PAN AIR Applications to Mutual Interference Effects

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The PAN AIR program has demonstrated its utility for analyzing complex aircraft configurations at subsonic and supersonic speeds The code, however, has not demonstrated the ability to predict mutual interference effects due to close proximity, particularly at supersonic speeds Comparisons with test data for stores in proximity to a two dimensional flat plate at supersonic speeds have shown that plate modeling, as well as nose bluntness, have a significant impact on the results Comparisons for stores in proximity to axisymmetric bodies indicate that, for three dimensional flowfields, mutual interference effects are better predicted Application of a procedure (COST) which dramatically reduces PAN AIR computer running time is also described It is also demonstrated how this procedure can be used to overcome linear theory limitations at transonic speeds

Nomenclature

C_A = axial force coefficient
C_N = normal force coefficient
C_m = pitching moment coefficient
C_P = pressure coefficient
D = body diameter
L = body length
M = Mach number
n = unit normal
v = perturbation velocity
V_∞ = freestream velocity
w = perturbation mass flux vector
x = Cartesian x coordinate, measured from plate leading edge
z = Cartesian z coordinate, measured normal to plate or body centerline
β = shock angle
θ = flow deflection angle
μ = Mach angle
ϕ = perturbation potential

Introduction

THE PAN AIR program previously has demonstrated its utility for analyzing the behavior of complex aircraft configurations at subsonic and supersonic speeds [1 6] Results for two studies,[7 8] where mutual interference effects due to close proximity predominate, have been somewhat contradictory Since one of the differences between the two studies was that the shock reflection surface was represented as a doublet sheet[7] and a plane of symmetry,[8] the different results might be attributed to the different modeling

This paper investigates the question of appropriate boundary conditions for a reflection plane simulation. Test data are also available for stores traversing vertically and horizontally relative to axisymmetric bodies Comparisons with these test data are used to evaluate PAN AIR's ability to predict the mutual interference effects

A procedure (COST) has been developed[6] recently which utilizes PAN AIR aircraft flowfield predictions to predict a store's loads as it traverses parallel to the parent aircraft, without the need of a separate PAN AIR calculation for each point along the traverse This procedure obviously can be used to predict the loads experienced by a store traversed parallel to an axisymmetric body Furthermore, since a finite difference code[9] can predict axisymmetric body flowfields at transonic speeds, the COST procedure enables us to calculate store loads in these flowfields at Mach numbers ($M = 0$ 95, 0 975, and 1 05) where PAN AIR is not applicable

All configurations in these studies were modeled using composite source doublet panels for the body and doublet only for the thin surfaces (i e , wings and tails) For supersonic flow the boundary conditions are: indirect velocity impermeability $[(v_u - v_l)n = -V_\infty n \quad \phi_l = 0]$ on the com

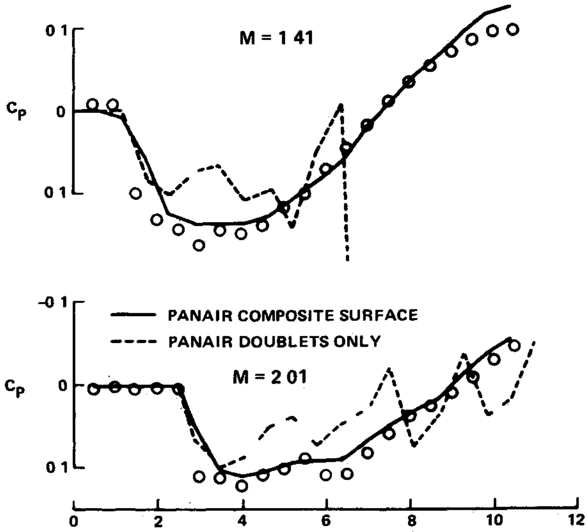

Fig 1 Axisymmetric body pressures at $M = 2$ 01 $Z/L = 0$ 1

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posite panels, and direct velocity $[\frac{1}{2}(v_u - v_2)n = -V_\infty n]$ on the thin surfaces Mass flux impermeability boundary conditions are recommended for subsonic conditions.

