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A New Approach to Weapon Separation Aerodynamics

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An innovative approach has been developed for predicting the aerodynamic forces and moments acting on a store during separation from a parent aircraft. The method utilizes data obtained for one store in the flowfield to predict the forces and moments of another store in the same flowfield by identifying the local angle-of-attack distribution in proximity to the parent aircraft. Extensive comparisons between theory and test are shown for two different parent models, each with two different stores (four stores in all) at supersonic speeds, indicating the excellent correlation achieved. The potential for substantial wind tunnel cost savings is identified.

Introduction

CURRENT methods for assessing the separation trajectory characteristics of stores from military aircraft require extensive wind tunnel testing of specific aircraft-store combinations. For the matrix of aircraft/store/flight condition combinations required to clear a complete release envelope, and with skyrocketing wind tunnel costs, methods are required to improve the cost-effectiveness of wind tunnel data. Attempts to generalize separation data from one store to another based on isolated store aerodynamic characteristics have heretofore proven unsatisfactory. It has long been recognized that this simple approach is unacceptable whenever the flow angularity varies significantly over the length of the store, making it impossible to define an "effective α" environment. The concept of applying a distributed α has been previously recognized,[1] and the idea of distinguishing between the angle of attack experienced by the nose, midsection, and tail of the store has been developed by others.[2-4] Practical implementation of these concepts has, until now, depended on using measured or theoretically determined parent aircraft flowfield angularity data and estimating nose, midsection, and tail-section force and moment contributions as a function of their respective local angle of attack. When these basic ideas are extended to their logical conclusion, one is led quite naturally to consideration of an influence function method (IFM) for predicting store aerodynamic characteristics during weapon separation. The objective of this paper is to present such a state-of-the-art prediction technique that predicts the interference forces and moments on stores that are released in the near field of the parent aircraft. By providing the aircraft designer with a tool to predict weapon aerodynamic characteristics during separation, the technical capability to design for improved aircraft-weapon compatibility is considerably enhanced. More importantly, the need to individually test each aircraft/store/flight condition is eliminated since the method predicts the aerodynamic characteristics of one store based on those of another for the same aircraft/flight condition. The method, although currently developed for supersonic speeds, is applicable in principle to all speed ranges.

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Methodology Development

The basic assumptions underlying the formulation and development of the influence function method are described in detail in Ref. 5. Only the highlights of the technique are repeated herein.

The influence function method implicitly assumes that a store's normal force and moment in a nonuniform flowfield may be represented as a function of the angle-of-attack distribution along the store and the store's influence coefficients, as defined by Eqs. (1) and (2):

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

$$C_m = \sum_{i=1}^{N} B_i (\alpha - \alpha_0)_i + C_{m_0} \tag{2}$$

where A_i is the C_N influence coefficient for the ith element; B_i is the C_m influence coefficient for the ith element; α_i is the local α at the ith element; α_0 is the isolated store α for zero lift; and C_{m_0} is the isolated store zero lift pitching moment.

The application of the influence function method requires several steps. First, the store to be "calibrated" (i.e., whose A_i, B_i influence coefficients are to be determined) is traversed (downstream to upstream) through a known nonuniform flowfield and the measured store balance force and moment noted. AFWAL/Grumman supersonic wind tunnel test experience shows that accurate store calibrations can be accomplished using a simple two-dimensional oblique shock flowfield generated by a flat plate at incidence. Using the known flowfield generated by the plate, in conjunction with the measured normal forces and moments, Eqs. (1) and (2) are solved by matrix inversion for the unknowns A_i and B_i.

Figures 1 and 2 show the experimentally derived normal force (A_i) and pitching moment (B_i) influence coefficient distribution for a representative winged supersonic standoff weapon at $M = 1.89$. In this case, the store was divided into 16 elements and the respective A_i, B_i for each element determined from a least-squares analysis of the C_N, C_m data taken during a store calibration through a 4-deg oblique shock wave.

