Supersonic Submunition Aerodynamics During Dispense

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This paper describes two store separation programs as applied to the prediction of submunition aerodynamics. The two programs are based on the Nielsen Engineering & Research supersonic store separation analysis programs, and are valid for the submunition outside of a dispenser missile. In both programs, the dispenser interference flowfield is calculated from source/sink and doublet distributions. The calculated dispenser flowfield contains a nonlinear correction to account for the presence of a bow shock. An equivalent streamline technique is employed to model dispensers with open cavity bays. In one program, the submunition aerodynamic body loads are calculated using slender body theory. In the other program, the submunition body is modeled by line singularities distributed along the axis or by panel methods, and surface pressure distributions are integrated to obtain body loads. Effects of reflected shocks are included. Fin forces and moments are calculated on the basis of slender body theory and/or panel methods. The methods show promise in terms of comparisons with experimental wind-tunnel data for submunition forces and moments in the presence of a dispenser with closed and open bays.

Nomenclature

C_m	= submunition pitching-moment coefficient, based on S_r and l_r
C_N	= submunition normal-force coefficient, based on S_r
D_d	= dispenser maximum diameter
D_s	= submunition maximum diameter
l_r	= reference length, submunition maximum diameter
M_∞	= freestream Mach number
x, r	= axial and radial coordinates of a body point in a cylindrical coordinate system with the origin at the body nose
X_s	= axial location of submunition moment reference center in the dispenser coordinate system, dispenser calibers, positive aft of nose ($XSMC = X_s \times D_d$)
S_r	= reference area, submunition maximum cross-sectional area
Z_s	= vertical location of submunition moment reference center in the dispenser missile coordinate system, dispenser missile calibers, positive below dispenser nose ($ZSMC = Z_s \times D_d$)
α_s	= submunition angle of attack with respect to the dispenser centerline, positive nose up toward the dispenser missile

Configuration Identification Code

S1	= submunition body with hemispherical nose
S2	= submunition body with two-caliber ogive nose
D1	= dispenser with covered submunition bays
D1F	= dispenser with front bay open
D1FCA	= dispenser with all bays open
T1	= tail fins

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Introduction

SYSTEMS in which submunitions are ejected from a dispenser have been under investigation for a number of years. Key elements in submunition ejection and dispensing systems include thorough knowledge of the flowfield about the dispenser and of the mutual aerodynamic interactions caused by the close proximity of each submunition to the dispenser. This interest has resulted in the collection of an experimental data base[1-4] of submunition aerodynamic coefficients where the submunition is in the presence of a dispenser. A number of dispenser/submunition configurations have been investigated over a range of Mach numbers and angles of attack. Data have been obtained for the submunition undergoing axial, vertical, and angle-of-attack sweeps in the presence of a dispenser.

At the same time, an analytical capability has been under development for predicting aerodynamic characteristics of submunitions in close proximity to a dispenser missile. A computer program containing applicable methodology must also have the capability to perform the aforementioned single variable sweeps in order to produce results in the same format as that in the data base. In addition, it must be reasonably inexpensive to run and relatively easy to use as a preliminary design tool. Finally, a trajectory calculation capability is required.

Initial work towards the development of submunition aerodynamics prediction technology is described in Ref. 5. The preliminary submunition aerodynamics analysis described in that reference is based on the earlier (1976) Nielsen Engineering & Research (NEAR) Supersonic Store Separation Computer Program.[6] This program employs panel methods and line singularities derived from linear supersonic theory to model the components of the parent aircraft. In this low-level method, store aerodynamic loads are calculated by modified slender body theory methods. This computer program was initially modified[7,8] to tailor it to the dispenser/submunition problem. The modified version, referred to as HIMACH2, can be run in an interactive mode, and includes options to perform axial and vertical traverses and angle-of-attack sweeps in addition to the six degrees-of-freedom trajectory calculation. In an effort to improve program efficiency, the wing/pylon modeling schemes were removed so that the parent aircraft model is reduced to a fuselage only for the purpose of modeling the dispenser body. In addition, determination of the fin lift curve slope and the aerodynamic center of pressure, as well as the crossflow drag coefficient, are automated in program HIMACH2. The preliminary method also includes a model for approximating the effects of cavities in the dispenser by establishing an equivalent streamline, or body, by means of an inverse solution technique. Recent modifications to program HIMACH2, presently referred to as the MICOM Dispense Code,[9] include a nonlinear correction to the dispenser flowfield to simulate the dispenser shock shape and the capability of modeling a submunition with two sets of fins.

An additional analytical capability of calculating submunition aerodynamics is the later (1980) version of the NEAR Supersonic Store Separation Program.[10] This store trajectory calculation program has not been optimized in the same manner as the early version[6] for use with the dispenser/submunition problem; however, it is of interest because of its capability of handling nonaxisymmetric bodies. The methodology contained within this program employs line singularities or panel methods for modeling the dispenser and submunition. The previously mentioned nonlinear correction to the dispenser flowfield is included, as well as a means to account for the effects on the submunition loads of the submunition shock reflected off the dispenser. In this intermediate level method, submunition loads are obtained by calculating surface velocities and the corresponding circumferential pressure distribution at a number of axial stations along the body. The pressures are integrated circumferentially and axially to obtain overall forces and moments. A version of this program with the capability of handling submunition axial and vertical traverses and angle-of-attack sweeps has been developed at Army MICOM. As part of the work reported in Ref. 9, the program[10] was updated and modified to run on the computers at Army MICOM. This version is referred to as the 1986 NEAR Supersonic Store Separation Program.

