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A NUMERICAL STUDY OF HYPERSONIC FOREBODY/INLET INTEGRATION PROBLEM

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JANNAF WORKSHOP ON CFD
CODE VALIDATION/CALIBRATION
FOR
HIGH-SPEED INLET FOREBODY INTERACTIONS

Introduction

- Propulsion-airframe integration is one of the most critical problems in the development of hypersonic airbreathing aircraft

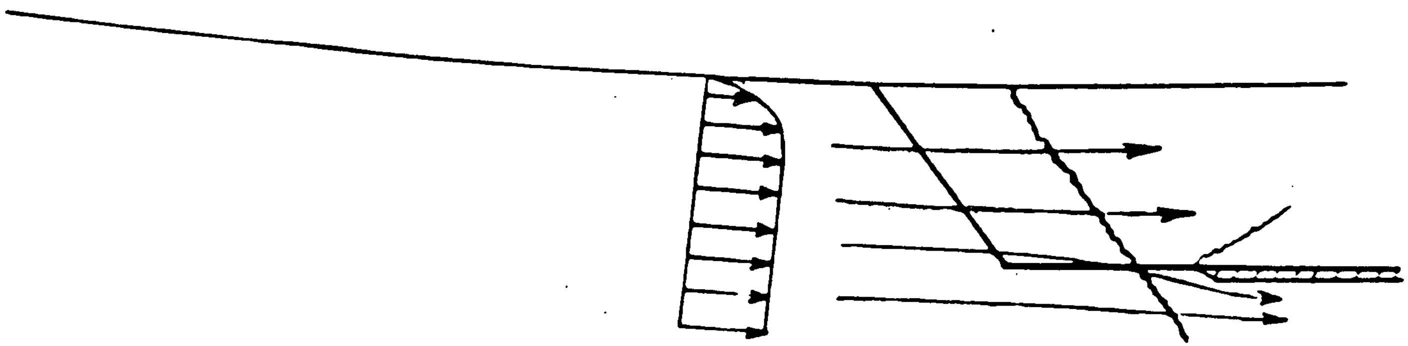
- Traditional wind tunnel-based solution to this problem is extremely difficult at high Mach no.

- CFD uniquely positioned to contribute to the problem

FOREBODY-INLET INTEGRATION ISSUES

- Forebody flow field and cross flow
- Shaping of forebody for uniform flow to all engine inlets including outboard inlets
- Boundary-layer ingestion by inlet
- 3–D effects
- Inlet flow field/spillage (fixed and variable geometry inlets)
- Inlet/inlet interactions
- Forebody/inlet interactions and inlet unstart
- Forebody/inlet design and optimization
    - — forebody shaping for uniform flow at inlet face by minimizing crossflow
    - — external v/s internal compression
    - — wave drag minimization
    - — inlet capture
- Performance prediction of forebody/inlet system

FOREBODY INLET INTEGRATION

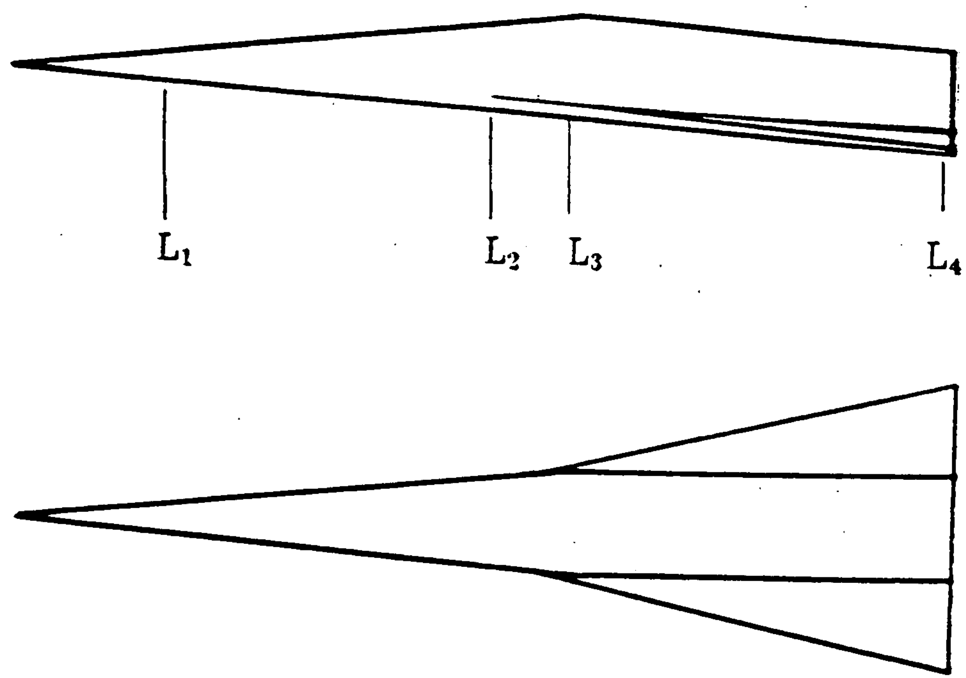


PHYSICAL/CHEMICAL MODELING

- Non equilibrium air chemistry for blunt forebody at high altitude
- Equilibrium air chemistry and real gas effects
- Transition/turbulence modeling on forebody
- Transition/turbulence modeling for inlet walls
- Shock/boundary-layer interactions and separation
- Shock/shock interactions and local regions of high heating and pressure
- Corner flows

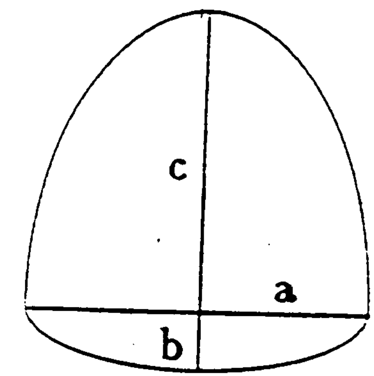
OBJECTIVE

- Establish a numerical procedure for integrated analysis of scramjet inlet with forebody
- Validate the procedure against experimental data



