NUMERICAL INVESTIGATION OF SUBSONIC FLOW OVER A TYPICAL MISSILE FOREBODY

Ismail H. Tuncer[*], Ron Marvin[†] and Max F. Platzer[‡]
Department of Aeronautics and Astronautics
Naval Postgraduate School
Monterey, California 93943

ABSTRACT

The NASA-Ames developed Navier-Stokes solver OVERFLOW and the panel code PMARC are applied to the computation of the flow over a typical missile forebody. The flowfields at low angles of attack from 0° to 14° are investigated. The surface pressures along the missile forebody predicted by OVERFLOW and PMARC agree well up to 10°. This favorable agreement suggests that the panel codes may be a computationally efficient tool for aerodynamic missile design purposes at low angles of attack.

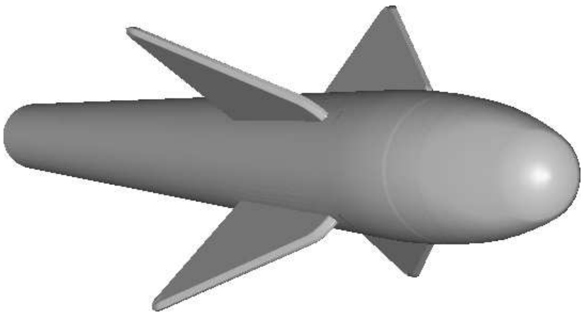

Fig. 1 Missile forebody.

INTRODUCTION

It is increasingly being recognized that the prediction of missile aerodynamics is becoming practical using Computational Fluid Dynamics (CFD) tools. In addition, the demands to improve the current prediction techniques have increased in recent years because air-to-air missiles currently deployed are not designed for high angle of attack launches from maneuvering aircraft. These missiles are aerodynamically stable and therefore "weather-cock" into the free-stream after launch from the aircraft. However, future air combat requires more agile missiles such that airframe control can be maintained over a wide range of angle of attack.

The recent advances in the aerodynamic prediction methodology for tactical missiles have been documented in Volume 142 of Progress in Astronautics and Aeronautics[1]. The current prediction methods range from semi-empirical methods, such as AP-95[2], to panel methods and complete Euler and Navier-Stokes computations. Each method has its own set of advantages and limitations, and much more work is required to fully understand the merits and applicability of these methods. Therefore, for the time being it appears advisable to retain all the methods in the missile aerodynamicist's tool kit.

Most of the previous work in prediction of missile aerodynamics was devoted to simpler configurations, especially to bodies of revolution,[3,4,5] delta wings,[6] double-delta wings,[7,8] and canard-wing-body combinations.[9,10] In a recent investigation, Ekaterinaris[9] and Hsieh et al.[11] used OVERFLOW and GASP Navier-Stokes solvers, respectively, to compute the flow over a typical missile configuration, consisting of a forebody, canards and tail fins. Ekaterinaris presented results for an angle of attack of 45°, whereas Hsieh et al. obtained results for 15°, 30°, 45° and 60° angles of attack. Hsieh et al. limited their computations to laminar flows only. Since no detailed flowfield or pressure data are currently available for this missile configuration, the computations were compared only with the wind tunnel force and moment measurements obtained in the Naval Postgraduate School[12] and NASA-Ames tunnels.[13]

*Research Assistant Professor, member AIAA
†Graduate student, now at NAWC China Lake, member AIAA
‡Professor, associate fellow AIAA.
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In the absence of detailed flowfield and pressure measurements, it is useful to compare the predictions of two different codes. At low angles of attack, an inviscid code can be expected to yield accurate results at significantly reduced computational cost. Therefore, the NASA-Ames developed PMARC code was chosen for this purpose. Agreement between the inviscid PMARC and viscous OVERFLOW predictions in this angle of attack range gives confidence in the use of both codes. At the same time, such comparisons enable an evaluation of the suitability of panel codes for aerodynamic missile design purposes. Currently, air-to-air missile aerodynamic design work is done primarily using prediction codes based on semi-empirical methods. These tools are limited to previously investigated missile configurations and flight regimes. Panel codes are therefore the next logical step in refining these tools because of their relative robustness and computational efficiency, and because they allow for any arbitrary configuration to be modeled within the limitations of inviscid aerodynamics. In a parallel study, Lambert and Platzer[14] evaluated the PMARC code by comparing its predictions with various experimental results.

