Recent Improvements in Prediction Techniques for Supersonic Weapon Separation

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The influence function method (IFM) has demonstrated a unique capability for accurately predicting store aerodynamic characteristics in an aircraft flowfield. To apply this method, one must know the force and moment influence functions of the respective stores involved. These are obtained from a separate "calibration" wind tunnel test where the forces and moments on the subject store are measured as the store is traversed through an oblique shock generated by a wedge or inclined plate. It was recently determined that these calibration forces and moments could be accurately predicted by the PANAIR pilot code, thus opening up the possibility for determining the required influence functions theoretically. This suggests that, in many instances, further economies in weapon separation testing are possible by using theoretically determined weapon calibrations. In addition, a procedure has been developed which combines PANAIR predictions of the parent aircraft flowfield with PANAIR store "calibrations." This process enables the calculation of supersonic store behavior without the need of any a priori experimental data, at a considerable cost savings compared to using the PANAIR pilot code to calculate the store forces and moments at every point in the traverse.

Introduction

THE fundamental assumptions underlying the influence function method (IFM) are explained in detail in Ref. 1. Only the highlights of the derivation are described herein.

The principal assumption is that a store's normal force and moment in a nonuniform flow can be correlated with the angle-of-attack distribution along the store length:

$$C_N = \sum_{i=1}^{N} A_i(\alpha - \alpha_0)_i \tag{1}$$

$$C_m = \sum_{i=1}^{N} B_i(\alpha - \alpha_0)_i + C_{mo} \tag{2}$$

where A_i is the C_N influence coefficient for the ith element; B_i the C_m influence coefficient for the ith element; α_i the local α at the ith element; α_o the local store α for zero lift; and C_{mo} the isolated store zero-lift pitching moment.

At supersonic speeds, the influence coefficients A and B can be determined by traversing a store through an oblique shock generated by a wedge of, say, 4 deg, and measuring the normal force and moment along the traverse. Since the flow angularity and the normal force and moment are known in this case, the influence coefficients A_i and B_i can be determined. These known influence coefficients, in conjunction with normal force and moment data for the same store in an aircraft flowfield, at a particular traverse height, are then used to determine the aircraft-induced flowfield angularity along that traverse by solving Eqs. (1) and (2) for α. Experimentally determined influence coefficients for a second store can then be used to predict that store's behavior in the aircraft flowfield.

This technique has demonstrated the ability to accurately predict[1,2] store forces and moments in complex aircraft flowfields. However, the requirement that, before any predictions for a store could be made, the store would have to be calibrated experimentally was an obvious disadvantage in applying the method, particularly when considering nonstandard or noninventory stores/weapons.

Since previous comparisons with test data[3] indicated that the PANAIR pilot code had the ability to accurately predict store behavior in wedge flowfields, the pilot code has been used to generate theoretical influence coefficients for four stores for which experimentally derived influence coefficients also exist.

Furthermore, PANAIR predictions of the flowfield under the aircraft, in conjunction with PANAIR store calibrations, have been used to predict supersonic store behavior. This procedure has the advantage of providing purely theoretical predictions of store behavior without the requirement for a separate PANAIR calculation at every store grid survey location.

The following terminology has been adopted to avoid confusion. When the IFM procedure is applied in the classic sense, i.e., experimental calibrations in conjunction with experimental grid survey data, the results are labeled Exp-Exp. When theoretical store calibrations (PANAIR) are combined with experimental grid survey data, the results are labeled Theory-Exp. Finally, when theoretical (PANAIR) calibrations are used in conjunction with theoretical flowfield calculations (PANAIR), the results are labeled Theory-Theory.

Theoretical Calibrations

Figures 1 and 2 show the geometry of the four stores considered in this paper. The PANAIR representation of these four stores appears in Figs. 3-6. Figure 7 shows a schematic of the experimental store calibration setup. The modeling used in the PANAIR code differed from that in Ref. 3 in two respects. The width of the plate was doubled to ensure that the Mach cone from the tips of the wedge would not intersect the store during its traverse (Fig. 8). Furthermore, the boundary conditions on the store were changed from velocity to mass flux (a PANAIR program option). This was done since use of velocity boundary conditions changes the angle by which the flow is deflected by the wedge[4]; this

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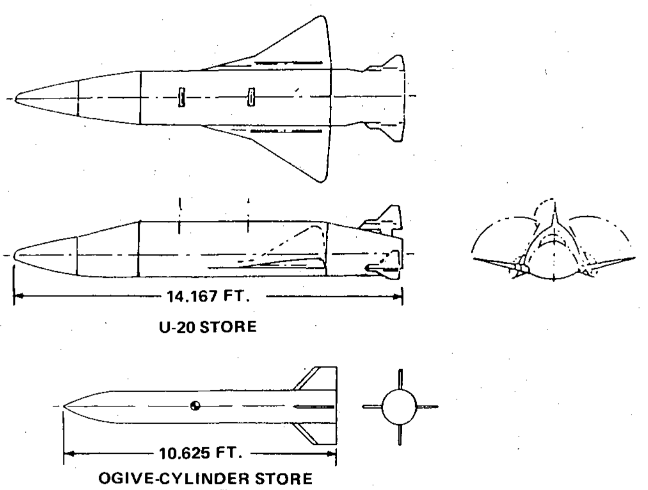

Fig. 1 AWECS stores configurations.