Maximum span for this delta-winged weapon occurs at missile station 132, which accounts for the large positive A_i (large positive C_N response) and large negative B_i (large negative C_m response) at that location. The negative A_i's over

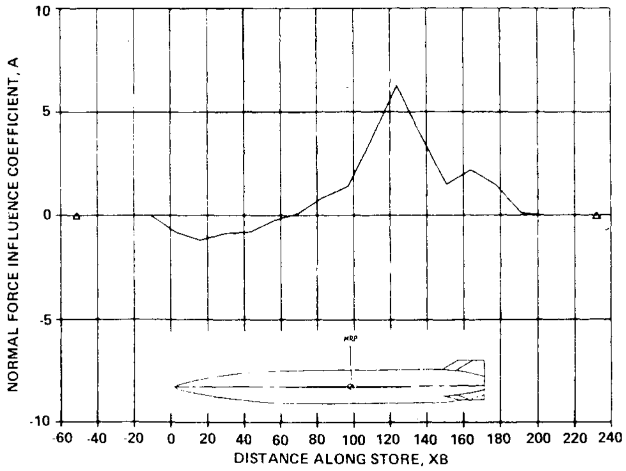

Fig. 1 Planar wing weapon normal force influence coefficient distribution, $M = 1.89$.

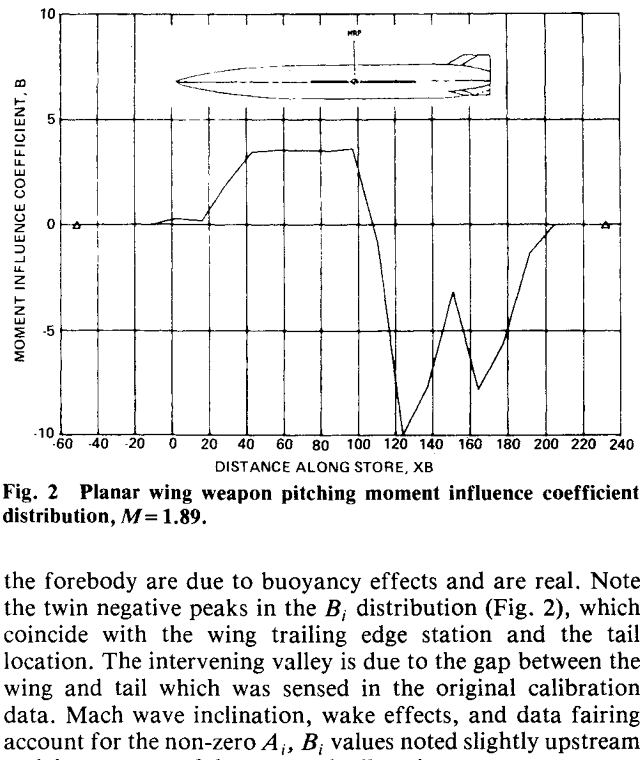

Fig. 2 Planar wing weapon pitching moment influence coefficient distribution, $M = 1.89$.

the forebody are due to buoyancy effects and are real. Note the twin negative peaks in the B_i distribution (Fig. 2), which coincide with the wing trailing edge station and the tail location. The intervening valley is due to the gap between the wing and tail which was sensed in the original calibration data. Mach wave inclination, wake effects, and data fairing account for the non-zero A_i, B_i values noted slightly upstream and downstream of the nose and tail stations.

All experience and evidence to date indicate that satisfactory experimental calibrations can be accomplished within the usual data accuracy standards associated with grid survey force and moment data. This observation is directly supported by wind tunnel data for $M = 1.5$-2.3, and there is no reason to expect contrary results at subsonic speeds.

Proceeding to the next phase in the application of the IFM technique to weapon separation, we now show how conventional grid survey force and moment data, taken in proximity to the parent aircraft, can be used to calculate the angle-of-attack distribution along the same traverse. The sting-mounted and previously calibrated store is assumed to traverse upstream, one store element length at a time, while the store balance data are recorded. These data, in conjunction with the previously determined influence coefficients, enable us to solve Eqs. (1) and (2) for the unknown flow angularity, α_i.

Figure 3 shows a typical least-squares estimate of the α distribution along a traverse in proximity to the parent aircraft. These particular results are based on conventional grid survey force and moment data taken at AEDC for a traverse location 166 in. (full scale) below the fuselage reference line

