AD-A134 178 NUMERICAL TECHNIQUES FOR HIGH INCIDENCE REENTRY AERODYNAMICS(U) LOCKHEED MISSILES AND SPACE CO INC PALO ALTO CA R WHITEHEAD ET AL. 23 SEP 83 N00014-82-C-0690

1/1

UNCLASSIFIED F/G 20/4 NL

END
DATE
FILMED
DTIC

1.0 4.5 2.8 2.5 5.0 3.2 2.2 5.6 3.6 4.0 2.0 1.1 1.8 1.25 1.4 1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

NUMERICAL TECHNIQUES FOR HIGH INCIDENCE REENTRY AERODYNAMICS
PROGRESS REPORT

September 23, 1983 AD-A134178

Contract Number: N00014-82-C-0690
Sponsor: Office of Naval Research
Period of Performance: 6-24-82 through 6-23-84
Technical Monitor: R. Whitehead (202) 696-4404
Project Leader: R. Conti (415) 858-4036

PROGRESS DURING THE REPORTING PERIOD

The investigation of reentry flowfields at very high incidence ~~conducted~~ under the previous contract (N00014-81-C-0380) showed that the Lockheed Navier-Stokes computer code is capable of producing accurate flowfield solutions at angles of attack up to about 60 degrees. ~~(see Interim Technical Report for that contract, document LMSC D876839)~~. Current work ~~under the present contract~~ is centered around: a) using this code as a tool to investigate the properties of high incidence flows, and b) extending the present code to allow it to compute flows at incidence beyond 60 degrees, in order to cover the full range of incidence encountered by the reentry vehicles of the Fleet Ballistic Missile (FBM) System. Progress made to date on the various tasks associated with this work is as follows:

Task 1. Assessment of turbulence in the near wake.

A literature search was conducted to determine whether turbulence modeling needs to be included in the high incidence code to treat the near wake. Data for flow in the wake of typical reentry shapes has been compiled by Browand, Finston, and McLaughlin (1967) and used to determine the laminar and turbulent regimes of the near wake along a typical trajectory (see figure 1). Their conclusion is that for typical trajectories the near wake is laminar at altitudes above about 27 km. The high-incidence regime of interest to the Fleet Ballistic Missile System occurs at altitudes above 75 km, where the incidence of reentry vehicles is typically greater than 35 degrees. At 27 km where transition in the near wake can be expected, the incidence is typically only a few degrees, and the near wake does not significantly affect the flowfield about the forebody. Therefore, there seems to be little point in including turbulence modeling for the near wake at high incidence.

Task 2. Checks on the validity of the conical approximation at high incidence.

The inviscid flow over a sharp cone is self-similar, as all flow variables are constant along rays through the cone tip. This convenient property holds locally for viscous flow, that is it may be assumed that derivatives of the flow variables are zero when taken along rays through the cone tip. This conical approximation applied to viscous flow over sharp cones was studied by McRae (1976) and it has proved valuable in simplifying the computation of sharp-cone flows. It allows a local solution to be formed independently at any axial station and thus reduces the sharp-cone problem from three dimensions to two. It was used extensively in our previous calculations and the results compared favorably with experiment. The computational capabilities developed under this contract give us a good oportunity to check this approximation against fully three-dimensional solutions. Thus, under this task numerical checks were made by comparing two-dimensional solutions obtained using the local conical approximation at single axial stations with three-dimensional solutions which cover much of the cone length. These latter solutions were marched from a location near the cone tip (cone length / 100), where lee-side vortices have not yet developed, to the cone base. Comparisons were made with the conical solutions at several stations between the tip and the base. Although some details of these tests are still being investigated, results to date have shown good agreement between the two calculations. Vortices developed during the marching procedure compare well with the vortices found in the calculations made using the local conical approximation. The results of these numerical experiments are doubly useful. Besides testing the local conical approximation they provide interesting data on the development of lee-side vortices, which is the subject of Task 3.

Task 3. Studies of vortex formation.

