Further Development of the Influence Function Method for Store Aerodynamic Analysis

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An innovative approach has been developed to predict the forces and moments acting on a store during separation from a parent aircraft. This technique, termed the Influence Function Method, was originally restricted to the prediction of store normal forces and pitching moments at supersonic speeds. It has now been shown to be equally valid at subsonic and transonic Mach numbers, for the prediction of loads in both the pitch and yaw plane. Furthermore, the utility of the method can be enhanced by combining it with existing codes that can determine aircraft flowfields.

Nomenclature

$A_i, A_i^*, A_i^{**}, B_i, B_i^*$	$= C_N, C_Y, C_A, C_m$, and C_η influence coefficients, respectively, for ith store element
C_A	= axial force coefficient
C_m	= pitching moment coefficient
C_η	= yawing moment coefficient
C_N	= normal force coefficient
C_Y	= side force coefficient
C_{m0}	= isolated store zero lift pitching moment
$C_{\eta 0}$	= isolated store zero side force yawing moment
IC	= influence coefficients
M	= Mach number
X, Y, Z	= Cartesian Coordinates in ft
BL, WL	= aircraft coordinates in ft
α_i	= local α at ith element
α_0	= isolated store α for zero lift
β_i	= local β at ith element
β_0	= isolated store β for zero side force
γ_i	= local total angularity $(\alpha_i + \beta_i)$ at ith store element

Introduction

THE Influence Function Method (IFM)[1-4] is a three-step process that alternatively employs the following equations:

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

$$C_m = \sum_{i=1}^{N} B_i (\alpha - \alpha_0)_i + C_{m0} \tag{2}$$

These equations represent the relationship between the forces and moments acting on a store and the interaction of the local flow angle on each store with the store normal force and pitching moment influence coefficients A_i and B_i, respectively, for that store segment. Note that although these equations are linear in form, they do not represent linearized aerodynamic effects. The equations are actually analogous to regression equations where the nonlinear effects are included in the influence coefficient terms as well as a general, nonlinear angularity represented by α_i.

The first step of the IFM process is the determination of the store's influence coefficients. Loads data for a store along an axial traverse in a known flowfield provide one set of equations for each axial position in the traverse. The two systems of equations are solved separately in a least squares sense for the unknown influence coefficients A_i and B_i by matrix inversion. In the second step, experimental C_N and C_m data from an axial traverse through an aircraft flowfield of a calibrated store may be used to determine the unknown flowfield through which the store has traversed. The final step combines the flowfield calculated in the second step with influence coefficients for another calibrated store to calculate the second store's forces and moments within the aircraft flowfield.

Calibrations

The determination of a store's influence coefficients is termed calibration. Originally this was done by traversing a store through a shock generated by a wedge and measuring the store's loads during the traverse. Equations (1) and (2) thus provided the supersonic influence coefficients A_i and B_i. It was subsequently demonstrated[2] that stove loads could be adequately predicted by a linearized potential flow method. This enabled the theoretical determination of supersonic influence coefficients.

For this study the influence coefficients were determined[5] by traversing the three stores shown in Fig. 1 parallel to an ogive-cylinder (calibrator body) at Mach numbers of 0.6, 0.8, 0.9, 0.95, 1.05, and 1.2. Force and moment data were taken for each store at each Mach number, while the flowfield generated by the calibrator body was estimated by the PAN AIR[6] code at the subsonic Mach numbers and the RAXBOD[7] code at $M = 0.9$, 0.95, 1.05, and 1.2.