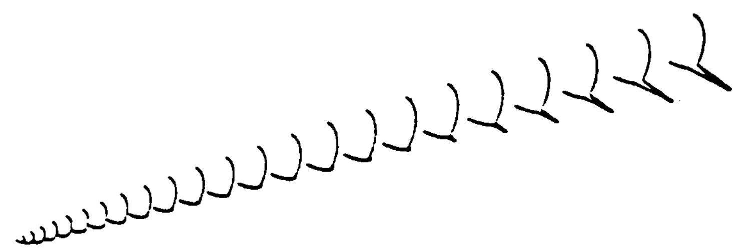
L_1 Transition begins
L_2 Wing emerges
L_3 Transition ends
L_4 Engine inlet face

Schematic view of forebody



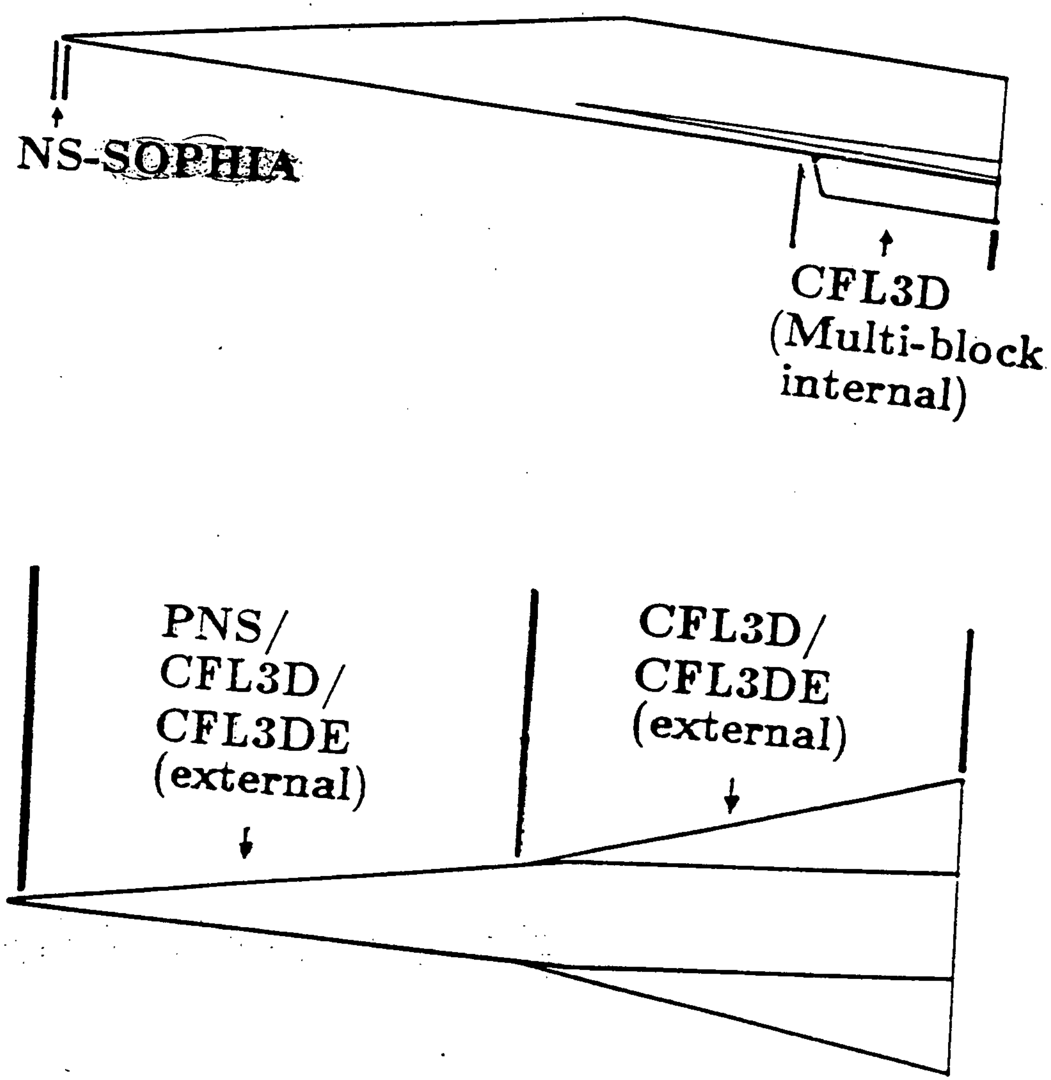
Aspect Ratio AR = a/b
a = Baseline body radius

