Workshop on Computational Turbulence Modeling
(Sept. 15-16, 1993)

A Comparative Study of Turbulence Models in Predicting Hypersonic Inlet Flows

by

Kamlesh Kapoor

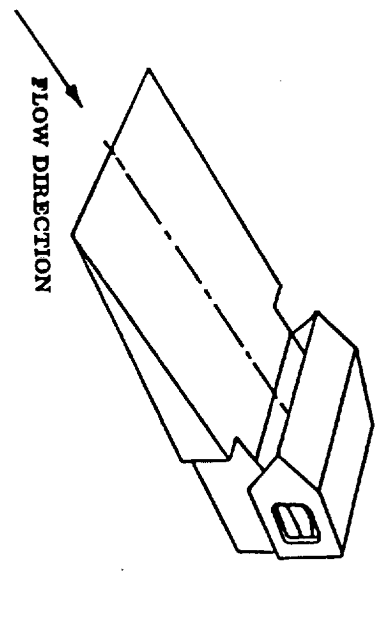
TEST CASE AND TURBULENCE MODELS CONSIDERED

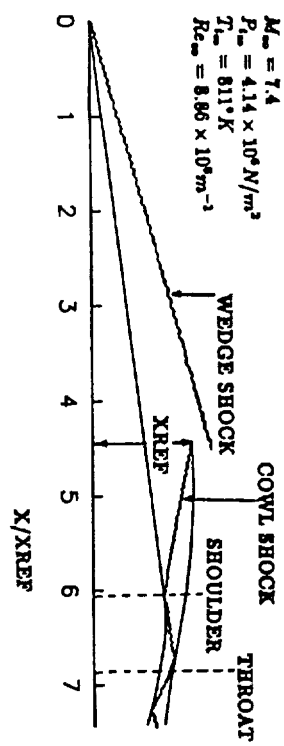
- THE NASA P8 INLET, WHICH REPRESENTS CRUISE CONDITION OF OF A TYPICAL HYPERSONIC AIR-BREATHING VEHICLE, WAS SELECTED AS A TEST CASE FOR PRESENT STUDY.
- PARC2D CODE, WHICH SOLVES THE FULL TWO-DIMENSIONAL REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS, WAS USED FOR THIS STUDY.
- THE RESULTS ARE PRESENTED FOR A TOTAL OF SIX VERSIONS OF ZERO- AND TWO-EQUATION TURBULENCE MODELS.
  - ZERO-EQUATION MODELS
    - THE BALDWIN-LOMAX MODEL
    - THE THOMAS MODEL
    - A COMBINATION OF THE B.L./THOMAS MODEL
  - TWO-EQUATION MODELS
    - LOW-REYNOLDS NUMBER MODELS
      - THE CHIEN MODEL
      - THE SPEZIALE MODEL
    - HIGH-REYNOLDS NUMBER MODEL
      - THE LAUNDER AND SPALDING MODEL

EXPERIMENTAL BACKGROUND

- THE EXPERIMENTAL INVESTIGATION OF THE P8 INLET WAS CONDUCTED AT NASA AMES' 3.5-FOOT HYPERSONIC WIND TUNNEL.
- THE INLET WAS A MACH 7.4 RECTANGULAR MIXED COMPRESSION (WITH INTERNAL COMPRESSION RATIO OF 8) DESIGN WITH EXITING SUPERSONIC FLOW.
  - INLET COWL HEIGHT - 18.33 CM.
  - OVERALL LENGTH - 136.2 CM.
- TEST CONDITIONS:
  - MACH NO - 7.4
  - TOTAL PRESSURE - 4.14×10^{6} N/m^2
  - TOTAL TEMPERATURE - 811°K
  - REYNOLDS NO - 8.86×10^{6}/m
  - MODEL WAS WATER COOLED AND ISOTHERMAL WALL CONDITIONS WERE MAINTAINED; THE WALLS TEMPERATURE - 302°K
- THE TRANSITION POINTS:
  - CENTERBODY - 40 PERCENT FROM WEDGE L.E. EDGE TO INLET ENTRANCE.
  - COWL - HALFWAY BETWEEN INLET ENTRANCE AND THROAT.