It was determined[3] that at the subsonic Mach numbers all influence coefficients (even theoretically determined supersonic ones) worked equally well. At the transonic Mach

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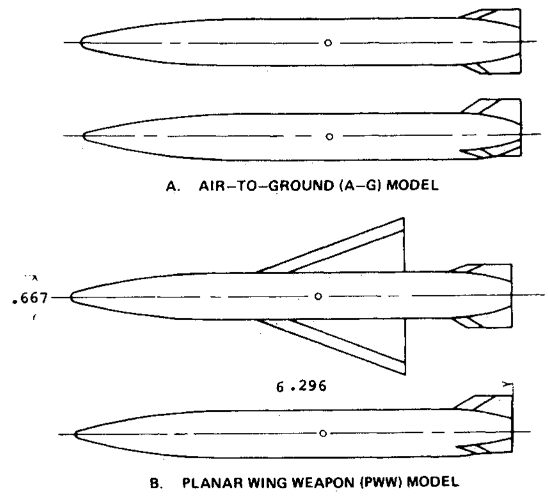

Fig. 1a 1/20-scale Grumman store models.

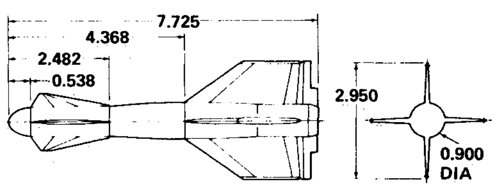

Fig. 1b 0.5-scale GBU-15 CWW store geometry.

numbers only the $M=0.95$, 1.05, and 1.2 influence coefficients gave good results. Since the three transonic influence coefficients gave essentially the same results, the $M=0.95$ coefficients were used in the subsequent comparisons.

Although the theoretically determined influence coefficients failed to provide good results at transonic speeds, it has been demonstrated[8] that the Interference Distributed Loads code[9] can accurately determine the transonic influence coefficients for the GBU-15 store (Fig. 1).

Side Force and Yawing Moment

The formulation for side force and yawing moment assumes that these loads are unique functions of the sidewash distribution along the store:

$$C_y = \sum_{i=1}^{N} A_i^*(\beta - \beta_0)_i \tag{3}$$

$$C_\eta = \sum_{i=1}^{N} B_i^*(\beta - \beta_0)_i + C_{\eta_0} \tag{4}$$

The side force and yawing moment calibrations were conducted by traversing the three stores on the side of (rather than above) the calibrator body. The sidewash was again theoretically predicted (due to symmetry of the calibrator body, the sidewash was the same as the pitch angularity at the same relative distance from the calibrator centerline).

Results

GBU-15 normal force and pitching moment predictions at $M=1.05$, based on aircraft flowfield angularity data derived from the PWW store's traverse, are shown in Figs. 2a and 2b. These comparisons were chosen because this particular case gave the poorest correlations. Other comparisons are available.[3-4]

Pylon side force and yawing moment comparisons are shown in Figs. 3a-4b. In all cases the side force and yawing moment comparisons were excellent.

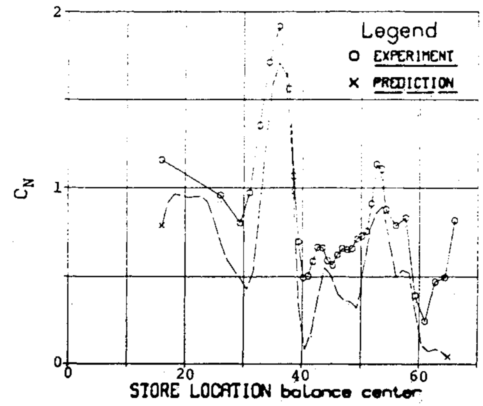

Fig. 2a $M=1.05$ **F-15 pylon force prediction (**$WL=4.1$, $BL=9.65$**) GBU-15 store from PWW.**

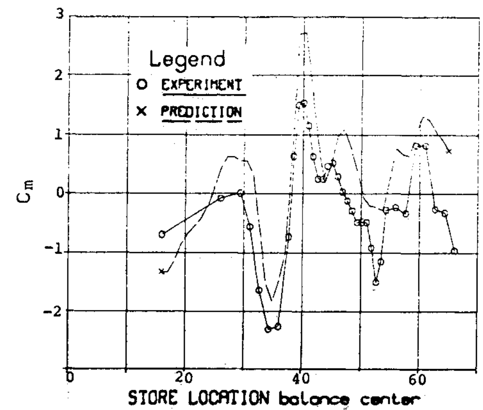

Fig. 2b $M=1.5$ **F-15 pylon moment prediction (**$WL=4.1$, $BL=9.65$**) GBU-15 store from PWW.**