During the previous contract and under Task 2 of the present contract numerical tools were developed and tested for use in the study of very high incidence flows. Under this task these tools have been applied to investigate the formation of lee-side vortices found on sharp and blunt cones at very high incidence in hypersonic flow. Various numerical experiments have been run to determine the effect of changes in Reynolds number, Mach number, and wall temperature on lee-side vortex formation. Table 1 shows the flow parameters for these numerical experiments, and figures 2 and 3 show selected results.

Figure 2 shows velocity vector plots for a variety of flows over a 10 degree half-angle sharp cone at 24 degrees angle of attack. The vector plots shown in this figure are arranged at the corners of a cube in a three-dimensional space in which variations of temperature, Mach number, and Reynolds number appear along the three coordinate axes. A case corresponding to the experimental conditions investigated in a wind tunnel by Tracy (1963) appears at the rear lower corner of the cube, and a case corresponding to nominal flight conditions in the opposite corner. These two cases differ in Mach number, Reynolds number and temperature. The effect of changes in any single parameter appear along edges of the cube. Vortices are clearly visible for the wind-tunnel case while they appear insignificant in the nominal flight case. The separation point is indicated by the arrows labled "s". The angular position of separation from the windward side is also given in degrees. As may be seen, Mach number and Reynolds number have a dominant effect on the development of the vortices, while temperature effects seem to be slight. Similar, though less complete results are shown in figure 3 for the same sharp cone at 40 degrees incidence.

Task 4. Computation of uncoupled base flow

The investigations performed under the previous contract and the early phases of the current one indicate that the high-incidence limit of the Navier-Stokes computer code (about 60 degrees) is due to upstream influence of the base flow on the windward flow when the latter becomes subsonic at high incidence (see Final Report of Contract N00014-81-C-0380 and AIAA Paper 83-1669). Therefore, to remove this limitation and extend the capability of the numerical simulation to higher incidence, one should include the base flow in the flowfield computation. One of the motivations for proceeding with this extension is the observation made in flight tests of the FBM system that at about 65 degrees of incidence there is an unexplained forward shift of the center of pressure, with the corresponding decrease of static margin. This phenomenon is accentuated at 75 degrees, and it creates some concern about the design of more advanced reentry vehicles, which are designed with a smaller static margin than the present ones.

To extend the capability of the present Navier-Stokes code to higher incidence a progressive plan has been formulated to compute first the uncoupled base flow at zero incidence, then at increasingly high incidence, and finally to couple it to the forebody flow. The first step has been achieved, and computations of the flow in the near wake of a sharp cone at zero incidence have been performed. To assess the validity of these computations, a literature search was made to collect relevant information. The major difficulty encountered in validating the numerical simulations with experimental data is the well-known fact that near-wake wind-tunnel experiments are very sensitive to support interference. Even the smallest wire supports can alter substantially the flow in the near wake (see Dayman, 1963). It appeared that the experiments performed by Blankson (1973) with a magnetically suspended model would circumvent the interference problem, and thus these data were chosen to validate the numerical simulation. A computer run was made for the same flow and model conditions used in these experiments, and results are shown in figure 4. These results are in qualitative agreement with the data, but there are discrepancies, which are particularly noticeable with respect to the extent of the recirculating flow region. Closer inspection of the Blankson data reveals some inconsistencies that leave the experimental results open to some question. For instance, as may be seen in figure 5 the bow shock location obtained by measurements of Blankson's figure is not where it should be and it is evident from the Pitot pressure outside the bow shock that there was a progressive increase in free stream Mach number along the wake from Mach = 6.46 to 6.68. This indicates significant non-uniformity in tunnel flow. Because of the doubts raised in regard to Blankson's experiments a computerized literature search was made in the hope of finding better data for comparison. The conclusion of our search is that, the only data which are suitably complete and for which the test conditions are appropriate were taken with a wire supported model (for example Schmidt, 1967). Comparison with a variety of experimental data is possible but doubts as to the accuracy of the experimental data are likely to persist.