Two-Ellipse configuration



Forebody cross sectional geometry

Generic forebody configuration



Solution procedure

Flow Conditions

Laminar Flow

Perfect Air

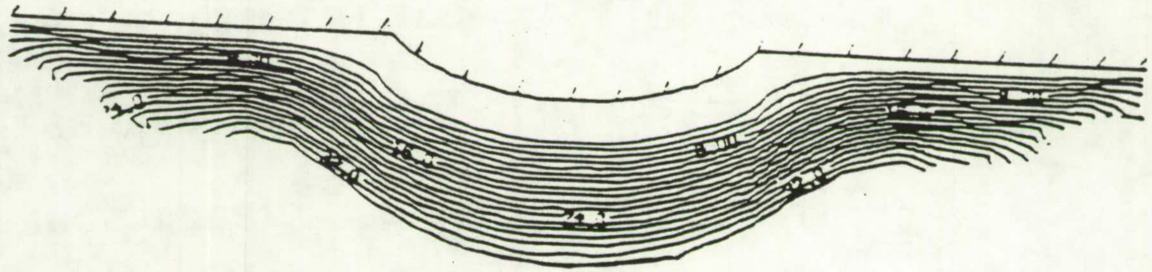
Mach Number = 16.0

Free Stream Pressure = 395 N/m^2

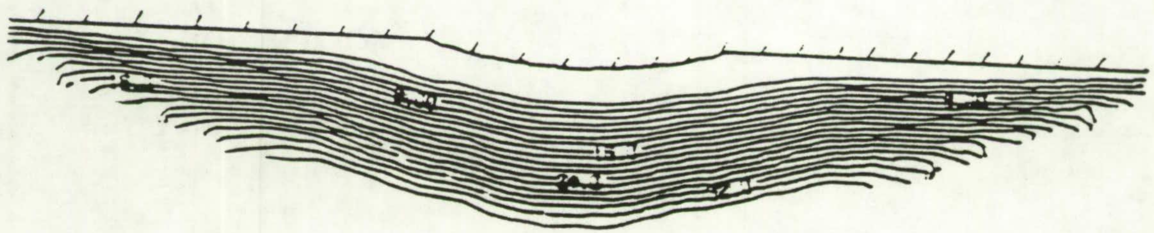
Free Stream Temperature = 243 K

Wall Temperature = 1110 K

Reynolds Number = 1.806×10^6 per meter

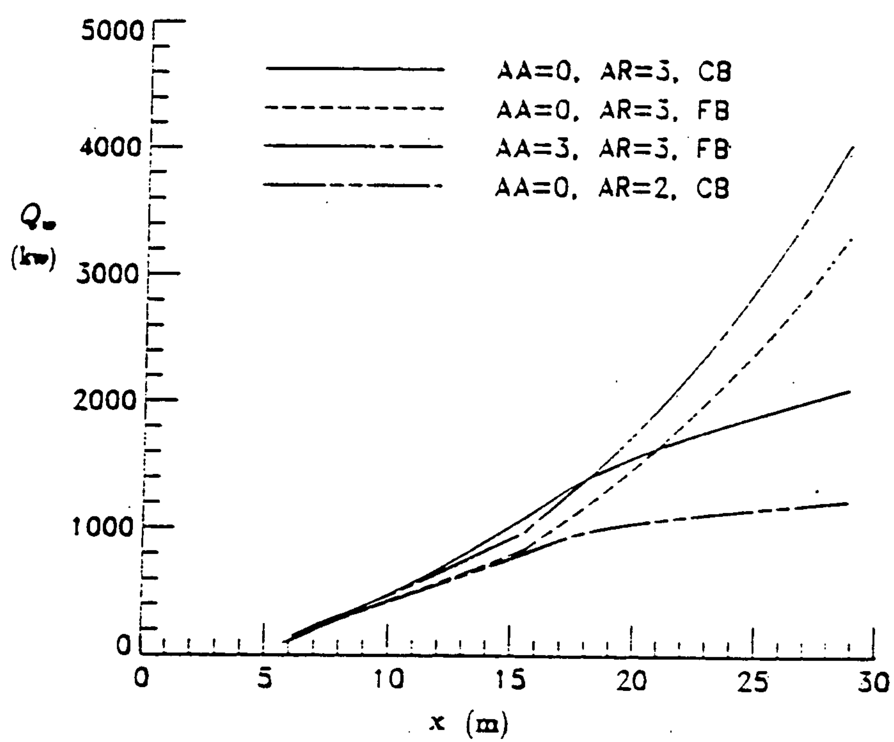


Forebody with wing, AR=2

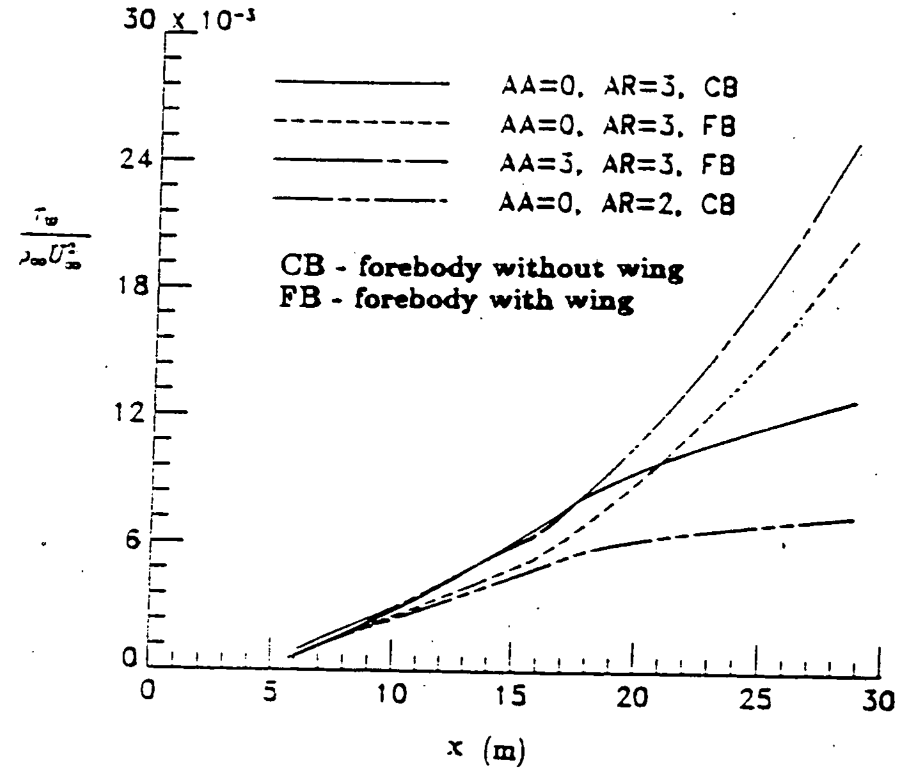


