Subject: A parametric study of a plug nozzle, using the Liquid Propellant Program (LPP) Code

By: Stuart S Dunn, Douglas E Coats, Software and Engineering Associates, Inc.

Abstract

The Liquid Propellant Program (LPP) computer code is a super-set of the industry standard Two Dimensional Kinetics (TDK) computer code, which has been developed by Software and Engineering Associates, Inc. (SEA, Inc.) over the past twelve years. The TDK code uses a Two-Dimensional Method of Characteristics solution with fully coupled finite rate kinetics for axially symmetric nozzles. The chemical reactions are modeled with a generalized reaction package that includes 3rd body efficiencies and four reaction rate forms. The code performs optional solutions for frozen or equilibrium flow. TDK evaluates discrete shocks, both attached or induced. The Transonic module models variable mixture ratio profiles from the combustion chamber injector. The Mass Addition Boundary Layer module (MABL) calculates the boundary parameters with the same chemistry options, and includes transpiration or tangential slot injection of gas at the wall.

The LPP upgrades include: planar nozzles, scarfed nozzles, plug nozzles, and scramjet nozzle configurations. The code evaluates both upper and lower wall flow simulation, and includes the interaction with the external flow. The MABL module evaluates equilibrium radiation heat transfer for both upper and lower walls. In addition, the LPP code models combustion effects due to injector inefficiencies with the Spray Combustion Analysis Program (SCAP) module. The LPP package provides extensive post plotting capabilities for flow visualization. The LPP is sufficiently fast and robust to provide performance predictions for extensive parametric studies and sufficiently accurate to provide flow field and performance solutions for detailed studies.

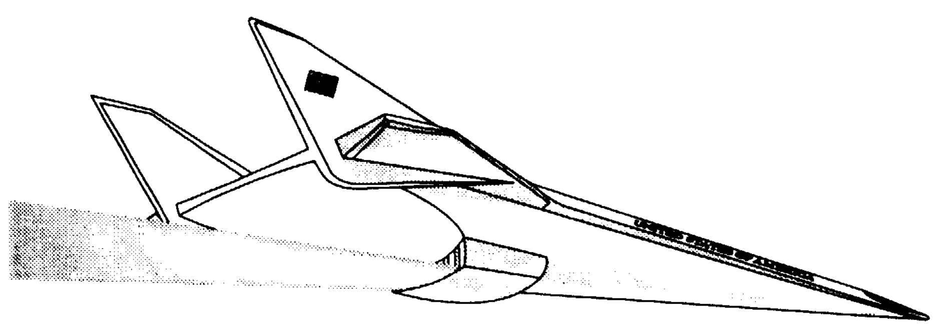
The evaluation of a planar or axially symmetric plug nozzle has received recent interest due to the SSTO studies. The LPP code allows easy modeling of a plug nozzle configuration, since the user is allowed to input an arbitrary inner and outer wall geometry (referred to as the plug and the cowl). The transonic analysis models both planar or axially symmetric annular flow, including straited and variable mixture ratio profiles. When the internal flow reaches the exit of the outer wall, a Prandtl-Meyer fan allows the flow to expand to the external pressure. At this point, a pressure boundary condition is applied for either quiescent sub-sonic, or super-sonic external flow. The MABL analyses is subsequently performed to evaluate the boundary layer losses for both the inner and outer walls. Following JANNAF standard procedures, the characteristic analysis is automatically repeated with the boundary layer compensated wall geometry.

The above procedure was employed to parametrically evaluate the performance of several plug nozzle configurations at different flight conditions. The altitude compensating effects are evaluated and related to ideal conventional nozzle performance. An optimization technique is presented, which includes chemistry, divergence, and boundary layer effects. Graphical output includes flow field contours, and wall property profiles.

Plug Nozzle Parametric Study Using The Liquid Performance Program (LPP)

Stuart S. Dunn and Douglas E. Coats

Software and Engineering Associates, Inc.
333 S. Carson Meadows, Suite 44
Carson City, NV 89701
702-882-1966



OUTLINE

- WHAT IS LPP
- PLUG NOZZLE DESCRIPTION
- LPP PLUG NOZZLE CAPABILITY
- EFFECT OF INLET AND COWL GEOMETRY ON PERFORMANCE

WHAT IS LPP?

The Liquid Performance Program (LPP) is a Super Set of the JANNAF TDK Code.

- Liquid Rocket Engine Performance
- Scramjets
- Plug and Aerospike Nozzles
- Efficient MOC Solver, Can Model Actual or Boundary Layer Displaced Walls Automatically
- Finite Rate and Equilibrium Chemistry
  - 3 different types of reactions including a global first order type
  - generalize symbolic reactions

WHAT IS LPP? (Continued)

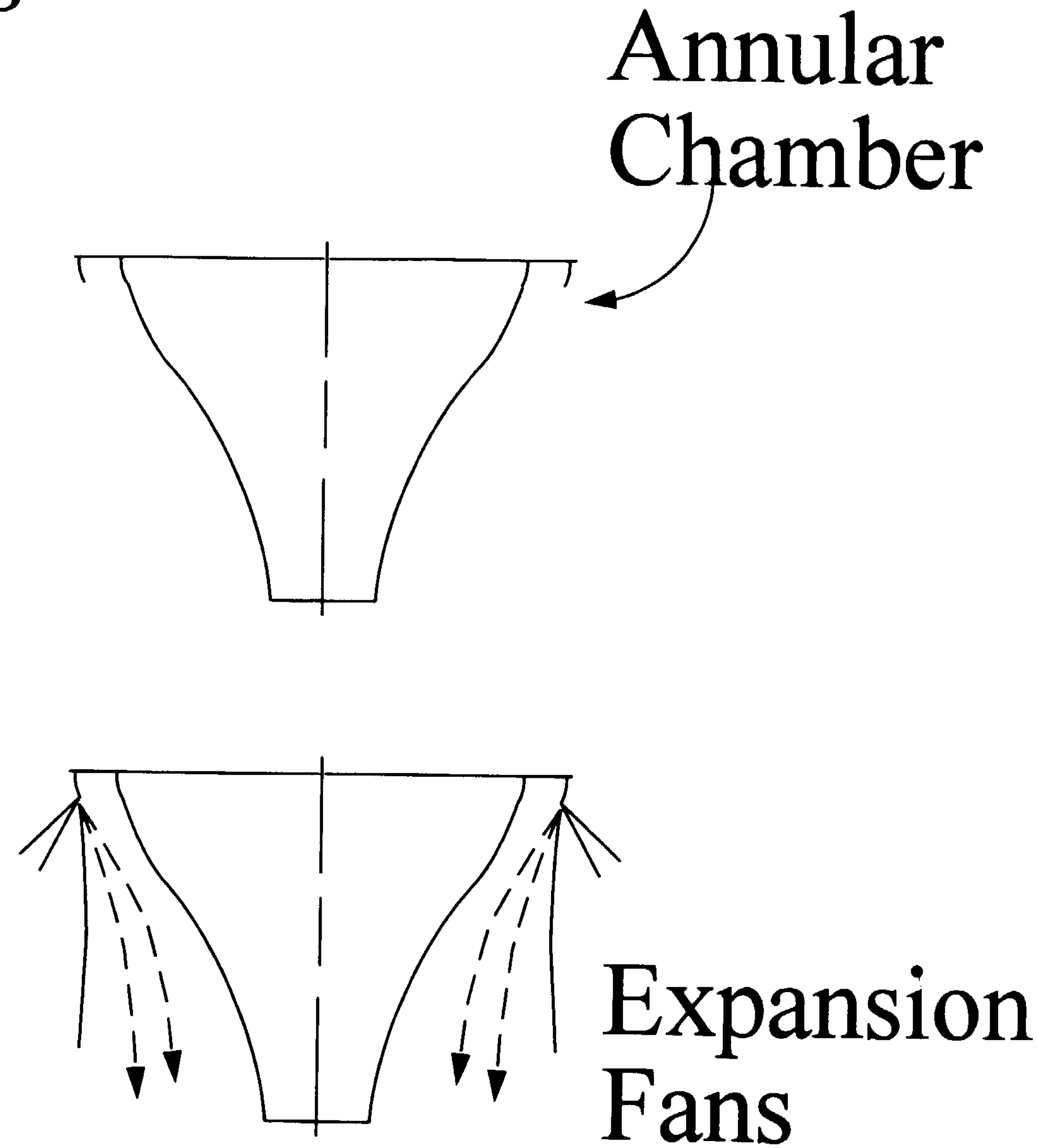
- Mass Addition Boundary Layer
  - Models Wall Equilibrium Radiation Heat Transfer
  - Calculates Boundary Layers On Both Upper and Lower Walls
  - Tangential Slot Injection or Transpiration Cooling
- Planar and Axisymmetric Flow
  - Handles External Flow Interactions