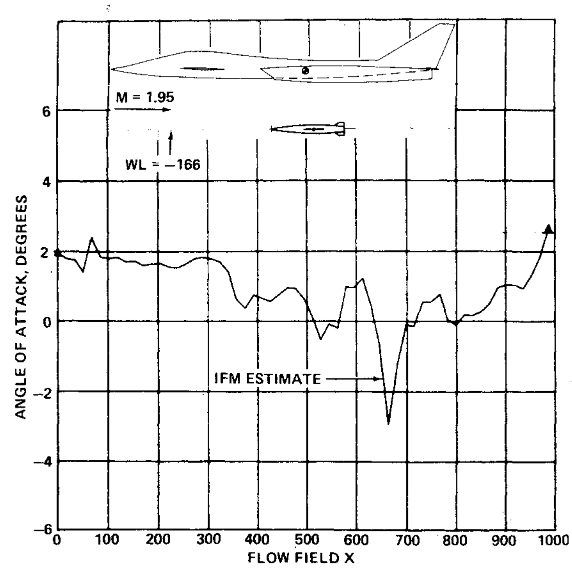

Fig. 3 "Estimated" local angle-of-attack distribution WL-166 traverse in proximity to Grumman STAC.

(FRL) of Grumman's 1/27-scale Supersonic Tactical Aircraft (STAC) wind tunnel model. As expected, each of the peaks and crests in this predicted α distribution is related to some prominent configuration feature such as the nose, canard, inlet, or wing.

The final step in the IFM prediction process requires nothing more than using the derived angle-of-attack distribution in proximity to the aircraft and the influence coefficient data for any "other" previously calibrated store to construct a normal force/pitching moment prediction for this "other" store.

As can be seen from Eqs. (1) and (2), C_N and C_m can be calculated by direct substitution for the known A_i, B_i, α_0, C_{m_0} and the known α_i along the traverse.

In principle, the process outlined above shows how grid survey force and moment data for one store can be used to estimate the force and moment characteristics of another store in the same flowfield. The essential requirement in this predictive process is that both stores were previously "calibrated" at the Mach number of interest.

In the interests of clarity, we have consistently described the mechanics of the present IFM in terms of an experimental/operational approach to emphasize that the concepts can be so implemented. In many cases, however, it may prove more economical to calibrate a particular store using theoretical/computational techniques to duplicate the experimental process described herein. AFWAL/Grumman experience to date shows excellent correlation[6] between theory and experiment for stores traversed through an oblique shock flowfield.

Comparison with Experiment

Representative IFM prediction-wind tunnel data correlations are included herein. The $M = 1.95$ data were taken in proximity to a 1/27-scale model of Grumman's STAC configuration (Fig. 4). In this case, the planar wing weapon (Fig. 5b) grid survey data were used to estimate the air-to-ground weapon (Fig. 5a) data along the water line (WL) $= -166$, butt line (BL) $= 0$ and WL $= -76$, BL $= 54$ traverses indicated in Fig. 6. Both stores were "calibrated" in the WPAFB Trisonic Gas-dynamics Test Facility using a 4-deg oblique shock calibration flowfield.

The IFM-predicted C_N, C_m for the air-to-ground store shows good agreement with the wind tunnel data at WL $= -166$ (Figs. 7 and 8). The theory-data discrepancy upstream of station 100 and downstream of station 800 is characteristic of IFM predictions near the "ends" of a traverse since the α's

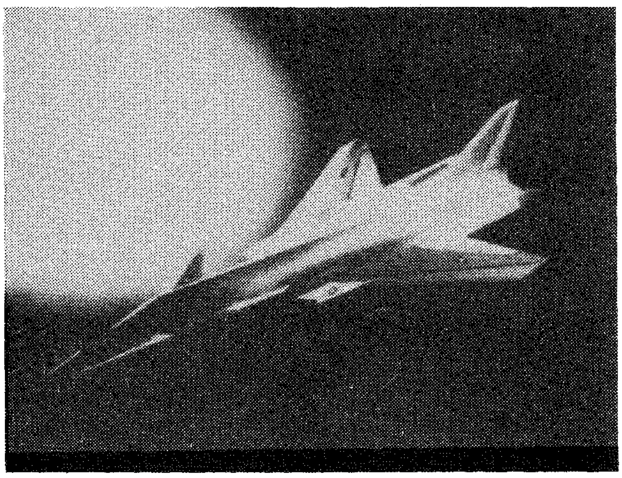

Fig. 4 Grumman supersonic tactical aircraft configuration (STAC).

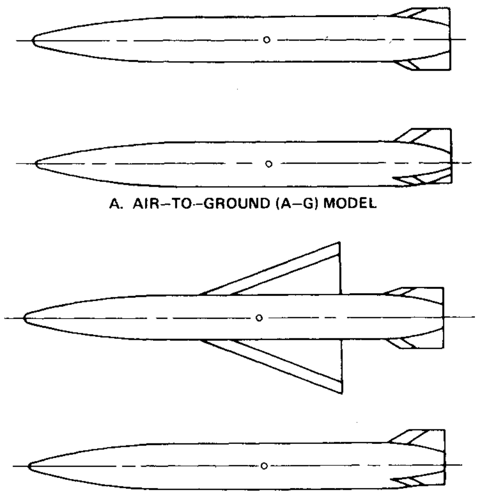

Fig. 5 1/27-scale Grumman store models.