Presentations.

R. P. Reklis, R. J. Conti, and P. D. Thomas, "Numerical Simulation of Separated Vortical Flow Over Cones at Very High Incidence", First Lockheed Corporate Symposium on Computational Aerodynamics, Burbank, CA, April 12-14 1983.

R. P. Reklis, R. J. Conti, and P. D. Thomas, "Numerical Simulation of Hypersonic Viscous Flow Over Cones at Very High Incidence", AIAA Paper 83-1669, AIAA 16th Fluid and Plasma Dynamics Conference, Danvers, Massachusetts, July 12, 1983.

References

1. Isaiah M. Blankson, "Experimental Study of the Mean Flow in a Laminar Axisymmetric Cone Near Wake at Mach Number = 6.3 Using Magnetic Model Suspension", AFOSR-TR-74-1516, 1973.

2. F. Browand, M. Finston, and D. McLaughlin, "Wake Measurements Behind a Cone Suspended Magnetically in a Mach Number 4.3 Stream" AGARD CP No. 19, 1967.

3. Bain Dayman Jr., "Support Interference Effects on the Supersonic Wake", AIAA Journal, 1, pp. 1921-1923, 1963.

4. David S. McRae, "A Numerical Study of Viscous Cone Flow at High Angle of Attack", AIAA Paper 76-97, 1976.

5. R. P. Reklis, R. J. Conti, and P. D. Thomas, "Numerical Simulation of Hypersonic Viscous Flow Over Cones at Very High Incidence", AIAA Paper 83-1669, 1983.

6. Edward M. Schmidt and Robert J. Cresci, "An Experimental Investigation of Hypersonic Flow Around a Slender Cone", Polytechnic Institute of Brooklyn Report No. 1031, 1967.

7. Richard R. Tracy, "Hypersonic Flow Over a Yawed Circular Cone" GALCIT Memo No. 69 Graduate Aeronautical Laboratory, California Institute of Technology (1963).

Table 1. Cases Run

Case	Re	Tw	T	M	α
1	360,000	327	58.55	7.95	24
2	36,000	327	58.55	7.95	40
3	36,000	327	58.55	16	40
4	36,000	327	58.55	24	40
5	360,000	163.5	58.55	7.95	24
6	360.000	81.75	58.55	7.95	24
7	36,000	327	58.55	7.95	24
8	3,600	327	58.55	7.95	24
9	360.000	327	58.55	16	24
10	360,000	327	58.55	24	24
11	360.000	376	188	7.95	24
12	36,000	376	188	24	24
13	360,000	376	188	24	24
14	36,000	327	58.55	24	24
15	36,000	376	188	7.95	24
16	3,600	327	58.55	7.95	40
17	36,000	327	58.55	24	40
18	36,000	376	188	7.95	40