It is the objective of the present study to apply OVERFLOW and PMARC to the forebody of the missile configuration (Figure 1) previously investigated by Ekaterinaris and Hsieh et al. However, in contrast to their work, a low angle of attack range, between 0° and 14°, was chosen, so that a comparison between the prediction of the two codes could be achieved and the PMARC code could be evaluated. The codes and the results are described in the subsequent sections.

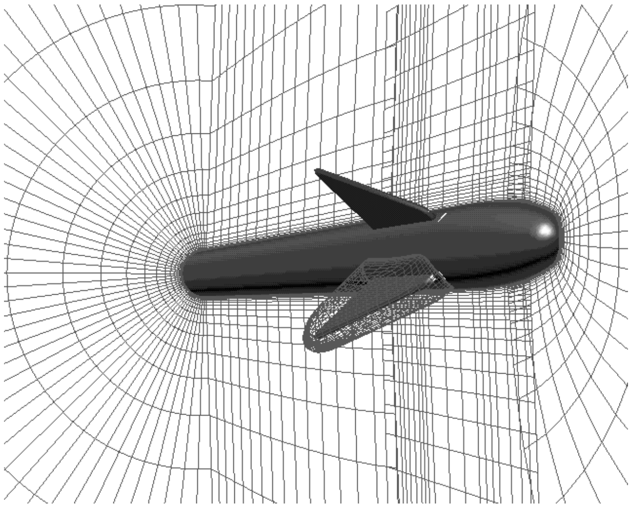

Fig. 2 Computational grid for the OVERFLOW solution.

NUMERICAL METHODS

In this work, we have employed two NASA-Ames developed flow solvers: OVERFLOW version 1.6ap and PMARC version 12.22.

Navier-Stokes Flow Solver: OVERFLOW

The NASA Ames developed OVERFLOW code is a thin-layer Navier-Stokes solver, which accommodates overset, Chimera type grid structures. In the Chimera approach, the computational domain may be discretized by uniform sub–grids suitable for each model components, such as the canards and the missile body, or for various flow regions. The sub-grids are then overset or overlapped with others to cover the whole computational domain. The PEGSUS code is used to determine the overset and overlapping sub-grid boundaries with grid blanking and to obtain the inter-grid interpolation data needed for the OVERFLOW solution.

The OVERFLOW solver has various integration schemes of the thin-layer Navier-Stokes equations. In the present computations, for the sub-grids in which one of the grid directions aligns with the free-stream flow direction, the two-factor, partial flux vector splitting algorithm is selected. Otherwise, the three-factor diagonal scheme is selected. The two-factor scheme employs the Steger-Warming flux vector splitting algorithm for discretization of the convection terms in the stream-wise coordinate direction, and central differencing in the other two coordinate directions. Implicit and explicit smoothing of flow variables are used along the coordinate directions in which central differencing is employed. Turbulence may be modeled by the Baldwin-Lomax or the Baldwin-Barth turbulence models which are built into the OVERFLOW solver. In this study, only the Baldwin-Lomax turbulence model in combination with the Degani-Schiff modification[15] is used. Reference 16 provides more mathematical details that support the code.

Potential Flow Solver: PMARC

The NASA-Ames developed PMARC code is a low–order potential flow panel code for modeling complex three-dimensional geometries. The flowfield is assumed to be inviscid, irrotational and incompressible. It solves the Laplace equation for the velocity potential over a closed body using doublets and source singularities placed on solid surfaces and wakes. The singularities are distributed with constant strength over each panel, which makes PMARC a low-order panel method