WHAT IS LPP? (Continued)

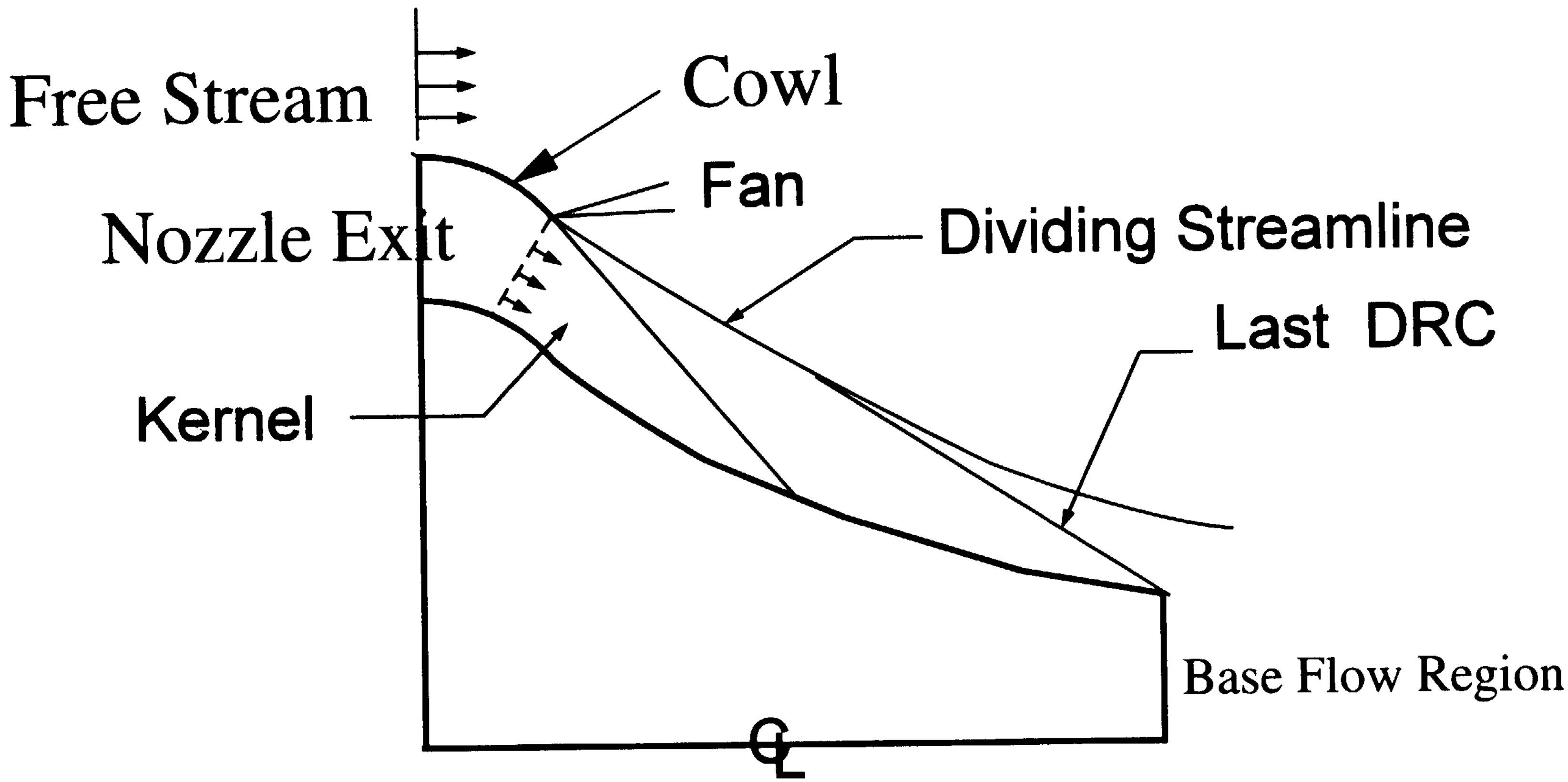
- Spray Combustion Module
- Standard Plume Flowfield (SPF) and Rao Optimum Nozzle Linkage
- Pre and Post Processors

Plug Nozzles

- Characteristics
  - Center Body
  - Short Nozzle Configuration
  - Automatic Altitude Compensating
  - Complex Structure
  - Difficult To Cool



