PAN AIR Applications to Complex Configurations

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The PAN AIR code has the potential of solving for the flow about complete aircraft configurations at both subsonic and supersonic speeds. Previous comparisons have demonstrated the superiority of this method over other panel codes, particularly at supersonic speeds. Applications to date have not, however, established the practical limits of this code, particularly for mutually interfering bodies. Comparisons with recently acquired test data have demonstrated the utility of this code in predicting mutual interference effects between complex configurations at both subsonic and supersonic speeds. However, the code failed to accurately predict store carriage loads at supersonic speeds.

Nomenclature

C = chord length
c.g. = center of gravity
C_N = normal force
C_P = pressure coefficient
C_m = pitching moment
M = freestream Mach number
X, Y, Z = Cartesian coordinates
α = angle of attack, deg
$2Y/b$ = nondimensional span station

Subscript

0 = zero α

Introduction

PAN AIR[1-3] is a computer program that solves the Prandtl-Glauert equation for the flow about arbitrary configurations at subsonic and supersonic speeds. The code uses a formulation of higher-order singularities (linear source, quadratic doublet), reducing the numerical stability problems that prevented other[4,5] surface paneling methods from working satisfactorily at supersonic speeds. Applications of this code for flows about isolated bodies[6] and several different aircraft configurations[7,8] have demonstrated the superiority of this technique to other panel methods at supersonic speeds. Results for configurations with regions of nonlinear flow,[6-8] and for mutually interfering bodies,[8-11] have not conclusively identified the limits of applicability of the technique.

Comparisons have been made with recently acquired test data, as well as with other linear and nonlinear techniques. Although all the comparisons have been made with the PAN AIR pilot code,[1] the production[2,3] version of the code should give comparable answers.

Previous experience has indicated that velocity boundary conditions produce better results at supersonic speeds than do mass-flux boundary conditions.[9,10] The reason for this was recently explained in a work by Melnik and Mason,[12] who demonstrated that the first-order mass-flux boundary condition formulation used in PAN AIR would benefit from the addition of a higher-order term. Since this term is multiplied by M^2, it becomes increasingly important at supersonic Mach numbers. They also demonstrated that properly formulated mass-flux boundary conditions give results essentially identical to those for velocity, since in this formulation the mass flux and velocity vectors are essentially identical. For this reason, all supersonic comparisons used velocity boundary conditions. At subsonic and transonic speeds, the mass-flux formulation, which saves computer time and conserves mass flux, was retained.

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Supersonic Tactical Aircraft Configuration

Experimental data[13] were available for the 1/27-scale Supersonic Tactical Aircraft Configuration (STAC). PAN AIR predictions for this configuration were compared with the Woodward[14] code, an early panel method program using constant-pressure mean surface panels, which was used to design this configuration. The PAN AIR representation of this configuration is shown in Fig. 1. Note that, while PAN AIR permits an accurate representation, geometric restrictions in this early version of the Woodward code require the nacelle to be modeled as a wing section. Figures 2 and 3 show the forces and moments predicted by the two codes for the canard-off and -on conditions at $M=1.5$. The Woodward code's inability to properly model the body and nacelle probably accounts for the C_{N_0} discrepancy for both the canard-off and -on configurations. However, the PAN AIR code's ability to properly model the body shows no apparent improvement in wing pressure predictions (Figs. 4 and 5). Apparently the body geometry had little effect on the wing pressures for this particular case, except that the Woodward code had to be run at different α to match the lift. Comparisons at other Mach numbers are similar.

For the STAC configuration, the advantages inherent in the PAN AIR code become apparent when an attempt is made to model the configuration with a store in the carriage position. The Woodward code could not properly model this case. Considering the complexity of the configuration, the PAN AIR predictions at $M=1.95$ show good agreement with the test data, Fig. 6.