Store Behavior in Proximity to a Flat Plate at Supersonic Speeds

To determine what effect singularity choice has on the PAN AIR solution, the shock reflection surface was represented as a doublet sheet, a composite surface, and a plane of symmetry for the axisymmetric body 0 1 body length away As may be seen in Figs 1 and 2, the doublet sheet representation gives erroneous results, whereas the composite surface representation is practically identical to using a plane of symmetry to produce the shock reflection effect The effect of plate singularity representation can be seen in Fig 3, which also indicates that at lower Mach numbers the discrepancy is more pronounced; this effect has also been observed elsewhere [7] The doublet sheet representation cannot model shock reflection effects properly

There was no apparent displacement[4] between the shock and Mach wave for this configuration: apparently this slender body produces a very weak shock

The generic store in proximity to a flat plate[7] was analyzed with the plate modeled as a doublet sheet and a composite surface Although the magnitude of the oscillations decreased for the composite surface, they did not disappear, Fig 4 Modeling the store's tail as a composite surface had no preceptible effect on the results

To understand the differences in the reflection plane modeling better, an understanding of the boundary conditions is needed A plane of symmetry as a reflection plane is the most effective model; it has the advantages of not requiring any additional paneling and offers perfect reflection. The PAN AIR program allows two planes of symmetry In this case, one plane can be used for configuration symmetry, while the other is used for the reflection plane.

Use of a doublet sheet reflection plane model requires that all disturbances be reflected by a quadratically varying doublet distribution The boundary conditions for this doublet distribution are in the form of impermeable normal velocity at panel center and network edge control points In supersonic flow, the normal velocity distribution that must be reflected is extremely complex and discontinuous, making it difficult for a finite number of control points to discern its