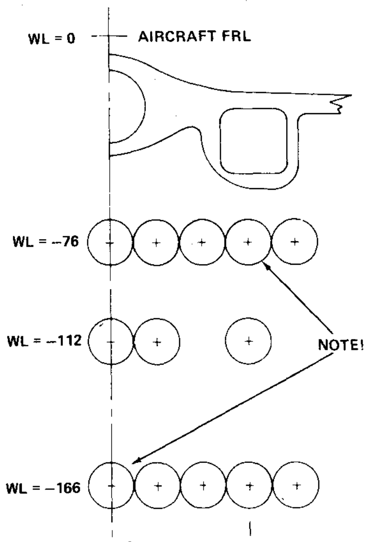

Fig. 6 Cross-sectional view of 1/27-scale STAC grid survey at AEDC.

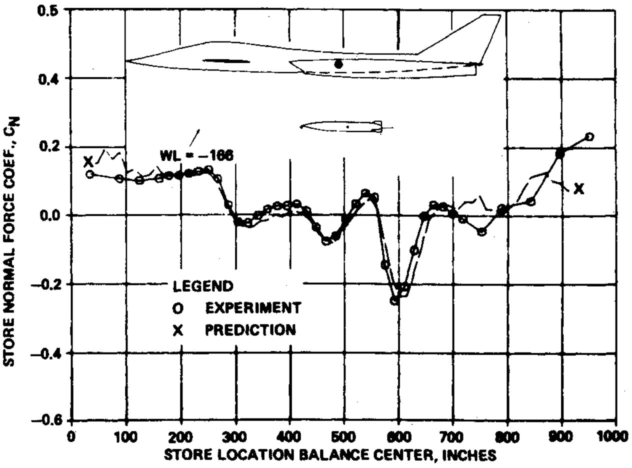

Fig. 7 Air-to-ground weapon IFM normal force prediction compared with wind tunnel data, WL = – 166, BL = 0, M = 1.95.

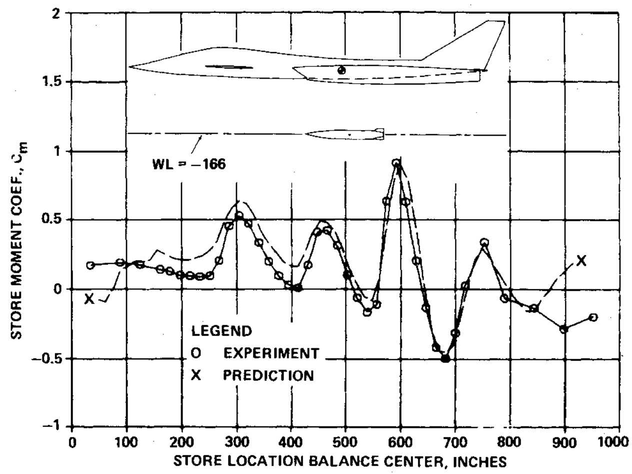

Fig. 8 Air-to-ground weapon IFM pitching moment prediction compared with wind tunnel data, WL = – 166, BL = 0, M = 1.95.

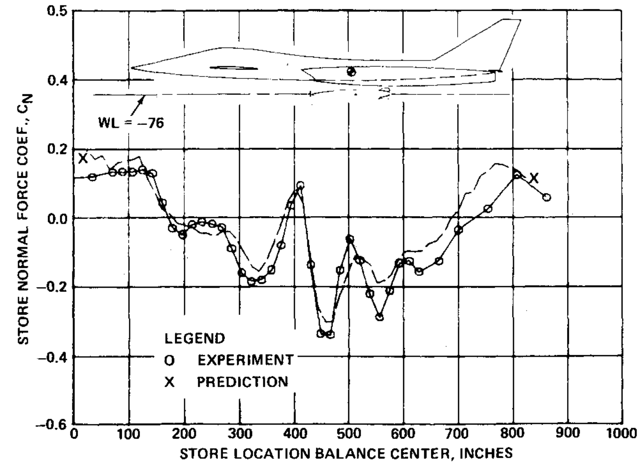

Fig. 9 Air-to-ground weapon IFM normal force prediction compared with wind tunnel data, WL = – 76, BL = 0, M = 1.95.

in this region are not accurately defined by the least-squares identification process. IFM predictions at WL = – 76, BL = 54 also show good agreement with air-to-ground test data (Figs. 9 and 10). In this case, the weapon traverse comes within one store diameter of the model nacelle.