SCHEMATIC DIAGRAM OF P8 INLET MODEL

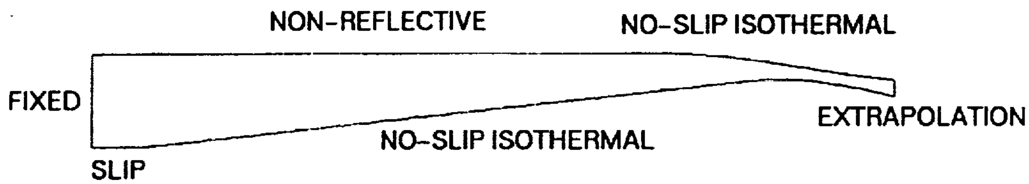




THE COMPUTATIONAL GRID

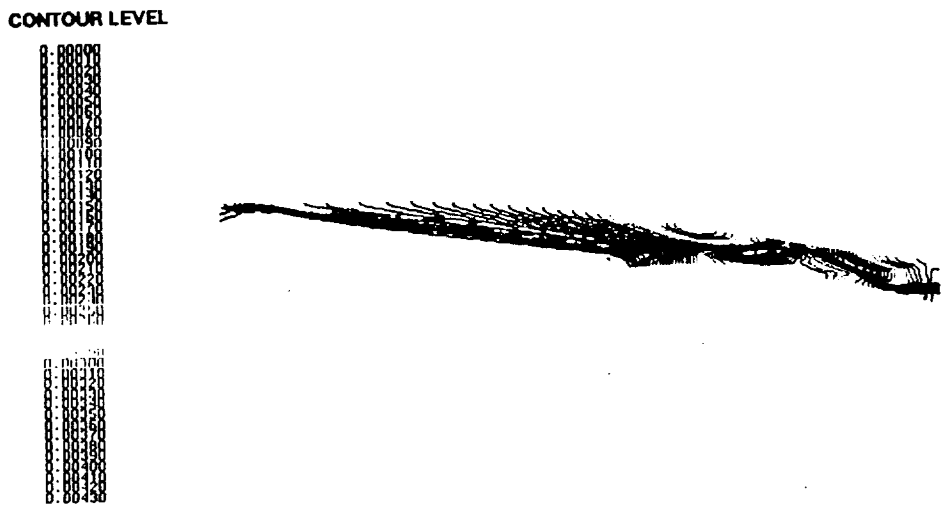
- GRID SIZE WAS 221 x 91.
- GRID WAS NONUNIFORM IN X DIRECTION:
  - PACKED ON BOTH ENDS FROM THE WEDGE L.E. TO THE COWL L.E.
  - GEOMETRICALLY STRETCHED FROM THE COWL L.E. TO THE EXIT OF THE INLET.
- IN Y DIRECTION, THE GRID WAS PACKED USING HYPERBOLIC TANGENT FUNCTION . YPLUS WAS APPROXIMATELY 1 AWAY FROM BOTH WALLS.
- A SEPARATE GRID WAS MADE FOR THE LAUNDER AND SPALDING MODEL AND YPLUS OF APPROXIMATELY 30 WAS USED AWAY FROM THE WALLS.