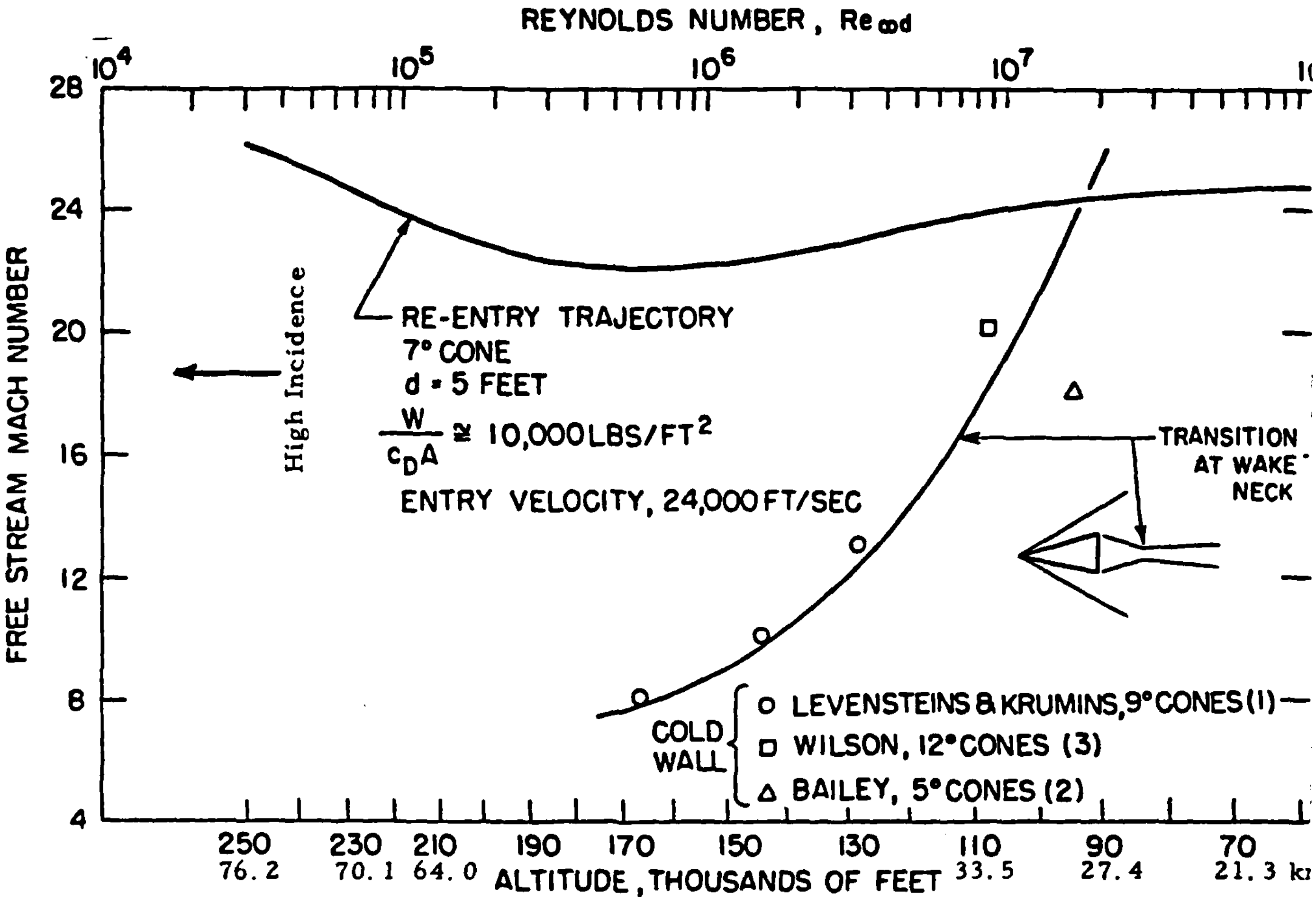

Fig. 1. Typical Reynolds number, Mach number history for a slender reentry vehicle. from Browand, Finston, and McLaughlin (1967)