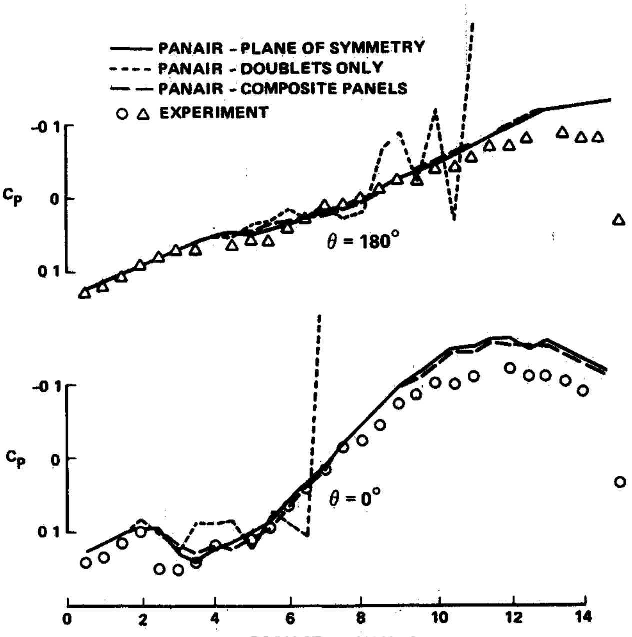

Fig 2 Axisymmetric body pressures at $M = 1\ 41$, $Z/L = 0.1$

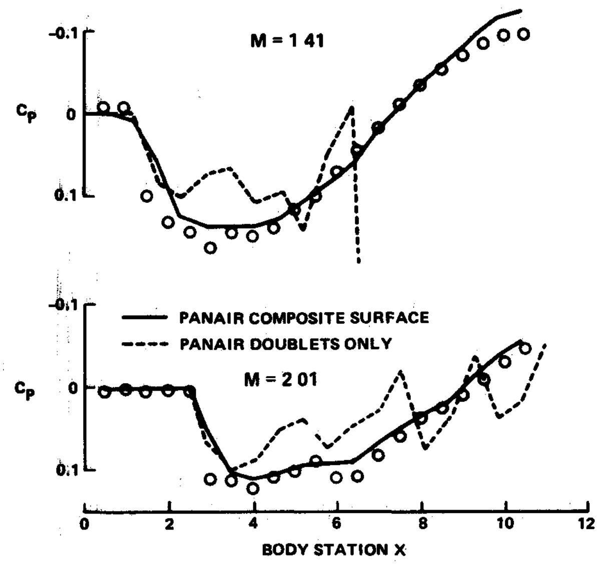

Fig 3 Flat plate pressures, $Z/L = 0\ 1$

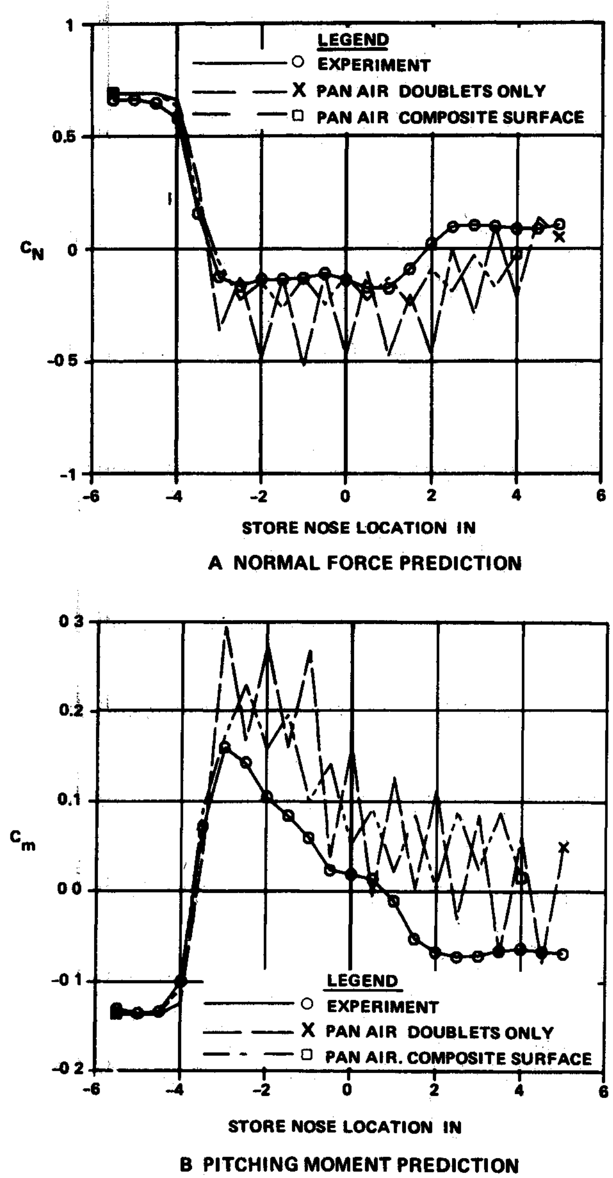

Fig 4 Generic store at $M = 1\ 5$, $Z = 2\ 45$, wedge flowfield

nature correctly As seen in Figs 1 3, this type of boundary condition cannot handle the interfering flow In subsonic flow, which lacks velocity discontinuities, the use of a doublet sheet for a reflection plane, if of sufficient extent, would be adequate

The composite surface paneling of a reflection plane yielded results that were essentially equivalent to those for the plane for symmetry Use of this model requires some special conditions to be satisfied First, the flow must be supersonic Second, the flow behind (the backside) the reflection plane paneling should be free of any disturbances The composite panel reflection plane uses indirect boundary conditions. The backside perturbation potential is set to zero, $\phi_l = 0$, implying freestream flow on all panel center control points and network edge control points Use of the backside perturbation potential, being zero, requires that its domain be isolated from the rest of the flow, which is the case inside of closed bodies or behind a paneling of sufficient extent in supersonic flow The difference between frontside and backside perturbation velocity, $[(v_u - v_l)n = -V_\infty n]$, is also specified at each panel center control point This type of indirect boundary condition imposes reflection in an integral sense and appears to have a superior ability to handle interfering flows.