Store Behavior in Simple Flowfields

It has been shown[10] that linear theory can accurately predict store behavior in the simple flowfield produced by a

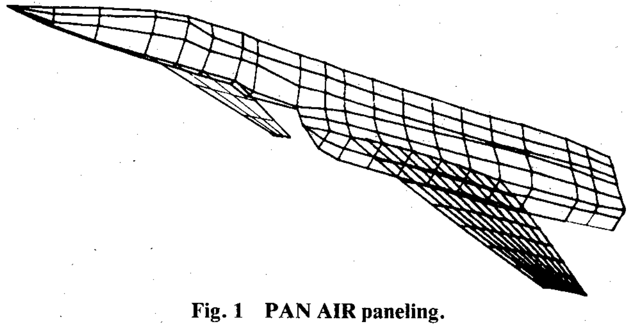

Fig. 1 PAN AIR paneling.

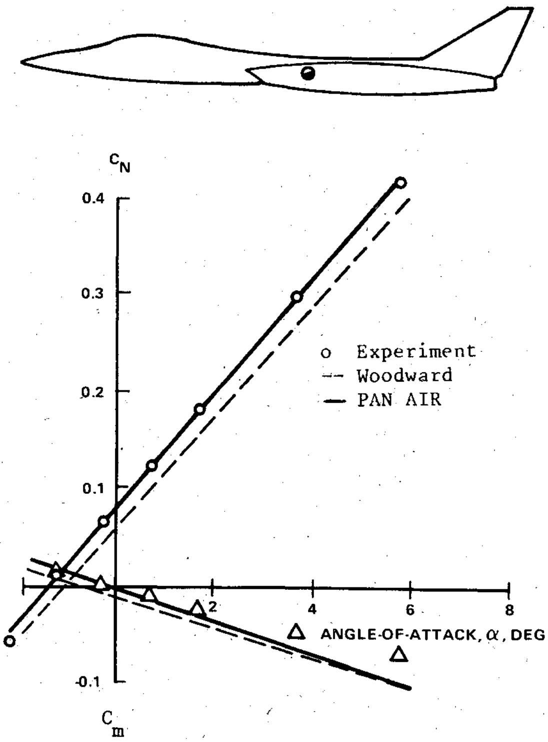

Fig. 2 STAC forces and moments: canard off, $M = 1.5$.

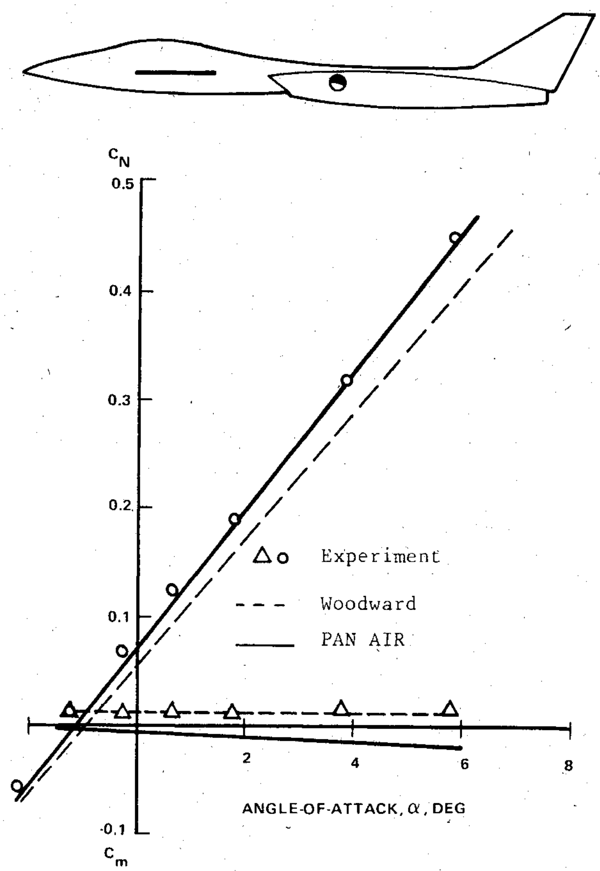

Fig. 3 STAC forces and moments: canard on, $M = 1.5$.