Examining the utility of the IFM in the reverse direction, a prediction was made for the planar wing weapon using the air-to-ground store's grid survey data to predict C_N and C_m (Figs. 11 and 12). In this case the comparison is shown for what would be expected to be the most difficult case at WL = – 76, BL = 54, and good agreement is again indicated.

Further investigation of the IFM's utility included its application to data sets with sparse data sampling rates (i.e., two store diameters) and between stores with vastly different geometric characteristics. One such data set satisfying both these criteria was obtained during the AFWAL advanced

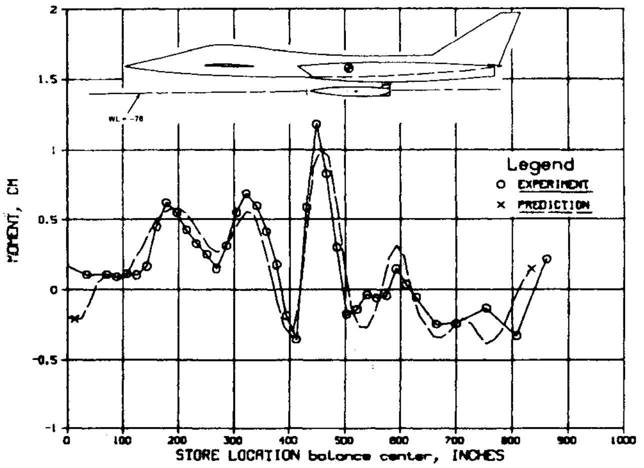

Fig. 10 Air-to-ground weapon IFM pitching moment prediction compared with wind tunnel data, WL = −76, BL = 0, M = 1.95.

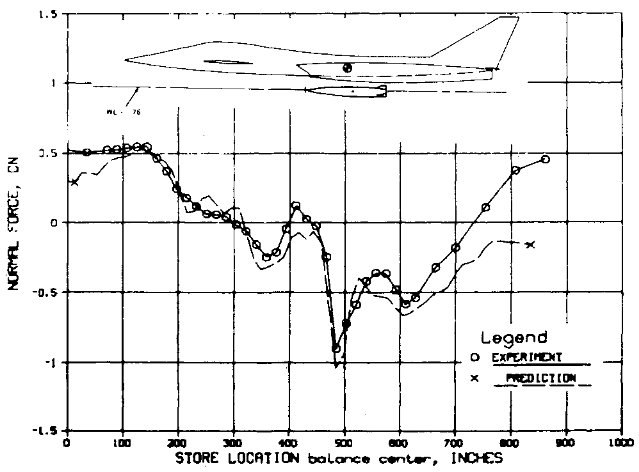

Fig. 11 Planar wing weapon prediction based on air-to-ground, WL = −76, BL = 54, M = 1.95.

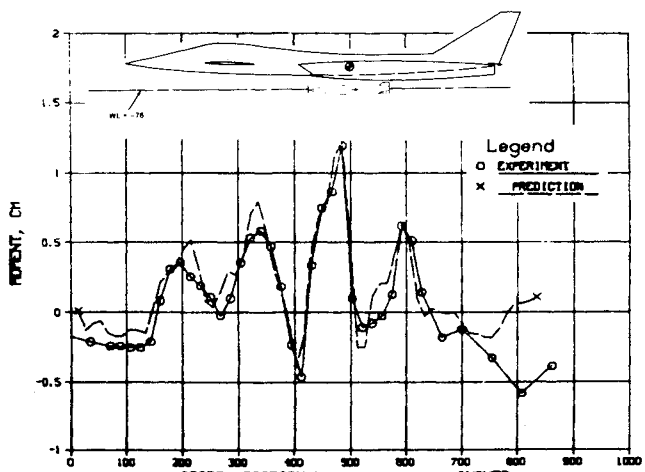

Fig. 12 Planar wing weapon prediction based on air-to-ground, WL = −76, BL = 54, M = 1.95.