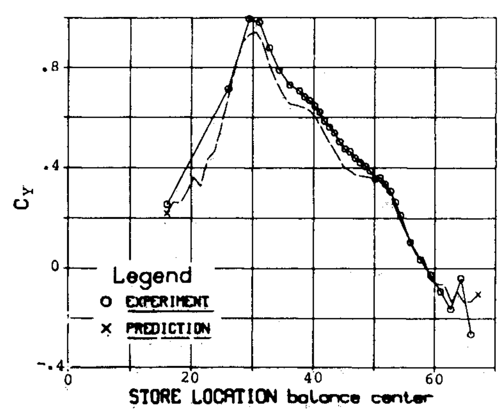

Fig. 3a $M=0.8$ **F-15 pylon side force prediction (**$WL=4.1$, $BL=9.65$**) GBU-15 store from PWW.**

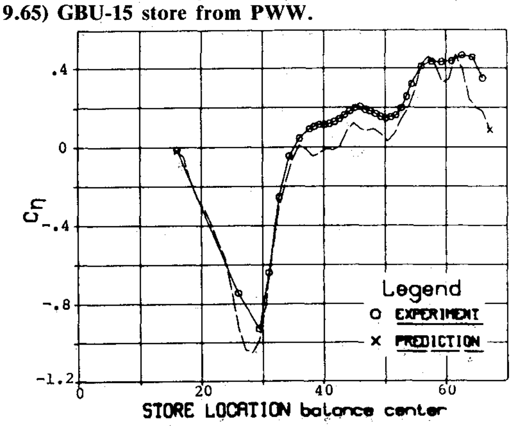

Fig. 3b $M=0.8$ **F-15 pylon yawing moment prediction (**$WL=4.1$, $BL=9.65$**) GBU-15 store from PWW.**

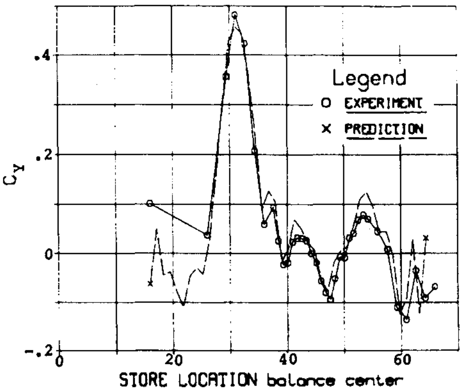

Fig. 4a $M=1.2$ **F-15 pylon side force prediction** ($WL=4.1$, $BL=9.65$) **PWW store from AG.**

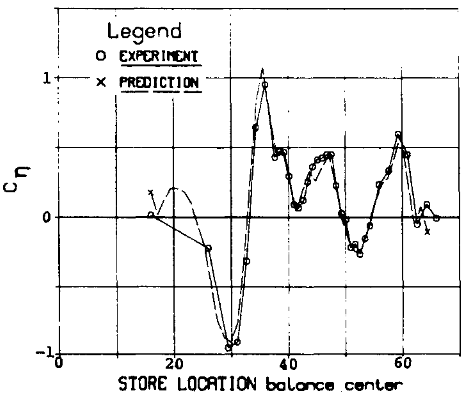

Fig. 4b $M=1.2$ **F-15 pylon yawing moment prediction** ($WL=4.1$, $BL=9.65$) **PWW store from AG.**