A number of comparisons of experimental data and predicted results obtained using the preliminary method (HIMACH2) are presented in Ref. 5. These comparisons include results for dispensers with closed and open cavity bays. Recent comparisons[9] using the MICOM Dispense Code for submunitions in close proximity to closed bay dispensers indicate improved predicted results due to the nonlinear shock correction to the dispenser flowfield.

In the following sections, brief descriptions of the methodology contained in the MICOM Dispense Code and in the 1986 NEAR Supersonic Store Separation Program are given. A selection of some of the most recent comparisons of predicted and experimental results is provided, limitations of the methods are discussed, and suggestions for improving the methods are given.

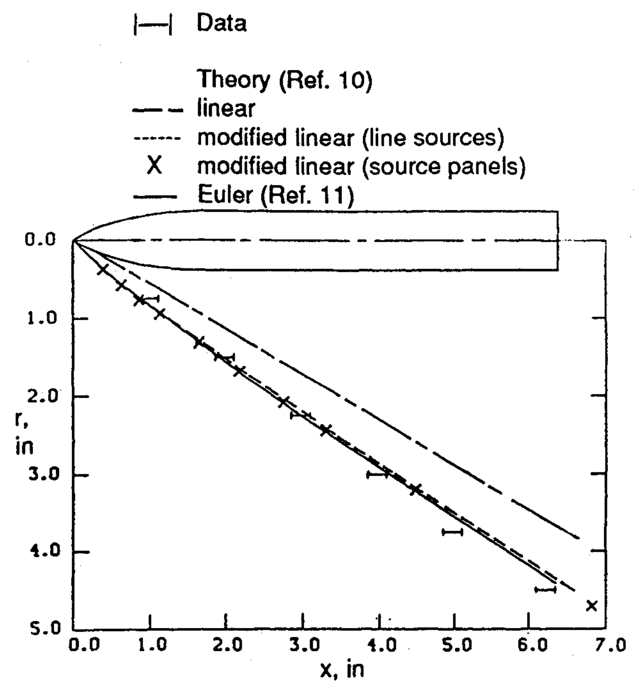


Fig. 1 Theoretical and experimental shock wave shapes on an ogive-cylinder at $M_\infty = 2.0$ and $\alpha = 0$ deg.

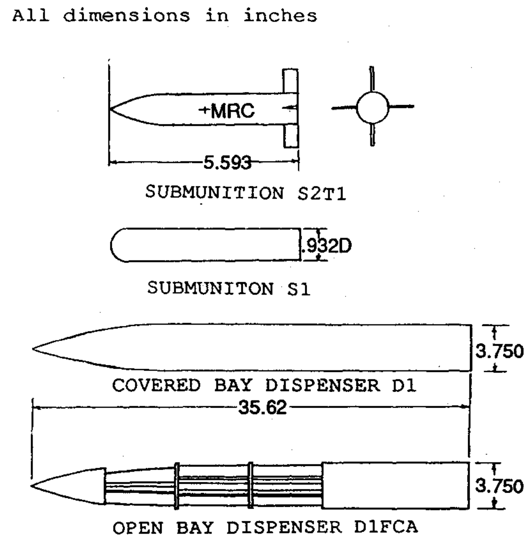


Fig. 2 Dispenser missile and submunition design.

Technical Approach

In general, the flow models for the dispenser and the submunition are based on distributions of singularities derived from linear supersonic theory for steady inviscid flow. Flow components at a given field point are provided by the summed influences of all the singularities. The particular flow models contained in the MICOM Dispense Code and the 1986 NEAR Supersonic Store Separation Program are summarized in this section.

MICOM Dispense Code

Details of the methodology contained in this program are presented in Ref. 6. In this program, the dispenser and the submunition are required to be modeled as axisymmetric bodies. The axisymmetric dispenser is represented by a distribution of line sources/sinks and doublets on the body centerline to account for volume and angle-of-attack effects, respectively. The strengths of these singularities vary linearly along the body, and the coefficients defining the strengths are determined from the flow tangency conditions at points on the body surface.

Linear theory causes disturbances to travel along waves associated with the supersonic freestream Mach number used in the solution of the line singularity strengths. In reality, the disturbances travel along curved Mach waves whose shapes are determined by the local Mach number variation along the waves. In particular, the disturbances from the dispenser nose travel along the nose shock wave. If linear theory is used in calculating the flowfield under the dispenser in the region in which a submunition is immersed, dispenser disturbances will strike the submunition in the wrong location. This will cause errors in the calculated forces and moments. In order to place the disturbances—particularly shock waves—closer to their correct locations, a series of nonlinear corrections are made to the linear theory results. As part of the development of the later supersonic store analysis program,[10] engineering-level nonlinear corrections are incorporated in the analysis. Such corrections involve the simulation of shock wave shapes for bodies and the calculation of flowfields based on local Mach number.