wedge at supersonic speeds. A comparable case at subsonic speeds would be predicting the store behavior in the flowfield produced by an axisymmetric body at zero angle of attack. Test data was available for two stores, the Planar Wing Weapon (PWW) and the GBU-15 cruciform fin weapon (Fig. 7a), traversed at a constant distance from an ogive-cylinder body (Fig. 7b). The PAN AIR predicted forces and moments for the GBU-15 store at $M = 0.6$ are shown in Figs. 8 and 9. The normal force prediction is excellent (Fig. 8). The moment prediction is quite good except for the aft portion of the traverse (Fig. 9). The C_N comparisons for the PWW store are similar (Fig. 10), while the C_m prediction is in generally better agreement than for the GBU-15 store (Fig. 11). Overall, the PAN AIR code appears capable of predicting the behavior of fairly complex stores at subsonic speeds.

Store Behavior in Complex Aircraft Flowfields

It has been demonstrated[9] that the PAN AIR code could predict the behavior of a store in the presence of a complex aircraft configuration both at subsonic and supersonic speeds. The subsonic predictions were excellent, while those at supersonic speeds overpredicted the store forces and moments in the vicinity of the inlet shock. Since experimental data were available for the PWW store in the STAC flowfield, a further attempt was made to evaluate the code's capability of predicting supersonic store behavior. A traverse at $M = 1.95$, $Z = -76$ was selected for comparison purposes because it should provide a severe test of the code's ability due to the store's close proximity. As may be seen in Figs. 12 and 13, the PAN AIR results provide a reasonable estimate of the PWW stores' forces and moments in proximity to an aircraft. One obvious discrepancy is the apparent phase shift in the C_N and C_m predictions in the region where the inlet shock intersects the traverse. This behavior was observed previously.[9,15] The shift results because linear theory assumes that flow disturbances propagate along straight Mach waves, while the physical process involves finite shock waves that are less inclined to the freestream. This defect could be corrected using the procedure described in Ref. 16.

Although the PAN AIR code provides reasonable estimates of store behavior at supersonic speeds, these results were

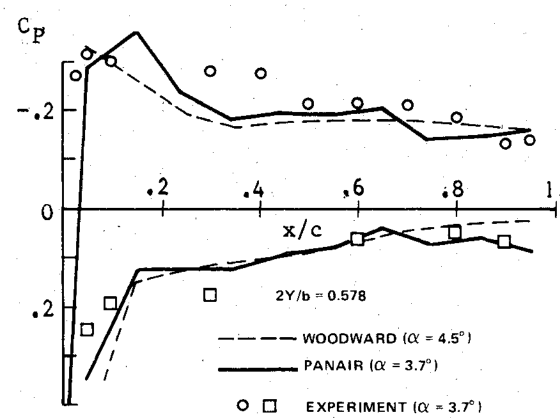

Fig. 4 $M = 1.5$ STAC wing pressures: canard off.

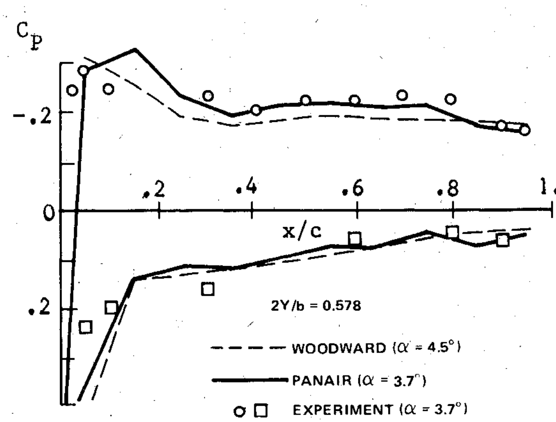

Fig. 5 $M = 1.5$ STAC wing pressures: canard on.