What has been learned with reflection plane modeling also has implications with the thin wing modeling that is frequency used to simplify the configuration paneling This wing modeling with doublet panels and direct impermeability boundary conditions is quite adequate for many analysis applications. However, if there is a store in close proximity which will produce a strong interfering flow with the wing, then a thick wing model using composite panels and indirect boundary conditions should be used In this case, the perturbation potential inside the wing would be zero For panel methods which utilize only direct impermeability boundary conditions, cases with strong interfering flows are likely to remain a problem Another difference between the configurations in Refs 7 and 8 was that the generic store[7] had a considerably blunter nose, violating the small perturbations assumptions of the theory Results for the Planar Wing Weapon,[7] a more slender configuration, at the same traverse height and Mach number as the generic store, are shown in Fig 5 Although the magnitude of the store response to the plate shock is underpredicted, the wiggles have almost disappeared (note that the predicted C_N and C_m were shifted to correspond to the experimental values when the store is clear of the shock, i e , $X \leq -4$, since the store is in a freestream flowfield of $\alpha = 4$ deg)

The PAN AIR code has demonstrated a very good ability to predict shock reflection effects on slender bodies when the resulting flow remains within the realm of linear theory However, this ability is degraded by blunter configurations which may lead to a violation of the small perturbation assumptions of linear theory

Store Behavior in Proximity to an Axisymmetric Body

It has been demonstrated[6] that PAN AIR can accurately predict the forces and moments of a store traversed parallel to

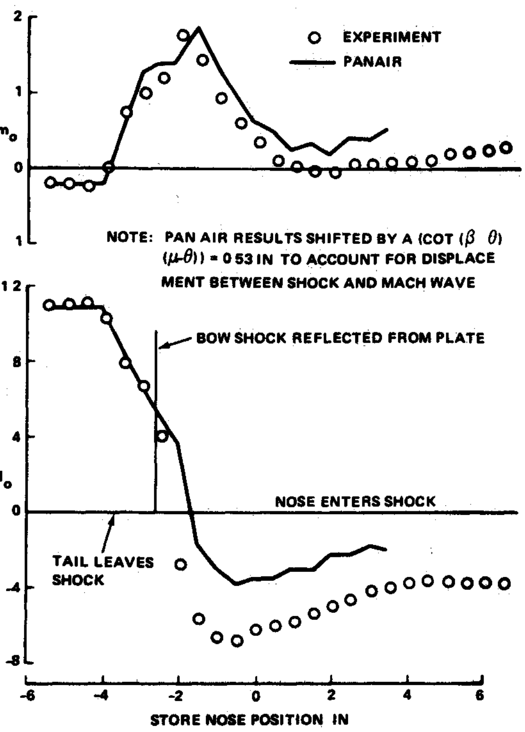

Fig 5 Planar Wing Weapon at $M = 1$ 5, $Z = 2$ 45, wedge flowfield.