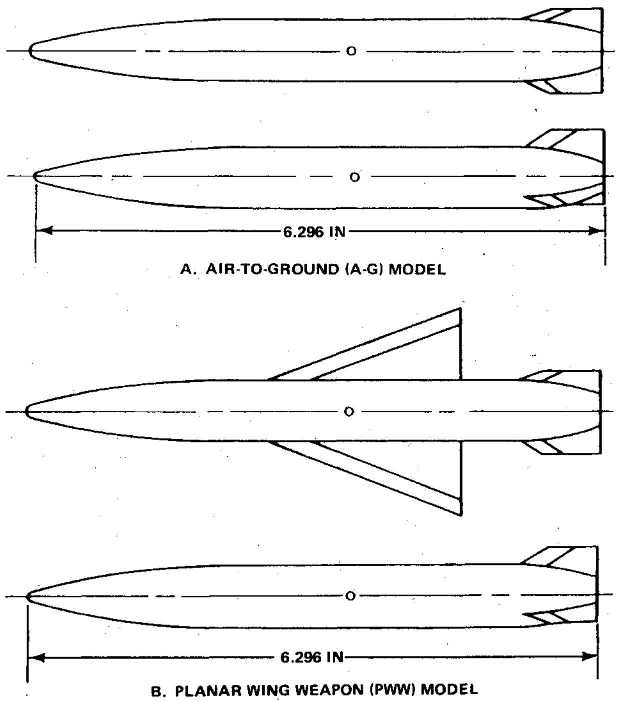

Fig. 2 1/27 scale Grumman store models.

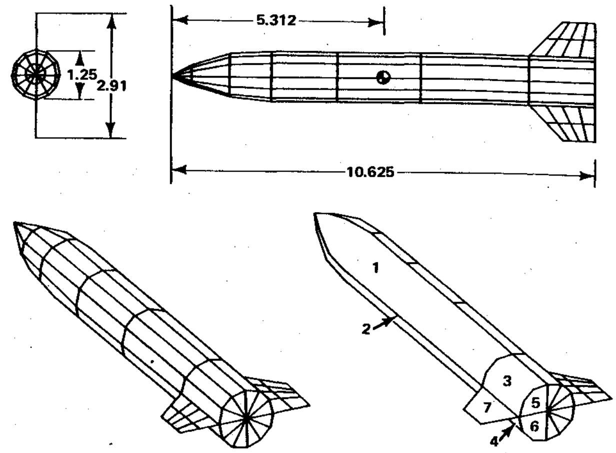

Fig. 3 Generic store network arrangement and paneling.

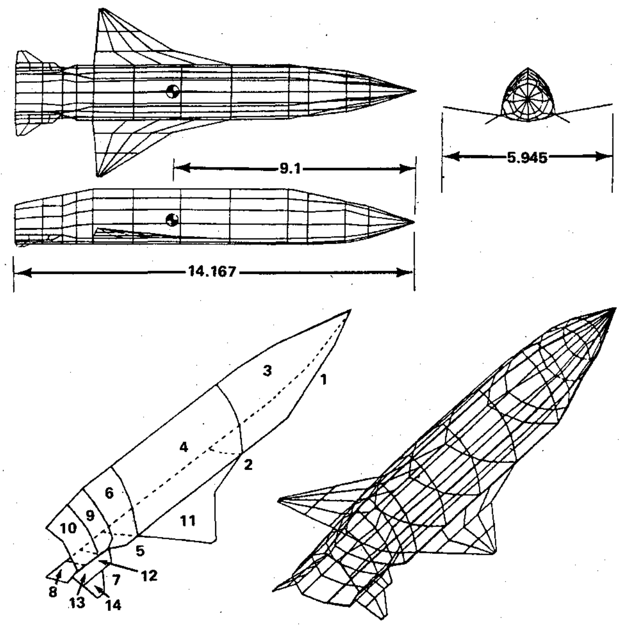

Fig. 4 Advanced store network arrangement and paneling.

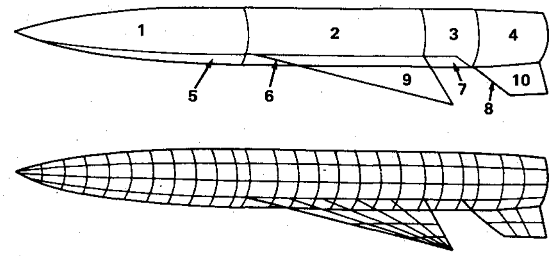

Fig. 5 Planar wing weapon network arrangement and paneling.

prevents the normal force and moment from going to C_{N_0} and C_{m_0} (as it should) for store positions behind the shock wave.

Figures 9 and 10 indicate the effect that the above modeling changes had on the PANAIR predictions for the planar wing weapon (PWW) store. The wind tunnel test was conducted at $M = 1.9$ for two store traverse heights, 2.5 and 6.2 in., below the wedge. In these figures, the $h = 2.5$ in. results have been shifted so that the shock from the wedge nose intersects the traverse at the same location as for $h = 6.2$ in. The PANAIR results for the wedge geometry as tested with velocity boundary condition follow the experimental data trends at the two traverse heights. In this case, the $h = 6.2$ in. traverse experienced side interference effects (when the store was in its downstream position) and, at $h = 2.5$ in., the nose shock of the store nose reflected back off the plate onto the store. The fact that the PANAIR results follow the experimental trends at the aft end of the store traverse indicates that the PANAIR code seems to predict these interference effects. The interference-free calculation also shown in Figs. 9 and 10 was calculated for a traverse at $h = 6.2$ in., with the wedge width doubled and the boundary conditions changed from velocity to mass flux. Although velocity boundary conditions appear to better agree with the upstream experimental data (store locations < 10), it was previously determined that they do not accurately represent the situation when the store nose is aft of the shock from the plate leading edge. In this case, the store should experience $\alpha = 0$ flow, but the velocity boundary conditions[4] characteristically introduce a relative error in α. Although this effect is small relative to the peak-to-peak disturbance, mass flux boundary conditions have been used for all of the following theoretical calibrations for the sake of consistency.