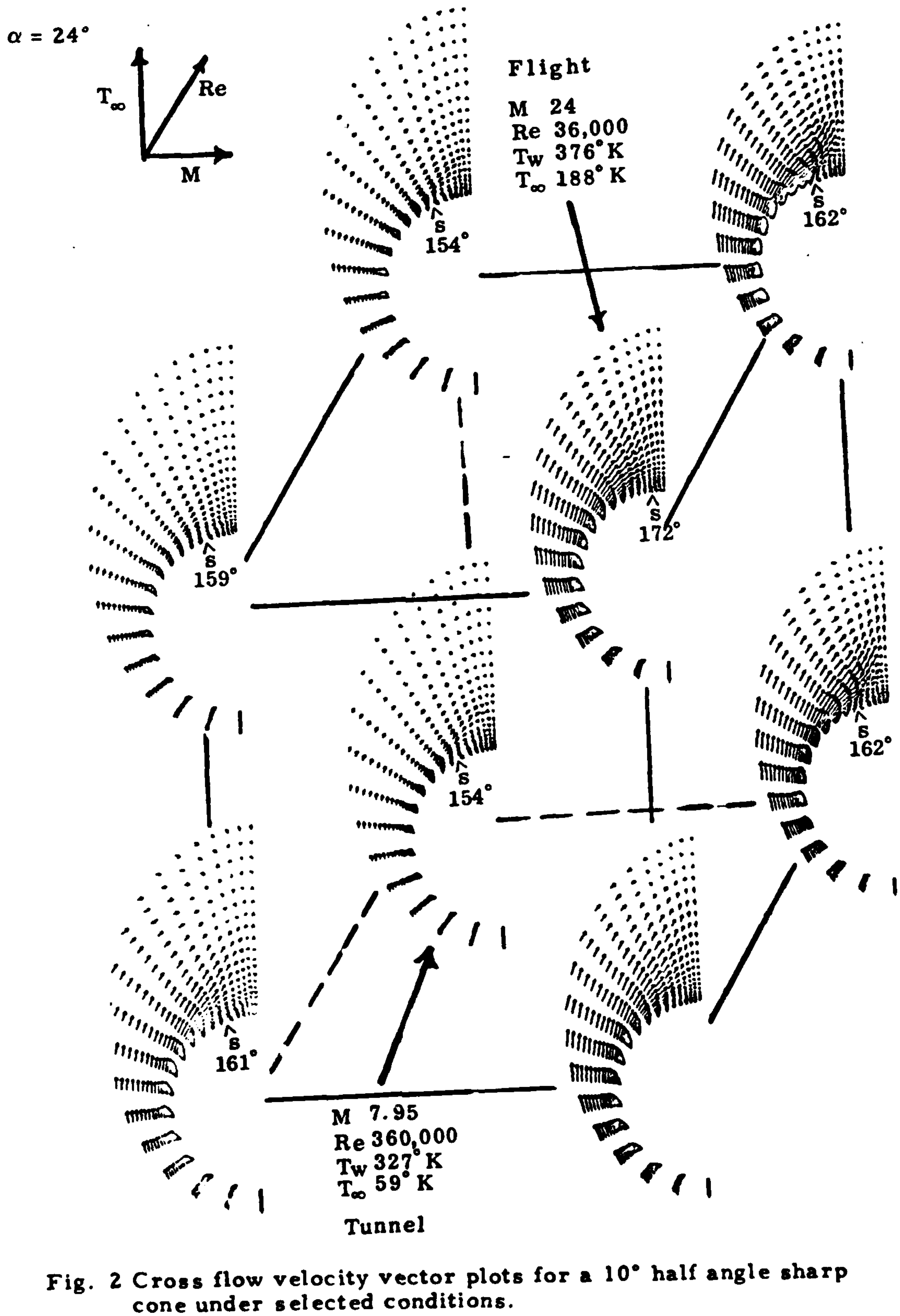

Fig. 2 Cross flow velocity vector plots for a 10° half angle sharp cone under selected conditions.

