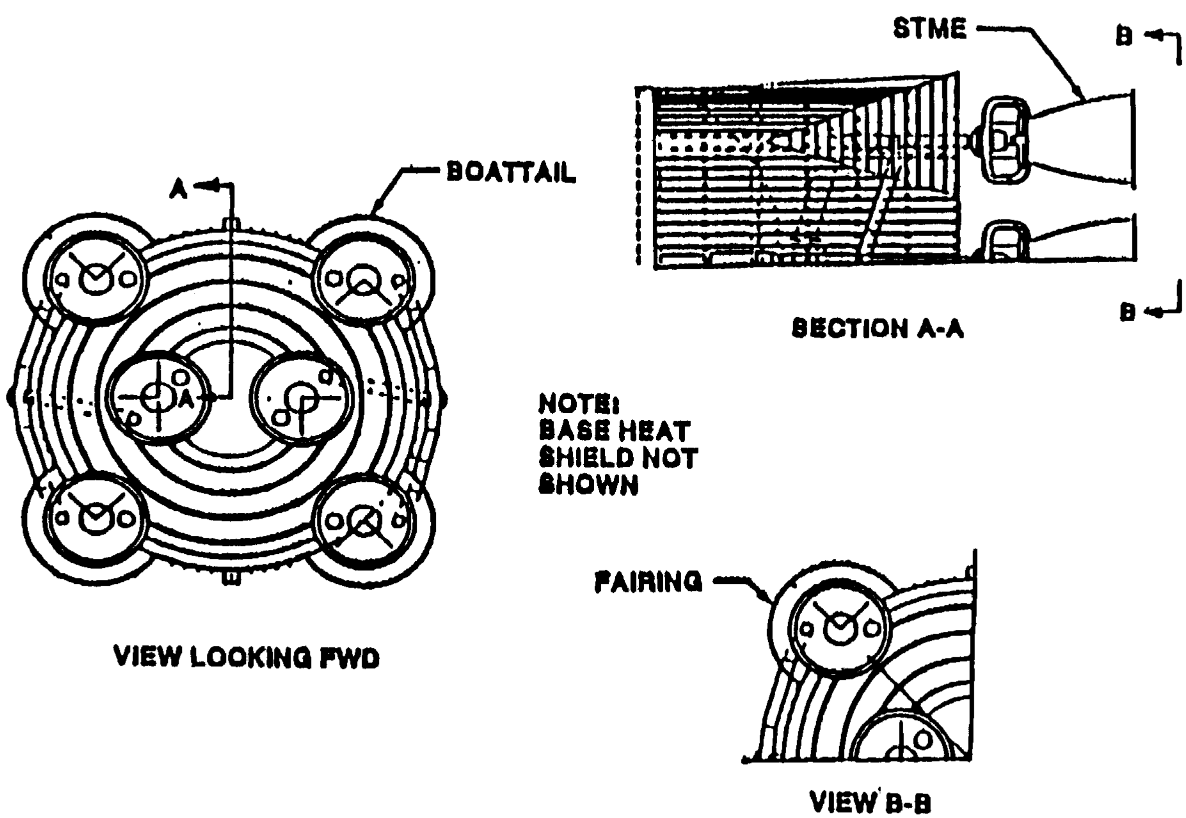
NLS/STME Plume and Base Region Results

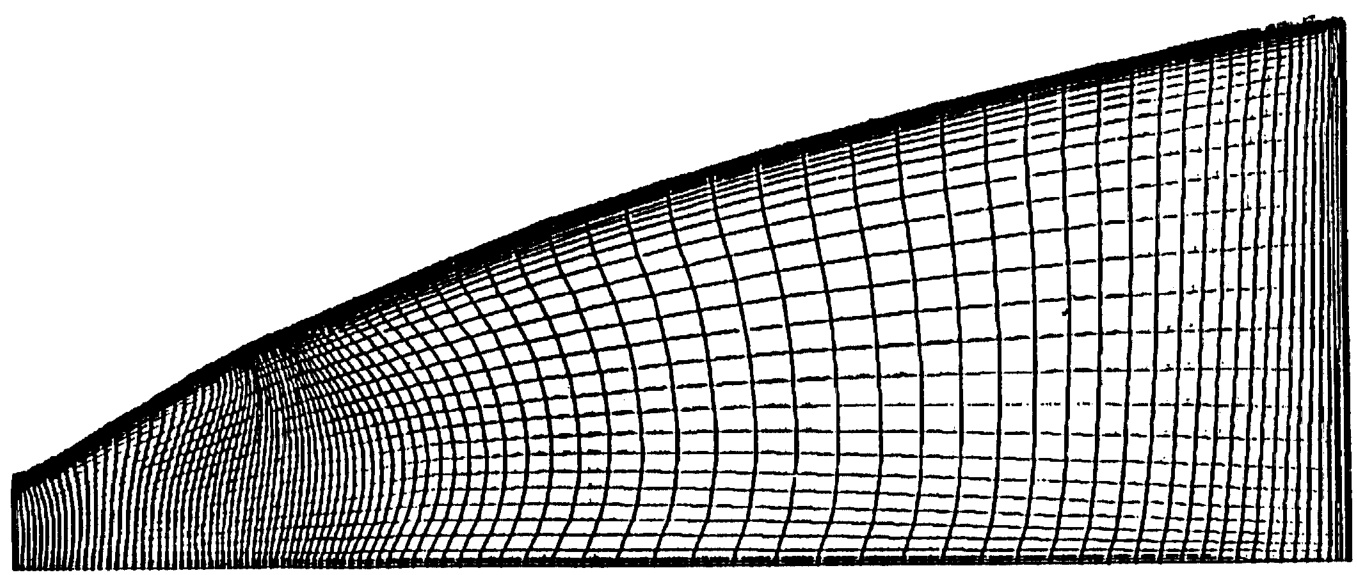
APPROACH

NLS 1.5 Stage Base



APPROACH