Figures 11 and 12 show the experimental ($h = 6.2$ in.) PWW normal force and moment influence coefficients and the theoretically derived ones. This type of agreement between the two sets of influence coefficients occurred for all four stores.

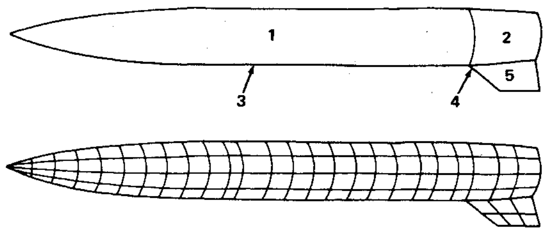

Fig. 6 Air-to-ground store network arrangement and paneling.

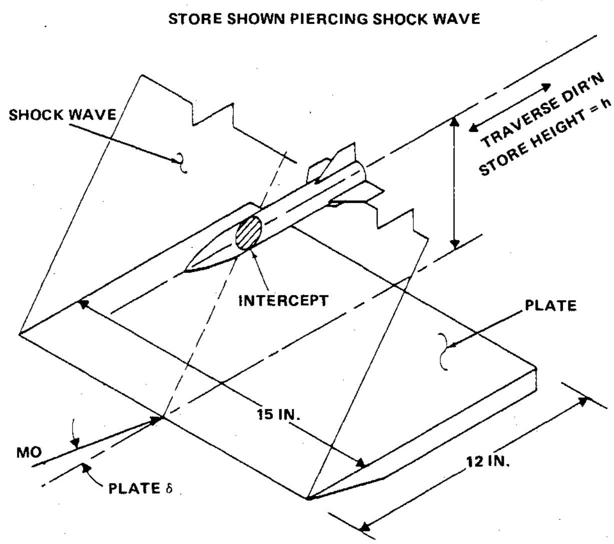

Fig. 7 Calibration test setup.

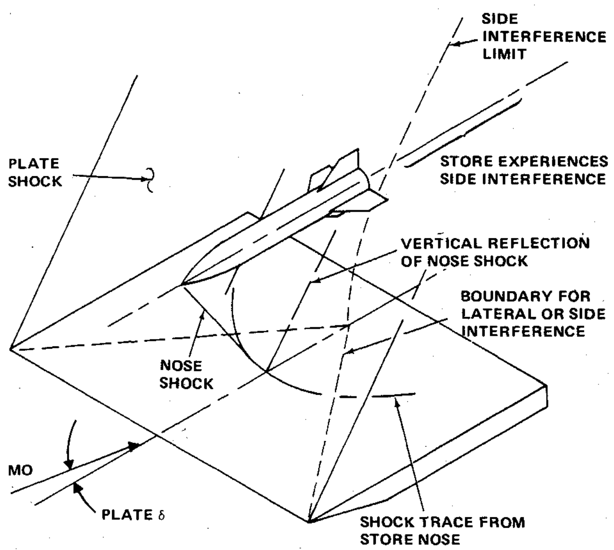

Fig. 8 Calibration flowfield and possible interferences.

Calibration data for the other three stores are available in Ref. 5.

IFM Applications

Supersonic grid survey test data for each of the aforementioned four stores in proximity to their parent aircraft were available. These consisted of STAC data[1] for the PWW and air-to-ground (AG) stores and aircraft weapons carriage and separation (AWECS) data[6] for the generic and U-20 stores. Figure 13 shows the STAC traverse locations, and Fig. 14 describes those for the AWECS configuration.

The critical step in the influence function method prediction technique of store behavior is the use of calibrated store influence coefficients and grid survey force and moment data for the same store to identify the angle-of-attack distribution in proximity to the parent aircraft. Figure 15 shows the angle-of-attack distribution in proximity to the Grumman STAC configuration, where one set of influence coefficients (IC) was derived from the PANAIR prediction while the other was derived from the experiment. Figure 16 shows a similar comparison for the AWECS configuration. The close agreement in the predicted angle-of-attack distribution, using either the experimentally or theoretically derived IC, indicates that both are equally valid.

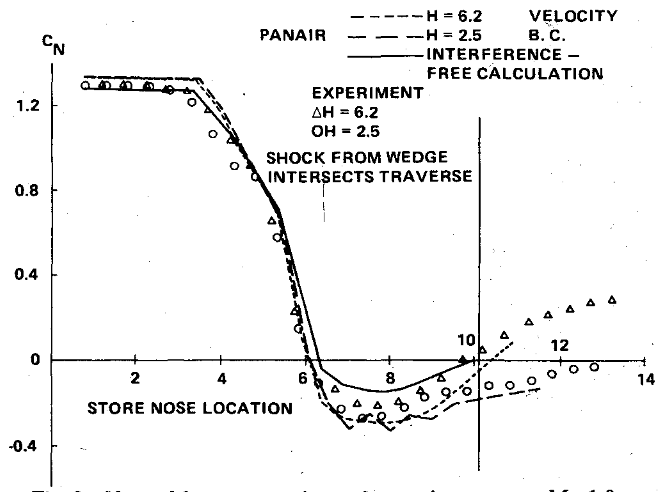

Fig. 9 Normal force comparison: planar wing weapon, $M = 1.9$.