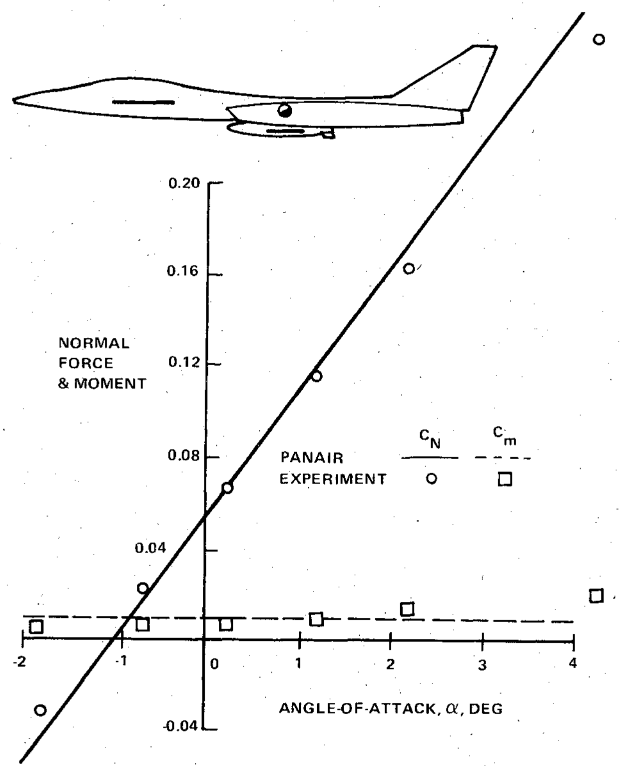

Fig. 6 STAC forces and moments: $M = 1.95$.

achieved at a high cost in computer resources. Each store position along the indicated traverse required about 2 h of CDC-Cyber-740 computer time, or approximately 30 h for the 15 traverse points shown in Figs. 12 and 13. Apparently, this could be reduced by a factor of 5 by using the CDC-Cyber-175 and a factor of 15 by using the CRAY-1.

Cost-Effective Option for Store Trajectories

Using the PAN AIR code for a trajectory calculation, which might require hundreds of separate grid survey locations, might prove unattractive. However, a technique has been recently developed[17] which relates the local angle-of-attack distribution along a store to that store's forces and moments. It has been shown that the PAN AIR code can be used to make reasonable predictions of flow angularity[18,19] under an aircraft, as well as the stores response[10] to a simple flowfield disturbance.

To calculate the behavior of any store in proximity to a specific aircraft, the PAN AIR code is used to provide flow angularity predictions at all grid surveying locations of interest. The store's behavior in a simple flowfield (i.e., passage through the shock produced by a wedge at supersonic speeds) is then calculated by the PAN AIR code to calibrate[17] that store. Store force and moment predictions can then be made at any point in the known aircraft flowfield.

An example of this procedure, denoted as Cost-Effective Option for Store Trajectories (COST),[19] is shown in Figs. 12 and 13. The quality of the results are comparable to those for the PAN AIR code at the cost of approximately 2 h of computer time. Furthermore, other y and z traverses could have been predicted at this Mach number using COST at no additional expenditure of computer time.

A subsonic application of the COST procedure is shown in Figs. 14 and 15 for $M = 0.6$. Also shown in the figures are three calculated PAN AIR points.[9] For this case it appears that the COST procedure provides a better estimate of store behavior than a straightforward PAN AIR calculation, despite the fact that the COST calculations are dependent on information produced by the PAN AIR code. An explanation of this effect is that linear theory predicts the aircraft