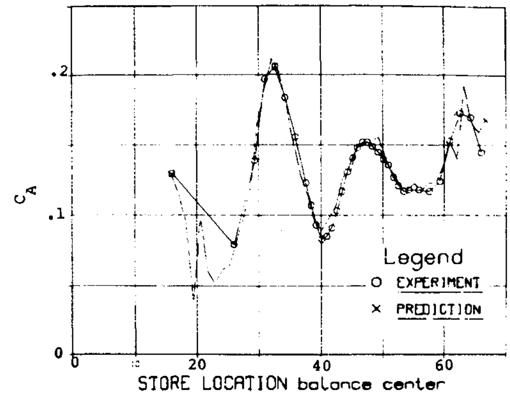

Fig. 5a $M=0.9$ **F-15 pylon drag prediction** ($WL=4.1$, $BL=9.65$) **AG store based on PWW.**

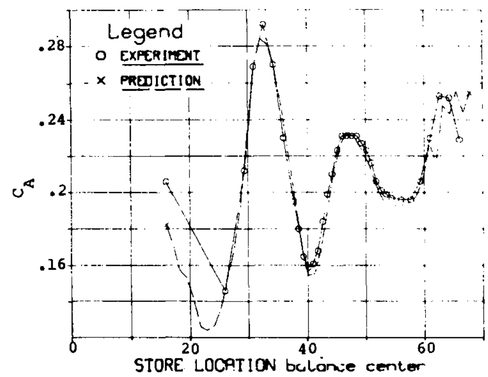

Fig. 5b $M=0.9$ **F-15 pylon drag prediction** ($WL=4.1$, $BL=9.65$) **PWW store based on AG.**

Axial Force and Rolling Moment

Although the IFM technique was originally developed for normal forces and pitching moments, and only extended to side forces and yawing moments during the subsonic/transonic development test,[5] the concept could be extended to include axial force and rolling moment. Limiting the present discussion to axial force, we have

$$C_A = \sum_{i=1}^{N} A_i^{**}(\gamma_i - \gamma_0) \tag{5}$$

As seen in Figs. 5a and 5b, the IFM technique gives excellent predictions of axial force. These comparisons may be misleading, since the PWW and AG stores are identical except for the presence of a thin wing on the PWW store. Another example of axial force prediction, this time for vastly different stores, is the PWW prediction based on GBU-15 data and vice versa, Figs. 6a and 6b. Considering that, at $M=0.9$, the GBU-15 store has exceeded its drag rise Mach number whereas the PWW has not, the IFM technique appears to at least provide a reasonable estimate of store axial force response in a nonuniform flow. The IFM rolling moment formulation has been validated for asymmetric and cruciform missiles.[3] An attempt is also being made to adapt the Distributed Loads Code to rolling moment predictions.[8]

Theoretical Aircraft/Weapon Predictions

The IFM was developed using experimental data for store calibrations and flowfield determinations. It has been demonstrated that Linear Theory[10] can also be used for store calibration and flowfield determination at supersonic speeds. Theoretical store calibrations at subsonic speeds are also feasible, as shown by GBU-15 and PWW correlations.[3]

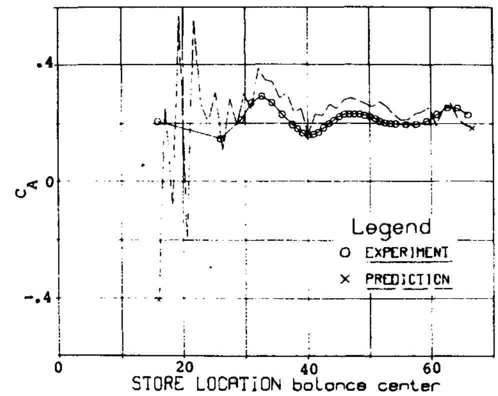

Fig. 6a F-15 pylon drag prediction: PWW store based on GBU-15 at $M=0.9$ ($WL=4.1$, $BL=9.65$).