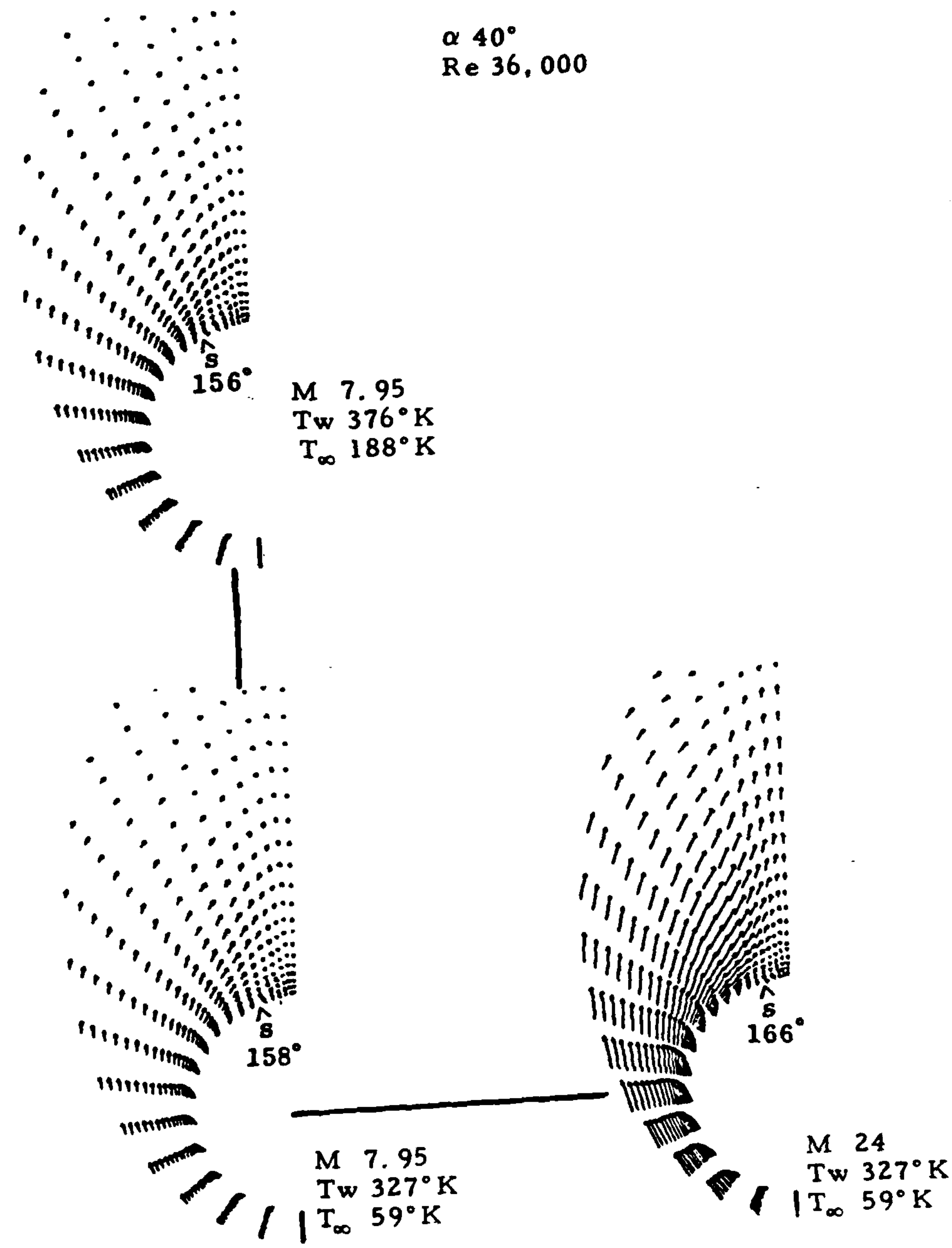

Fig. 3 Cross flow velocity vector plots for a 10° half angle sharp cone under selected conditions.