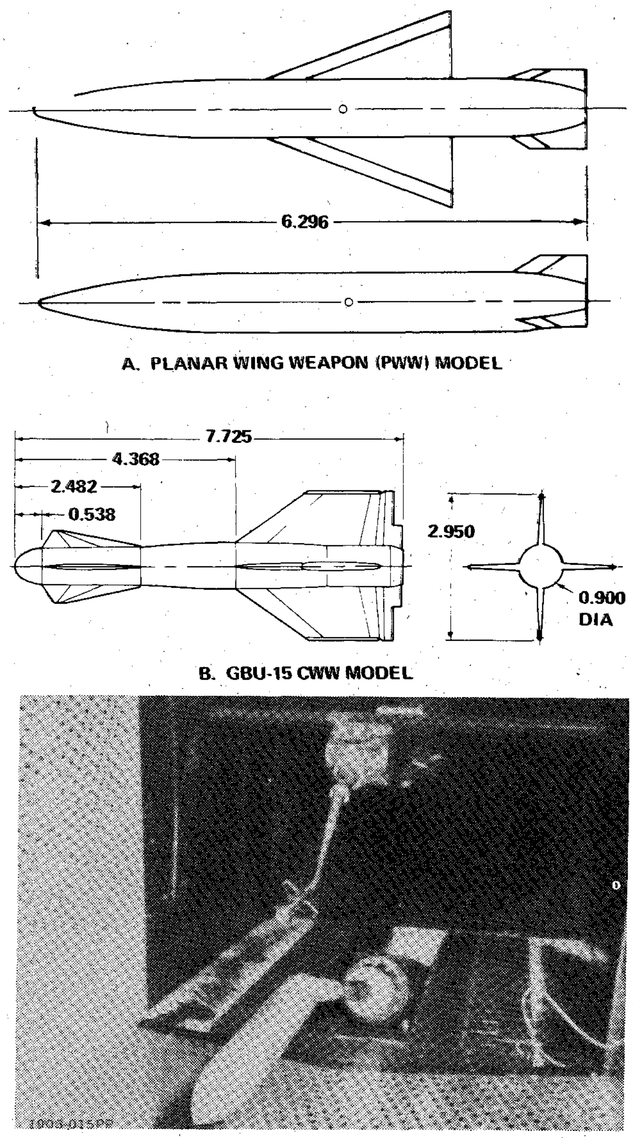

Fig. 7 a) Store geometries. b) Calibration test setup.

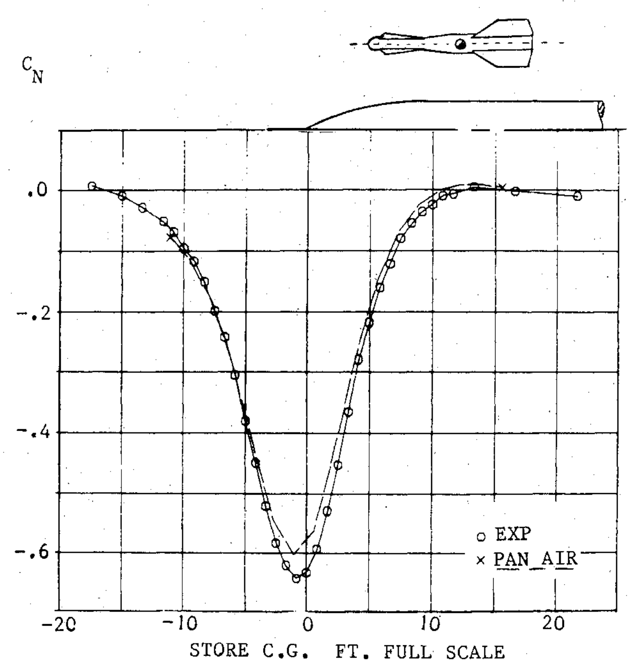

Fig. 8 Experimental C_N on GBU-15 during traverse parallel to ogive cylinder at $M = 0.6$, $Z = -6.89$ ft.