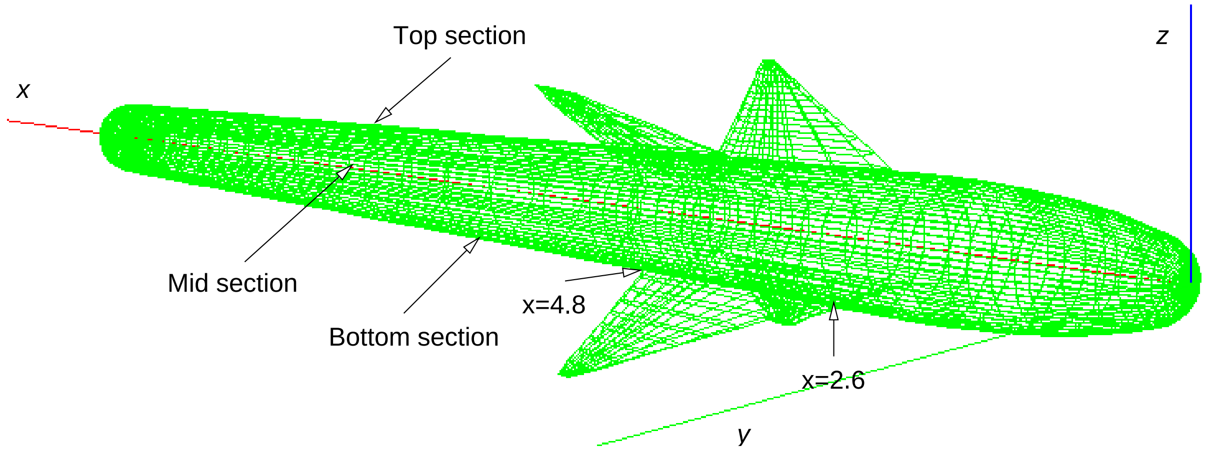

Fig. 3 Surface panel distribution for the PMARC solution.

in contrast to higher order methods where singularity strengths are allowed to vary linearly or quadratically over each panel. Unknown doublet and source strengths are solved using an iterative matrix solver. Once the unknown doublet and source strengths are determined, tangential velocity components and pressure coefficients at each panel are evaluated. Further details of the PMARC code may be found in reference 17.

In PMARC, wakes can be shed from trailing edges of lifting surfaces or from known separation lines. The Kutta condition is used to determine shed doublet strengths. However, in this preliminary work, only the Kutta condition was employed along the trailing edges of the canards and no attempt was made to incorporate the wakes shed from the canards or from the body.

RESULTS AND DISCUSSION

We have computed flowfields over the missile forebody at 0°, 2°, 6°, 10° and 14° angles of attack employing the OVERFLOW and PMARC codes. The flow features at these incidences are presented by means of particle traces and surface streamlines computed by the OVERFLOW solver. Computed surface pressures along the missile body are compared against PMARC predictions.

In the OVERFLOW computations, the computational domain is discretized with six sub-grids as shown in Figure 2. These sub-grids were originally employed by Ekaterinaris[9] for the computational study of a full missile configuration with canards and tails. The missile forebody in the present study extends about 17.5 diameters. Since the missile is oriented in X configuration, the flow is assumed to be symmetric about the x-z plane and the flowfield is computed only in the half plane. The sub-grids define the missile nose, near mid-body, outer mid-body, rear body and the canards. The total number of grid points is about 875,000. The PEGSUS code is used to determine the overset and overlapping sub-grid boundaries with grid blanking and to obtain the inter-grid interpolation data. All the flowfields were computed at a free-stream Mach number of 0.3 and a Reynolds number of $2 \cdot 10^6$ with the assumption of fully turbulent flow. A typical run for a converged solution takes approximately 4000-6000 time steps and 40-60 CPU hours on a CRAY Y-MP. We accepted the flowfield as converged when the L_2 norm of the density residuals dropped about 6 orders of magnitude.

In the PMARC computations, the full missile body is modeled with approximately 5000 surface panels as shown in Figure 3. In the present study, only one panel distribution is employed. Panels are clustered around the missile nose, canard-body junction, and leading and trailing edges of the canards. The Kutta condition is applied at the trailing edges without introducing source and doublet singularities in the wake. A typical PMARC run takes approximately 20 minutes on a CRAY Y-MP.