Forebody with wing, AR=3

Mass flow rate at inlet face

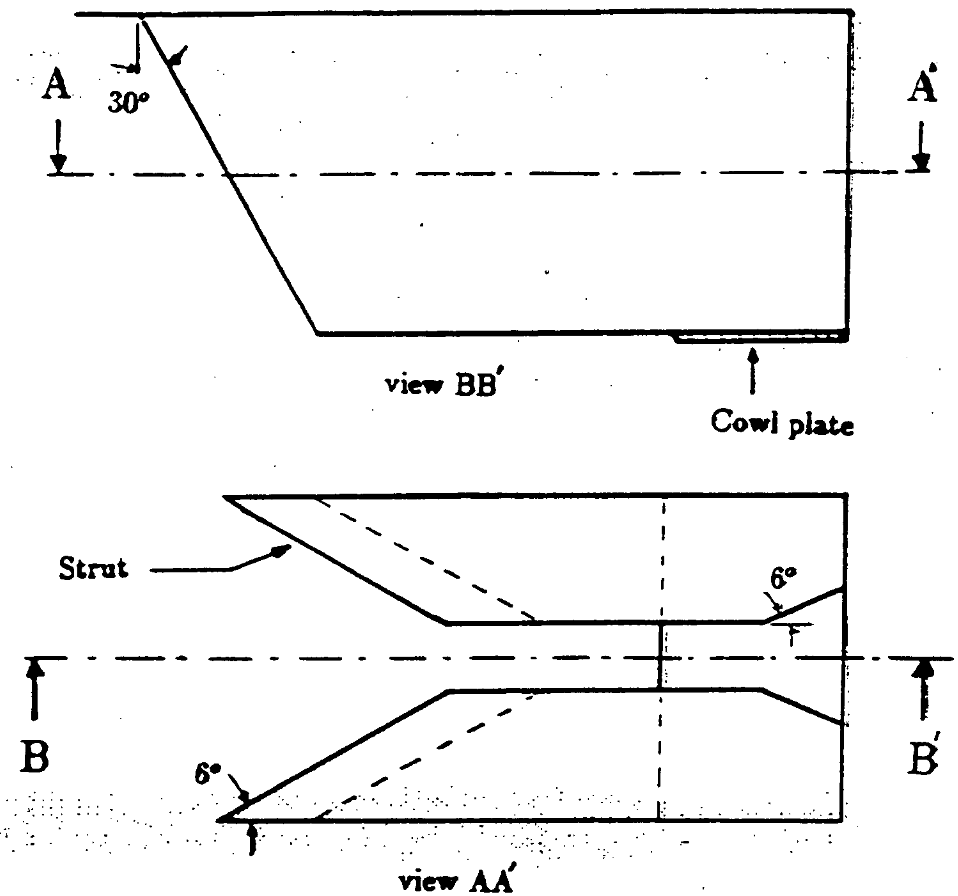


Heat transfer rate (total)

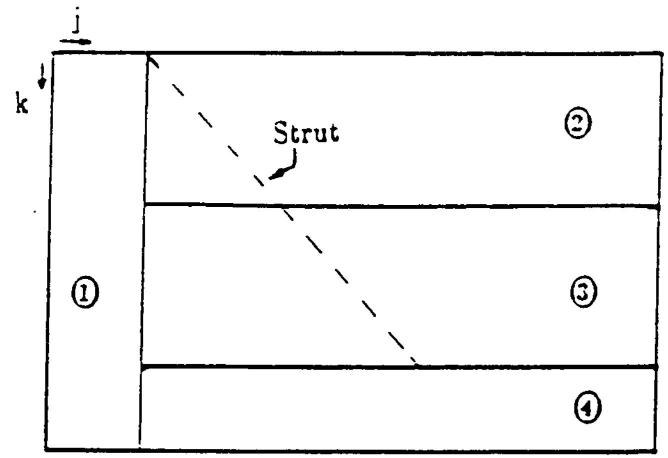


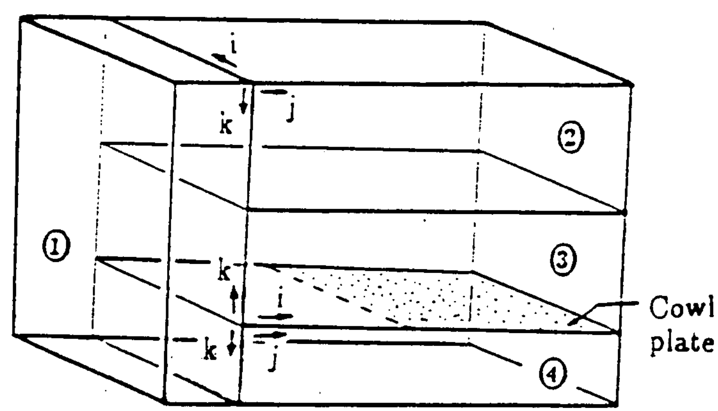
Skin friction load (total)

Heating and skin friction loads

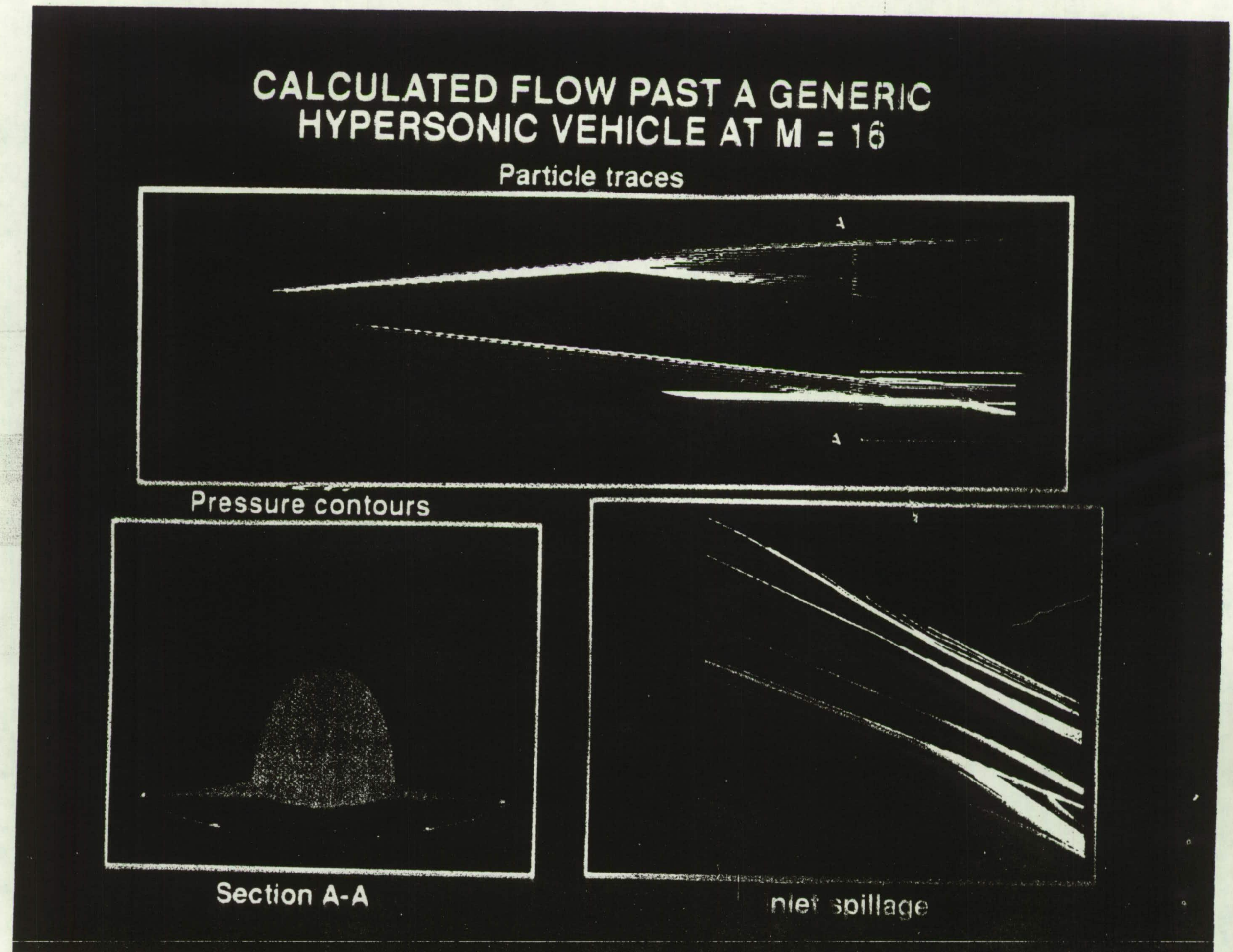


Schematic view of inlet module





Multiple block system


CALCULATED FLOW PAST A GENERIC
HYPERSONIC VEHICLE AT M = 16
Particle traces
Pressure contours
Section A-A
nlet spillage

