Influence Function Method Applications to Cavity Flowfield Predictions

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Preliminary results of a recently completed wind-tunnel test indicate that the critical test conditions occur at the aft end of a densely packed cavity. Furthermore, it appears that empty-cavity grid test data should not be used to predict trajectories for conditions where several bombs are still present in the bay. An attempt to apply the influence function method to a cavity environment showed promise. Further testing and analysis will be required before its validity can be demonstrated.

Nomenclature

A_i = normal force influence coefficient
B_i = pitching moment influence coefficient
C_m = pitching moment coefficient
C_N = normal force coefficient
D = cavity depth, ft
L = cavity length, ft
W = ejection velocity, ft/s
Y = Cartesian Y coordinate, measured from cavity edge, ft
$YREL$ = Y displacement along inertial axis of store's c.g. relative to initial c.g. before launch, ft
Z = Cartesian Z coordinate, measured from cavity top, ft
$ZREL$ = Z displacement along inertial axis of store's c.g. relative to inital c.g. before launch, ft
α = store body-axis pitch angle of attack, deg
β = store body-axis yaw angle of attack, deg
α_i = local flowfield angle of attack, deg

Introduction

WITH increasing emphasis on improved aircraft performance and stealth, the ability to carry weapons internally is becoming a consideration in new (and upgrade) aircraft designs. Although many hours of wind-tunnel data, as well as several computer codes, exist for the analysis of store trajectories from external aircraft mounts such as pylons and wing tips, carriage and release of stores from internal weapons bays has not been systematically explored. Recently, under the Weapons Internal Carriage and Separation (WICS)[1] program, the U.S. Air Force has established a data base for the internal carriage and release of stores from a generic cavity. This data base did not adequately address the problem of store-to-store interference in a densely packed weapons bay. The recently completed Naval Internal Carriage and Separation (NICS)[2] test addressed the problem of safely separating eight MK-82 bombs from a generic bay which would fit in the channel under the F-14 aircraft.

The NICS test consisted of various store arrangements, ranging from an empty cavity to one where one to three dummy stores were in close proximity to the bomb that was released, at $M = 0.85$ and 1.2 and the cavity at a relative angle of 0 and 5 deg to the freestream. In support of future full-scale testing, the test was conducted for a one-thirteenth scale model of the MK-82 bomb and cavity. The cavity was scaled to the dimensions of the channel formed by the nacelles of the F-14A, 15.73 ft long, 4.33 ft wide, and 2.925 ft deep full scale for an L/D of 5.38. Preliminary analysis of the test data indicates that the critical launch conditions are for stores mounted at the side of the aft end of a densely packed bay for $\alpha = 0$ deg. Since it was not possible to achieve a clean separation for this arrangement at $M = 1.2$, even with an initial ejection velocity of 30 ft/s that far exceeds the capabilities of present-day bomb racks, the analysis concentrated on the $M = 0.85$ test data.

Another concept that the wind-tunnel test was designed to address was whether the influence function method (IFM) could be used in a cavity environment. Although the IFM-predicted store loads for a traverse close to the shear layer appear reasonable, further testing will be required to evaluate the method's applicability.

Approach

The conventional procedure for determining safe trajectory characteristics for a particular aircraft/weapon combination is the grid method.[3] This consists of taking store force and moment data in a dense grid under the aircraft, and then using this force and moment data, in conjunction with the store freestream characteristics, in a six-degree-of-freedom program to predict store trajectories for a variety of initial conditions.

As explained in Ref. 3, the grid method cannot be used in a cavity environment because the dynamic pressure within the cavity has no relationship to the freestream dynamic pressure,

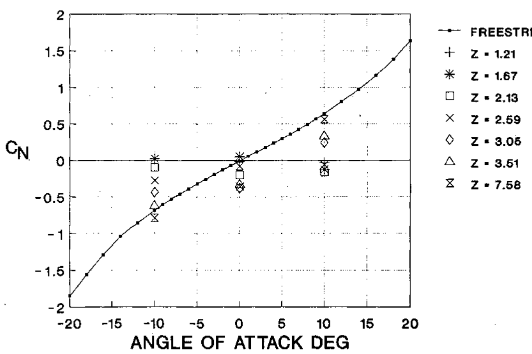

Fig. 1 MK-82 freestream data ($M = 0.85$).