weapons carriage and separation (AWECS) study. Two of the stores tested in this program and illustrating great dissimilarity were an ogival-cylinder with a cruciform tail and a winged trisided store (U-20) with an inverted-Y tail, the latter having approximately double the volume of the former (Fig. 13). For this data set, the U-20 store was used to determine the flowfield angularity (Fig. 14) and to predict the ogive-cylinder normal force and pitching moment (Figs. 15

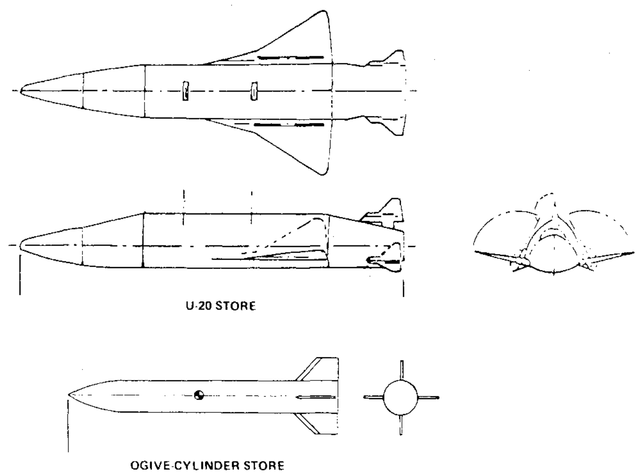

Fig. 13 AWECS store configurations.

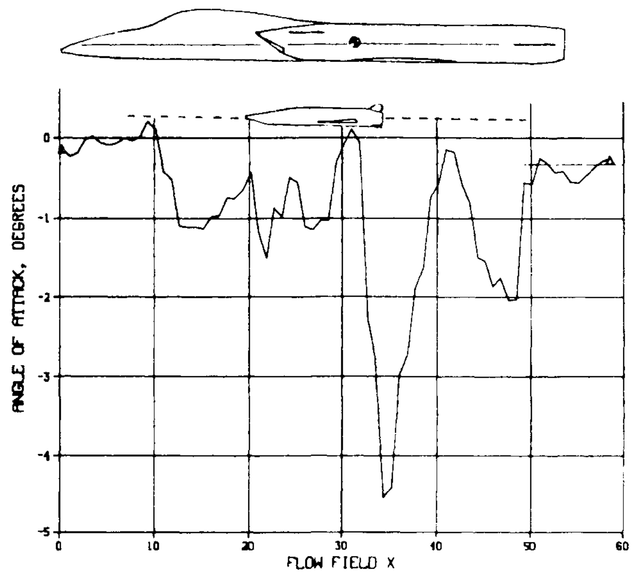

Fig. 14 AWECS flowfield U-20, Z = −10.56, Y = 0, M = 1.5.

and 16). Here again, the worst case is shown and reasonably good agreement with experiment is indicated despite the sparseness of the data.

The foregoing IFM predictions were based on parent aircraft flowfield angularity distributions determined from grid survey store force and moment data. None of the angularity estimates were corrected for secondary flowfield effects due to the weapon itself.

Judging from weapon/flat plate proximity data from the WPAFB Trisonic Facility at M = 1.5 and 1.9, it appears that the weapon-induced effect is less than 20% of the total store force and moment to within 1 diameter of the carriage position. In exceptional cases, or where greater prediction accuracy is required, a theoretical proximity correction could be applied. The accuracy level demanded of the correction would be modest, e.g., a 25% error in a theoretically calculated correction would result in only ~5% error in the total store force and moment estimate. The calculation of such a correction is much less demanding or difficult than attempting to calculate the total aircraft flowfield since only the reflection effect need be modeled. As noted in Ref. 7, the volume effect of the store nose is probably the only induced interference effect that may need to be considered.

Extension of Results

The application of the IFM is predicated on a knowledge of the force and moment influence coefficients of the respective