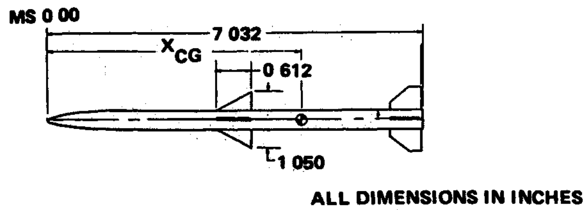

Fig 6 AMRAAM missile

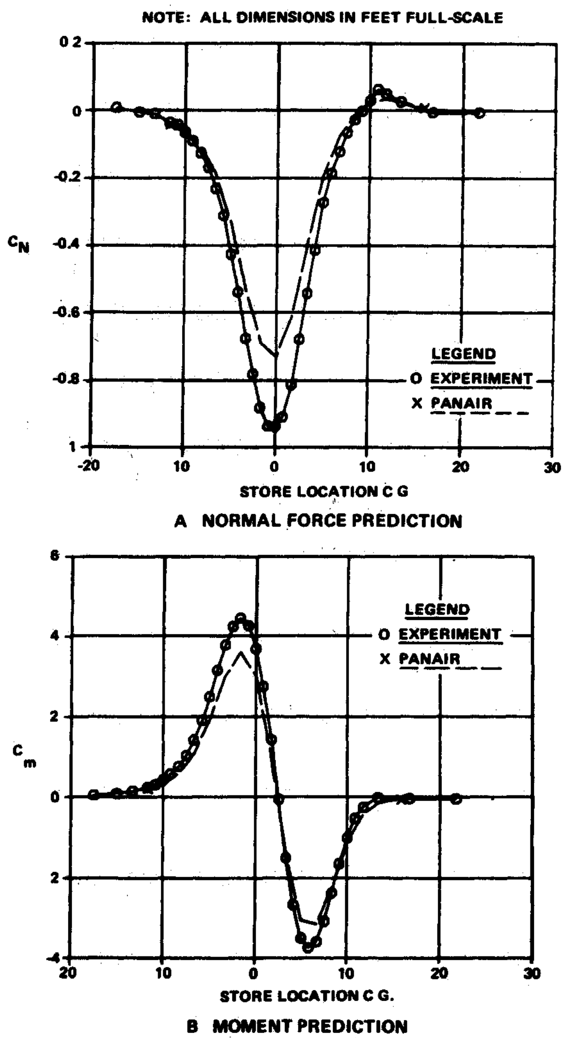

Fig 7 AMRAAM configuration in calibrator flowfield at $M = 0$ 8, $Z = 6$ 89

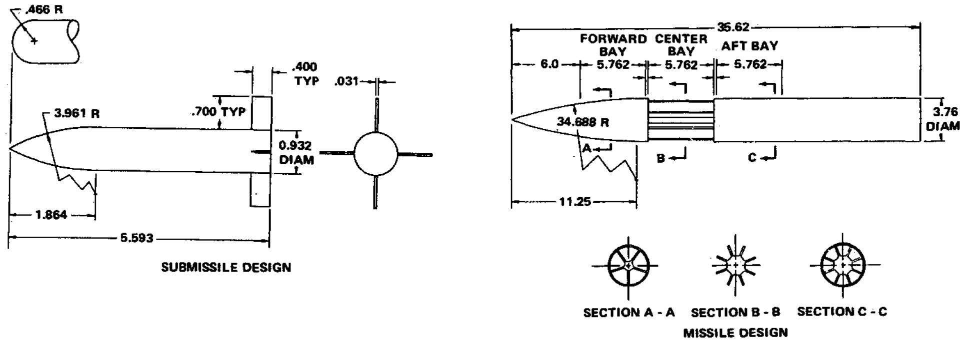

Fig. 8 Dispenser missile design.