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which is used to scale all of the force and moment data. For this reason, the NICS test was structured to take store force and moment data at −10, 0, and 10 deg pitch for all grid positions. As may be seen from Figs. 1 and 2, the C_N and C_m data for various vertical positions within the cavity, from the ejection position at $Z = 1.21$, show wide variation and do not match the freestream values at even the outermost vertical displacement, 7.5 ft full scale from the cavity base. Furthermore, the pitching moment at zero pitch attitude cannot be estimated from its values at ±10 deg. Linearly interpolating between these endpoints could lead to errors in the trajectory predictions.

The six-degree-of-freedom (SDOF) program[4] was modified by estimating the store pitch-plane loads within the region of influence of the cavity flowfield by linearly interpolating the grid at each vertical position between the three pitch attitudes for every time step. The store yaw-plane loads were assumed to be those at zero sideslip for the angle of attack in question, since it was not possible to test for sideslip angles other than zero within the cavity. This simplification was not expected to significantly detract from the validity of the predictions, since sideslip angles greater than 1.5 deg within the cavity would cause all of the MK-82 launched from the side to impact with the cavity walls.

The densely packed cavity, which demonstrated the most severe instability at launch with two dummy stores on the side and one forward (Fig. 3), was designated as configuration 405 in the test. The modified SDOF program showed good correlation with actual trajectory test data in Figs. 4–7 for an initial ejection velocity W of 30 ft/s. As shown in Figs. 8 and 9, the trajectory program was also able to predict the store's impact with the cavity side for the initial ejection velocity of 20 ft/s, which occurred because at the store sideslip angle of 1.5 deg, and at the negative pitch attitude of 2 deg, the tail just clipped the bottom edge of the cavity.

When the configuration 405 grid data were used to estimate the trajectory of a bomb launched from the same position in the empty cavity at the same initial conditions (configuration 105), the prediction was overly conservative (Figs. 10 and 11). The empty-cavity trajectory test data, which show a smaller pitch and yaw variation with vertical displacement, imply that at an ejection velocity of 20 ft/s the MK-82 might separate safely.

The grid data for the configuration shown in Fig. 3 were unable to predict the behavior for a similar arrangement, with the front dummy store located at the opposite side of the cavity (configuration 408); see Figs. 12 and 13. Although the MK-82 bomb was able to clear the cavity in both cases and the pitch variation was unchanged, the yaw variation was considerably more pronounced for configuration 408.

It appears that separate grid data must be taken for all possible cavity arrangements to establish a safe launch envelope. On the basis of the present test, it has been established that a safe launch sequence could be achieved at $M = 0.85$ by releasing the two front middle bombs first, followed by the front outside, the rear middle, and last the two back outside stores at $W = 20$ ft/s (which is within the scope of present-day ejectors). This would ensure that the critical condition for the rear outside stores would occur for an empty-cavity arrangement. Safe ejection at $M = 1.2$ does not appear feasible for this configuration.

IFM Applications to Cavity Flowfields

The influence function method (IFM)[4] has established the capability of accurately predicting aircraft flowfields on the basis of store force and moment data taken in a horizontal grid traverse. If the IFM technique could be used to predict cavity flowfields, the amount of wind-tunnel testing needed to clear a particular store/cavity arrangement could be greatly reduced. Since the IFM technique is based on the assumption that the freestream velocity is unchanged along the traverse, which is known not to be the case within the cavity, the traverse normal force and moment data were scaled by the ratio of the freestream/local cavity axial force, since this ratio should be proportional to the freestream and cavity dynamic pressure ratio.[3] As may be seen in Figs. 14 and 15, the scaled force moment data for a horizontal traverse along the shear

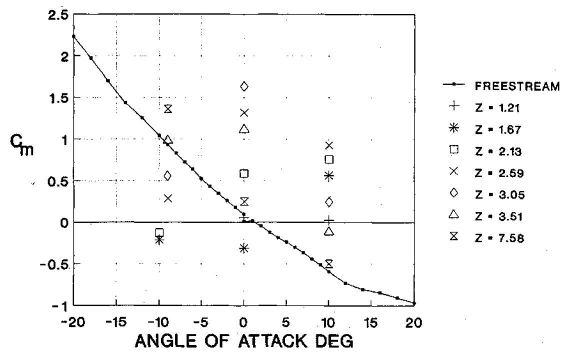

Fig. 2 MK-82 freestream data ($M = 0.85$).