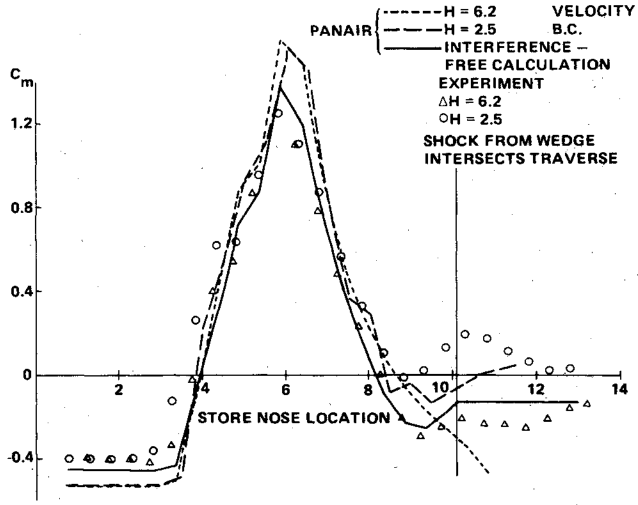

Fig. 10 Moment comparison: planar wing weapon, $M = 1.9$.

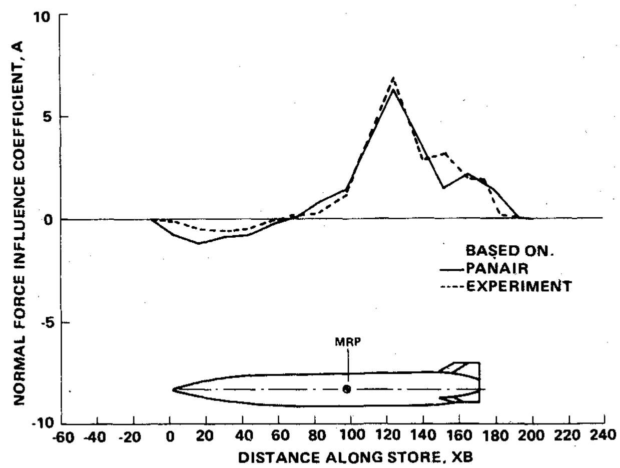

Fig. 11 Planar wing weapon C_N calibration at $M = 1.89$.

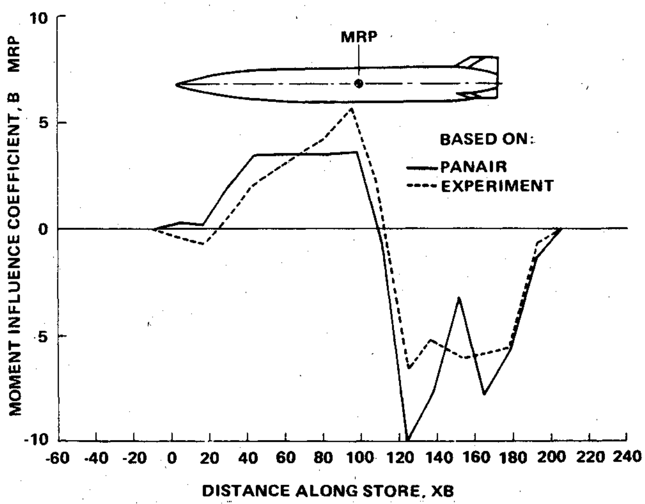

Fig. 12 Planar wing weapon C_m calibration at $M = 1.89$.

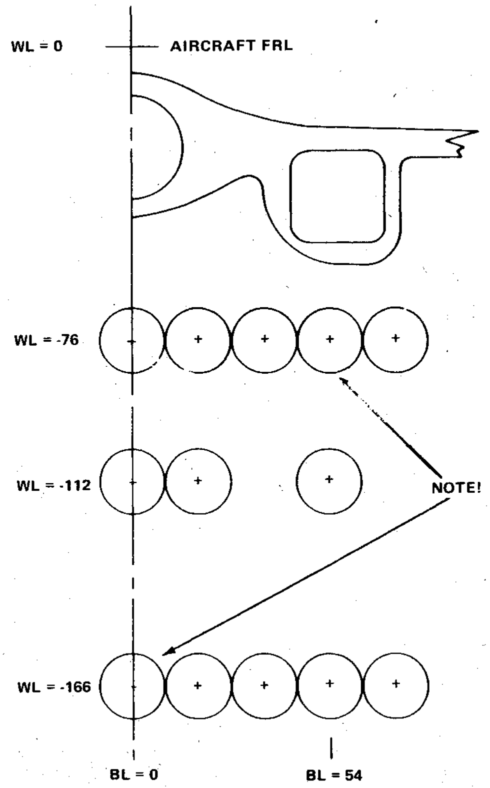

Fig. 13 1/27 scale STAC grid data from AEDC.