BOUNDARY CONDITIONS

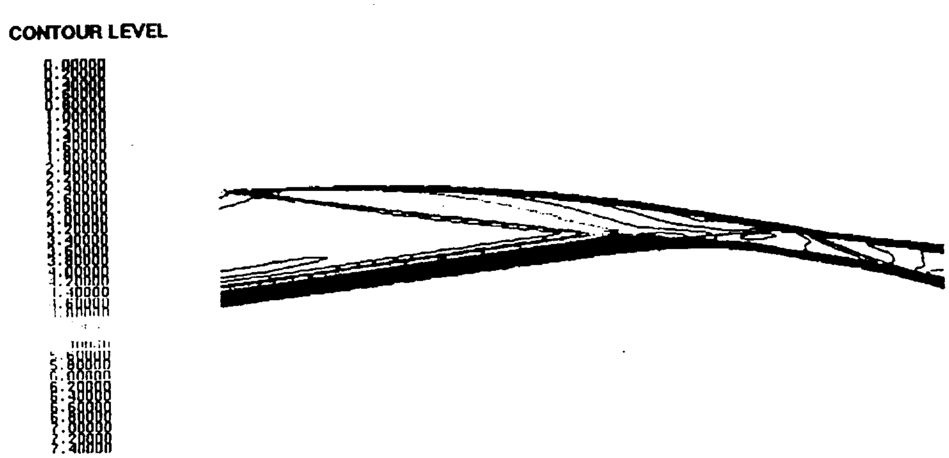


DENSITY CONTOURS FOR P8 INLET

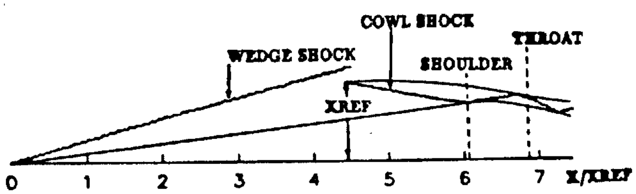
PRESSURE CONTOURS FOR P8 INLET

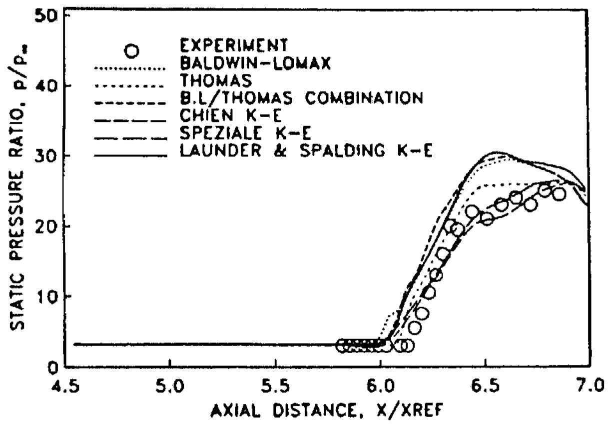


MACH NUMBER CONTOURS FOR P8 INLET