Figure 4 shows particle traces originating from the mid-body section and the leading edges of the canards, and the surface pressure contours predicted by OVERFLOW. Up to 6° incidence, the flow stays attached over the forebody. At 6°, development of a vortex over the leading edge of the canards is observed. Yet, the flow stays mostly attached over the canards as well. At 10° and 14° incidences, the flow separates over the aft-body and the canard vortices become stronger. Side and top view of the surface streamlines are also given in Figures 5 and 6. Flow separation and re-attachment lines over the upper canard surfaces are clearly observed at 10° and 14° incidences. Similarly, the flow separation line over the aft-body is seen in the top view. The flowfield between the canards also becomes highly complex starting from 6° incidence with the development of corner flows around the canard-body junctions and the leading edge vortices. The flow above the canard leading edges is first strongly deflected away from the canards and then sucked in under the influence of the canard vortex as shown in Figure 6. In general, it is observed that starting from 10° incidence, the viscous effects begin to dominate the flowfield with strong canard vortices, corner flows and flow separation over the aft-body.

In Figures 7, 8 and 9, surface pressures computed by OVERFLOW and PMARC are compared along the missile body past the trailing edges of the canards at the top, bottom and mid sections depicted in Figure 3. As seen, the overall agreement is remarkably good except at the suction peak. It is likely that this discrepancy is caused by coarse panel distribution near the suction peak in the present PMARC solution. Past the trailing edge of the canards, the increase in pressure also appears to be overstated in the PMARC prediction, which may be attributed to the absence of wakes. Starting from 10° incidence, the OVERFLOW solution predicts higher suction on the top surface past the canard leading edge, which is attributed to the suction induced by the canard vortex. On the bottom surface where the flow stays attached and the effect of the canard vortices is minimum, the agreement is quite good up to 14° incidence. Although the flowfield between the canards is predicted to be highly vortical by the OVERFLOW solution, the computed pressure fields agree remarkably well. At 14°, the suction predicted by the OVERFLOW solution past the trailing edge may again be attributed to the wake effects.

CONCLUDING REMARKS

The computational efficiency of PMARC suggests to extend the calculations to higher angles attack than explored in the present work. We believe that this can be done by including the unsteady wakes shed from the canards and from properly chosen separation lines on the body of revolution. The range of applicability of this approach will then be assessed by comparison with OVERFLOW Navier-Stokes solutions.