An example taken from Ref. 10 is shown in Fig. 1. Shock wave shapes for an ogive-cylinder at an angle of attack of 0 deg and freestream Mach number of 2.0 are shown in this figure. The horizontal bars show the shock wave location as estimated from experimental flowfield data. The results marked "linear theory" are obtained as the locus of points where first influences are predicted by the line singularities used to model axisymmetric bodies. The same linear results are obtained if the surface of the body is covered by a layout of source panels. The modified or corrected linear theory shock wave shape approximations using the method of Ref. 10 lie ahead of the linear theory Mach cone, and there is good agreement with the experimental data. No appreciable difference can be discerned between the corrected results calculated with the line singularities and the source panels. Also shown is a result obtained with the Euler equation approach of Ref. 11. The corrected linear theory results agree well with the Euler result. Note that the simulated shock shape for the axisymmetric body is determined for $\alpha = 0$ deg, and the body is rotated relative to the shock for nonzero angle-of-attack cases. This is based on data which show that, for an axisymmetric body at small angles of attack, there is little movement of the shock wave relative to the freestream when compared with the shock wave produced by the same body at 0 deg angle of attack. The shock simulation method based on the line singularities[10] is applied to the dispenser only in the MICOM dispenser code.

A special technique is employed for modeling dispensers with open bay cavities. Details of this technique were developed by J. L. Sims.[5] This modeling is based on the assumption that cavity flow effects can be approximated with the program if a bounding streamline shape is known. Essentially, definition of an equivalent streamline to model cavity effects is accomplished by an inverse technique in which the shape of the cavity streamline is assumed, the corresponding dispenser flowfield calculated, and the submunition aerodynamics computed for $\alpha_s = 0$ deg and a selected Mach number. When the calculated and experimental aerodynamics are in sufficiently close agreement, it is assumed that the cavity bounding streamline is determined. This streamline shape is then used to calculate forces and moments for other submunition configurations and other submunition angles of attack. Note that the equivalent streamline generated by the supersonic linear theory will predict expansion and/or compression waves, depending on the particular streamline shape defined by the above procedure.

Once the dispenser flowfield (including nonlinear effects of the dispenser shock) has been determined, the submunition is immersed in this flowfield. Slender body theory is the basis for calculating the submunition body normal- and side-force distributions due to the dispenser flowfield. Submunition-on-dispenser interference is neglected, and a simplified method of accounting for buoyancy is included. A means to model boundary-layer separation using simple viscous crossflow theory[12] is also included. Determination of the crossflow drag coefficient is formulated in the program as a function of crossflow Mach number and the slenderness ratio of the submunition.[13]

The method used to calculate empennage forces and moments[14] is based on a combination of reverse flow theorems and slender-body theory. The effects of interference between the body and the fins are accounted for. A simple correction factor method is implemented in the program to account for effects of the upstream fins on downstream fins. In this method, the angle of attack used to calculate the normal force on the downstream fins is modified by a factor obtained from a correlation of data. Effects of nonuniform flow are included in this simplified interference account. The program is applicable to planar or cruciform fin layouts.

1986 NEAR Supersonic Store Separation Program

This computer program is applicable to dispensers and submunitions with circular and noncircular cross sections. The methodology contained in the program for modeling each type of configuration is summarized below.

Circular Cross-Sectional Bodies

The models for the axisymmetric dispenser missile are the same as described above for the MICOM Dispense Code. Line singularities are distributed along the body axis, and a nonlinear correction is included to account for the presence of the dispenser shock shape.

The axisymmetric submunition body is also modeled by line singularities in this program. Supersonic line sources and sinks are distributed along the submunition centerline to account for volume effects. The nonuniform upwash and sidewash fields in which the submunition is immersed are accounted for by two distributions of supersonic line doublets on the longitudinal axis; one distribution models the upwash effects, and the other models the sidewash effects. Submunition loads are obtained by integrating calculated circumferential pressure distributions at a specified number of axial stations along the body and summing the loads on each body section into which the body has been divided. Note that in the development of this methodology,[10] it was decided to only include effects induced by the store singularities in the calculation of store pressures. This was based on comparisons of predicted and measured pressure distributions on an ogive-cylinder store in the region of a simple wing-body configuration. This procedure essentially reduces the effects of buoyancy.

Empennage forces and moments are obtained using the same methodology described above for the MICOM Dispense Code.

A method to account for submunition-on-dispenser interference is included in this program. This method employs an imaging scheme in which the submunition shock wave reflection is accounted for by imaging the submunition singularities inside the dispenser.[10] Note that the noncircular cross-sectional body methodology described next is also applicable to circular cross-sectional dispensers and submunitions.

Noncircular Cross-Sectional Bodies

The body is modeled using quadrilateral supersonic body source panels that can be inclined to the flow, thereby accounting for both volume and angle-of-attack effects.[10]

Calculation of the simulated shock shape for noncircular bodies is similar to that for circular bodies, except that the shock shape is calculated in a number of meridian planes for the noncircular case. The simulated shock wave shape for a noncircular cross-sectional dispenser is calculated from the velocities induced by the body source panels whose strengths are determined with the dispenser at angle of attack. The shock shape for a noncircular submunition is calculated for the source panel solution at $\alpha = 0$ deg, and the submunition is rotated within the shock for angle-of-attack cases. The simplification in the shock simulation for the submunition was originally incorporated in Ref. 10 to reduce computation time.