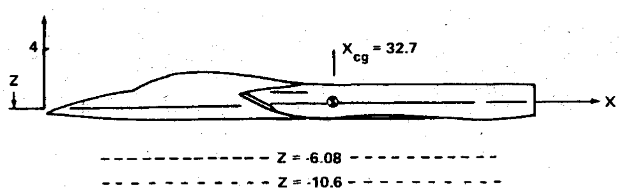

Fig. 14 AWECS configuration data comparison locations.

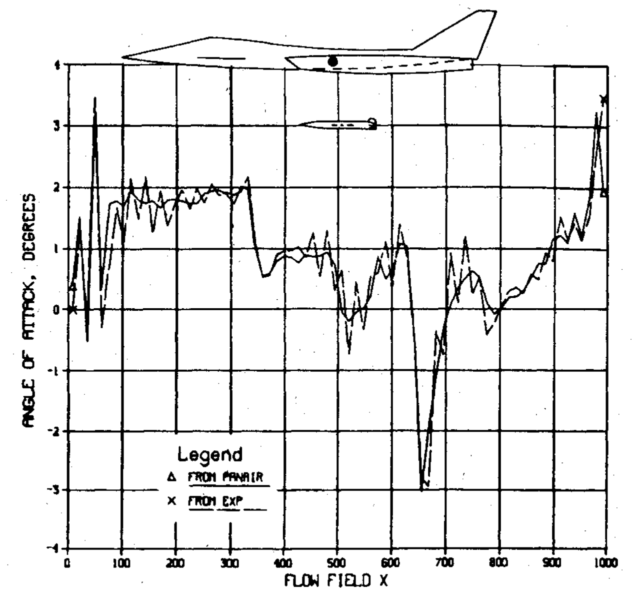

Fig. 15 STAC flowfield, planar wing weapon: $Z = 166$, $BL = 0$, M-1.95.

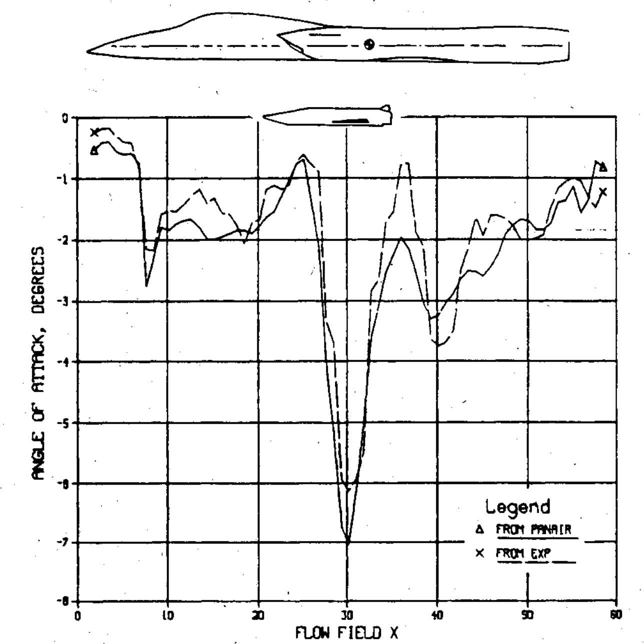

Fig. 16 AWECS flowfield: U-20, $Z = 6.08$, $Y = 0$, $M = 1.5$.

Figures 17 and 18 show the $M = 1.95$ predictions for the AG weapon based on the PWW store at $Z = -166$, $y = 0$ for the STAC configuration, and Figs. 19 and 20 show the comparison at $M = 1.5$, $Z = -76$, $y = 54$, a much more difficult case since the store is within 1 diameter of the nacelle. At this Mach number and traverse height, several reflections of the store nose shock between the aircraft and store should occur. The close agreement between the predictions and test data for this case may be surprising, considering the implied linearity of the analytical model represented by Eqs. (1) and (2). This model, however, does not restrict the technique to linear, potential flow aerodynamics; rather, it implies the existence of a linear input/output relationship similar to the usual practice of approximating aircraft stability characteristics with aerodynamic derivatives obtained by sloping wind tunnel data. To date, the technique has shown excellent correlation with test data to within 1 store diameter of the aircraft, although reflection effects are not explicitly accounted for. Lack of grid traverse test data at store locations closer than 1 diameter to the aircraft surface is the only reason no such comparisons are shown.

It should also be noted that for both STAC traverses the force and moment predictions based on theoretically derived influence coefficients are practically identical to those based on experimentally derived coefficients.

Since the U-20 traverse data are classified, only a one-way comparison of generic store force and moment predictions, based on U-20, is presented in Figs. 21 and 22. As was the case for the AG store, the predictions based on PANAIR

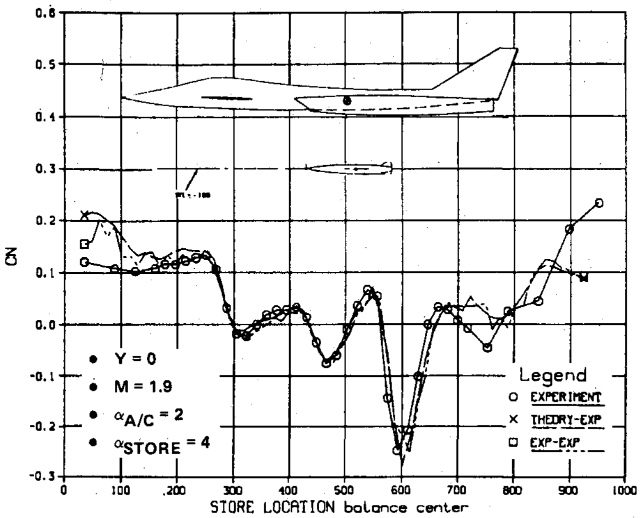

Fig. 17 Air-to-ground force prediction: STAC, $Z = -166$.