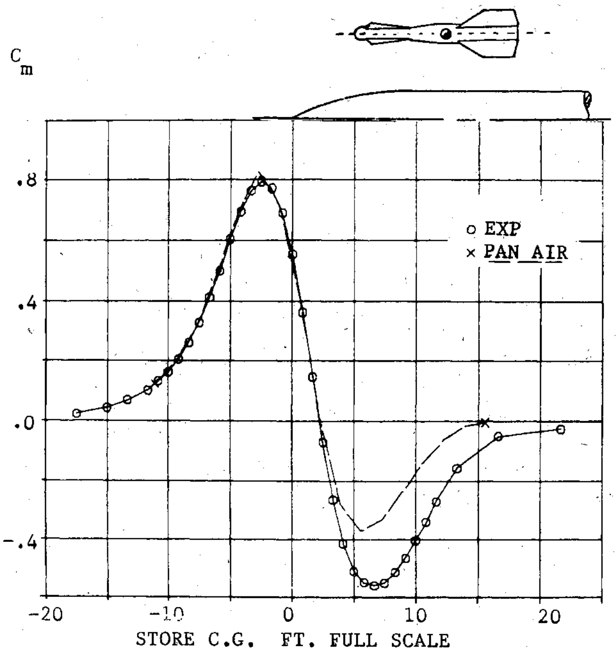

Fig. 9 Experimental C_m on GBU-15 during traverse parallel to ogive cylinder at $M=0.6$, $Z=-6.89$ ft.

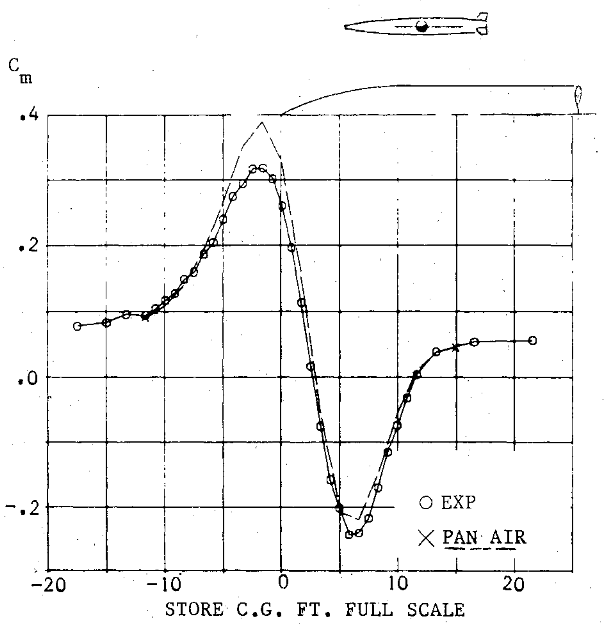

Fig. 11 Experimental C_m on PWW store during traverse parallel to ogive cylinder at $M=0.6$, $Z=-6.89$ ft.

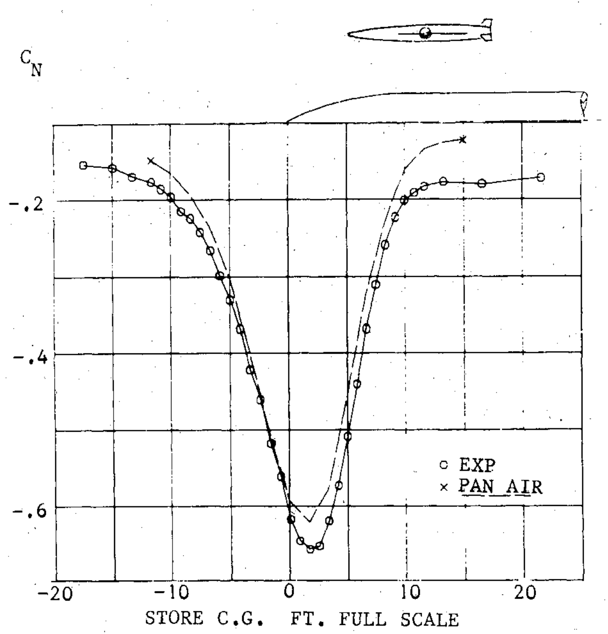

Fig. 10 Experimental C_N on PWW store during traverse parallel to ogive cylinder at $M=0.6$, $Z=-6.89$ ft.