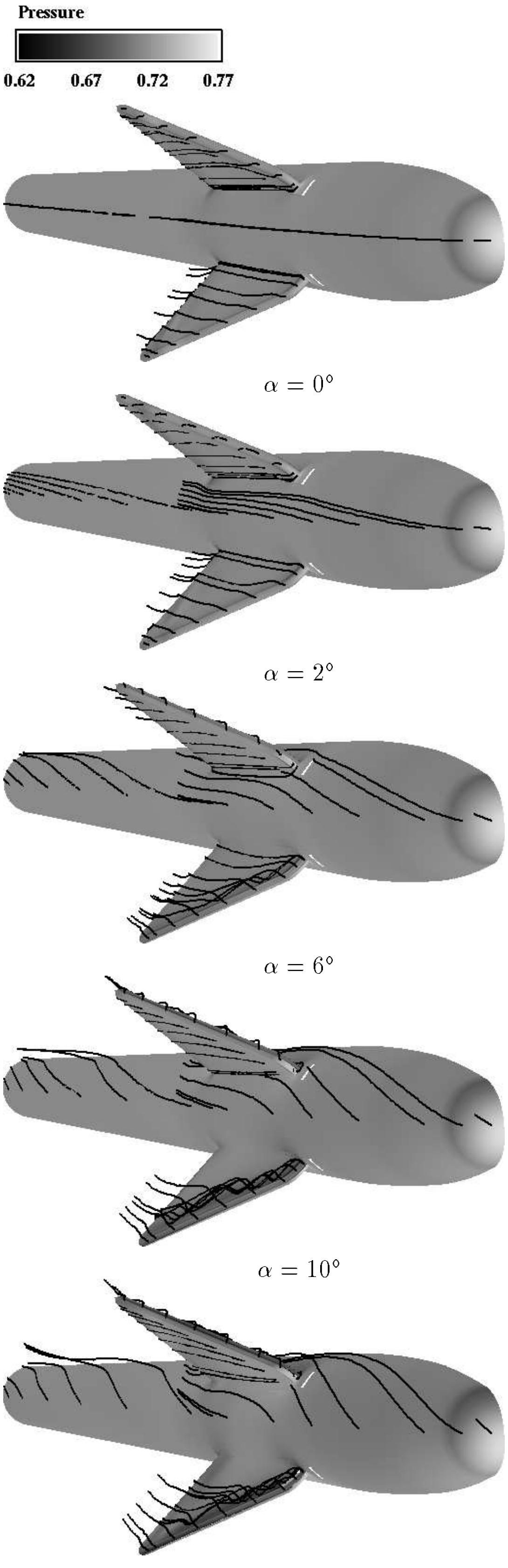

Fig. 4 Surface pressure contours and particle traces.

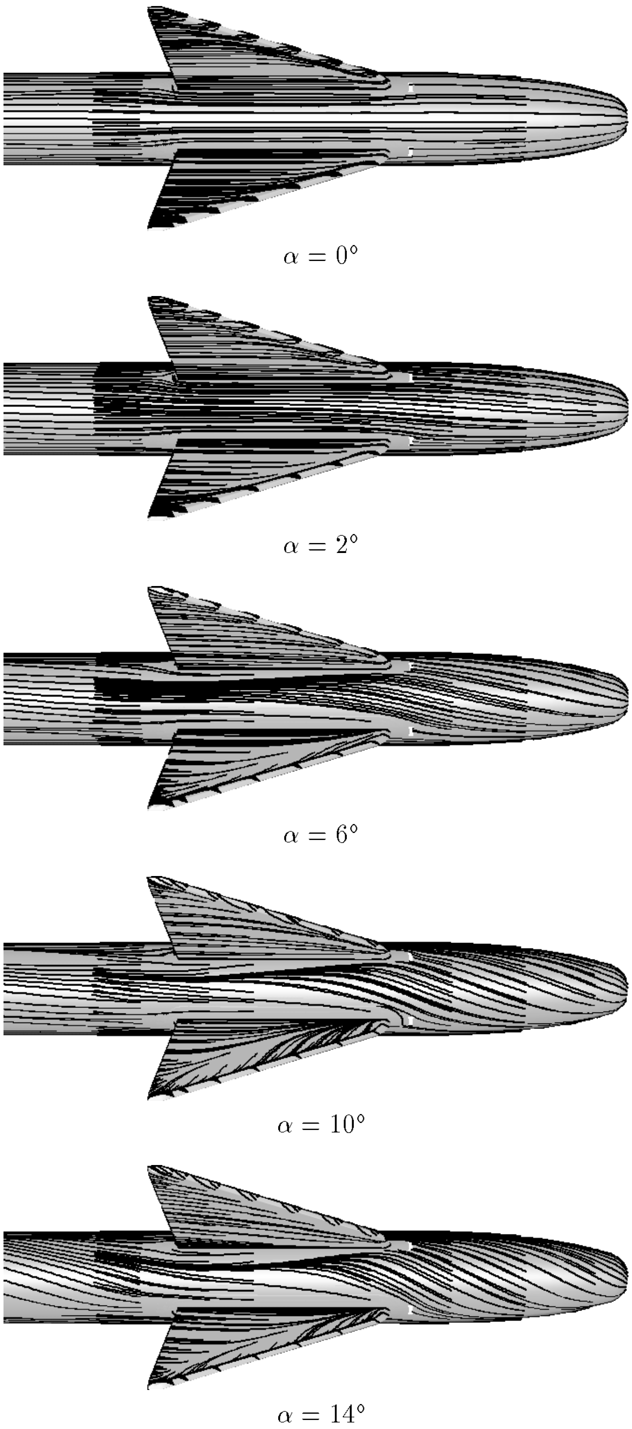

Fig. 5 Surface streamlines, side view.