Flow Characteristics



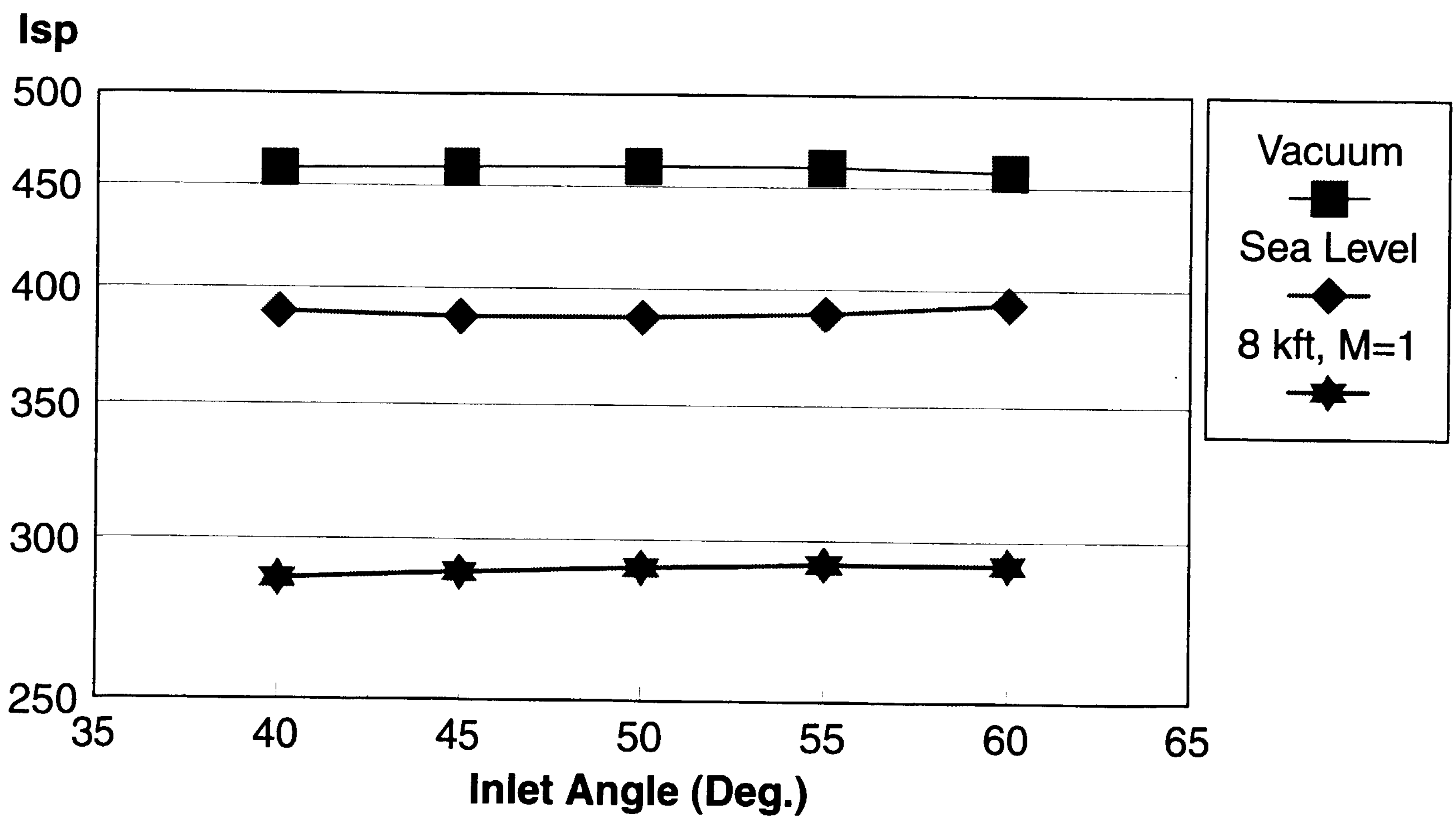
LPP Plug Nozzle Capability

- 2D or Axisymmetric Flow
- External Flow Modeled With Newtonian Pressure Boundary
- Boundary Layer Computed On Both Upper and Lower Walls
- Base Flow Region Not Modeled

SSTO Base Line Plug Nozzle

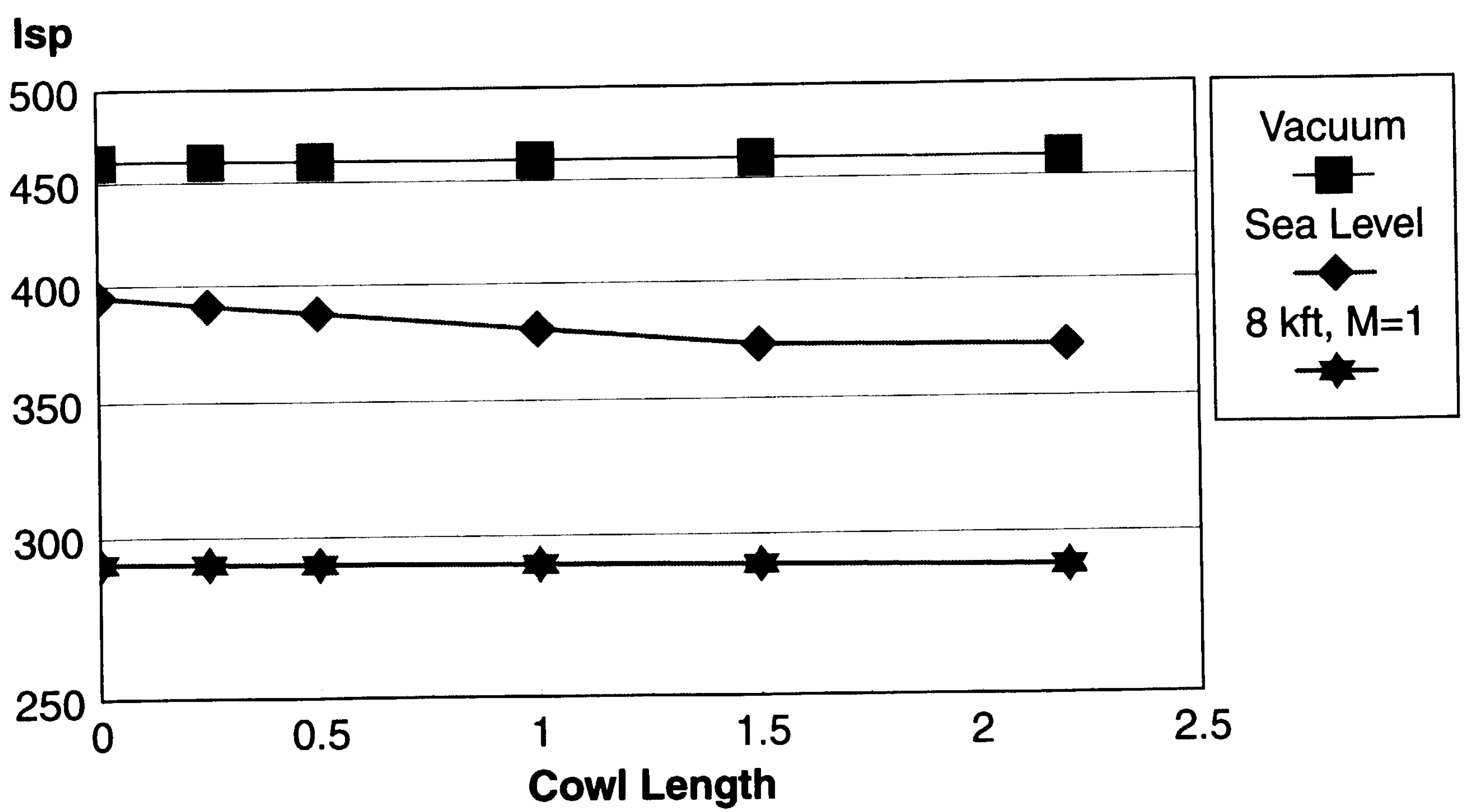
- 1,000,000 lbf Thrust Class
- 2630 psia Chamber Pressure
- Annular Nozzle With 50 psia Exit Pressure and Mach 3 Flow
- L H_2 - L O_2 Propellants at an O/F=6