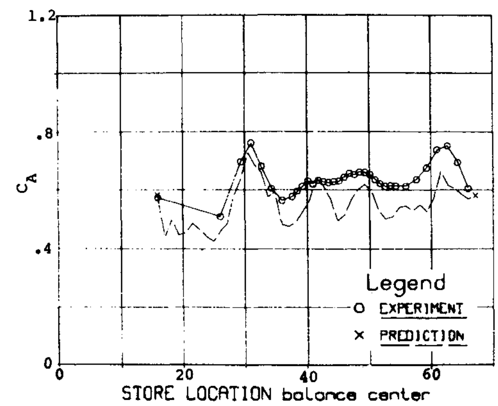

Fig. 6b F-15 pylon drag prediction GBU-15 store based on PWW at $M=0.9$, ($WL=4.1$, $BL=9.65$).

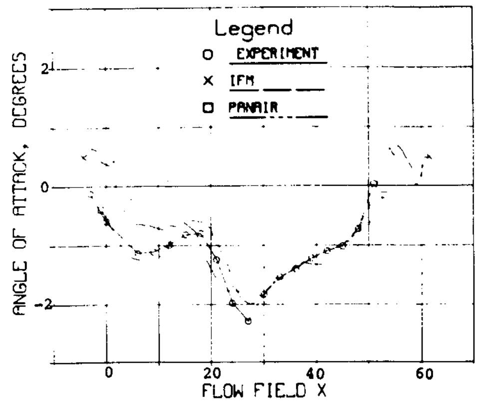

Fig. 7a Prediction of aircraft flowfield: AWECS flowfield based on ogive-cylinder test data, $Z=-6.08$, $Y=0$, $M=0.6$.

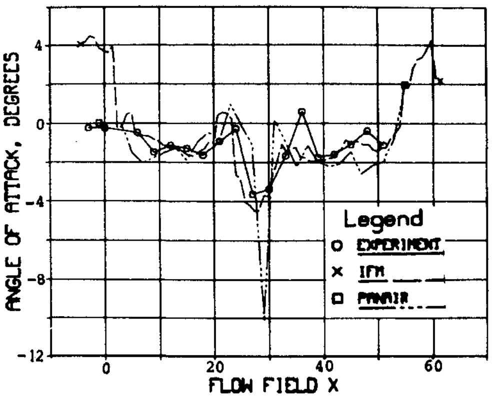

Fig. 7b Prediction of aircraft flowfield: AWECS flowfield based on ogive-cylinder test data, $Z=-6.08$, $Y=0$, $M=1.2$.

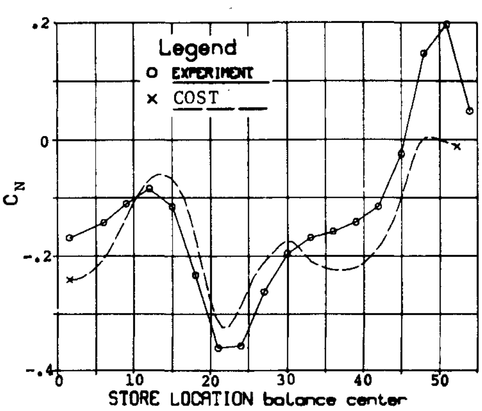

Fig. 8a Generic store centerline force prediction: AWECS, $Z=-6.08$, $M=0.6$, $Y=0$.

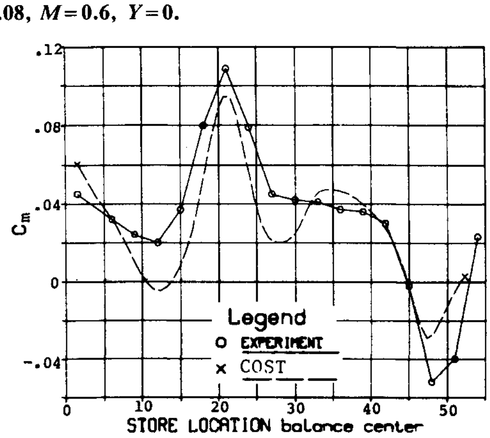

Fig. 8b Generic store centerline moment prediction: AWECS, $Z=-6.08$, $M=0.6$, $Y=0$.