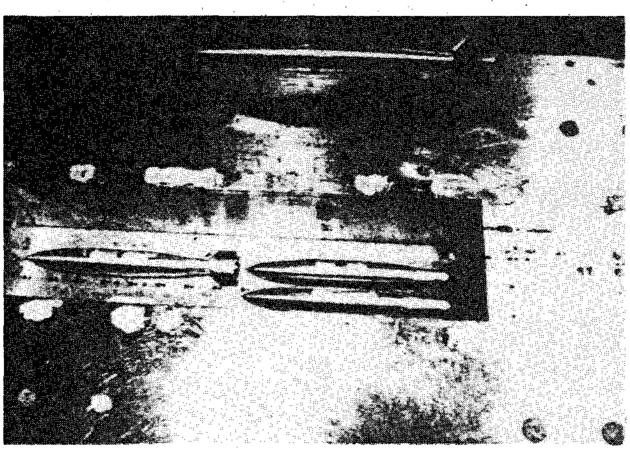

Fig. 3 Test arrangement for configuration 405.

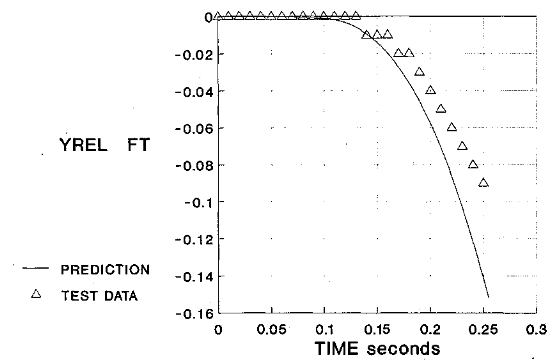

Fig. 4 MK-82 trajectory ($W = 30$ ft/s).

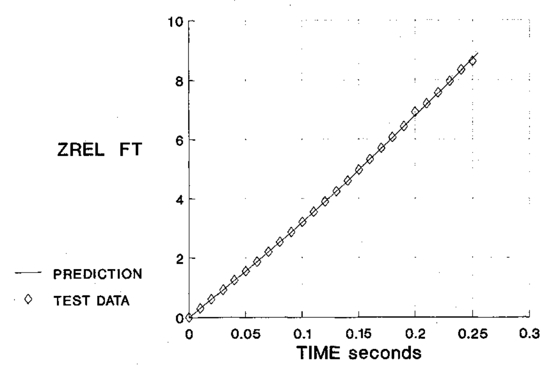

Fig. 5 MK-82 trajectory ($W = 30$ ft/s).

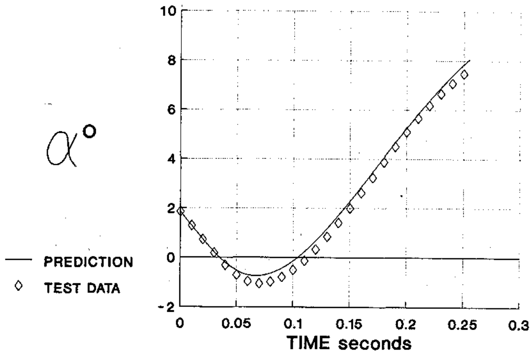

Fig. 6 MK-82 trajectory ($W = 30$ ft/s).

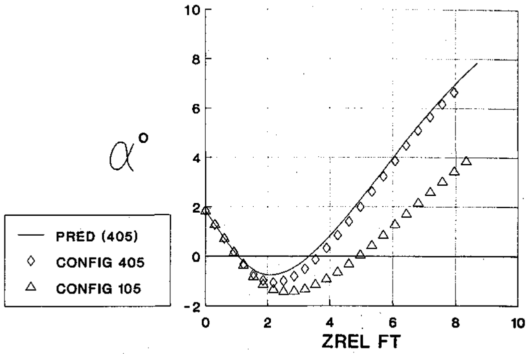

Fig. 10 MK-82 trajectory ($W = 30$ ft/s).

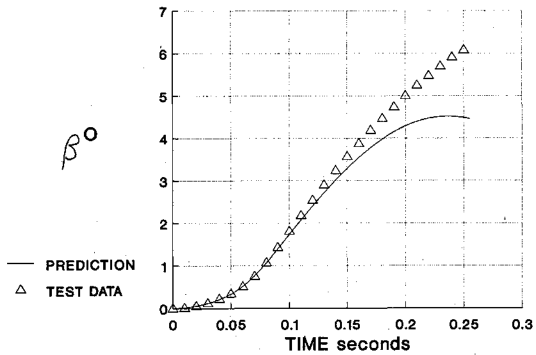

Fig. 7 MK-82 trajectory ($W = 30$ ft/s).