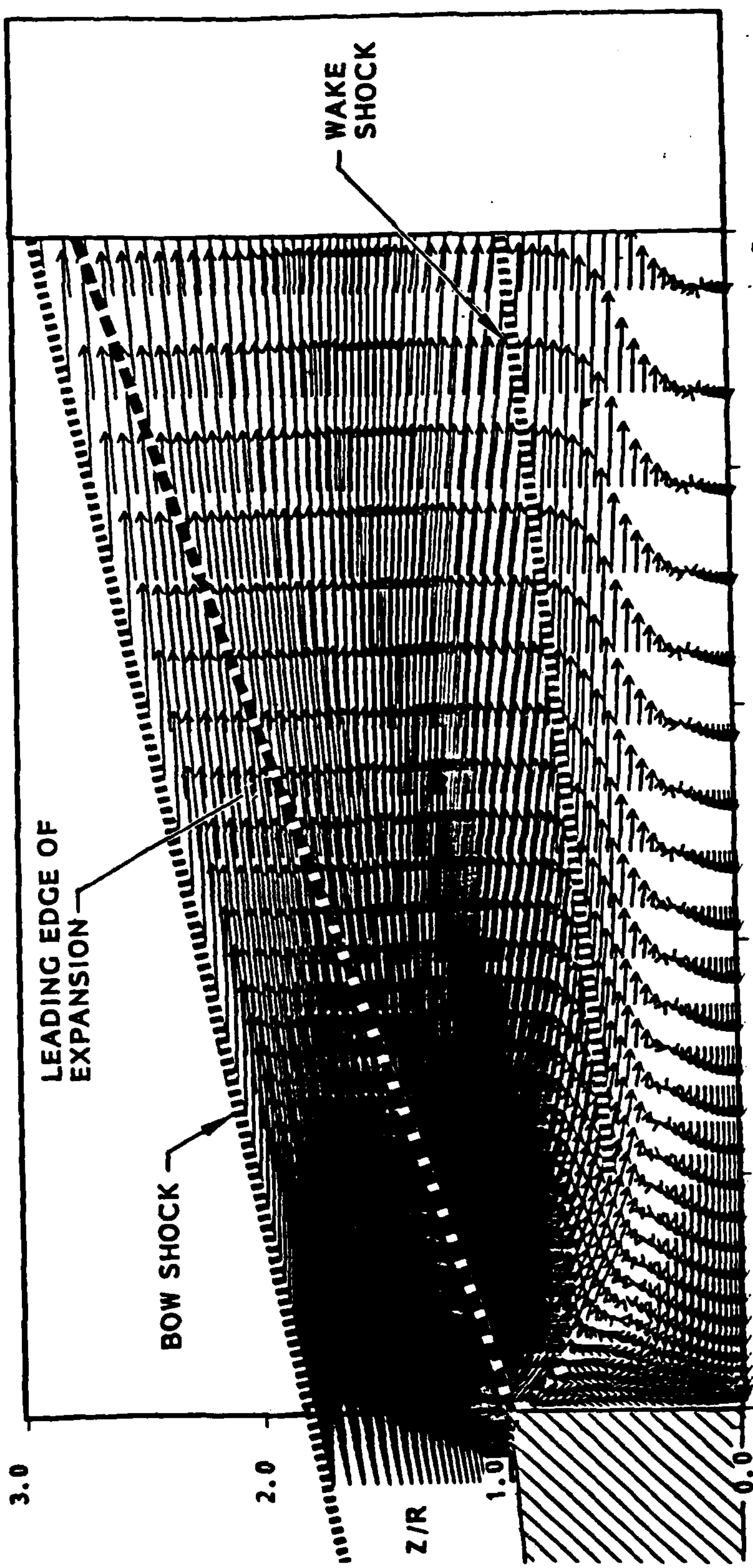

Fig.4 Velocity vectors in the laminar near wake of a sharp 7 degree cone in hypersonic flow ($M = 6.32$, $Re_D = 86,000$). from Reklis, Conti, and Thomas (1983)