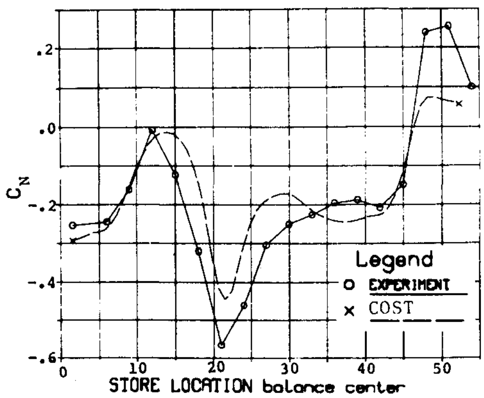

Fig. 9a Generic store centerline force prediction: AWECS, $M=0.9$, $Z=-6.08$, $Y=0$.

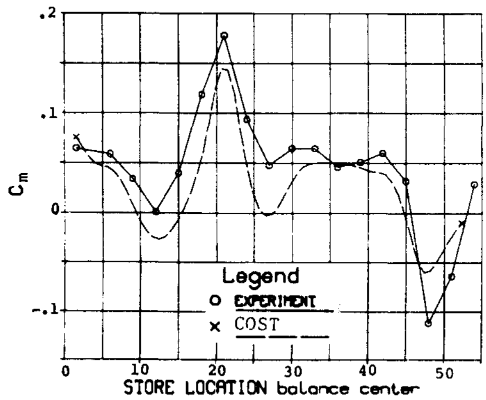

Fig. 9b Generic store centerline moment prediction: AWECS, $M=0.9$, $Z=-6.08$, $Y=0$.

The PAN AIR code capability to predict the parent aircraft's flowfield angularities can be assessed by comparing with AWECS[11] flow angularity probe data at $M=0.6$ and 1.2. As may be seen from Figs. 7a and 7b, the PAN AIR flow angularity predictions show reasonable correspondence to the experimental test data, as well as to the angularity predicted by IFM from ogive-cylinder forces and moments along the traverse. This implies that using PAN AIR angularity predictions as well as PAN AIR store calibrations in Eqs. (1) and (2) to predict store forces and moments is a reasonable alternative to using PAN AIR code for every point in the traverse when no a priori experimental data are available. This procedure (formerly termed theory-theory) will henceforth be called COST (Cost-effective Option for Store Trajectories). Rather good correlation was obtained when this procedure was applied to the ogive-cylinder store in the presence of the AWECS configuration at $M=0.6$ and 0.9, Figs. 8a through 9b. The corresponding predictions at $M=1.2$ were not as good (Figs. 10a and 10b) since the behavior in the vicinity of the nacelle inlet shock is considerably overpredicted. This behavior is similar to what occurred at $M=1.5$ for this configuration.[11]

Another application of the COST procedure is shown for the PWW store theoretically calibrated at $M=1.9$ in the F-15 flowfield at $M=0.6$ in Figs. 11a and 11b. An example of the COST application to another configuration at supersonic speeds is available.[10]

Considering that all the predictions shown in Figs. 8a through 11b were theoretically obtained (without the need of any a priori experimental data), the agreement was quite good. It appears that COST should provide the designer with another alternative for determining store loads in proximity to an aircraft.

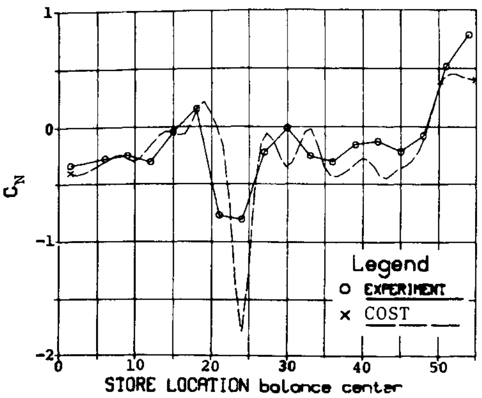

Fig. 10a Generic store centerline force prediction: AWECS, $M=1.2$, $Z=-6.08$, $Y=0$.