Generic Option #2
3–D Forebody/Inlet Integration Model

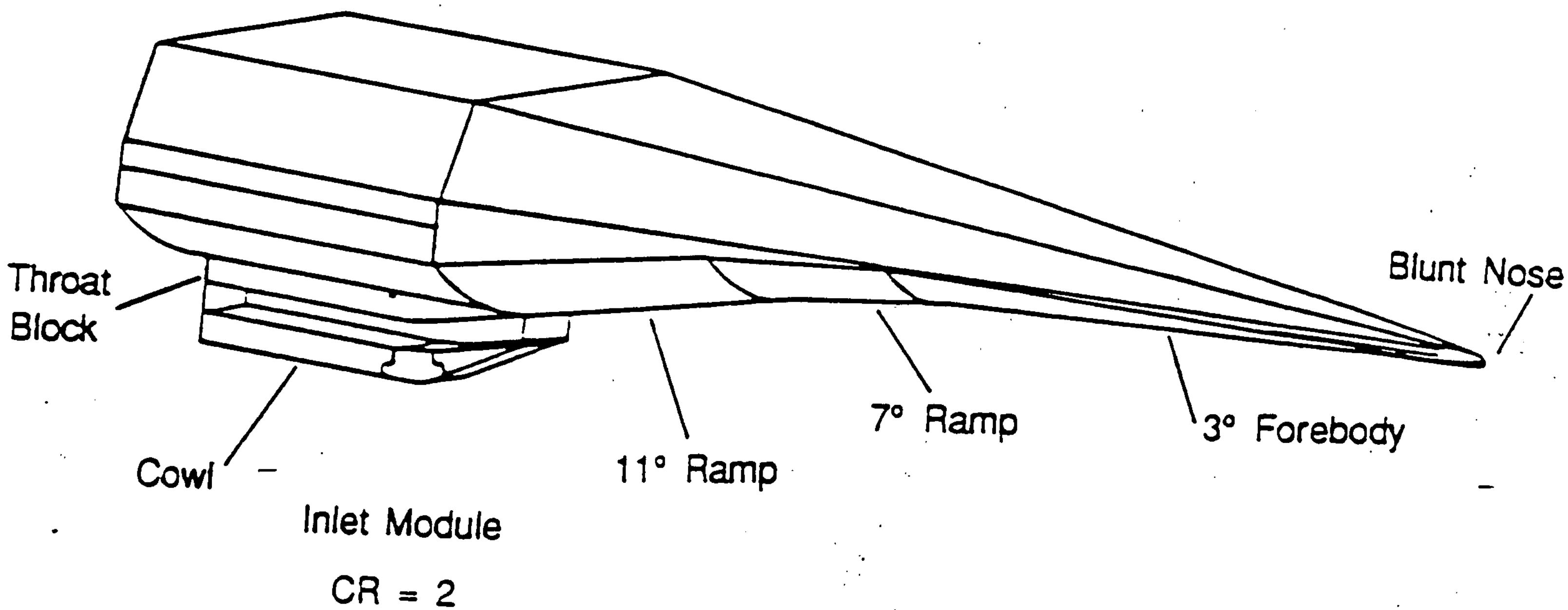