Isp Variation With Inlet Angle

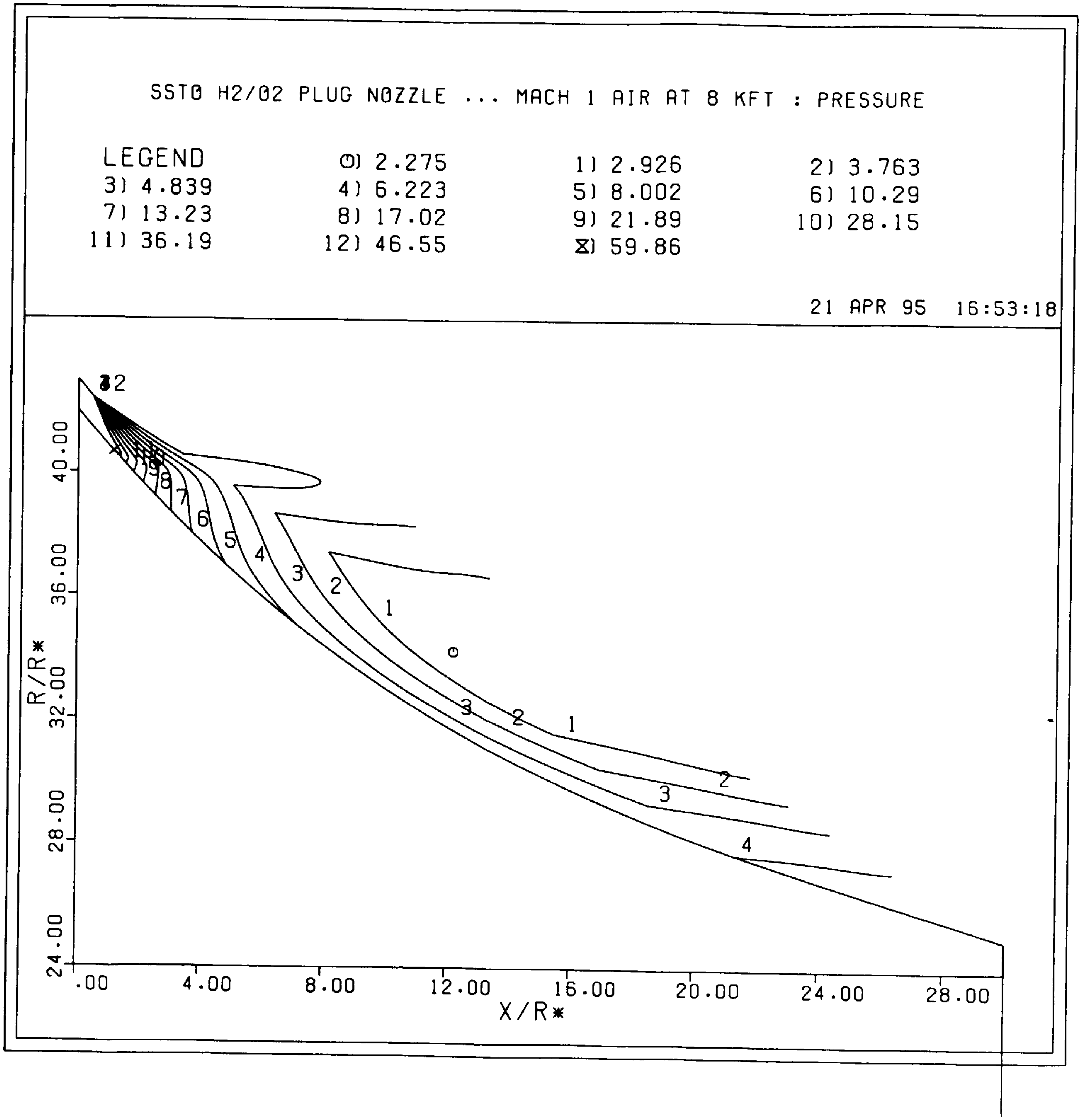


SEA 4-26-95/13 th Propulsion CFD Workshop

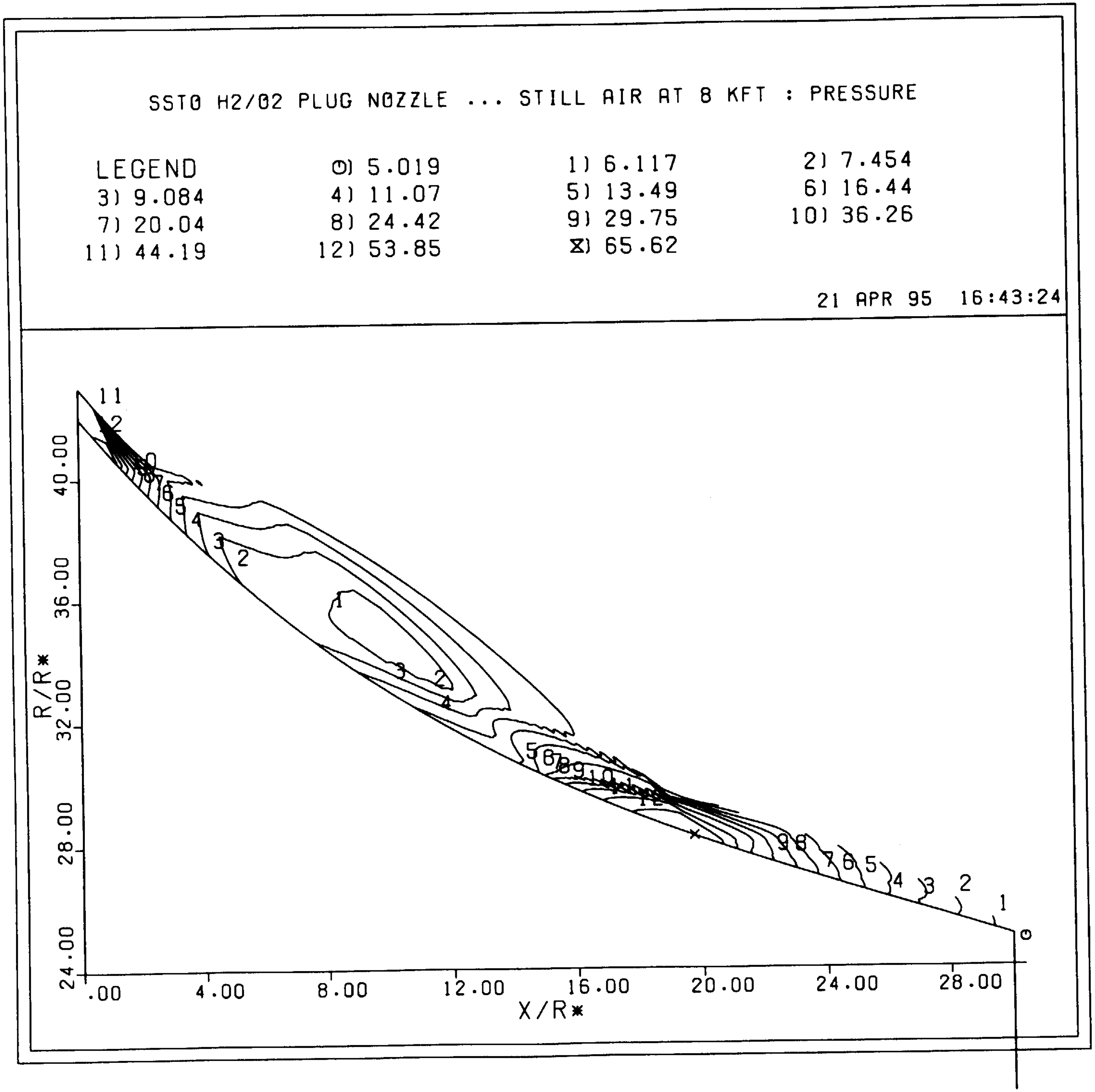