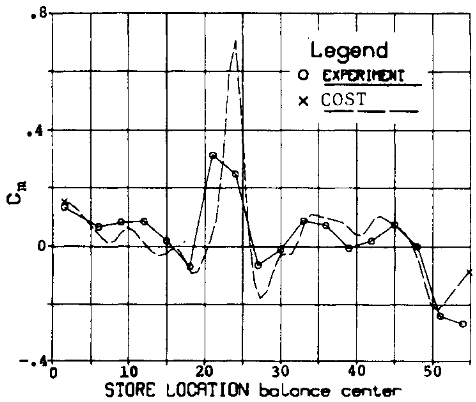

Fig. 10b Generic store centerline moment prediction: AWECS, $M=1.2$, $Z=-6.08$, $Y=0$.

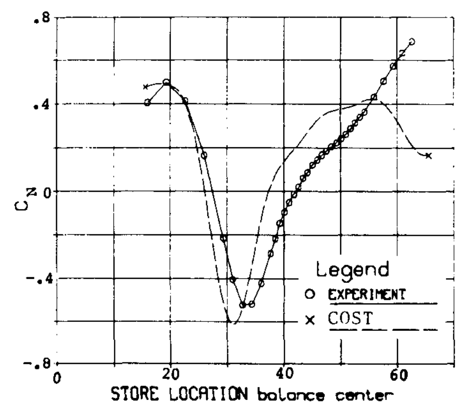

Fig. 11a Centerline force prediction: planar wing weapon in F-15 flowfield at $M=0.6$, ($WL=3$, $BL=0$).

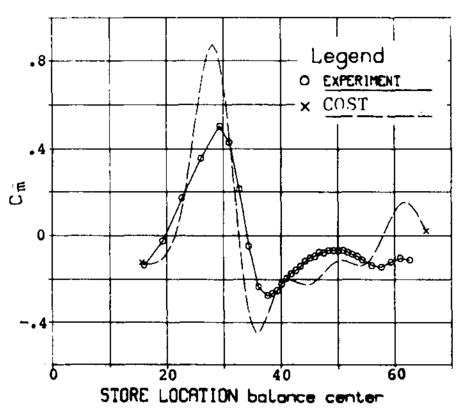

Fig. 11b Centerline moment prediction: planar wing weapon in F-15 flowfield at $M=0.6$, ($WL=3$, $BL=0$).

Since the Boppe[12] Code has shown the ability to accurately predict[13] transonic flowfields, COST should prove to be applicable at all Mach numbers.

Conclusions

The IFM has considerably expanded the technology available for assessing the separation trajectories of stores from fighter aircraft. Where previous grid survey test data are available, the IFM technique can directly estimate store loads for any other calibrated store at the same freestream Mach number. Since store calibrations can be theoretically performed, the method can be applied to most existing test data.

It has also been shown[3,4] that the IFM technique can accurately predict store grid loads, up to the carriage position, based on aircraft flowfield probe data. Since experimental angularity data exists for most existing fighter aircraft, the technique should prove quite useful in certifying new stores on production aircraft. One such application is described in Ref. 14.

For cases where no experimental data are available, IFM can use theoretical angularity predictions (in the COST context) to predict store loads. This procedure was used to predict[4] Advanced Medium Range Air to Air Missile (AMRAAM) carriage loads for the F-14 aircraft at $M=0.95$.

The IFM technique has now been coupled with a six-degree-of-freedom trajectory program. Excellent correlation with GBU-15 trajectory data at $M=0.95$ was achieved utilizing PWW grid data for the F-15 aircraft.[3] In another application, F-15 probe angularity data were used to predict the PWW store's trajectory at $M=0.95$. The correlation was equally good.[4]

Acknowledgment

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