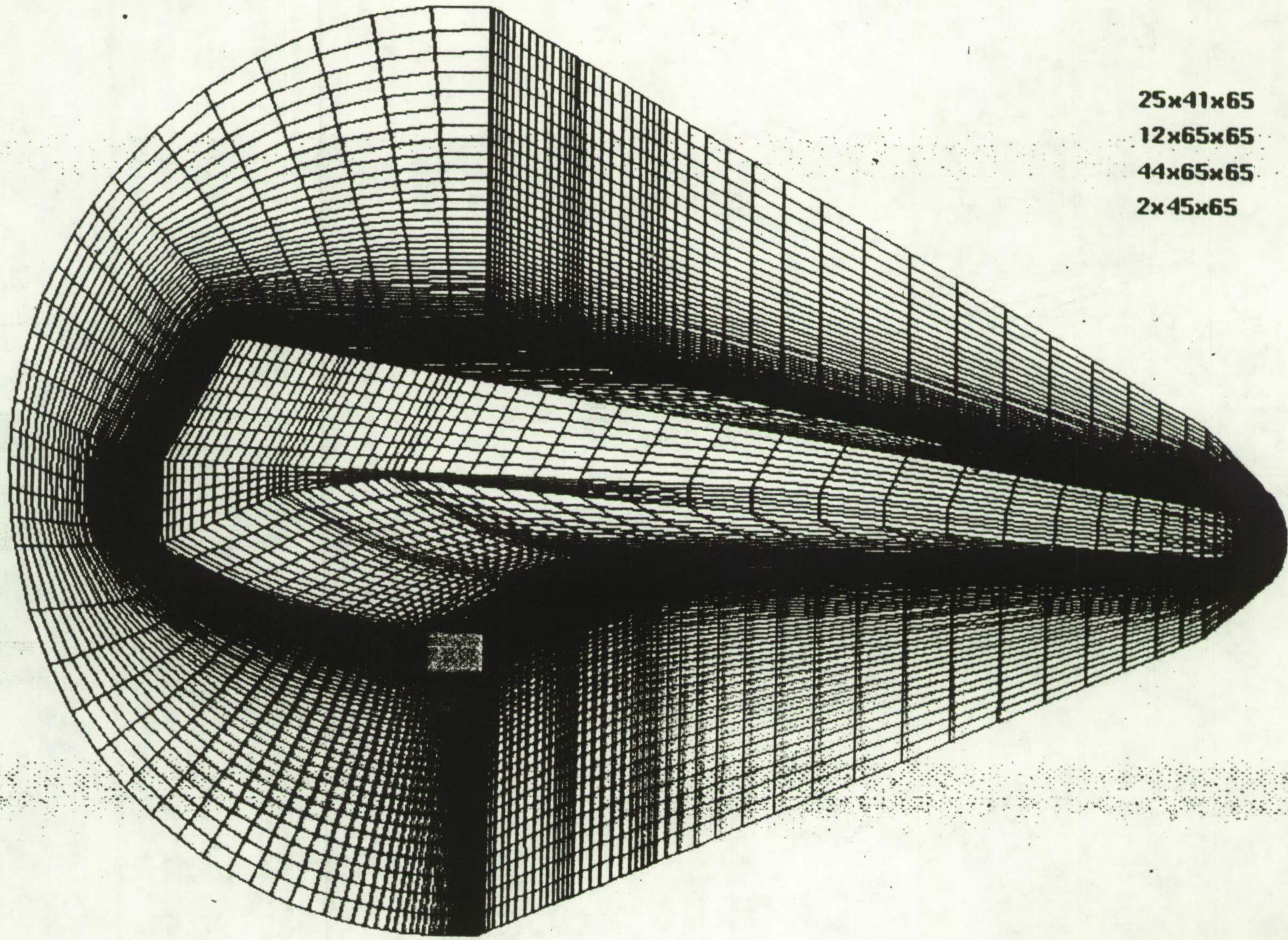
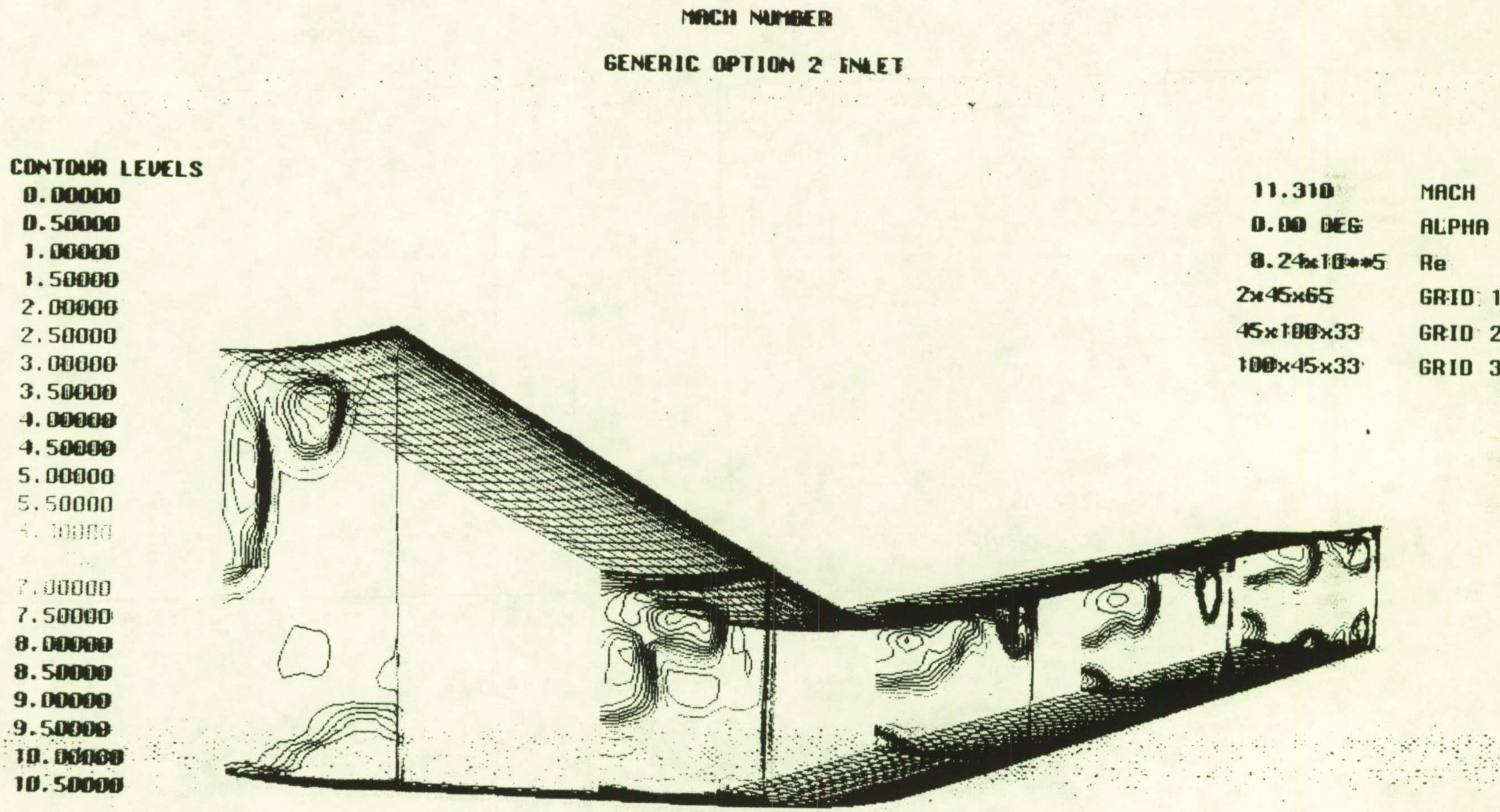