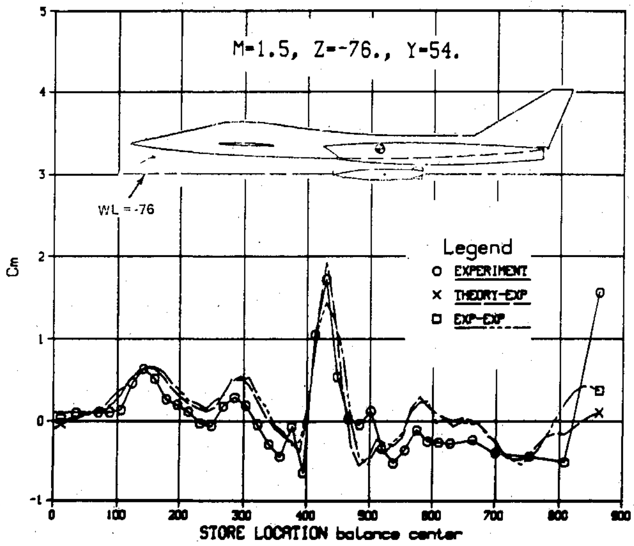

Fig. 20 Air-to-ground store C_m in STAC flowfield.

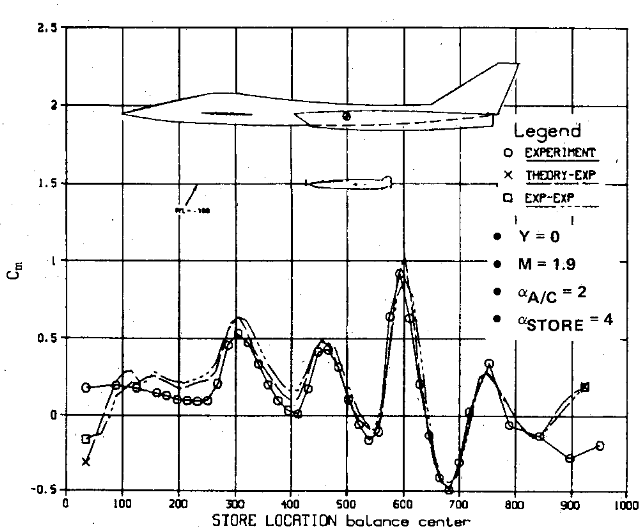

Fig. 18 Air-to-ground moment prediction: STAC, $Z = -166$.

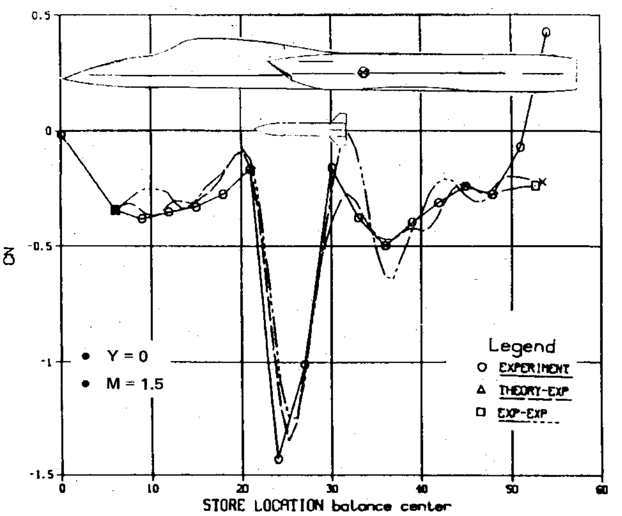

Fig. 21 Generic store force prediction based on U-20: AWECS, $Z = -6.08$.

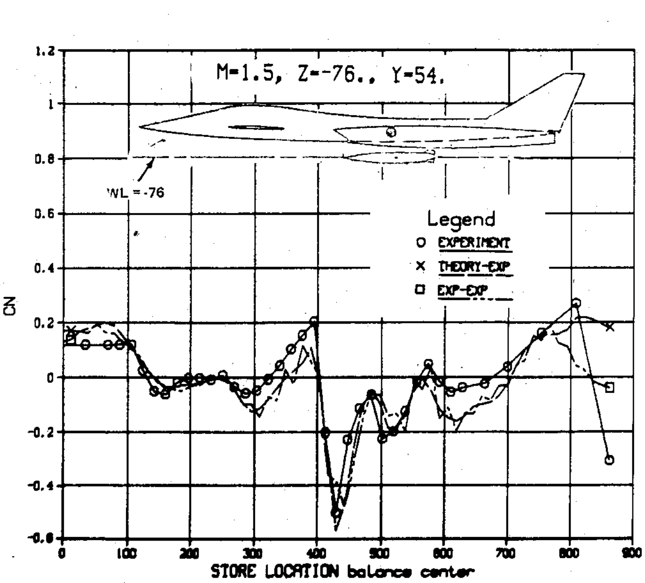

Fig. 19 Air-to-ground store C_N in STAC flowfield.