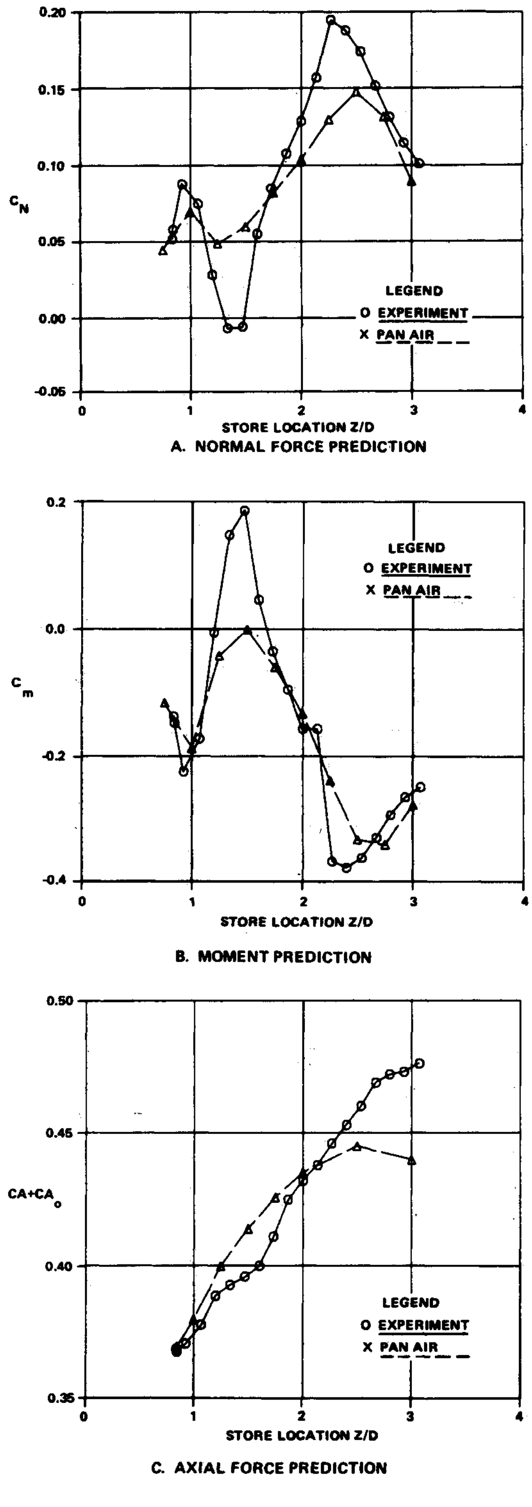

Fig. 9 Submissile at $M=1.2$, $X/D=4$.

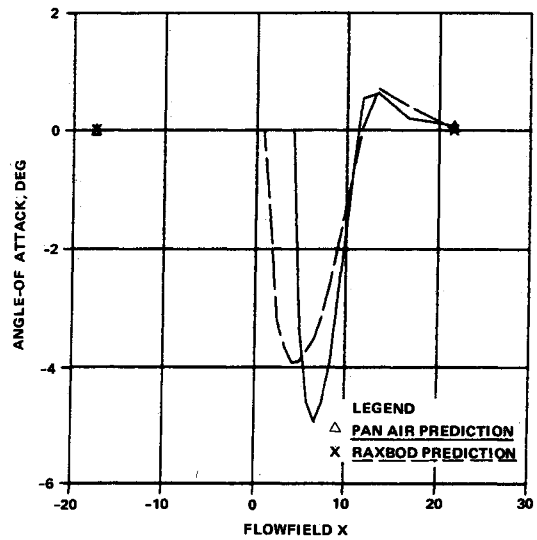

Fig. 10 Prediction of calibrator flowfield at $M=1.2$, $Z=6.89$.

an axisymmetric (calibrator) body at subsonic speeds accurately Recently, test data for the AMRAAM store, Fig. 6, in a traverse 1.5 diameters below this body were acquired at $M=0.8$, 0.9, 0.95, 0.975, and 1.2. PAN AIR predictions for this store at $M=0.8$ are compared to test data in Fig. 7 Although PAN AIR underpredicts the magnitude of the disturbance, it provides a good qualitative estimate of the store's behavior. The underprediction might be due to the wake model from the front fin, which was represented as passing just over the rear fin.

Test data were also available[10] for a submissile in the presence of a dispenser missile, Fig. 8. Predictions for the submissile in a vertical traverse relative to the dispenser missile (with the bays closed) at $M=1.2$ are compared with the test data in Fig. 9 Compared to the NEAR[11] predictions for the submissile (without fins),[10] the PAN AIR results are in reasonable agreement with the test data.

Cost Reducing Application of PAN AIR

A procedure which related the local angle-of-attack distribution along a store to its forces and moments (IFM) was introduced.[12] Reference 6 described how the IFM technique, combined with the PAN AIR program (COST), could provide good estimates of store behavior in proximity to an aircraft at a fraction of the computer time required for a straightforward PAN AIR calculation. An obvious application of the COST technique is the prediction of store forces and moments in a traverse parallel to an axisymmetric body

An advantage inherent in the COST procedure is that it is not restricted to flowfields calculated by the PAN AIR program. As may be seen in Fig. 10, the flowfield predicted for the calibrator body by a transonic finite-difference