Figure 3. Schematic of 3-D Forebody/Inlet Integration Model.

GEOMETRY

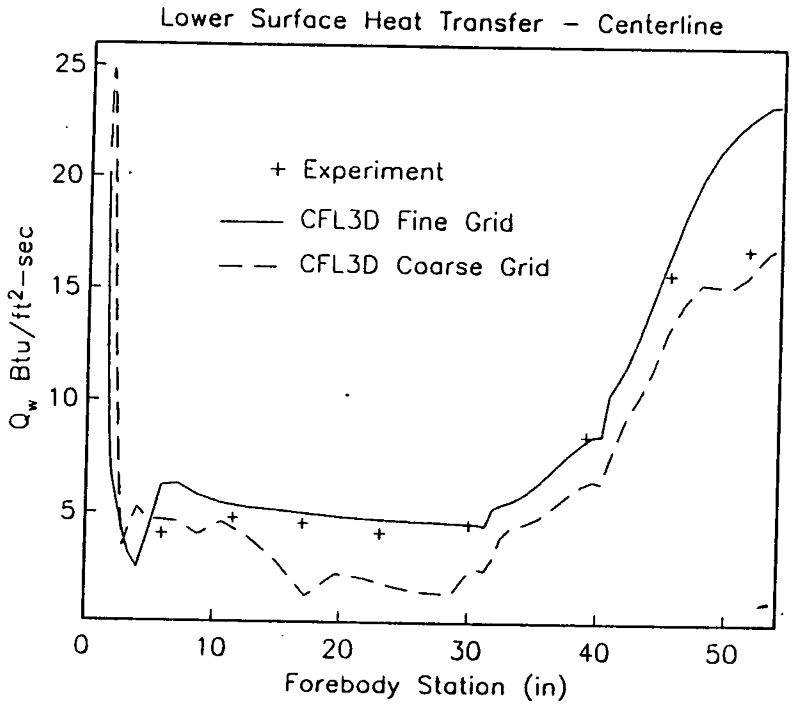
GENERIC OPTION 2 FOREBODY/INLET

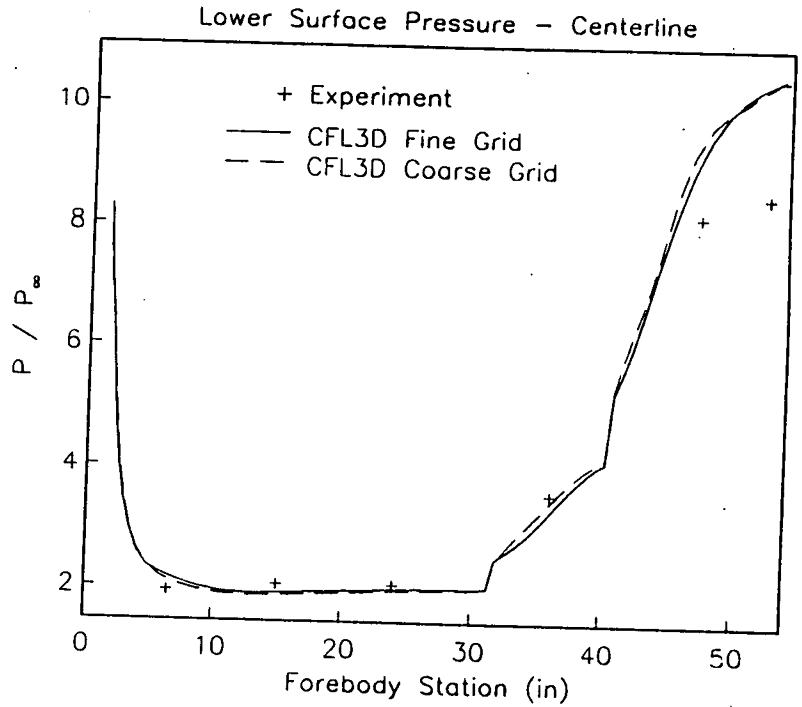




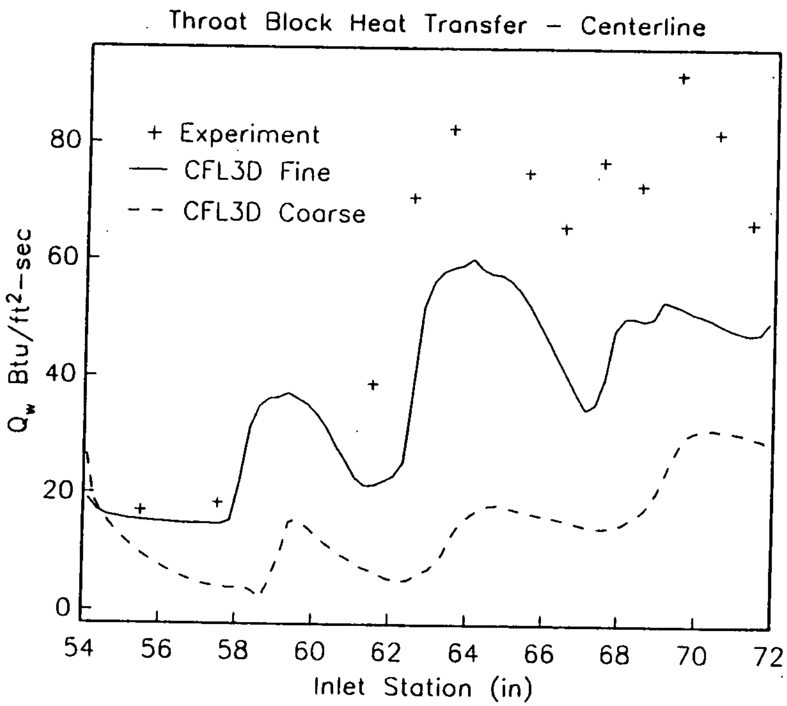
ORIGINAL PAGE IS
OF POOR QUALITY

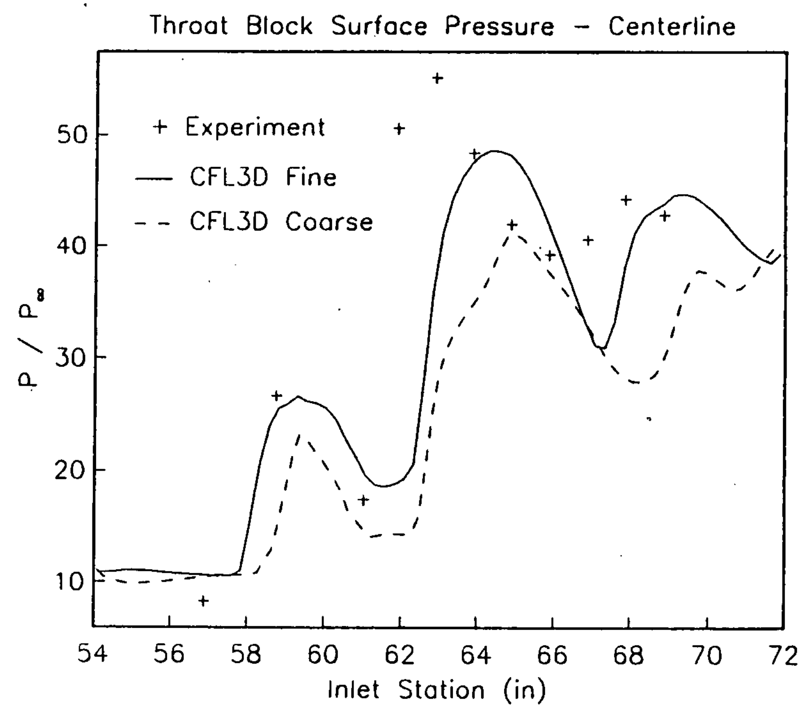
Lower Forebody Surface
Centerline Heat Transfer and Pressure