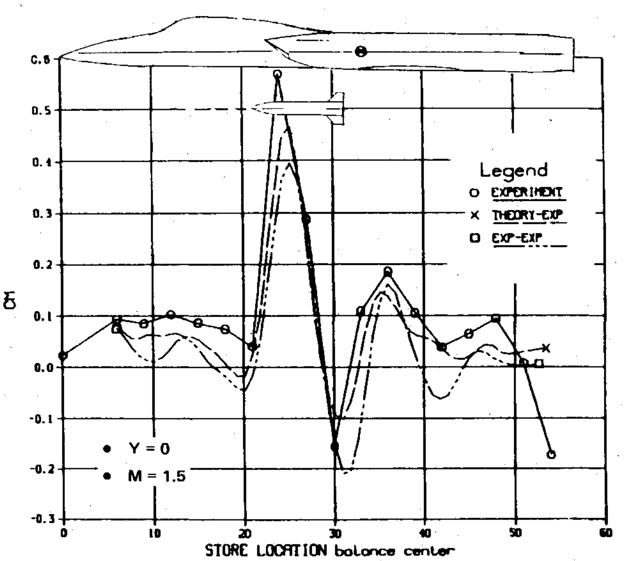

Fig. 22 Generic store moment prediction based on U-20: AWECS, $Z = -6.08$.

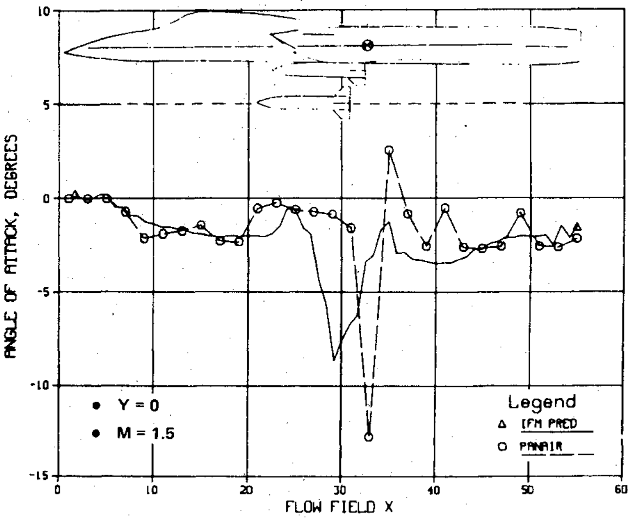

Fig. 23 Prediction of aircraft flowfield: AWECS ogive-cylinder, $Z = -6.08$.

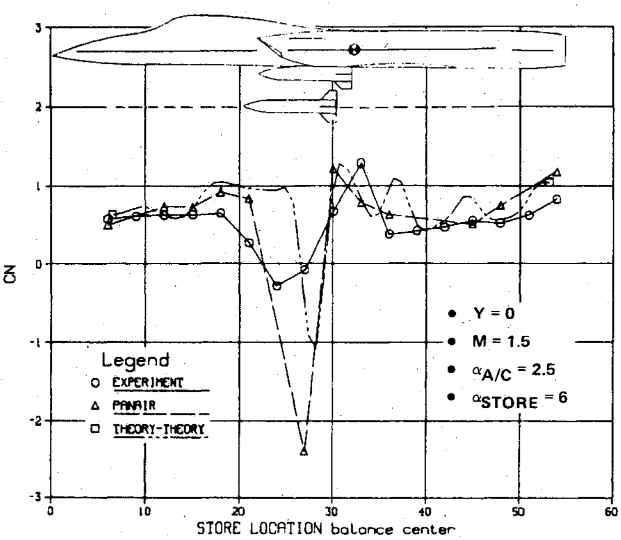

Fig. 24 Ogive-cylinder force prediction: AWECS, $Z = -6.08$.

generated influence coefficients are as good as those based on the experimentally derived influence coefficients.

Theoretical Flowfield Predictions

Figure 23 compares the IFM predicted flowfield for the AWECS configuration (based on the measured generic store forces and moments along the traverse) with the flowfield predicted by the PANAIR pilot code. There are two areas of disagreement between the two curves. The PANAIR predicted location of the nacelle inlet shock is considerably further aft along the traverse than that predicted by the IFM procedure. Furthermore, the strength of this shock is considerably greater for the PANAIR predictions. Both these effects have been observed previously. 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. A simple approximate procedure[7] could be used to correct this error in the PANAIR predictions but was not performed for the present paper. The preferred approach would be to modify the PANAIR code to actually calculate the proper shock position, as was done in Ref. 8. As was also noted in Ref. 7, the strong compression shock of the nacelle inlet is, strictly speaking, beyond the scope of linear theory analysis and must be accounted for in a pragmatic manner. The close agreement

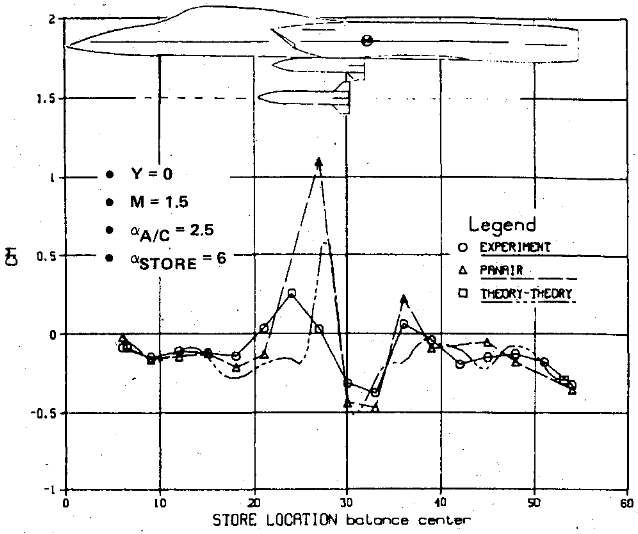

Fig. 25 Ogive-cylinder moment prediction: AWECS, $Z = -6.08$.

between the IFM and PANAIR predicted flow angularity elsewhere along the traverse, however, indicates that the PANAIR code can be usefully employed in predicting complex aircraft flowfields, particularly if modifications to the code are made to account for the proper shock position.