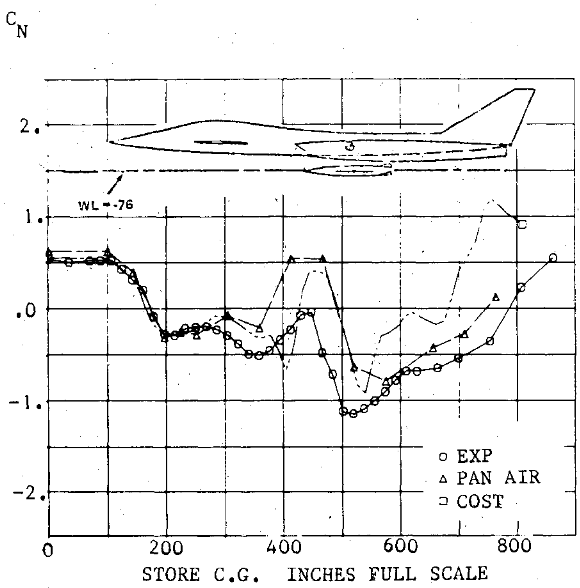

Fig. 12 Force prediction: planar wing weapon in STAC flowfield at $M=1.95$, $Z=-76$, $Y=0$.

flowfield more accurately than the corresponding store loads.[20] Since the store calibrations are obtained from a relatively simple calculation of a store's behavior in a wedge flowfield, it appears that combining the calibrations with the PAN AIR flowfield determination may sidestep the most difficult aspect of a linear theory store load calculation.

Other applications of the COST procedure may be seen in Refs. 10 and 19.

Weapons Carriage

The PAN AIR code appears capable of estimating total configuration lift and moment for an aircraft with weapons mounted in the carriage position[7] (Fig. 6). A considerably more difficult problem is predicting store forces and moments in the carriage position, particularly at supersonic speeds. Results for the PWW store in the STAC carriage position are shown in Fig. 16 for $M=1.5$ and 1.95. The correlation with the test data is somewhat poor. The normal force trends seem to be adequately predicted, but the same cannot be said for the moments. Although the results are somewhat disappointing, it should be remembered that PAN AIR is the only method that currently offers any practical hope of solution to this problem for complex geometries.

Conclusions

PAN AIR provides the user with considerable freedom and flexibility in modeling complex configurations. For regions where linear theory is valid, it provides good correlation with test data. For some configurations, it provides the only practical solution method without gross simplifications of configuration details.

The PAN AIR method also provides reasonable estimates of store behavior in complex aircraft flowfields, both at subsonic and supersonic speeds. One drawback to using PAN AIR directly for store load calculations is the considerable

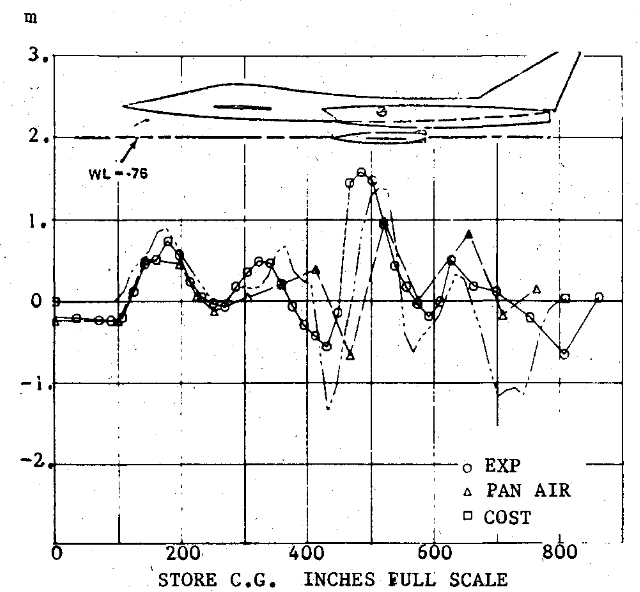

Fig. 13 Moment prediction: planar wing weapon store in STAC flowfield at $M=1.95$, $Z=-76$, $Y=0$.