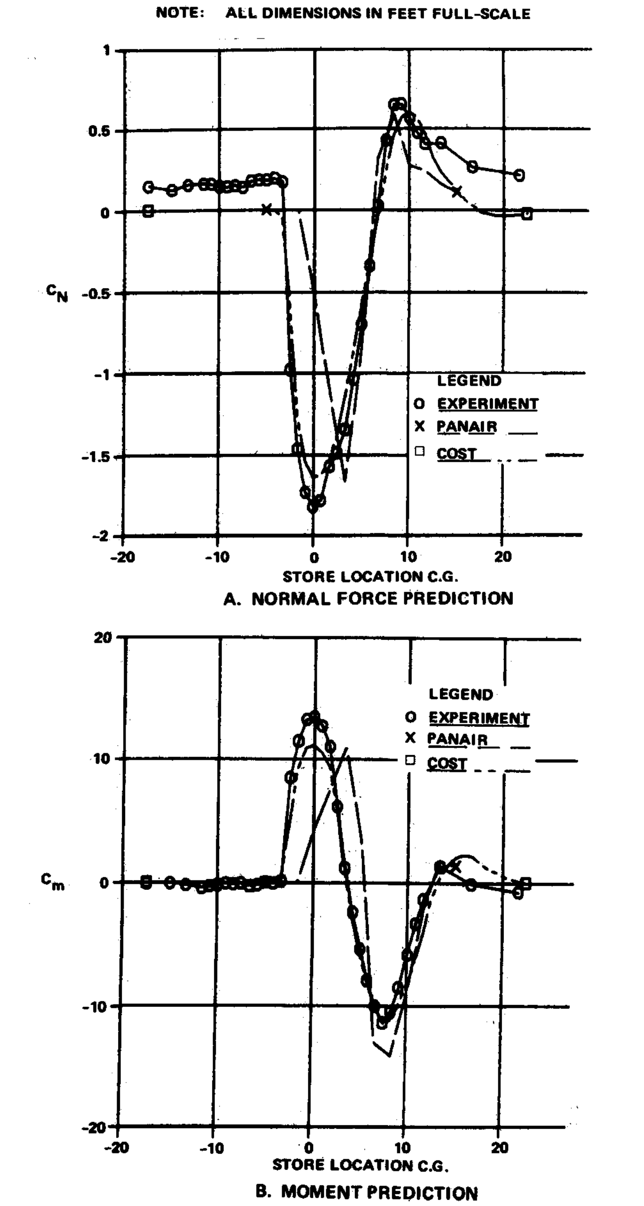

Fig. 11 AMRAAM configuration in calibrator body flowfield at $M=1.2, Z=6.89$.

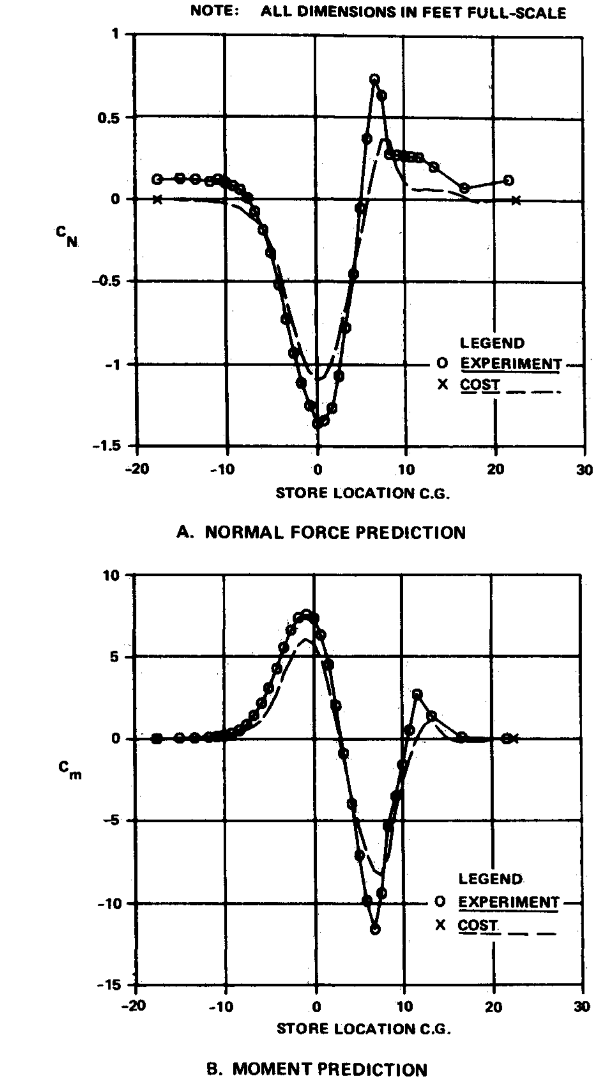

Fig. 12 AMRAAM configuration in calibrator body flowfield at $M=0.975, Z=6.89$.