Figures 24 and 25 compare IFM predictions for the generic store based on PANAIR flowfield predictions and a PANAIR weapon calibration with PANAIR calculated generic store forces and moments. Additionally, both sets of predictions are compared with experimental data along the same traverse. At first, the two theoretical predictions look rather disappointing. This is, in part, because the IFM procedure applied in the conventional sense (Exp-Exp and Theory-Exp, Figs. 21 and 22) gave much better results. However, when no experimental store traverse data are available, the two sets of theoretical results can, at least, provide a reasonable estimate of probable store behavior. Furthermore, shifting the location of the nacelle inlet shock, as was done in Ref. 7, should considerably improve the quality of the Theory-Theory comparison.

Although the flowfield and weapon calibration were both obtained from PANAIR, the Theory-Theory force and moment predictions do not agree exactly with the PANAIR calculation. As was stated in Ref. 9, linear theory predicts the aircraft flowfield more accurately than the corresponding store loads. The somewhat smaller discrepancy between the Theory-Theory prediction and test data, compared to the PANAIR prediction, in the region of the large nacelle-inlet shock might be attributed to this observation.

Conclusions

Theoretically determined weapon/store influence coefficients for four stores have been shown to yield accurate IFM store force and moment predictions in proximity to an aircraft. Considering the diversity of the stores examined in this study, it would appear that the use of theoretically determined influence coefficients is a practical and cost-effective (as well as time-effective) alternative to the use of experimental weapon calibrations for general IFM applications at supersonic speeds, since one theoretical calibration requires only about 20 min of CDC Cyber-740 CPU time. The use of theoretically determined influence coefficients also enables the influence function method to be applied in a preliminary design environment.

In addition, it has been shown that when experimental weapon data are unavailable, theoretical parent aircraft flowfield predictions, in conjunction with theoretical weapon calibrations, can be used in the IFM context to provide store separation predictions equal to those calculated by direct application of the PANAIR pilot code at a fraction of the cost. A Theory-Theory calculation for an entire grid survey required 110 min of CPU time on the CDC Cyber-740 computer (20 min for the calibration and 90 min for the aircraft flowfield) compared with a 90-min time requirement for a PANAIR calculation of each grid point location (i.e., 1080 min for the case shown).

One practical shortcoming of using theoretically calculated aircraft flowfields for weapon predictions at this time is the inability of present-day linear codes to adequately describe the strong shock system generated by inlet cowls or the flow spillage process. The development of semiempirical corrections for these errors should considerably improve the accuracies of purely theoretical store separation predictions.

Although the IFM technique has to date been used only to calculate supersonic grid store forces and moments, the technique is presently being extended to the subsonic speed regime under Air Force Contract F33615-82-3007.

Acknowledgment

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References

[1]Meyer, R., Cenko, A., and Yaros, S., "An Influence Function Method for Predicting Store Aerodynamic Characteristics During Weapon Separation," paper presented at the 12th Navy Symposium on Aeroballistics, David Taylor Naval Ship Research and Development Center, Bethesda, Md., May 1981.

[2]Tessitore, F., Cenko, A., Meyer, R., Dyer, R., and Waskiewicz, J., "A New Approach to Weapon Separation Aerodynamics," *Journal of Aircraft*, Vol. 19, Dec. 1982, pp. 1070-1075.

[3]Waskiewicz, J., DeJongh, J., and Cenko, A., "Application of Panel Methods to the Aerodynamic Analysis of Proximity and Mutual Interference Effects on Store Separation at Supersonic Speeds," *Journal of Aircraft*, Vol. 20, Feb. 1983, pp. 153-158.

[4]Tinoco, E., Boeing Commercial Airplane Company, private communication, Feb. 1981.

[5]Cenko, A., Tessitore, F., and Meyer, R., "Prediction of Aerodynamic Characteristics for Weapon Separation," AFFDL-TR-82-3025, April 1982.

[6]Vore, D.A., "Wind Tunnel Test of Advanced Configurations and Various Weapons for Mach Numbers 0.6 to 1.6," AEDC TSR 79-P69, 1979.

[7]Cenko, A. and Tinoco, E.N., "PANAIR-Weapons, Carriage and Separation," AFFDL-TR-79-3142, Sept. 1979.

[8]Dillenius, M.F.E., Goodwin, F.K., and Nielsen, J.N., "Prediction of Supersonic Store Separation Characteristics," AF-FDL-TR-76-41, May 1976.

[9]Nielsen, J.N., "Missile Aerodynamics—Dim Past and Indefinite Future," Paper presented at the 12th Navy Symposium on Aeroballistics, David Taylor Naval Ship Research and Development Center, Bethesda, Md., May 1981.