Imaging of a noncircular submunition to model dispenser-submunition interference effects is performed in a manner similar to that described for imaging a circular submunition. (The method is described in detail in Ref. 10.)

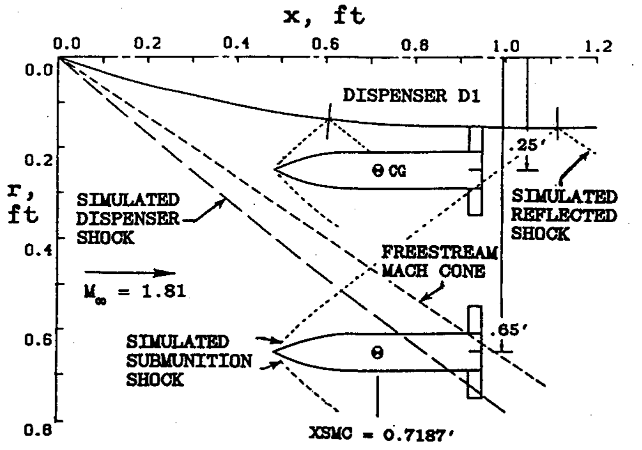
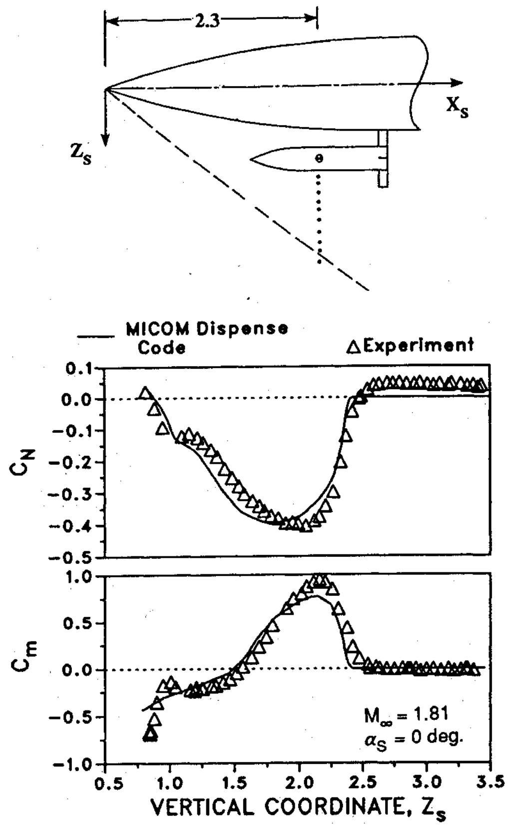
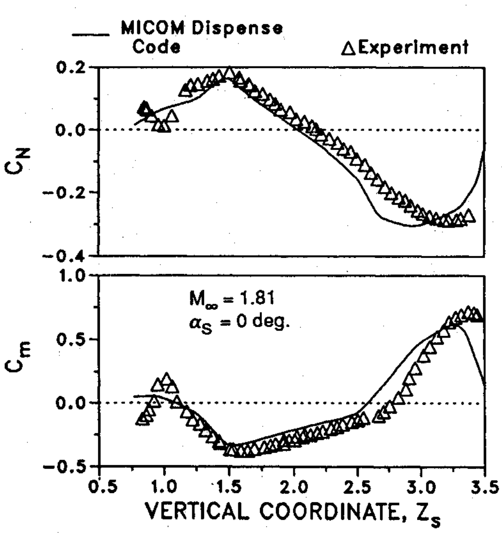


Fig. 3 Sketch showing typical simulated shocks and reflected shocks for configuration D1S2T1.



a) X_s = 2.3



b) X_s = 3.9

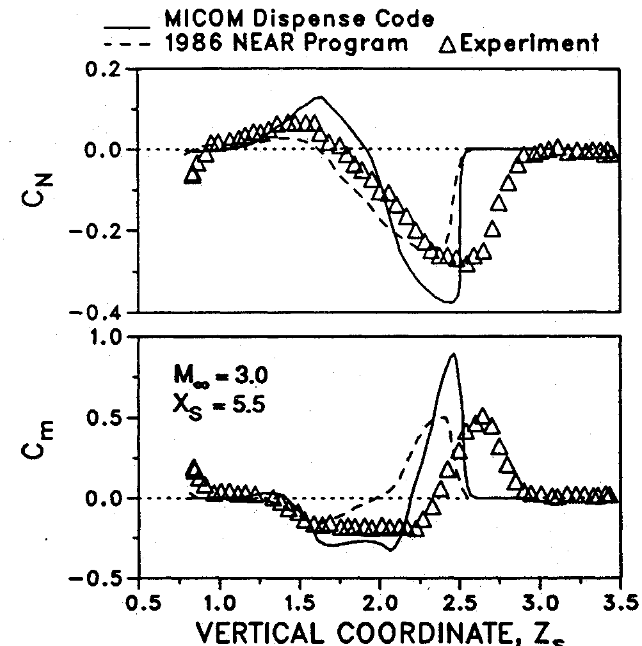
Fig. 4 Measured and predicted vertical variation of aerodynamic coefficients on submunition S2T1 under dispenser D1; M_∞ = 1.81, α_s = 0 deg.