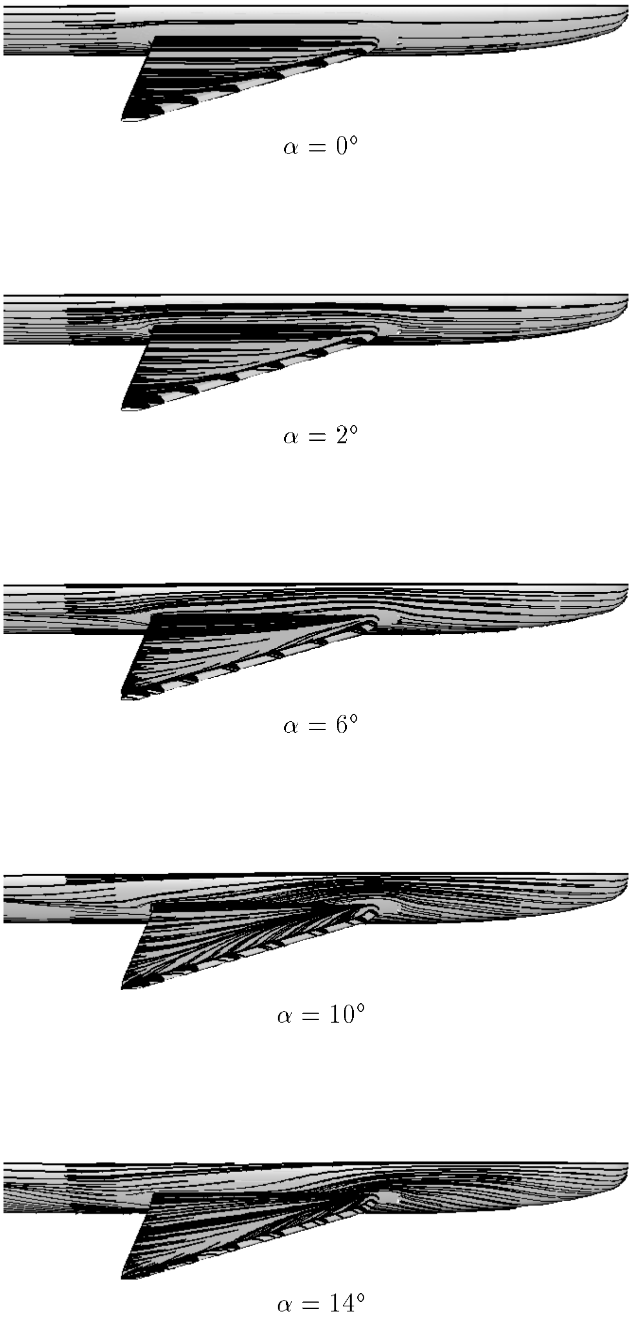

Fig. 6 Surface streamlines, top view.