(RAXBOD) code[8] differs substantially from the PAN AIR prediction. The AMRAAM store was calibrated[12] with the PAN AIR program at $M=1.5$ by calculating its behavior in passing through a two-dimensional shock wave at $M=1.5$ and the RAXBOD-predicted flowfield was used in the COST procedure to calculate the store forces and moments during the traverse. Obviously, the RAXBOD angularity prediction is a better estimate of the actual flowfield, since it provides for a considerable improvement for the COST prediction, Fig. 11.

It should be noted that neither the COST prediction nor the PAN AIR calculation exhibit the oscillatory behavior seen for the traverses in proximity to the flat plate (Fig. 4). Since the stores were traversed at approximately the same distance (the relative separation from the flat plate was 2.45 in., and 2.79 in. from the calibrator body), the three-dimensional flowfield of the calibrator body minimizes shock reflection effects.

The COST procedure also provides a good estimate of AMRAAM behavior at $M=0.975$, Fig. 12. Note that the underprediction of the magnitude of the response is quantitatively similar to the PAN AIR prediction at $M=0.8$.

Another example of the COST procedure is shown in Fig. 13 where the PWW store[7] is traversed parallel to the calibrator body at $M=1.05$. Considering the nonlinear flowfield expected at this Mach number, the prediction is excellent.

Conclusions

For slender bodies, where the nose shock wave does not differ from the linear theory Mach wave substantially, the PAN AIR program can accurately predict shock reflection effects from composite panels. For blunter nose shapes with a resultant strong bow shock, the PAN AIR code cannot accurately predict the shock strength or location, which considerably affects the quality of the results. A procedure which would calculate the propagation of disturbances along actual shock waves would greatly improve the utility of the code.

To account properly for shock reflection effects, the thin wing doublet sheet simplification cannot be used. This has obvious implications in modeling stores in proximity to an aircraft wing.

A procedure (COST), which was developed to minimize PAN AIR computing expense for stores traversing relative to an aircraft, can also overcome linear theory limitations for simpler shapes where nonlinear codes can provide and adequate flowfield prediction.

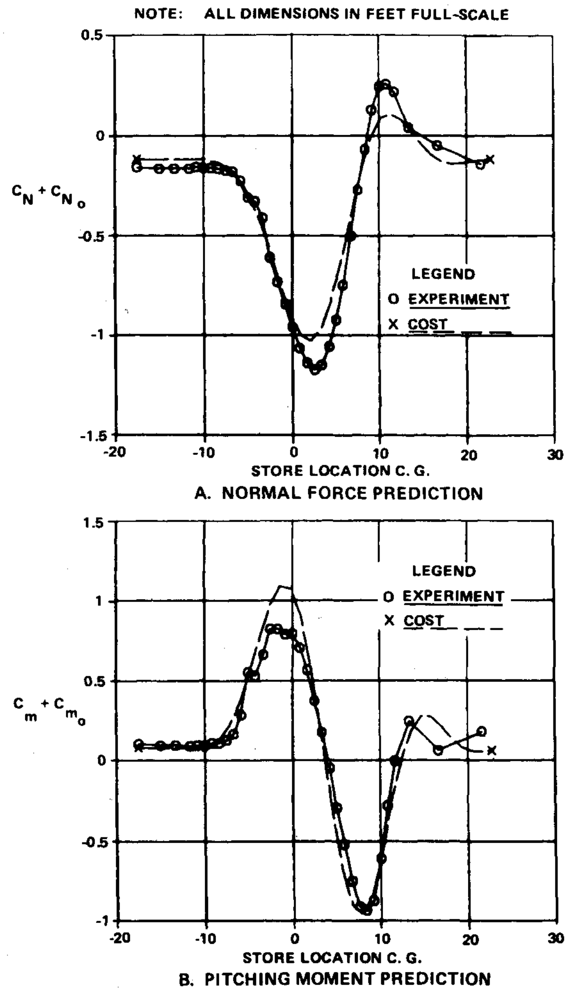

Fig. 13 PWW store in calibrator body flowfield at $M=1.05$, $Z=6.89$.

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