Noncircular submunition forces and moments are obtained from the strengths of the source panels modeling the body. The boundary conditions on these panels include the nonuniform velocity field in which the submunition is immersed. The pressure coefficient at the control point of each panel is assumed to act over the entire panel, and the summation of the forces on all panels results in the force distribution on the submunition body.

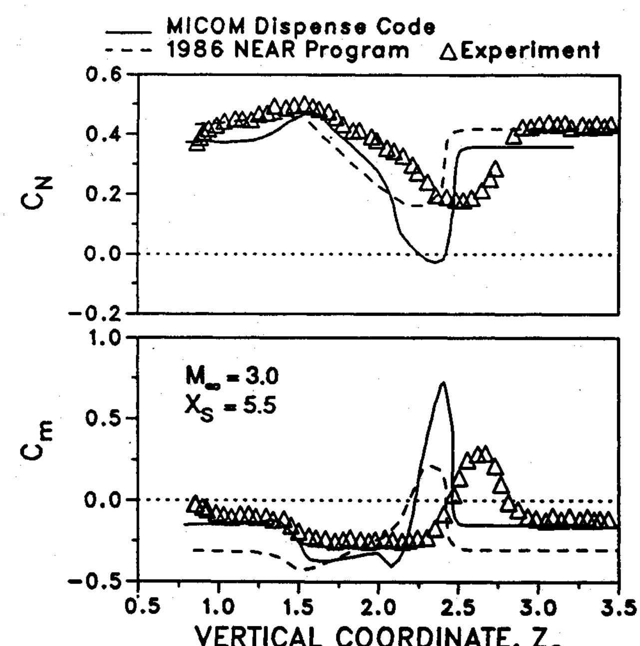
Up to two sets of fins can be positioned on the submunition body if it is nonaxisymmetric and modeled by panels, and each set can have from one to four fins. The fins and the interference shell placed on the body to account for fin-on-body lift carryover are modeled by constant u-velocity panels. Induced velocities from the dispenser and the image store system are included in the panel boundary conditions. For a submunition with two sets of fins, the effects of trailing edge vorticity from the forward set of fins is included in the calculation of forces and moments on the aft set of fins and interference shell. The pressure coefficient at the control points of all the constant u-velocity panels is determined, and the total forces and moments acting on the fins and the length of body covered by the interference shell are obtained by summing the individual panel forces and moments.

Experimental Data Base and Configurations

The U.S. Army Missile Command has conducted a number of wind-tunnel tests to determine the aerodynamic characteristics of several different submunitions in the presence of closed and open bay dispensers. This data base was obtained using a two-sting arrangement, where the submunition could be



a) α_s = 0 deg



b) α_s = 5 deg

Fig. 5 Measured and predicted vertical variation of aerodynamic coefficients on submunition S2T1 below dispenser D1; M_∞ = 3.0, X_s = 5.5.

moved in angular, axial, or vertical directions with respect to the dispenser missile. A sketch of the dispenser used to obtain the data presented in this paper is shown in Fig. 2. This model has the capability of having each bay (i.e., front, center, and aft) open separately from the others, or of having various combinations of bays open at the same time. A number of submunition designs that have been tested in conjunction with the closed and open bay dispenser are also shown in Fig. 2.

The experimental data base consists of submunition forces and moments as a function of selected submunition parameters that are 1) submunition vertical position, 2) submunition longitudinal position, or 3) submunition angle of attack with respect to the dispenser missile centerline. Only one parameter is varied during a particular run.

Results

Selected comparisons of measured and predicted forces and moments on submunitions in the vicinity of a dispenser missile are presented in this section. A wide variety of submunition and dispenser configurations and flow conditions are presented to illustrate the capabilities of the computer programs described herein. For some cases, simulated shock shapes are shown to aid in the understanding of the predicted results. Results obtained primarily with the MICOM Dispense Code are discussed below; however, some results obtained with the 1986 NEAR Supersonic Store Separation Program are also shown, and results from the two programs are compared for two cases. Covered bay dispenser results are presented first, followed by results for open bay dispensers. Note that all results are for the dispenser at 0 deg angle of attack and for the submunition under the centerline of the dispenser (*YSMC* = 0.0).

Covered Bay Dispenser

Figure 3 shows typical simulated dispenser, store, and reflected store simulated shock shapes for submunition S2T1 in the vicinity of dispenser D1 (configuration D1S2T1). Shocks associated with the submunition are shown for two vertical positions; *ZSMC* = 0.25 and 0.65 ft below the dispenser centerline. The freestream Mach cone is also shown in this figure. The simulated dispenser shock is used in both the MICOM Dispense Code and the 1986 NEAR Supersonic Store Separation Program. The simulated submunition shocks are used only in the latter program.