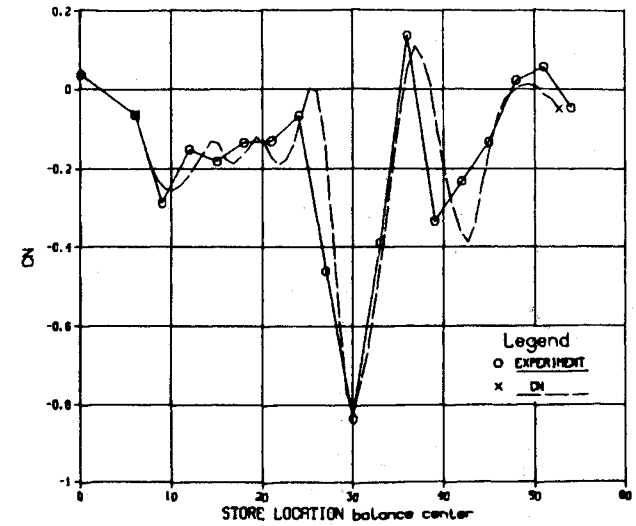

Fig. 15 Generic store force prediction based on U-20 AWECS, $Z = -10.6$, $Y = 0$, $M = 1.5$, coarse traverse.

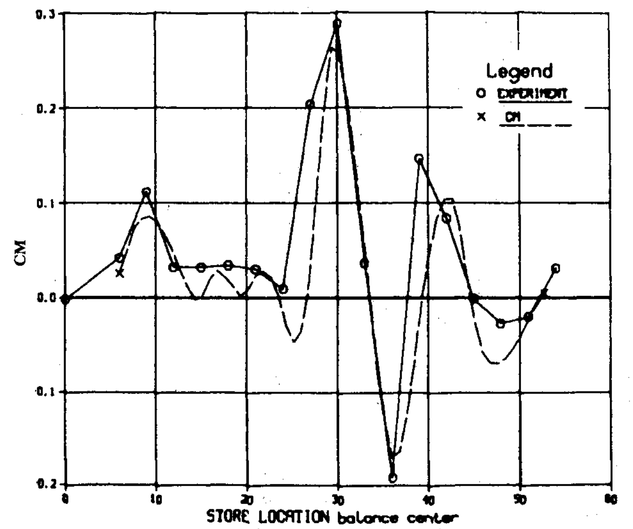

Fig. 16 Generic store moment prediction based on U-20 AWECS, $Z = -10.6$, $Y = 0$, $M = 1.5$, coarse traverse.

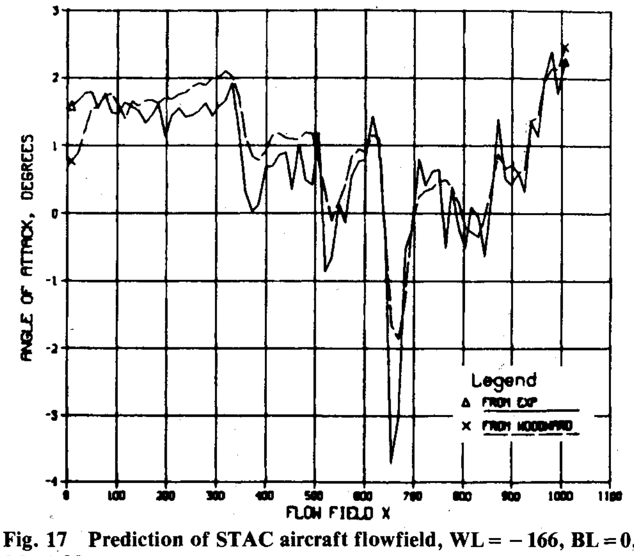

Fig. 17 Prediction of STAC aircraft flowfield, WL = −166, BL = 0, $M = 1.95$.

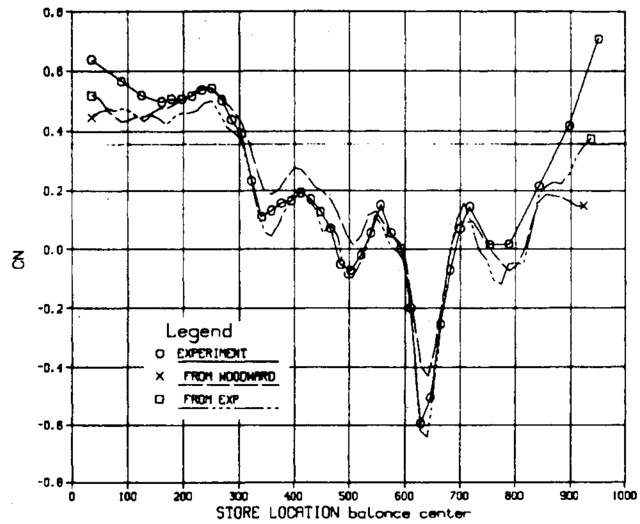

Fig. 18 Planar wing weapon force prediction based on air-to-ground STAC, WL = −166, BL = 0, $M = 1.95$.