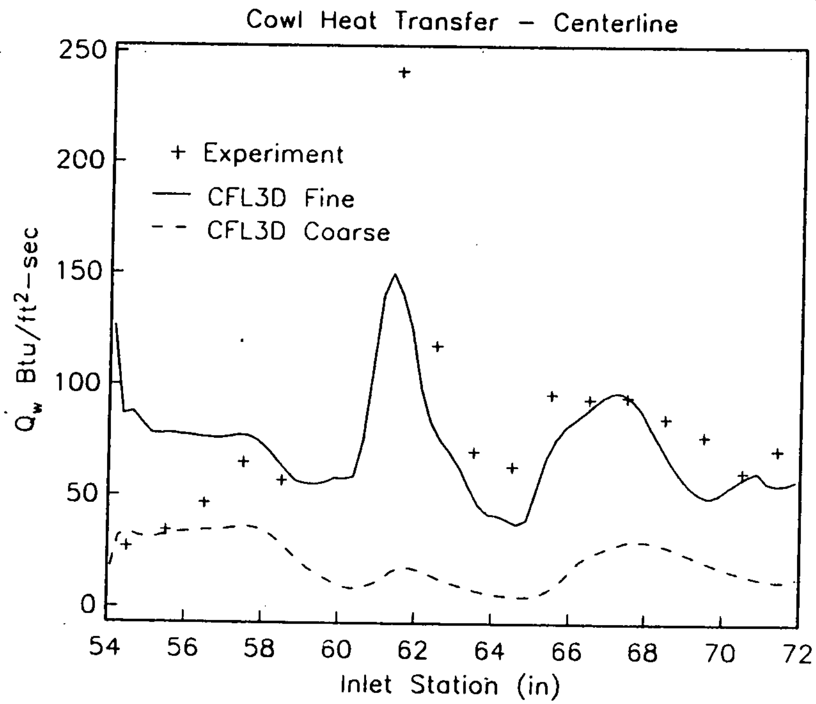


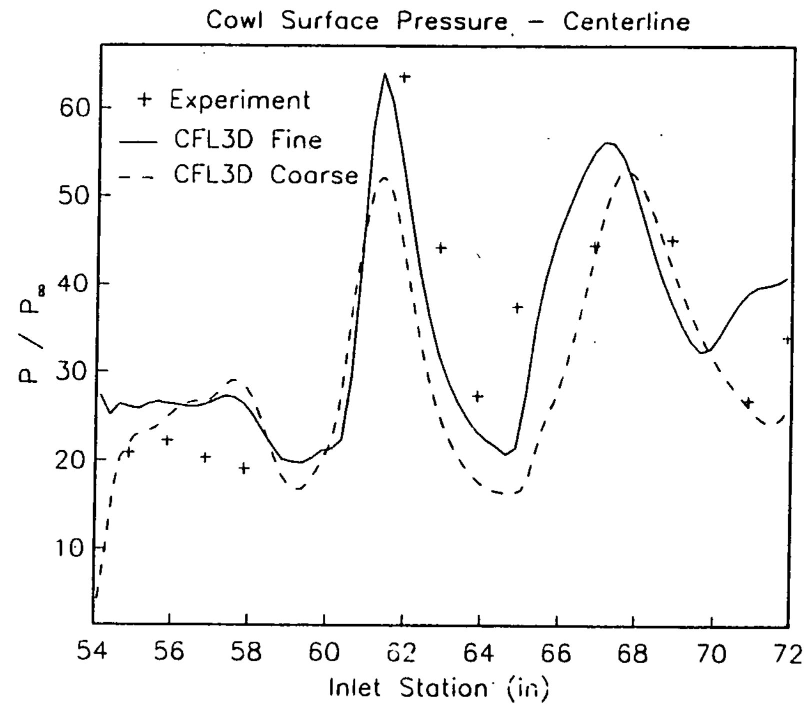
Throat Block
Centerline Heat Transfer and Pressure





Cowl
Centerline Heat Transfer and Pressure





SENSITIVITY STUDIES IN FOREBODY/INLET INTEGRATION

- CFD extremely useful tool to assess incremental changes in performance due to:
  - — geometry changes
  - — off-design conditions
  - — flow nonuniformities
  - — changes in transition onset location and extent
  - — changes in turbulence modeling

OMIT

DISCUSSION OF PAPERS PRESENTED BY RAMESH AGARWAL AND BY JOHNNY NARAYAN

John Porter: Can you use that "frozen" CFD code to define the effect of delta changes in the experiments?

Johnny Narayan: You can use the same set of grids from Mach 6 to 16. That type of calibration has not been done on many codes.

Dave Dolling: If both the experiment and computations are perfect gas and laminar, why is the heating rate half the experiment? What is wrong with code?

Johnny Narayan: The flow conditions are valid for what was presented earlier. This set of data is turbulent.

Robert Whitehead: Looking at the coarse grid and the fine grid, do you think a finer grid would be even better?

Johnny Narayan: We didn't try it. We only tried the two grids and showed that it did change with the fine grid. You can get closer to the data by finer grids.

David Dolling: That is not necessarily true because you see the peak heat rates go up by 200% and are still only 70% of the experiment.

Robert Whitehead: Why does the rate go up so rapidly? Is it due to shock impingement?

Johnny Narayan: Most probably. This is an LT code which also has a PNS version. There are probably many reasons for non-agreement not only the turbulence model.

Sanford Dash: This is an indication that we are not completing the job. We are stopping short, which should be done before proceeding with the next job.

Joe Marvin: Why didn't you do grid resolution studies in the spanwise direction? Did you do turbulence model variations to determine the influence of these models on the simulation? This information may be critical in providing the right information in the experimental data base.

Johnny Narayan: The point that you raise is valid. The issues associated with the turbulence models have to be addressed systematically such that the models and coding and so on are verified.

Joe Marvin: In transonic flows, the turbulence model's influence is very significant on the flowfields.

Johnny Narayan: On supercritical airfoils, we can see the same results with the codes independent of the turbulence model that was used.