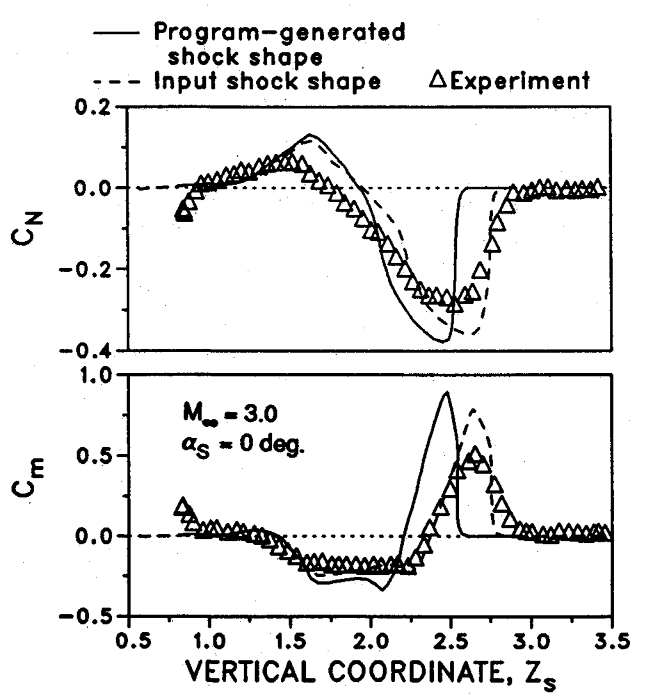


Fig. 6 Measured and predicted vertical variation of aerodynamic coefficients on submunition S2T1 below dispenser D1; M_∞ = 3.0, α_s = 0 deg, X_s = 5.5.

Comparisons of measured and predicted C_N and C_m vs Z_s for M_∞ = 1.81, α_s = 0 deg, and two axial positions are presented in Fig. 4. The vertical traverse is carried out from approximately 0.80 to 3.6 dispenser diameters (0.25 to 1.125 ft, respectively) below the dispenser centerline and is depicted in the sketch at the top of the figure. Predicted results were obtained using the MICOM Dispense Code. Note that only the dispenser shock is included in this method. The calculated results shown in Fig. 4 exhibit a slight horizontal shift with respect to the data, and the maximum pitching-moment coefficient is underpredicted slightly; however, the trends of the data are predicted very well.

Comparisons of measured and predicted C_N and C_m vs Z_s for configuration D1S2T1 at M_∞=3.0, α_s=0.0, and 5.0 deg are presented in Fig. 5. For this case, a vertical traverse is carried out with the submunition CG located 5.5 dispenser diameters aft of the dispenser nose. Results from both the MICOM and 1986 NEAR codes are shown in Fig. 5. In general, fair agreement between theory and data is shown, with the vertical position at which the submunition experiences maximum normal force and pitching moment predicted better by the MICOM code, and the magnitude of these peaks predicted better by the NEAR code. Effects of angle of attack are indicated well by both programs.

The results presented in Fig. 5 indicate that the simple shock simulation model may have limited capabilities at high Mach numbers. In order to examine the range of applicability of the dispenser shock shape simulation on the computed submunition loads, an Euler code[15] was used to generate a dispenser shock shape for input to the MICOM Code. Results with calculated and input (i.e., Euler) dispenser shock shapes are compared with experimental data in Fig. 6. The conditions are the same as those presented in Fig. 5. The input shock shape provides a better indication of the vertical position at which the submunition experiences maximum C_N and C_m, as well as the level of these maxima. In the present shock calculation procedure, only a single iteration of the local flowfield is carried out to obtain the simulated shock shape. The comparisons shown in Fig. 6 indicate that more iterations may be required to simulate shock shapes more accurately at higher Mach numbers.

Open Bay Dispenser

As discussed in the technical approach, models for the open bay dispenser were developed by J. L. Sims[5] using an inverse technique in which a cavity streamline is assumed, and calculated submunition loads are compared with data. For a given Mach number, results from a vertical traverse with the body-alone submunition configuration at α_s = 0 deg are used to calibrate the predicted results. A manual iterative procedure is carried out to obtain a "best fit" comparison of data and theory over the entire vertical traverse, thereby arriving at a cavity streamline for the given Mach number and configuration.

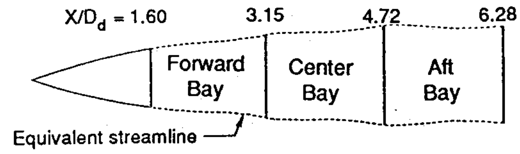
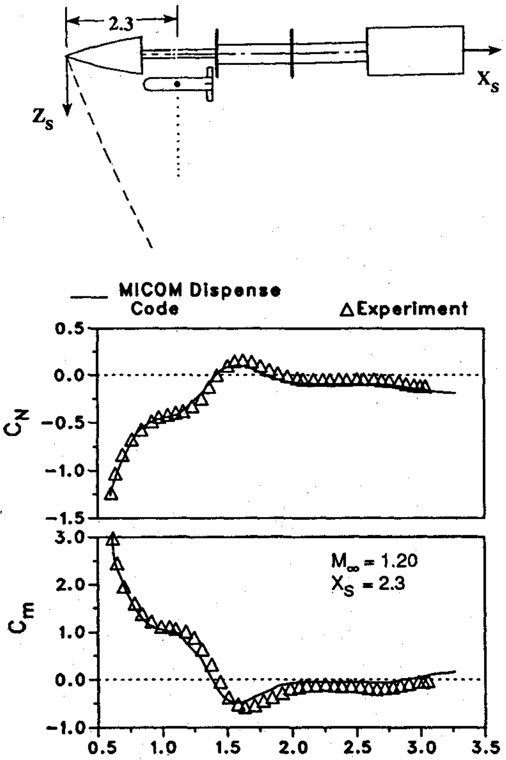
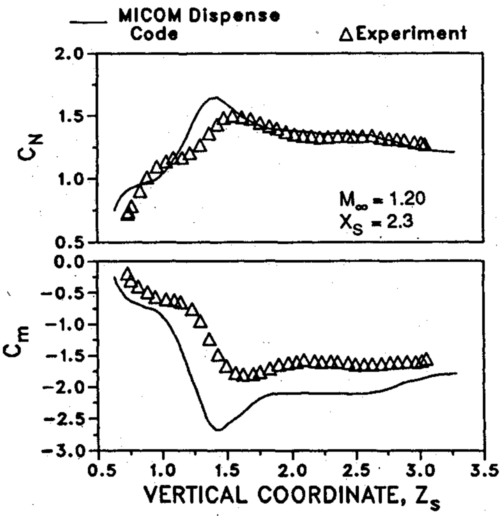