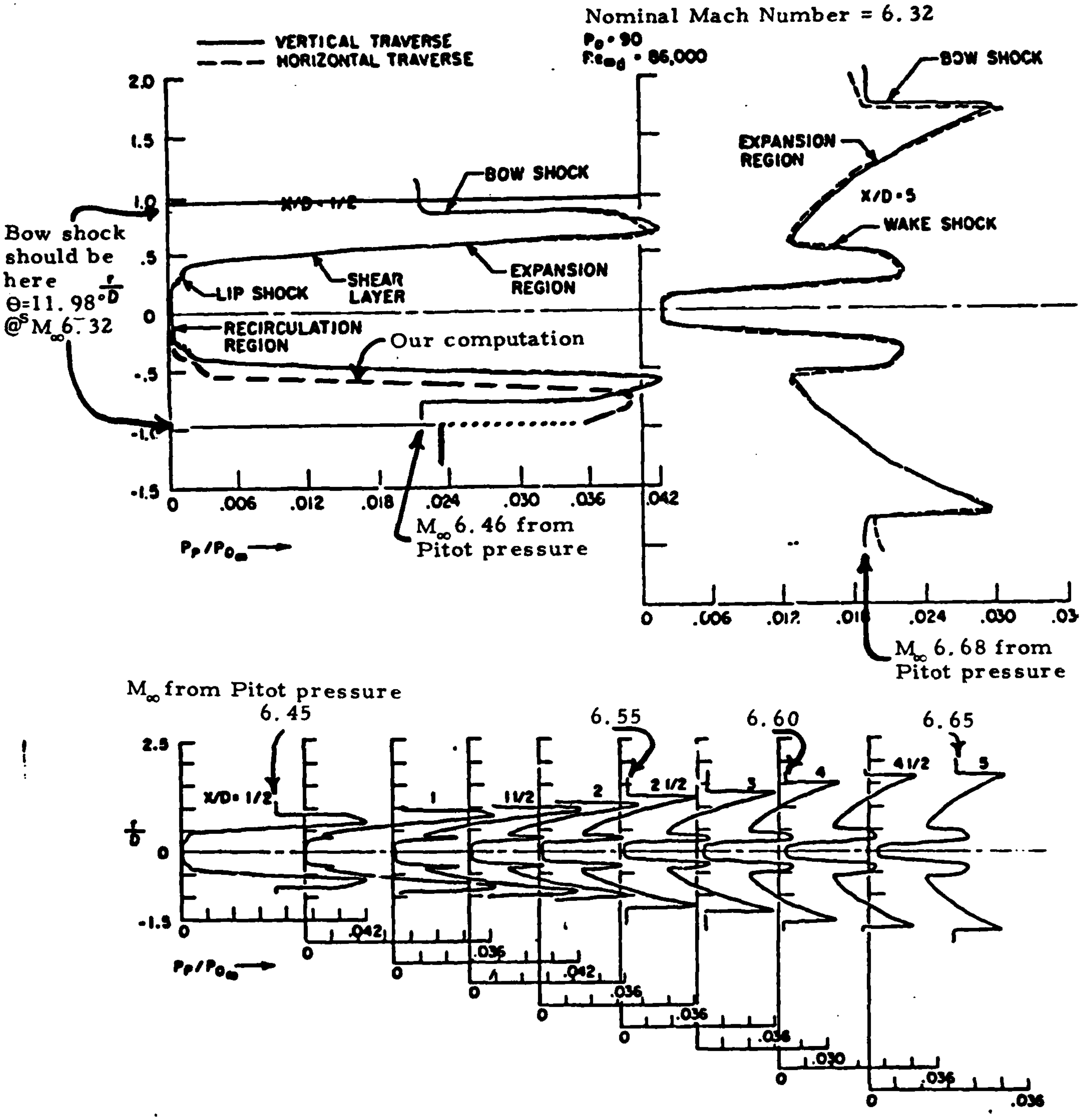

Fig. 5 **Pitot pressure profiles at zero angle of attack (sharp cone). Re_{∞_D} =86,000**

Experimental Pitot pressure profiles shown above are taken from Blankson (1973). The nominal Mach number in the free stream given for the experiment was 6.32. Note that the actual free stream Mach number steadily increased over the wake region. Note also that the experimental and computed pressure profiles differ significantly and that the experimental and computed bow shock locations also differ. The bow shock angle should be about 12 degrees for this case (NACA 1135).

CONTRACT NO. N00014-82-C-0690
"NUMERICAL TECHNIQUES FOR HIGH
INCIDENCE RE-ENTRY AERODYNAMICS"

FUNDS EXPENDED
THIS QUARTER
(FEE INCLUDED): $33,840

CUM TO DATE: $138,054

% OF TOTAL CONTRACT
FUNDS SPENT TO DATE: 64.6%

MAN HOURS EXPENDED
THIS QUARTER: 459

CUM TO DATE: 2023

% OF TOTAL MAN HOURS
SPENT TO DATE: 61.8%

8

DTIC