stores involved. Up to this point, predictions of store forces and moments were accomplished using influence coefficients obtained by experimental means, i.e., an instrumented store being traversed through a known nonuniform flowfield in a wind tunnel. In many instances, further weapon separation economies are possible using theoretical calibrations in lieu of experimental ones. The feasibility of applying panel methods for analyzing proximity effects was explored in Ref. 6. For weapons whose aerodynamic characteristics can be easily represented by linear theory it is observed that all three codes investigated in Ref. 6 are capable of qualitatively predicting store proximity and mutual interference effects, the primary differences being their capacity for geometric representation. The benefit of using these codes is to further limit the amount of experimental data required to employ the IFM in predicting store aerodynamic characteristics in proximity to a specific aircraft. Conceivably, the behavior of any variety of stores could be predicted given only the force and moment data for *one* store tested in that aircraft flowfield.

The ultimate test of the utility of a calibration, whether experimentally or theoretically derived, is its ability to predict the flowfield under an aircraft. One way to check the consistency of the calibrations is to compare the α distribution predicted by each method along one particular STAC grid survey traverse; the predicted α distributions should be the same. Using the air-to-ground (AG) store, the α distributions generated by the experimentally determined and theoretically[8] derived influence coefficients agree remarkably well (Fig. 17) considering that the AG store's predictions have consistently been inferior to those generated by the planar wing weapon (PWW) store. The theoretically derived influence coefficients for the PWW store were used in conjunction with the theoretically derived α distribution to generate the normal force and pitching moment on the PWW store along the traverse. These were then compared against both the experimental results and the prediction obtained using experimental calibration data. As may be seen in Figs. 18 and 19, the PWW predictions based on theoretical calibrations of the AG and PWW stores are nearly as good as those based on experimental calibrations, and both agree rather well with the experimental grid survey data.

Conclusion

A method has been developed and validated for predicting the aerodynamic forces and moments acting on a store during weapon separation based on previous wind tunnel data for another store in the same flowfield. Predicted forces and moments based on this influence function method (IFM) show excellent correlation with supersonic test data. This work is currently being extended to the subsonic/transonic speed

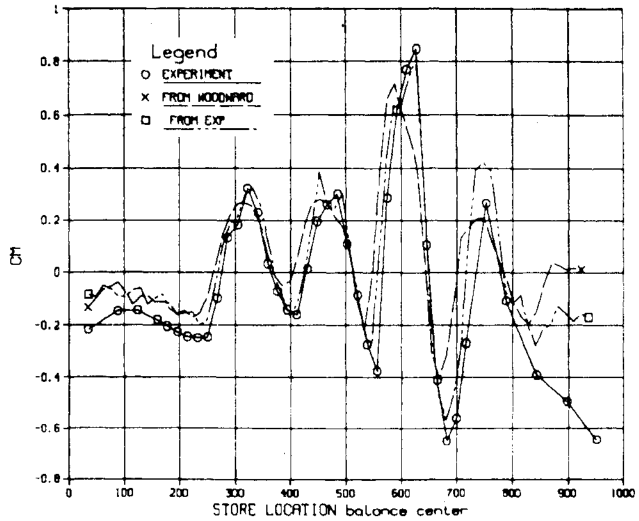

Fig. 19 Planar wing weapon moment prediction based on air-to-ground STAC, WL = −166, BL = 0, M = 1.95.

range, and should provide a comprehensive and unified approach to predicting store separation aerodynamics. The technique offers the designer a tool for assessing weapon release characteristics from advanced aircraft configurations and provides early insight to store compatibility design requirements. Continued development of this technique is expected to result in substantial improvements in the cost-effectiveness of future weapon separation test programs.

The IFM technique can be implemented as a strictly experimental/operational procedure to significantly increase the cost-effectiveness of wind tunnel prediction of weapon separation characteristics. Further weapon separation testing economies are possible utilizing panel-method techniques to obtain theoretical store calibrations in lieu of experimental. Eliminating the need for experimental store calibrations not only provides a substantial cost savings but also extends applicability to the preliminary design environment where early experimental data may be unavailable.

The present IFM has been successfully applied to a significant number of supersonic grid survey data sets; those shown here are representative. Grumman is presently under contract to AFWAL/FIMM to finalize the IFM technique for supersonic applications, develop user oriented codes, and address specific issues related to future subsonic/transonic applications.

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