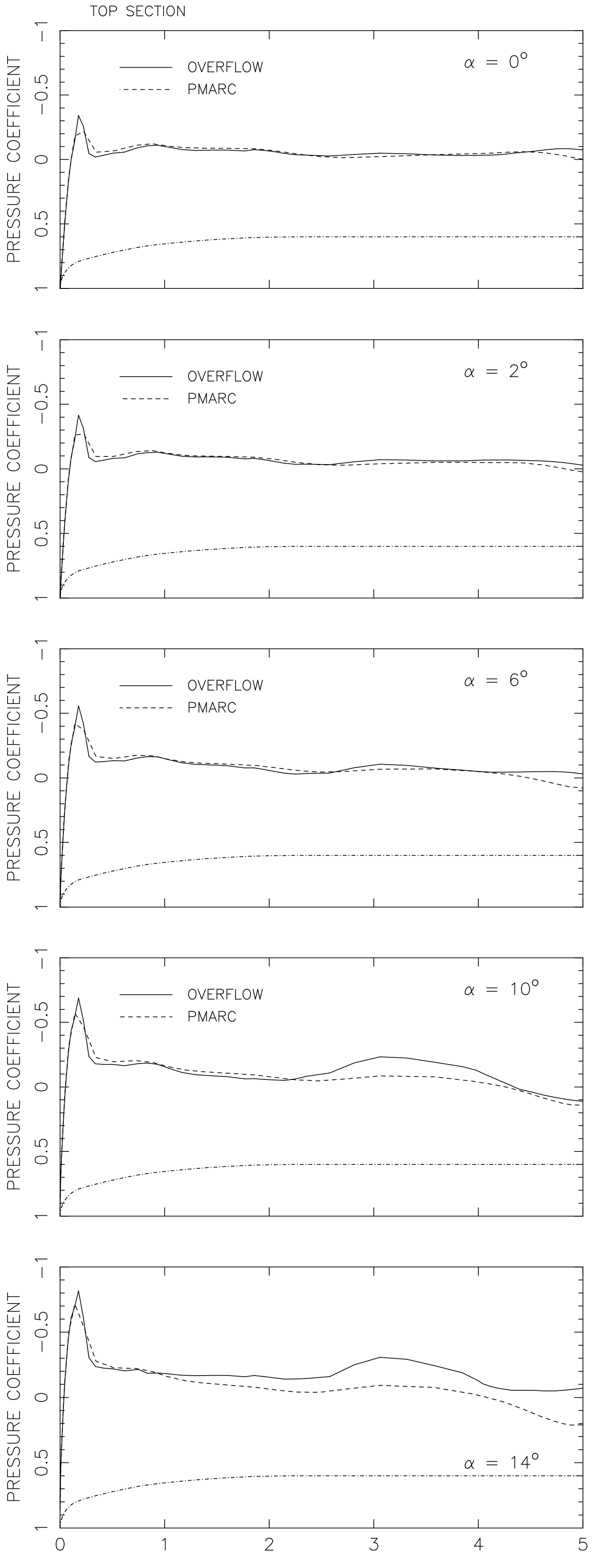

Fig. 7 Top section surface pressure comparisons. (Missile profile is shown at the bottom)