Fig. 7 Equivalent streamline representation for open bay dispenser D1FCA, M_∞ = 1.20.

A sketch of the modeled shape developed for the open bay dispenser at M_∞ = 1.2 is shown in Fig. 7. The dashed lines shown in this figure are the modeled equivalent streamlines, with solid vertical lines separating the bays. The axial limits of each region are indicated above each division. These representations of the open bays were obtained by the technique mentioned above, using force and moment data for the hemi-



a) $\alpha_s = 0$ deg



b) $\alpha_s = 10$ deg

Fig. 8 Measured and predicted vertical variation of aerodynamic coefficients on submunition S1T1 below dispenser D1FCA; M_∞ = 1.20, X_s = 2.3.

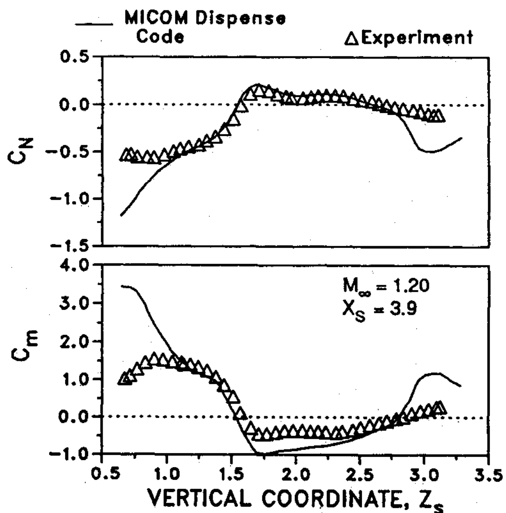
sphere-cylinder submunition configuration S1 (body alone) at $\alpha_s = 0$ deg with respect to dispenser D1FCA. Predicted results were then obtained for configuration S1T1 (body with tail fins) at $\alpha_s = 0$ and $+10$ deg and $X_s = 2.3$ calibers using the MICOM Code. This axial position represents the release of the submunition from the front bay; therefore, only the dispenser ogive nose and forward open bay are modeled for this case.

Comparisons of C_N and C_m vs Z_s for submunition S1T1 at $\alpha_s = 0$ deg, shown in Fig. 8a, indicate excellent agreement between measured and predicted results. A sketch depicting the vertical traverse of S1T1 under open bay dispenser D1FCA is shown at the top of Fig. 8a. For $\alpha_s = 10$ deg, shown in Fig. 8b, the calculated normal force variation with vertical coordinate agrees very well with data. Pitching moment results from the MICOM Code show the same trends exhibited by the data; however, the magnitude of C_m is much larger than that seen in the data. This may in part be attributable to an error in the user-specified lift-curve slope for the fins.

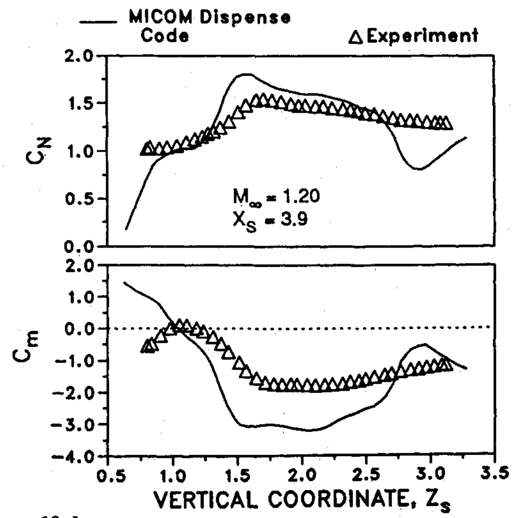
Comparisons at $X_s = 3.9$, analogous to those in Fig. 8, are shown in Fig. 9. This axial location represents the submunition being launched from the center bay; therefore, only the dispenser ogive nose and front and center bays are modeled for this case. For $\alpha_s = 0$ deg in Fig. 9a, the nonlinear variation of C_N and C_m are predicted well. Over most of the vertical traverse, C_N agrees quantitatively with measurement. The major differences are seen for the submunition close to the dispenser ($Z_s < 1.0$), where measured effects due to the cavity are much larger than those indicated by the calculations, and for $Z_s > 2.75$, where the computed results show a disturbance not indicated by the data. Similar discrepancies between theory and experiment for $Z_s > 2.75$ exist for the S1 body-alone calibration run.

In Fig. 9b, the trends shown by the experiment are indicated fairly well by the MICOM Code for the region $1.0 \leq Z_s \leq 2.75$. As also seen in Fig. 8b, the magnitude of the calculated C_m is larger than that indicated by the data.