STME Nozzle Grid



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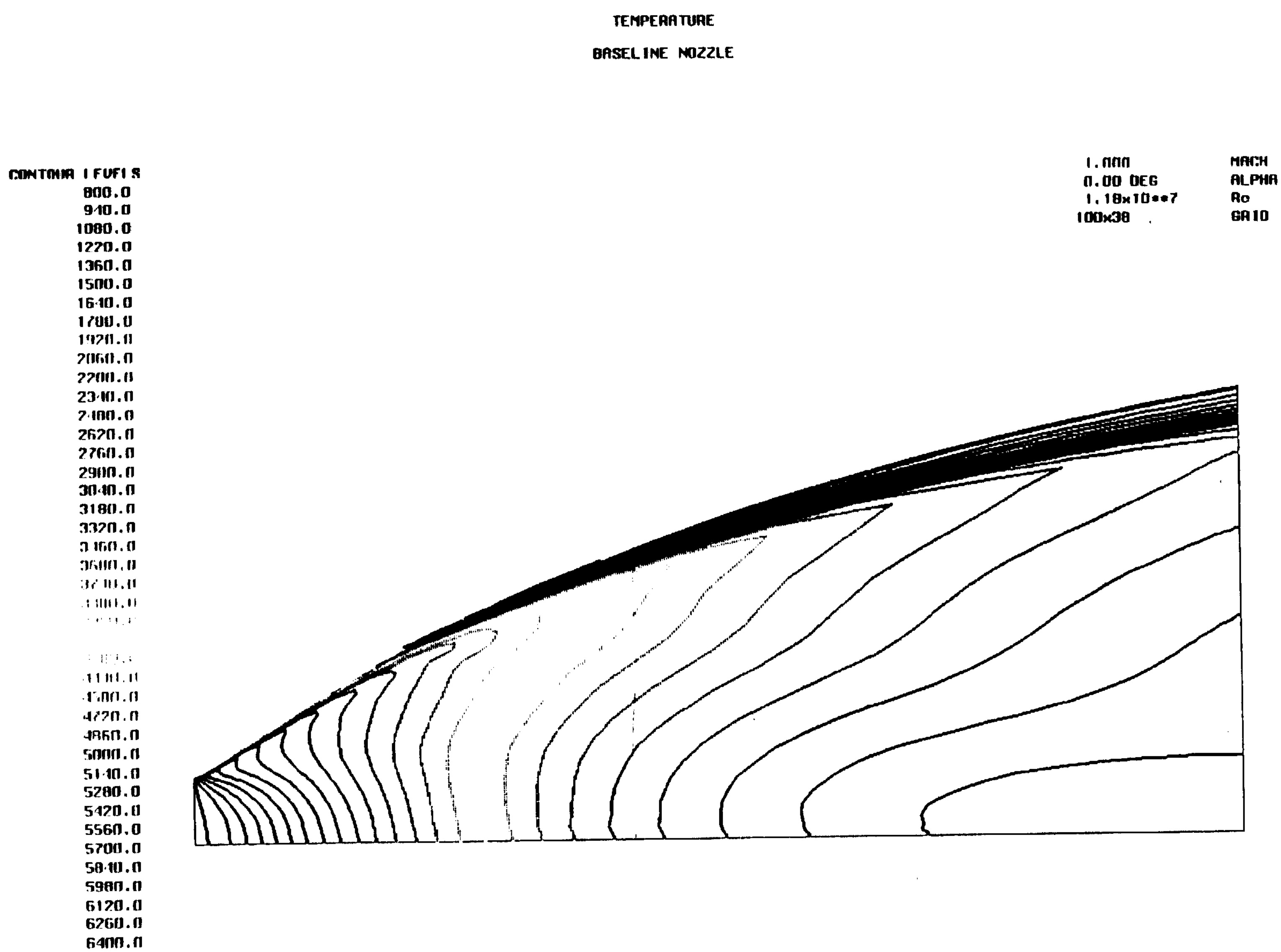
NLS/STME Plume and Base Region Results