Isp Variation With Cowl Length

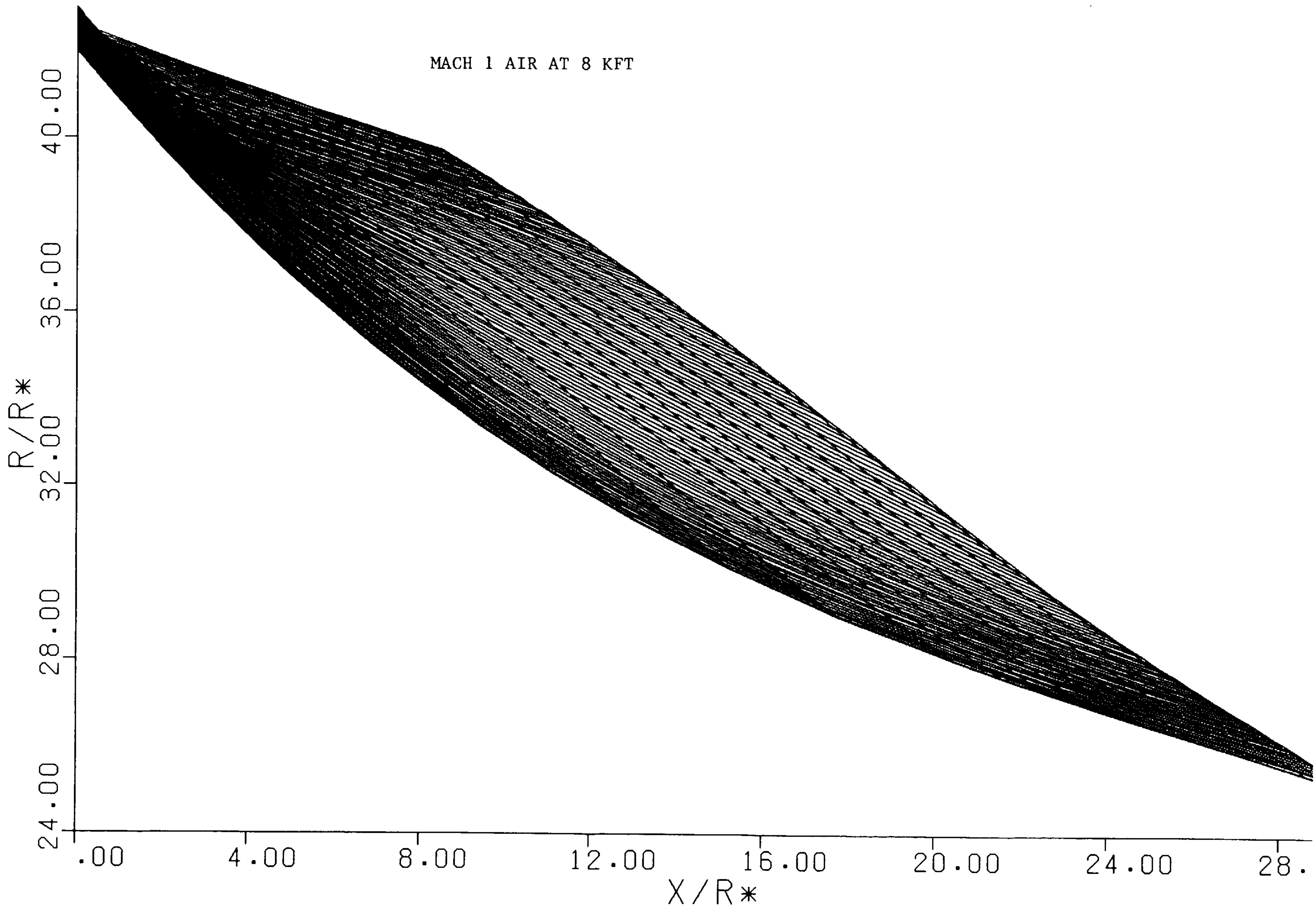


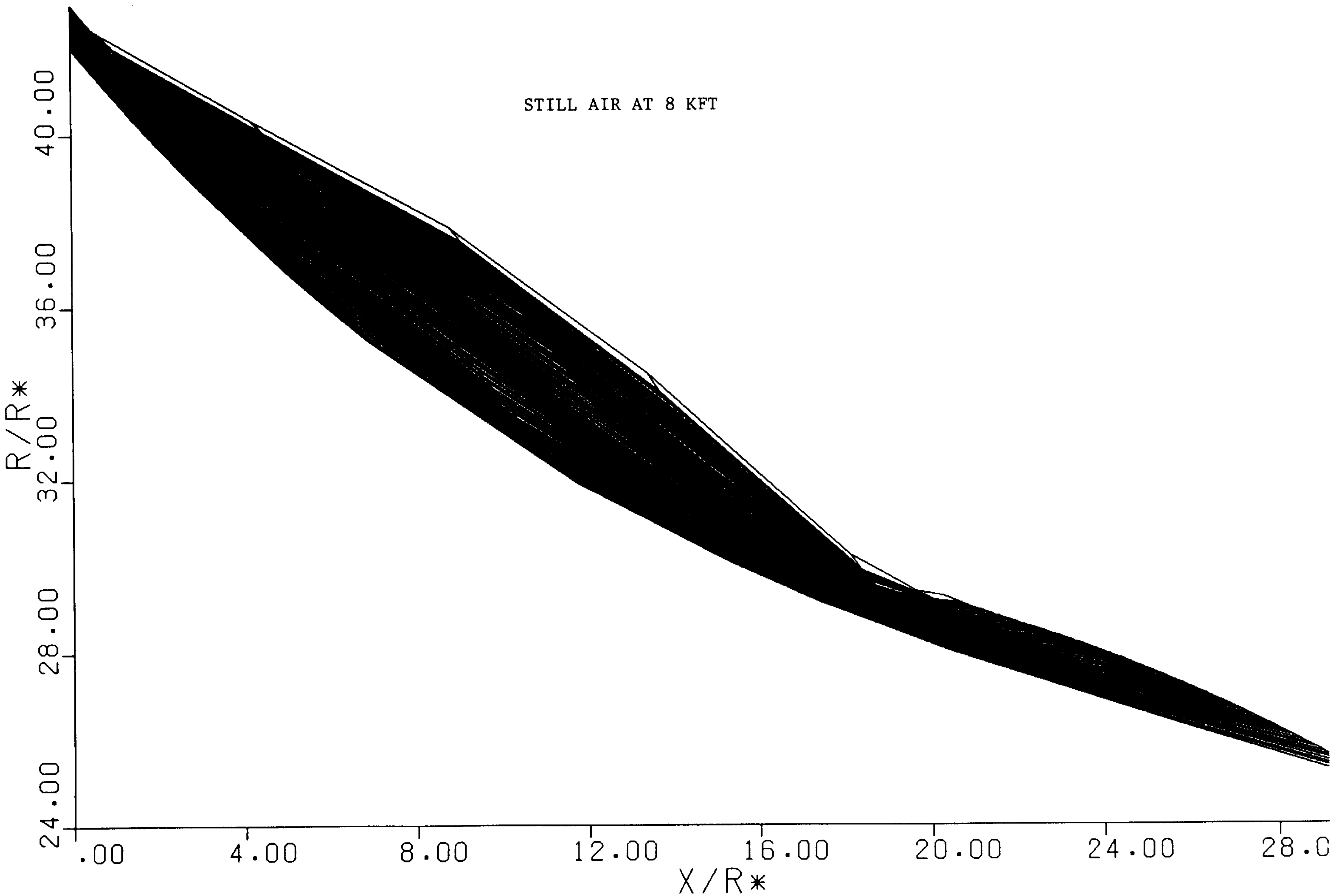
SEA 4-26-95/13 th Propulsion CFD Workshop