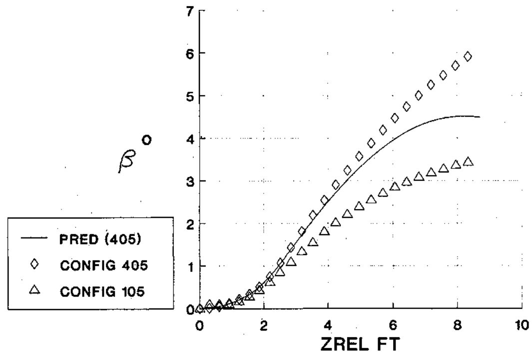

Fig. 11 MK-82 trajectory ($W = 30$ ft/s).

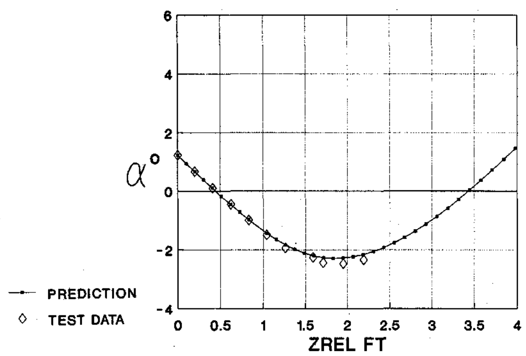

Fig. 8 MK-82 trajectory ($W = 20$ ft/s).

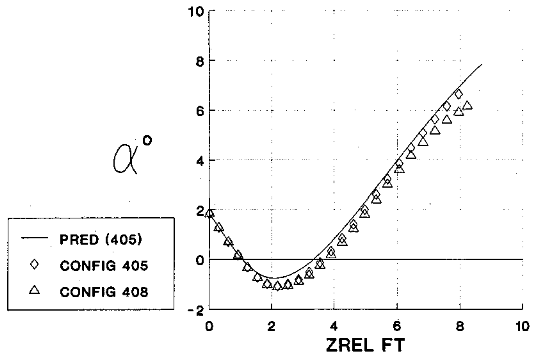

Fig. 12 MK-82 trajectory ($W = 30$ ft/s).

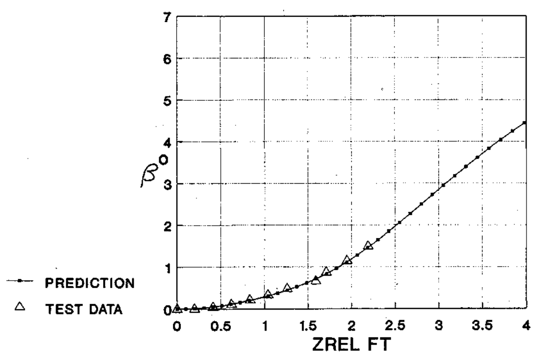

Fig. 9 MK-82 trajectory ($W = 20$ ft/s).

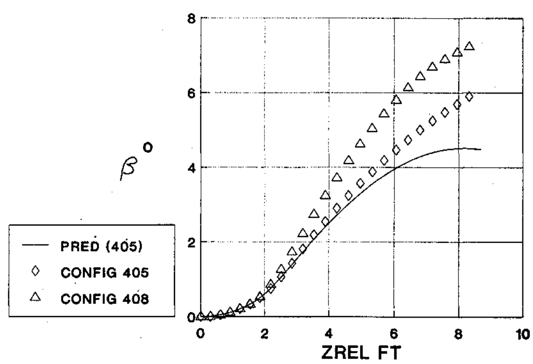

Fig. 13 MK-82 trajectory ($W = 30$ ft/s).

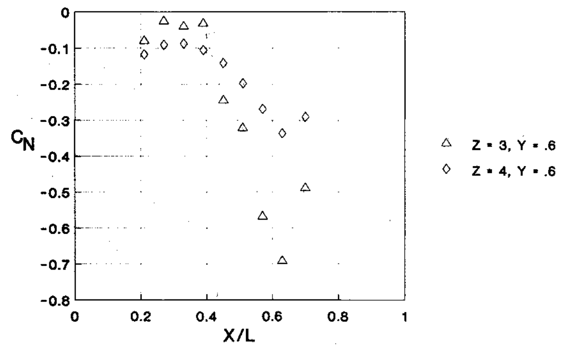

Fig. 14 Normal force along X traverse.