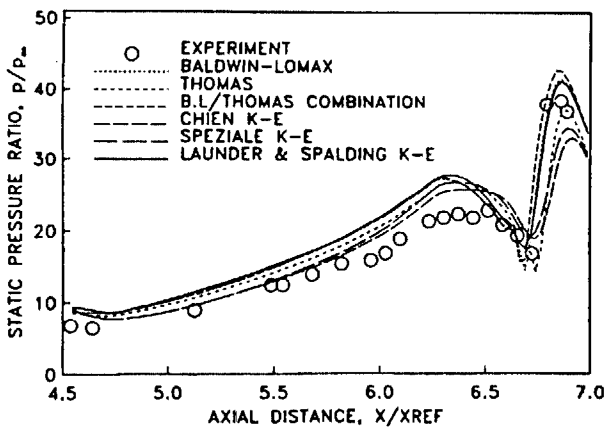


SURFACE PRESSURE DISTRIBUTIONS



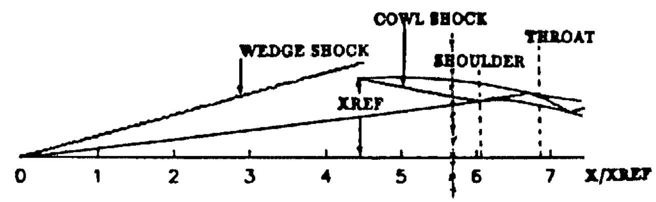


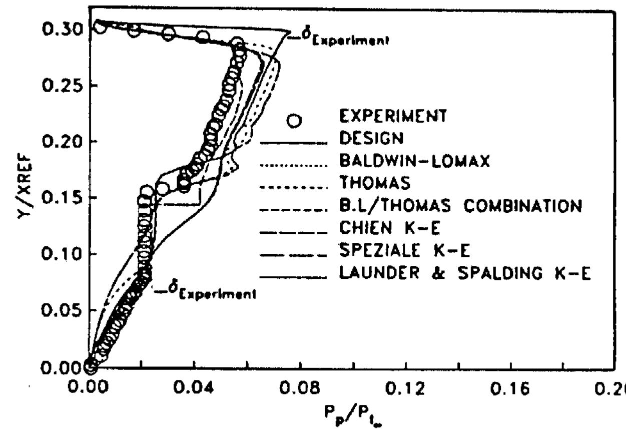
(A) ON THE CENTERBODY

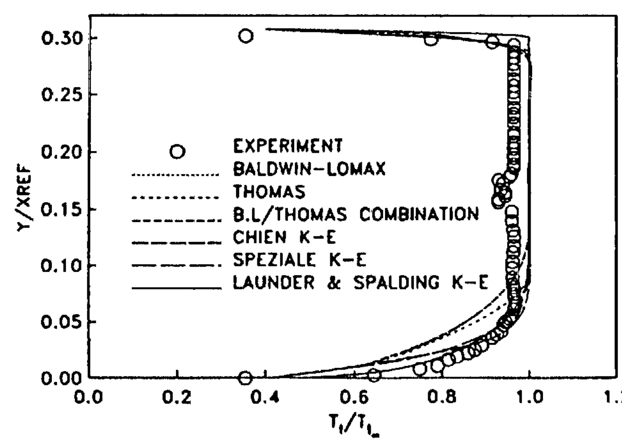


(B) ON THE COWL