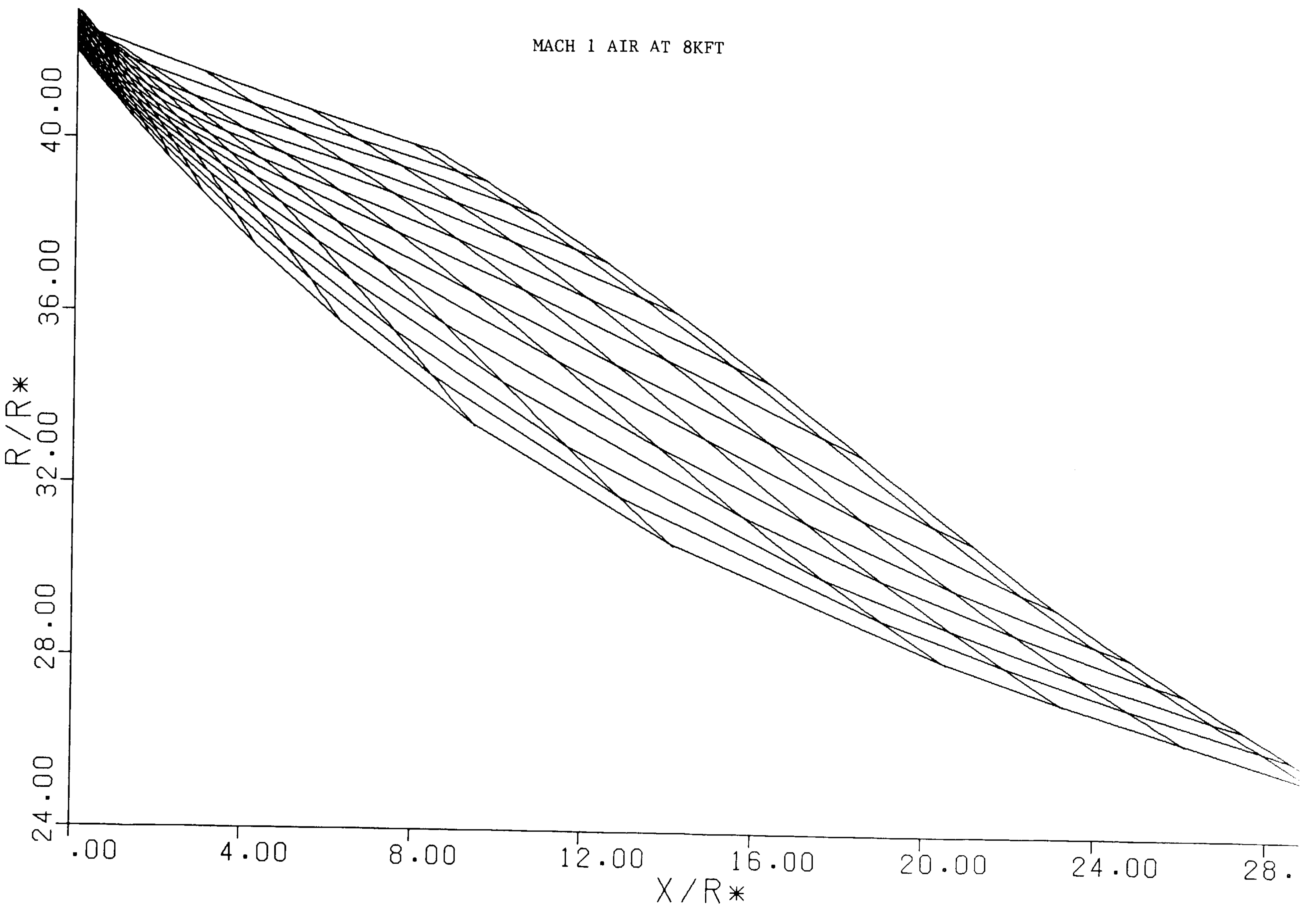


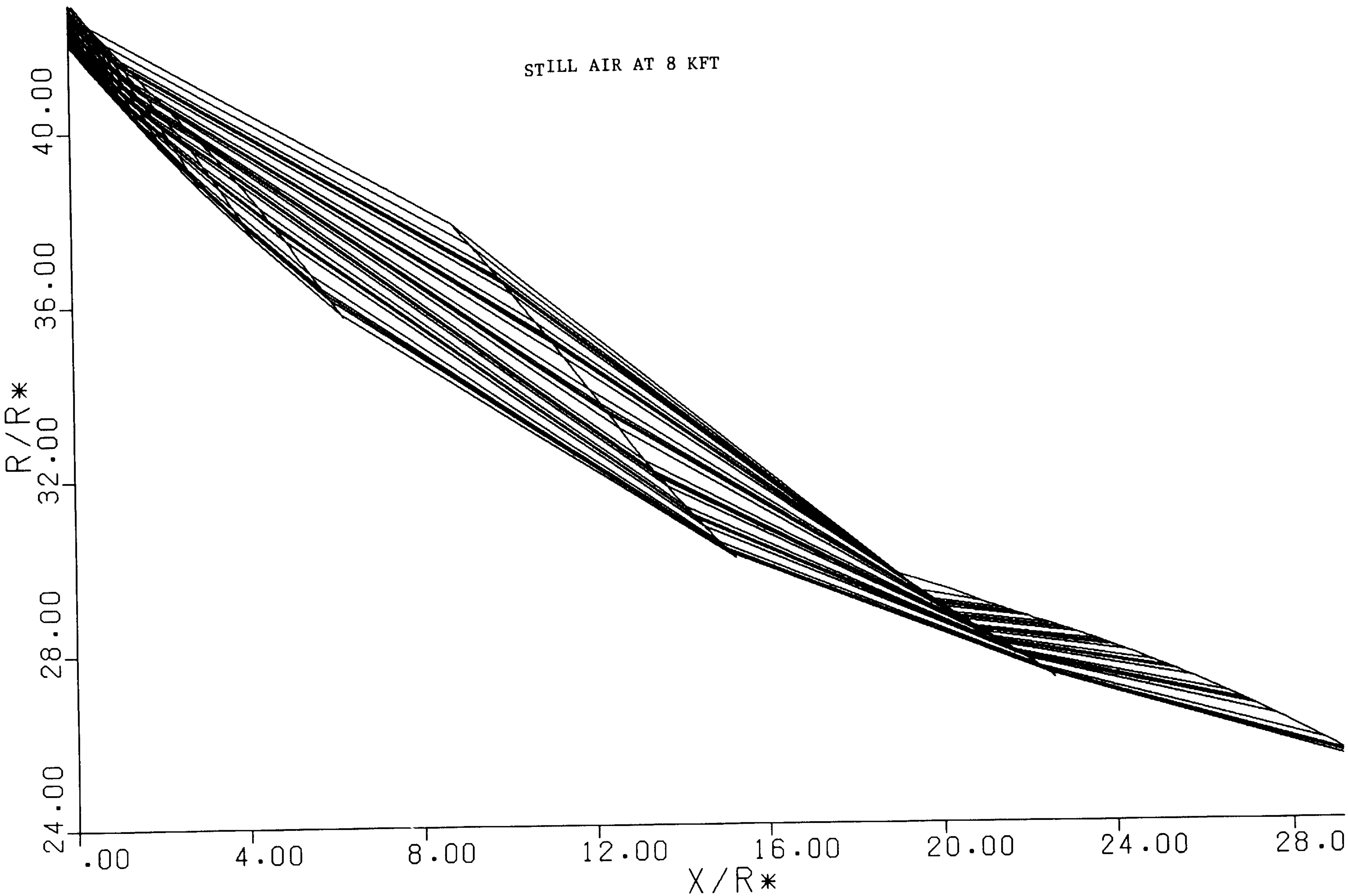
SSTØ H2/02 PLUG NØZZLE ... MACH 1 AIR AT 8 KFT : PRESSURE
LEGEND
0) 2.275
1) 2.926
2) 3.763
3) 4.839
4) 6.223
5) 8.002
6) 10.29
7) 13.23
8) 17.02
9) 21.89
10) 28.15
11) 36.19
12) 46.55
X) 59.86
21 APR 95 16:53:18
R/R*
X/R*


SSTØ H2/02 PLUG NØZZLE ... STILL AIR AT 8 KFT : PRESSURE
LEGEND
ⓞ) 5.019
1) 6.117
2) 7.454
3) 9.084
4) 11.07
5) 13.49
6) 16.44
7) 20.04
8) 24.42
9) 29.75
10) 36.26
11) 44.19
12) 53.85
Ⓧ) 65.62
21 APR 95 16:43:24
R/R*
X/R*
24.00
28.00
32.00
36.00
40.00
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00