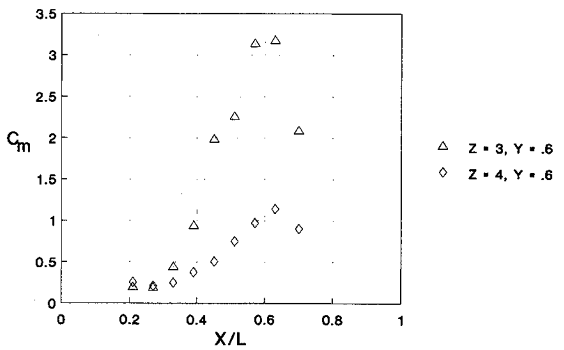

Fig. 15 Moment along X traverse.

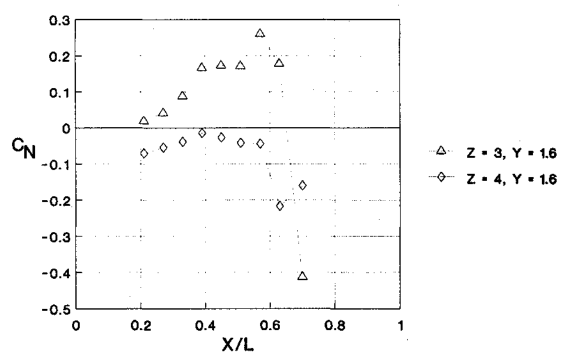

Fig. 16 Normal force along X traverse.

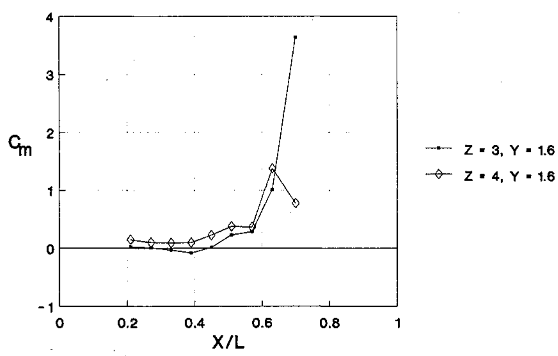

Fig. 17 Moment along X traverse.

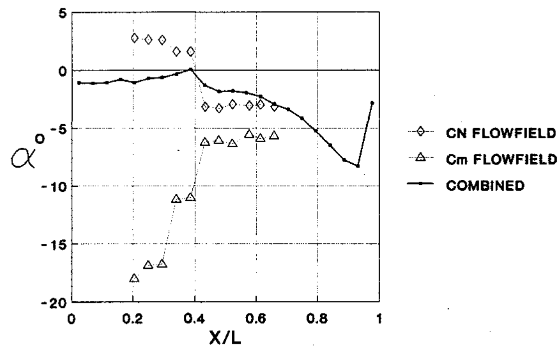

Fig. 18 X flowfield ($Y = 0.6$; $Z = 4$).

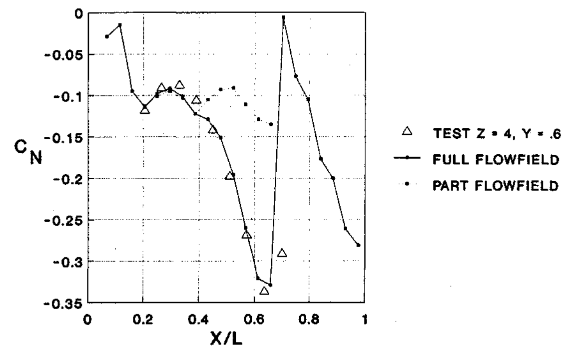

Fig. 19 IFM predicted normal force.

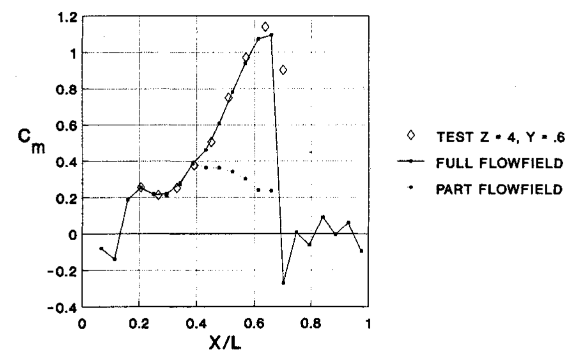

Fig. 20 IFM predicted moment.

layer at the cavity edge ($Y = 0.6$ ft) show significant variation with the X position, which rapidly decays with Z displacement. The traverse location closest to the back of the wall, $X/L = 0.69$, exhibited the greatest differences, as was expected based on the results Ref. 1.