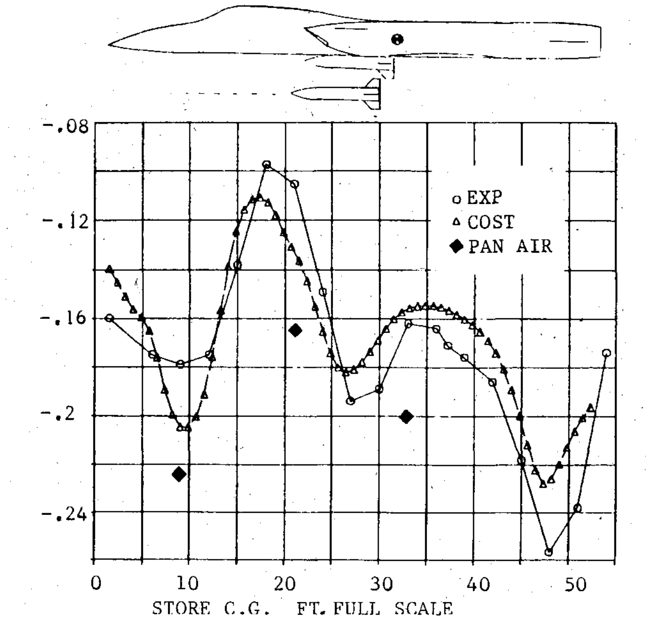

Fig. 15 Generic store moment prediction: AWECS, two stores, $Z=-6.08$, $Y=0$, $\alpha_{AC}=2$, $\alpha_{store}=6$.

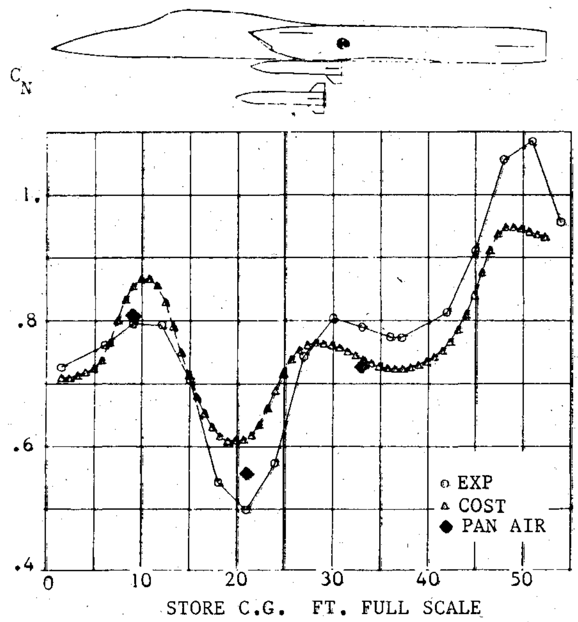

Fig. 14 Generic store force prediction: AWECS, two stores, $Z=-6.08$, $Y=0$, $\alpha_{AC}=2$, $\alpha_{store}=6$.

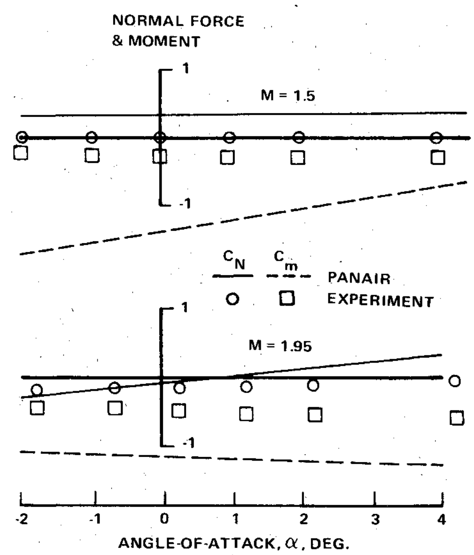

Fig. 16 Planar wing weapon forces and moments, STAC carriage.

cost involved. COST, a procedure which dramatically reduces the associated PAN AIR computer requirements for a grid survey calculation is an alternative.

Although PAN AIR calculations of store carriage loads are not that good, they do seem to provide some estimate of normal force behavior. Other comparisons will have to be made before this question is resolved.

Acknowledgment

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