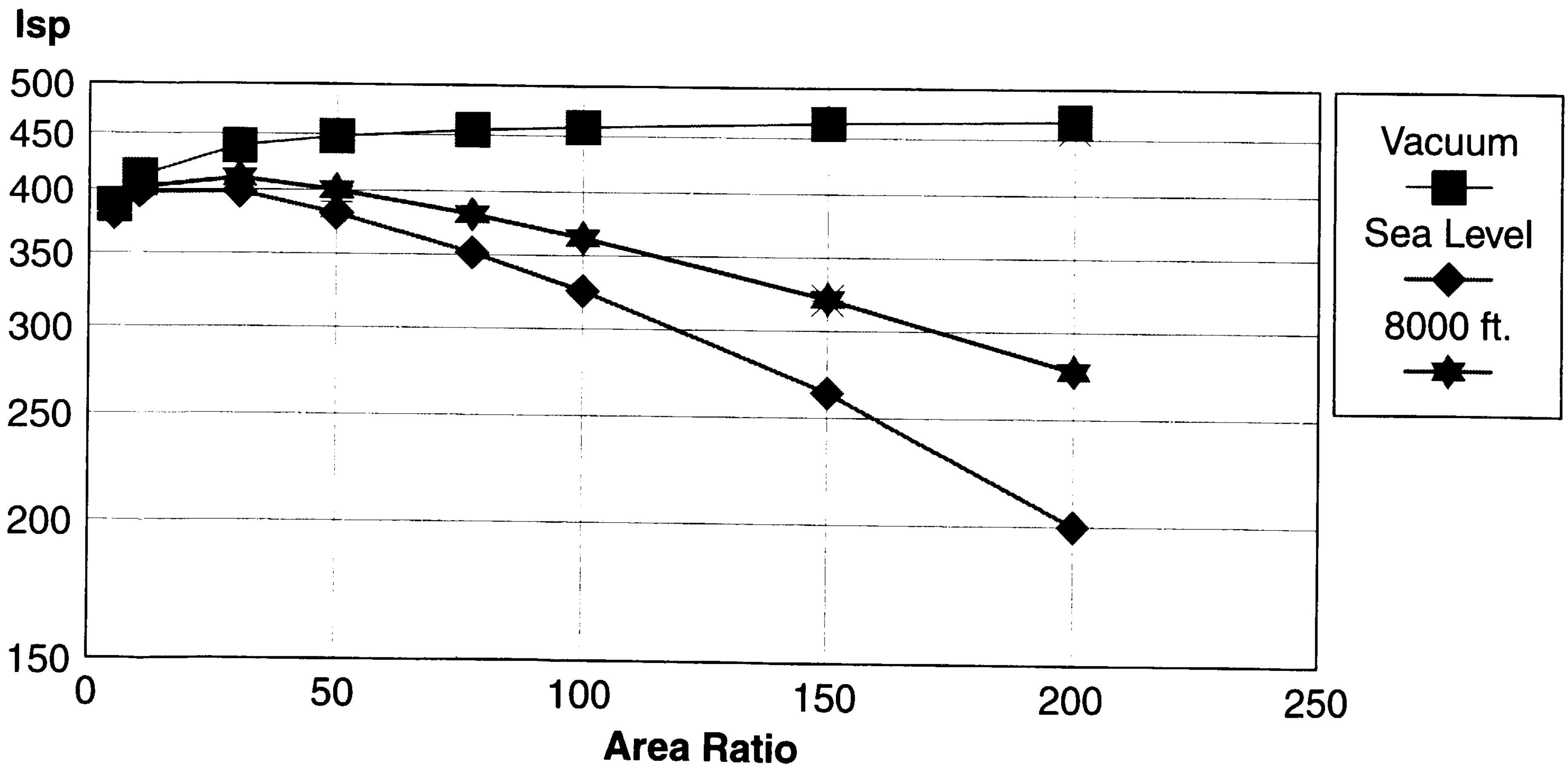

MACH 1 AIR AT 8 KFT
R/R*
40.00
36.00
32.00
28.00
24.00
X/R*
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.


STILL AIR AT 8 KFT
R/R*
40.00
36.00
32.00
28.00
24.00
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.0
X/R*

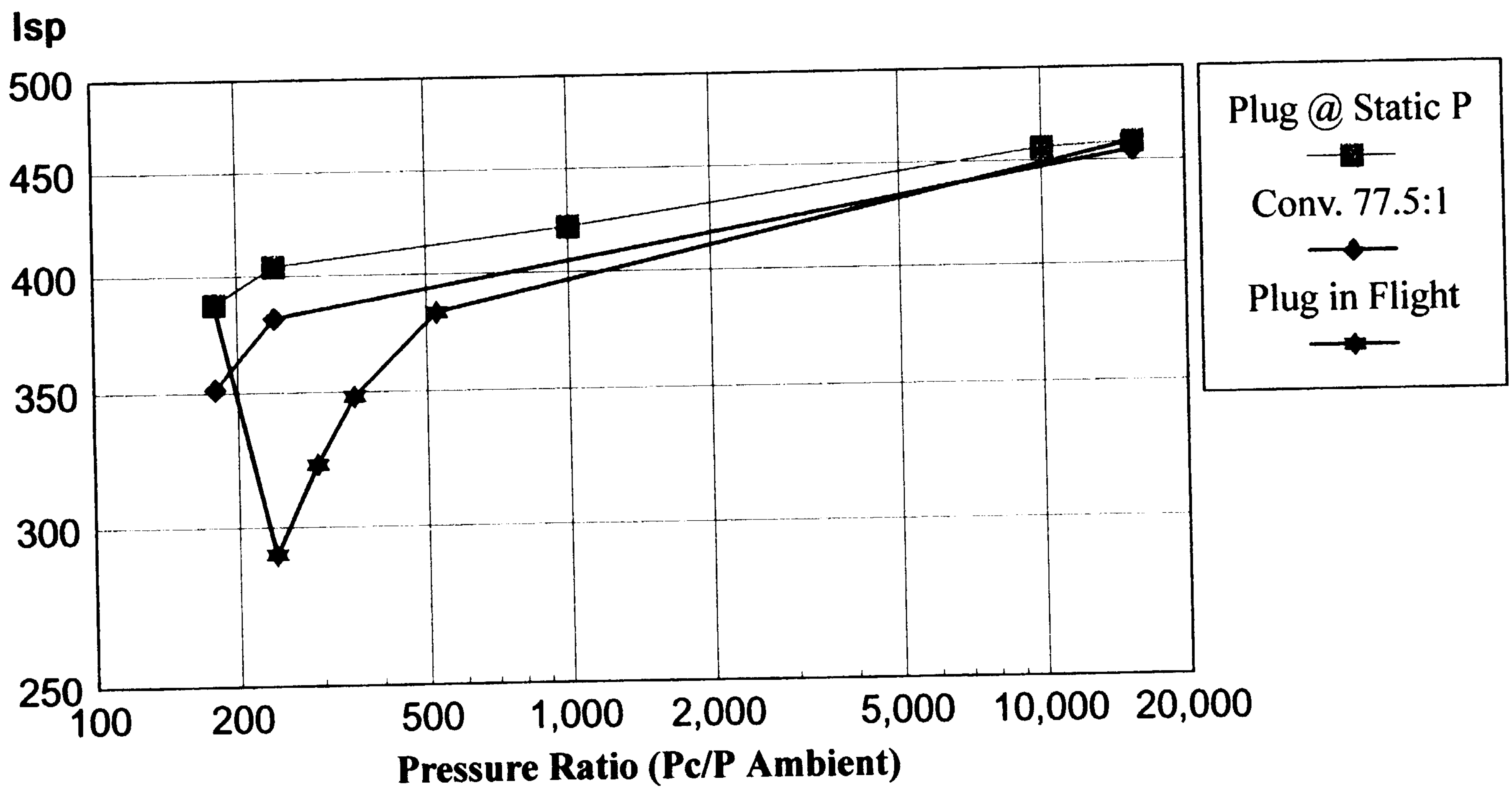

MACH 1 AIR AT 8KFT
40.00
36.00
32.00
28.00
24.00
R/R*
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.
X/R*


STILL AIR AT 8 KFT
R/R*
40.00
36.00
32.00
28.00
24.00
X/R*
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.0

Isp vs. Area Ratio For an SSME Type Engine (Pc=2630psia)



Isp Variation With Pressure Ratio



CONCLUSIONS

- Demonstrated The Ability Of LPP To Compute Performance of Plug Nozzles
- Performance Is Best With Short Cowls
- Performance Is Improved When The Flow Is Channeled Parallel To The Plug
- Showed That The Altitude Compensation Of Plug Nozzles Is Highly Dependent On The Flight Trajectory

RECOMMENDATIONS

- That An Automatic Trajectory Option Be Added To LPP
- That A Simple Base Flow Model Be Added To LPP