The MK-82 exhibited similar behavior for the traverse closer to the middle of the cavity ($Y = 1.6$ ft); see Figs. 16 and 17.

The fundamental assumption underlying the IFM technique is that the store force and moment coefficients can be correlated with the aircraft induced-angle-of-attack distributions along the store length. For a finite number of store subdivisions N, the relationship may be expressed as

$$C_N = \sum_{i=1}^{N} A_{ii} \tag{1}$$

$$C_m = \sum_{i=1}^{N} B_{ii} \tag{2}$$

The first step in the IFM process is calibration, i.e., determining the store's influence coefficients A_i and B_i so that its response to a nonuniform flowfield can be estimated. This requires at least N values of C_N, C_m, and angularity along an axial traverse. The N equations are then solved by matrix inversion for the unknown influence coefficients. The Interface Distributed Loads/Influence Function Method (IDL/IFM) code has established[5] its ability to provide a good estimate of an axisymmetric store's influence coefficients. The default procedure for this code is to pass the store through a 5-deg flowfield discontinuity, which was done for this study.

Once the influence coefficients have been determined, Eqs. (1) and (2) may be solved for the unknown angularity distribution along an axial traverse. The procedure adopted has been to solve the two equations separately as well as jointly to arrive at three estimates of the angularity distribution: one from C^{N}, one from C_m, and from a combined simultaneous solution.

The combined flowfield formulation has more equations than unknown angularities, thereby providing for an overdetermined solution of the equations. Since it has invariably exhibited the best correlation with probe flowfield test data,[6,7] it is the default option in the code.[8] The angularity predicted from the C_N and C_m equations has generally been in close agreement with the combined solution.

When the IFM technique was applied to the force and moment data for the axial traverse at $y = 0.6$ and $Z = 4$ ft, there was considerable variation in the three predicted angularities (Fig. 18). Furthermore, since the C_N and C_m derived flowfields showed totally opposite trends, they are obviously incorrect. The combined flowfield prediction appears reasonable, even in regions at the front and back of the cavity where no force and moment test data exist.

Since the IFM technique was not developed for the purpose of calculating aircraft flowfields, its ability to provide an estimate of the flowfield induced by the cavity is not the central consideration. As an example of its utility, the IDL/IFM influence coefficients for the MK-82 bomb, in conjunction with the combined flowfield shown in Fig. 18, were used to estimate the MK-82 forces and moments at the same traverse (see Figs. 19 and 20). The normal force and moment test data are measured at the store's c.g. – to make a prediction of the store loads along a traverse, some assumption has to be made about the flowfield ahead of the store c.g. at the forward end of the traverse, and behind the c.g. at the aft end. At present, the assumption made in the code is that the upwash and sidewash are constant and equal to their values at the endpoints. Although this assumption is quite reasonable for axial traverses next to an aircraft, cavity flowfields show the largest variation at the cavity ends. Since the combined flowfield prediction can be made for the entire cavity length, this extended flowfield was used for the force and moment preductions. They are in excellent agreement for the traverse region where test data are available, and an indication of their validity may be that they predict the trends in C_N and C_m evident in the test data at the cavity end for the next closer traverse (see Figs. 14 and 15). Obviously, validation of the IFM technique's utility for cavity flowfields awaits a separate test for a different store at the same conditions. Another method of validating the technique would be to use a Navier–Stokes solution[9] for the same cavity configuration to compare with the IFM flowfield predictions.

Conclusions

Store force and moment data taken in a grid inside and underneath a cavity can provide good trajectory predictions for various initial conditions. Care has been taken in the way the test is structured: the grid data have to be taken at several pitch attitudes, and empty-cavity data cannot be generalized to account for a densely packed cavity. Since for the present test the number of possible store arrangements exceeded 20,000, it was obviously impractical to evaluate all imagined combinations.

A method of using data from one test to estimate the behavior of another store in the proximity of the same cavity would be of considerable value. The influence function method might prove applicable. Further analysis and, in particular, further testing on another store with the same cavity will be required to properly address that issue.

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