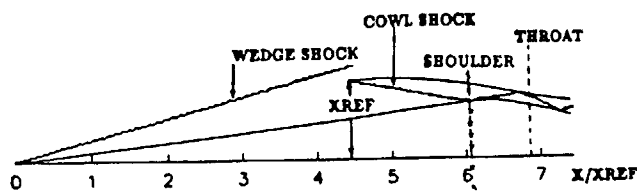
PITOT PRESSURE AND TOTAL TEMPERATURE DISTRIBUTIONS AT X/XREF = 5.67

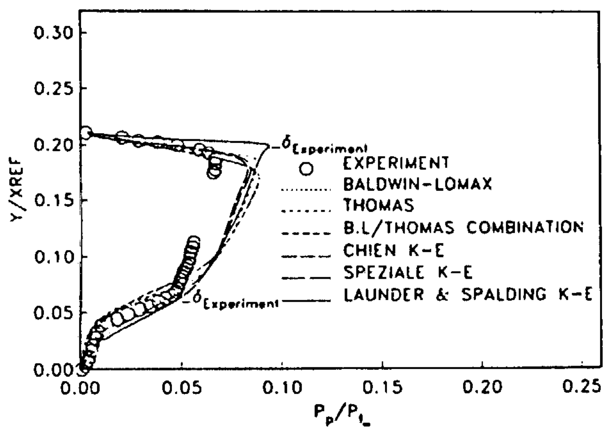


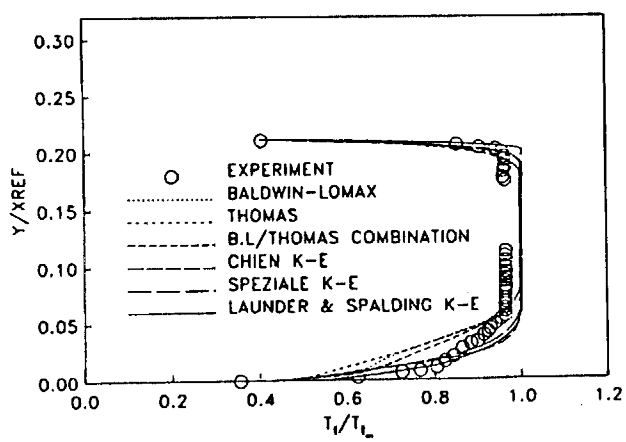




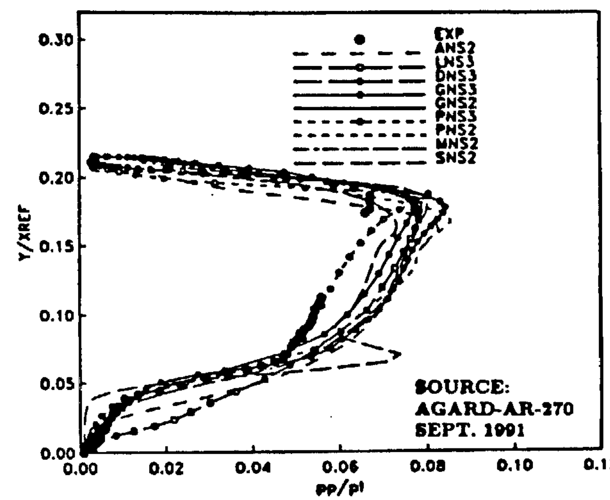