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NLS/STME Plume and Base Region Results

APPROACH

NOZZLE CASES

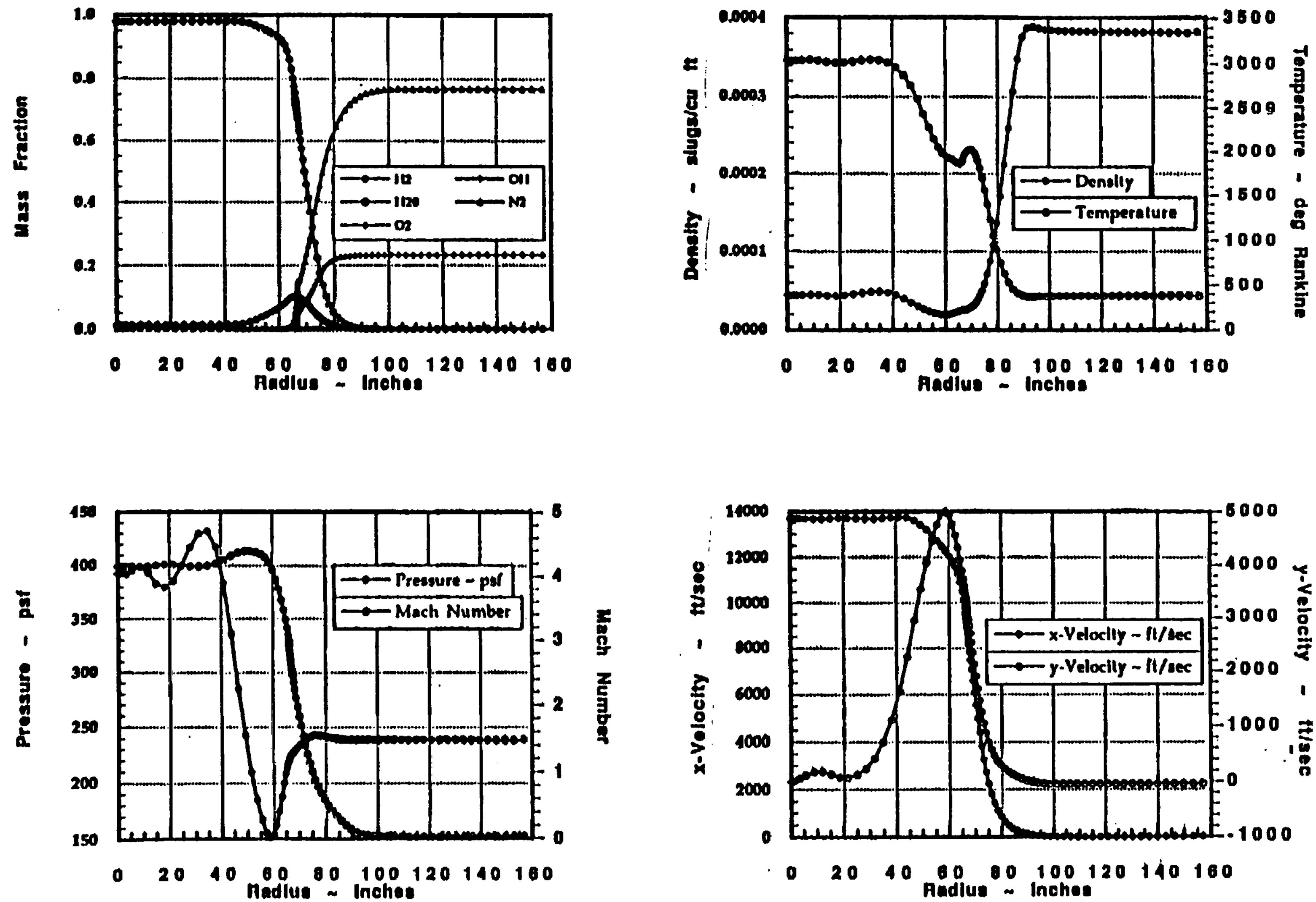
- Baseline
  - Frozen
  - Reacting
- Modified
  - Frozen
  - Reacting