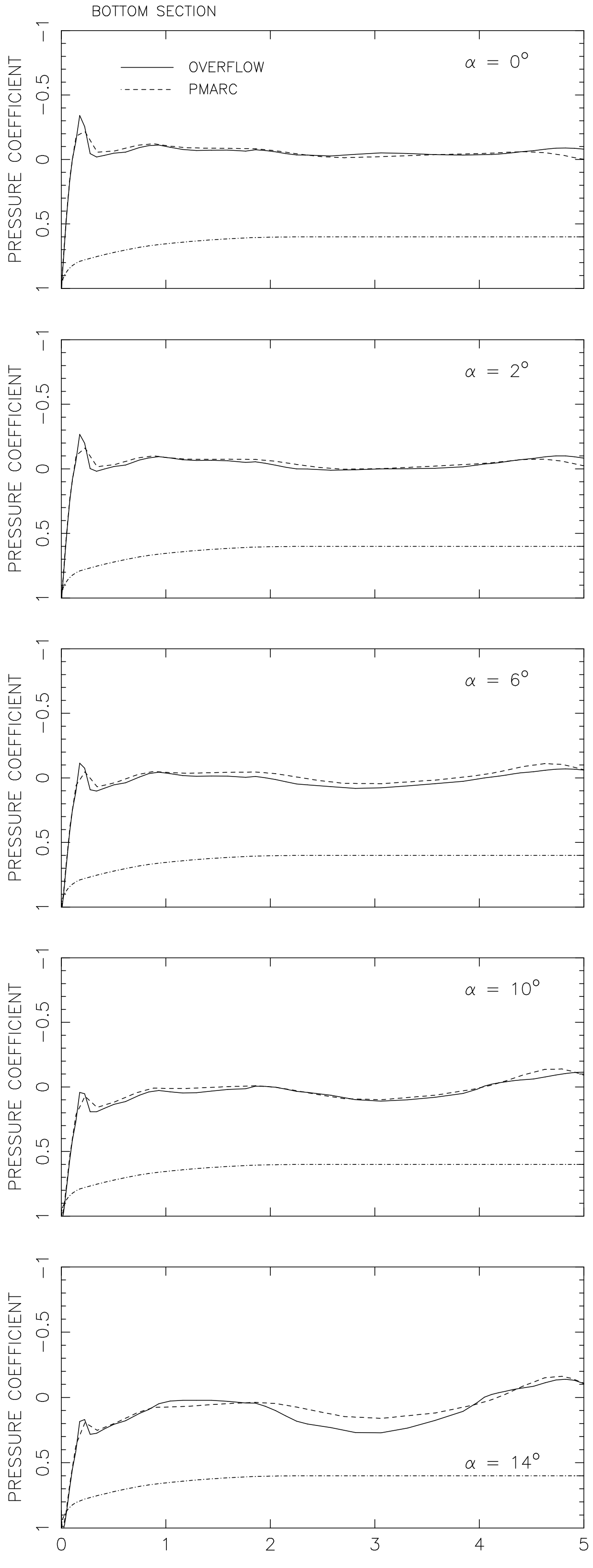

Fig. 8 Bottom section surface pressure comparisons. (Missile profile is shown at the bottom)

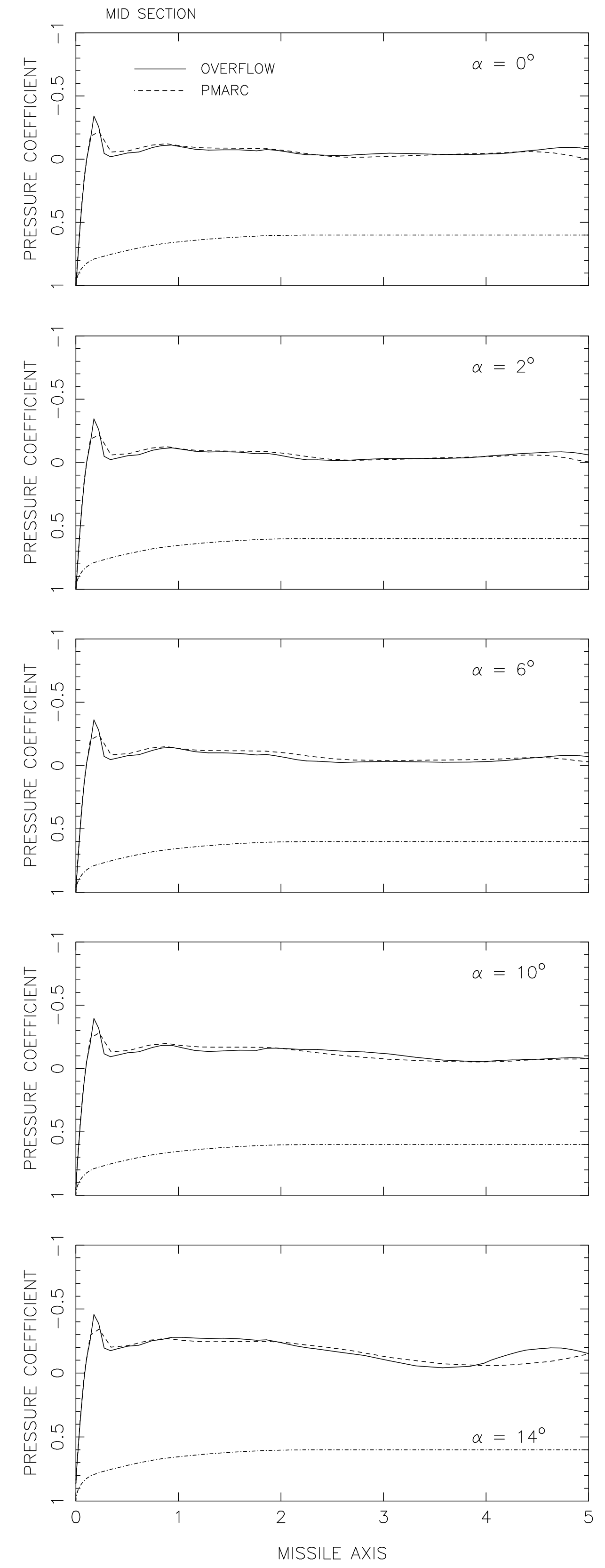

Fig. 9 Mid section surface pressure comparisons. (Missile profile is shown at the bottom)

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