PITOT PRESSURE AND TOTAL TEMPERATURE DISTRIBUTIONS AT X/XREF = 6.09







PITOT PRESSURE DISTRIBUTITIONS



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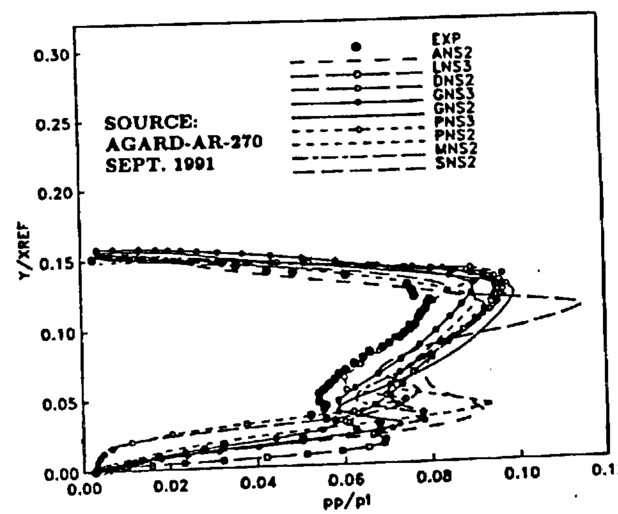
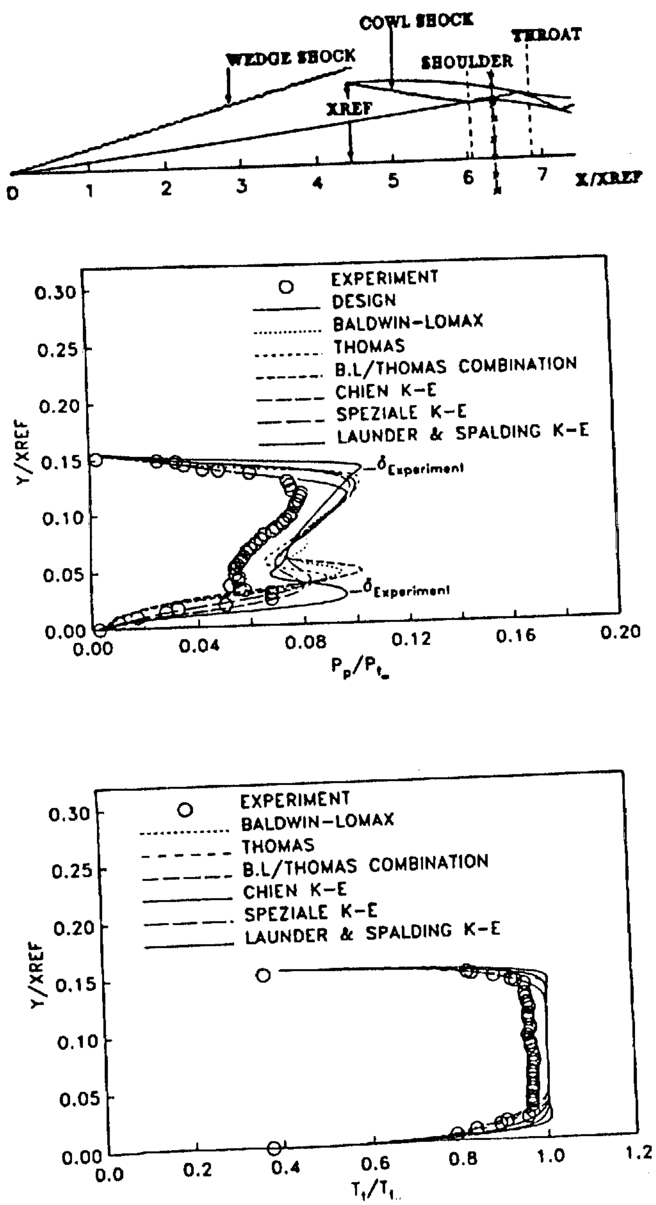
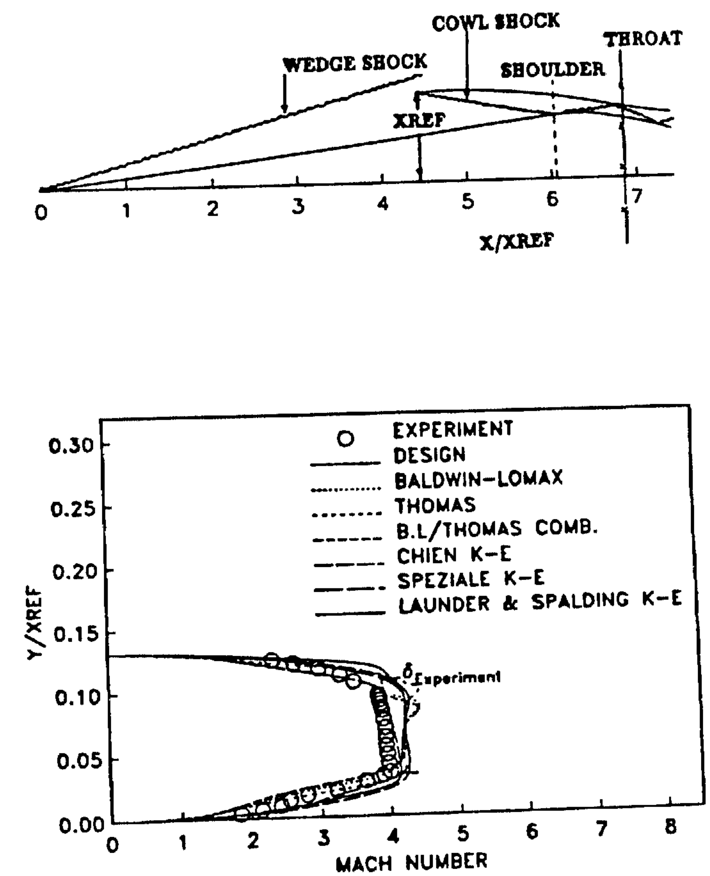