PLUME/BASE CASES

- 10kft
  - Baseline
    - Frozen/Quiescent
    - Reacting/Quiescent
    - Frozen/Freestream
    - Reacting/Freestream
  - Modified
    - Frozen/Quiescent
    - Reacting/Quiescent
    - Frozen/Freestream
    - Reacting/Freestream
- 50kft
  - Baseline
    - Frozen/quiescent
    - Reacting/Quiescent
    - Frozen/Freestream
    - Reacting/Freestream
  - Modified
    - Frozen/Quiescent
    - Reacting/Quiescent
    - Frozen/Freestream
    - Reacting/Freestream

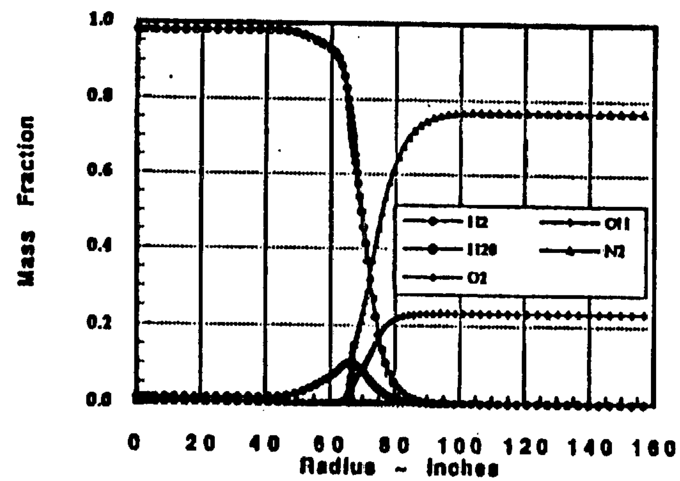
RESULTS

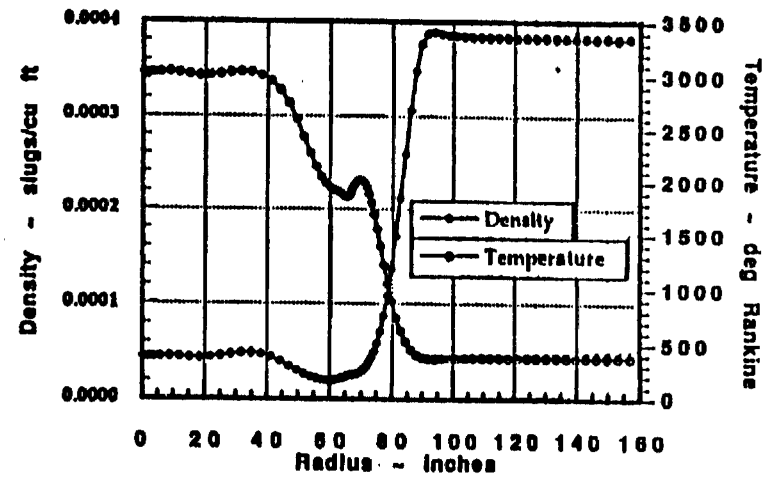
50kft Baseline Reacting Flow - Quiescent Freestream (x/R = 1)

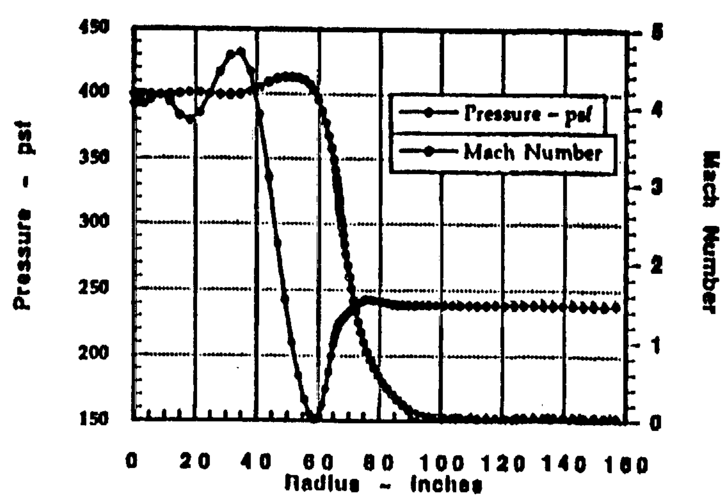


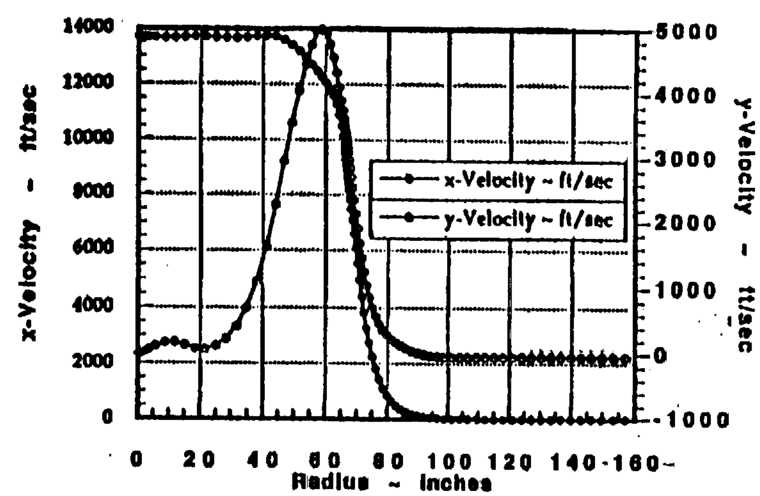
RESULTS

50kft Baseline Reacting Flow - Quiescent Freestream (x/R = 1)









STATUS/SUMMARY

- Frozen & finite rate calculations of STME plume complete for 10kft and 50kft
- Burning exhibited in plume shear layer for all cases
- Shear layer burning occurs further downstream at higher altitudes
- Shear layer burning from the modified nozzle occurs slightly upstream of baseline nozzle plume
- Shear layer gradients were delivered to ED33 for analysis & comparison to S1-C/F1
- Preliminary calculations at high altitudes indicate:
  - at 1/2 radius downstream of nozzle more combustibles (approx. 2:1) in NLS/STME shear layer
  - at 1 radius downstream of nozzle , combustible ratio is about even