AT X/XREF = 6.37

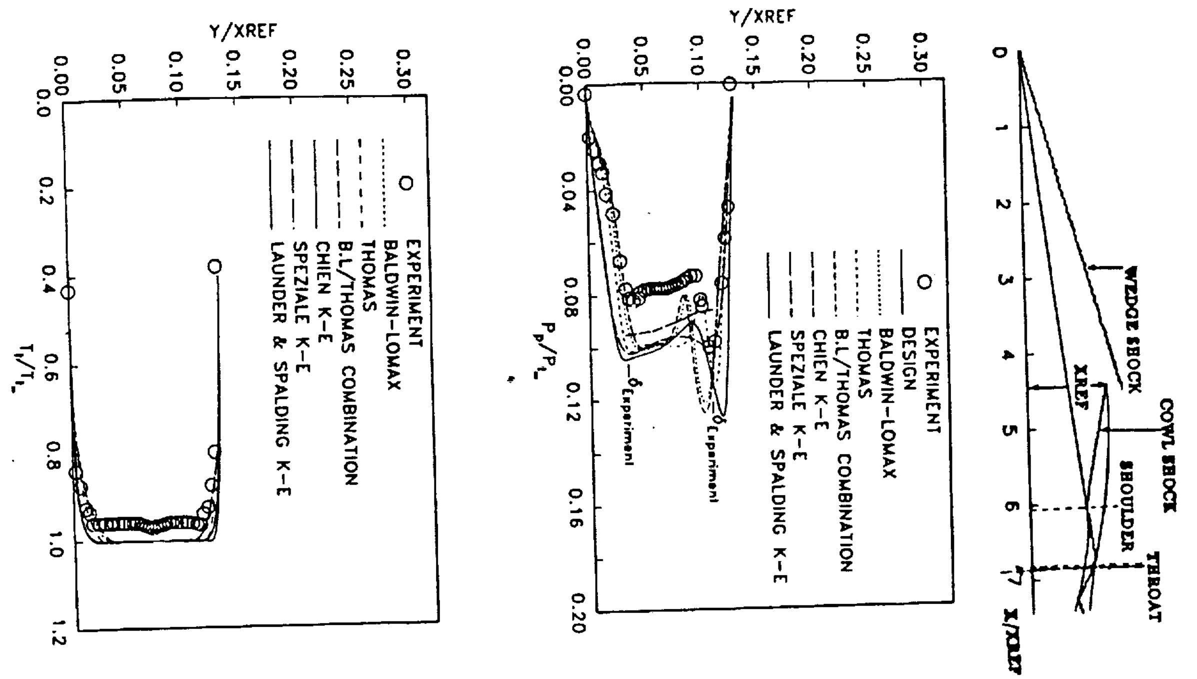
PITOT PRESSURE AND TOTAL TEMPERATURE DISTRIBUTIONS AT X/XREF = 6.37



MACH NUMBER DISTRIBUTITIONS AT THE THROAT



PITOT PRESSURE AND TOTAL TEMPERATURE DISTRIBUTIONS AT THE THROAT



CONCLUSIONS

- A COMPUTATIONAL STUDY HAS BEEN CONDUCTED TO EVALUATE THE PERFORMANCE OF VARIOUS TURBULENCE MODELS.
- THE THOMAS MODEL COMPARES VERY WELL WITH THE EXPERIMENTAL DATA, AND IT PERFORMS BEST AMONG THE ZERO-EQUATION MODELS.
- THE BALDWIN-LOMAX MODEL AND ITS COMBINATION WITH THOMAS MODEL ARE NOT ABLE TO RESOLVE THE PROBLEM OF SHOCK WAVE AND BOUNDARY-LAYER INTERACTION ACCURATELY. THE BALDWIN-LOMAX MODEL PREDICTS SEPARATION NEAR THE INTERACTION OF THE COWL SHOCK WITH THE WEDGE BOUNDARY LAYER, WHERE NONE IS KNOWN TO EXIST IN EXPERIMENTS.
- THE CHIEN AND SPEZIALE MODEL COMPARE VERY WELL WITH THE EXPERIMENTAL DATA, AND PERFORMS BETTER THAN THE THOMAS MODEL, PARTICULARLY NEAR THE WALLS. THE LAUNDER AND SPALDING MODEL DOES NOT PERFORM AS GOOD AS THE CHIEN AND SPEZIALE MODELS.
- AS THE CPU TIME REQUIRED FOR THE THOMAS MODEL IS FAR LESS THAN THE TWO-EQUATION MODELS, IT IS CONCLUDED THAT THE THOMAS MODEL IS BEST SUITED FOR THE PREDICTIONS OF PRESSURE DISTRIBUTIONS, AND THE CHIEN AND SPEZIALE MODELS ARE BEST TO CALCULATE FLOW QUANTITIES NEAR THE WALLS.