Comparisons of measured and predicted results for an axial traverse of submunition S1T1 at a vertical location 1.0 dispenser diameter below dispenser D1FCA are shown in Fig. 10. For these comparisons, $M_\infty = 1.20$ and $\alpha_s = 0$ deg. The ogive nose and all open cavities of the dispenser are modeled for this



a) $\alpha_s = 0$ deg



b) $\alpha_s = 10$ deg

Fig. 9 Measured and predicted vertical variation of aerodynamic coefficients on submunition S1T1 below dispenser D1FCA; M_∞ = 1.20, X_s = 3.9.

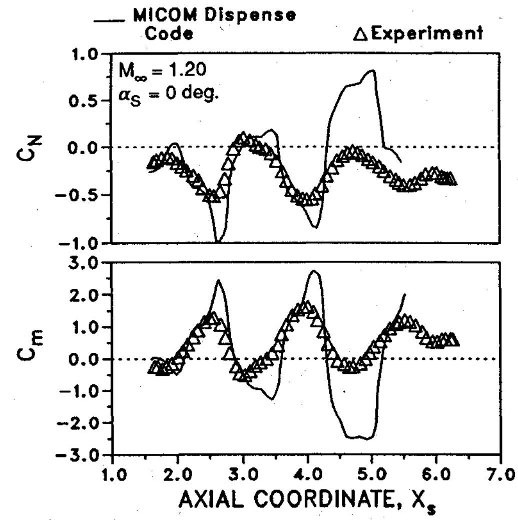


Fig. 10 Measured and predicted axial variation of aerodynamic coefficients on submunition S1T1 below dispenser D1FCA; M_∞ = 1.20, α_s = 0 deg, Z_s = 1.00.

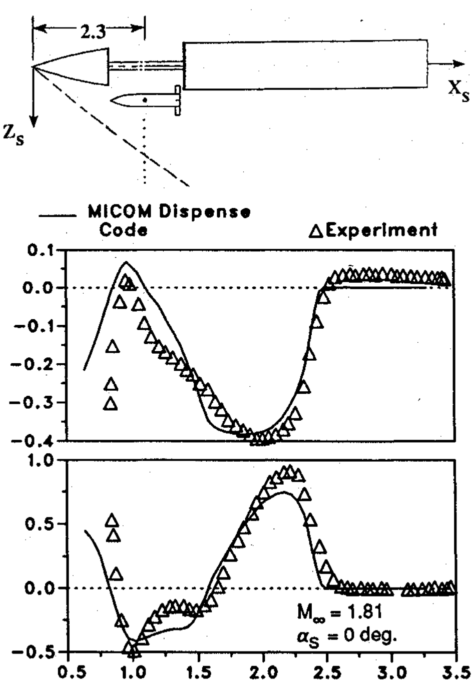


Fig. 11 Measured and predicted vertical variation of aerodynamic coefficients on submunition S2T1 below dispenser D1F; M_∞ = 1.81, α_s = 0 deg, X_s = 2.3.

case. The measured trends of the data and the axial locations of the peak loads are indicated very well by the theory, although the predicted peak loads are considerably higher than the measured values. This is especially evident in the region of the aft bay, where cavity effects are not predicted well using the equivalent streamline technique. The overestimation of peak loads may also be due in part to the slender body theory method used for the submunition loads. As seen in Fig. 5, the line singularity/pressure distribution method incorporated in the 1986 NEAR Supersonic Store Separation Program produces appreciably lower peak loads acting on the submunition than the slender body theory employed in the MICOM dispenser code.

The final comparisons are for submunition S2T1 in the vicinity of dispenser D1F at M_∞ = 1.81 and α_s = 0 deg, shown in Fig. 11. For this case, a vertical traverse is carried out with the submunition CG located 2.3 dispenser diameters aft of the dispenser nose, as depicted in the sketch at the top of the figure. As was done for the M_∞ = 1.20 cases, the equivalent streamline shape for the front bay was calibrated using body alone (i.e., submunition S2) data. Very good agreement between calculated and measured C_N and C_m is shown in Fig. 11, with some disagreement in the region very close to the dispenser ($Z_s < 1.0$). Generally, the strong variations in the force and moment are well predicted. Note that the behavior of C_N and C_m is essentially the same as shown in Fig. 4a for the closed bay, except in the region closest to the dispenser. In this region, the submunition experiences reversals in normal force and pitching moment. The sharp reversals are predicted well by the theory. The nose-up pitching moment can cause problems in that the submunition may be driven upwards towards the dispenser.

Conclusions

Predicted supersonic aerodynamic characteristics for a submunition in close proximity to a covered-bay dispenser missile have been obtained using two computer programs: the MICOM Dispense Code and the 1986 NEAR Supersonic Store Separation Program. Predicted results for an open-bay dispenser have been obtained using the MICOM Dispense Code in conjunction with an inverse technique for determining equivalent streamline shapes for the open cavity. In general, measured trends are well predicted; in some cases, very good quantitative agreement with experimental data is indicated. For a given dispenser shape, a typical traverse requires less than five minutes CPU time on a VAX 11/780 computer.

Comparisons of predicted results with data have indicated several areas of improvement for these computer programs. Validation and verification of simulated shock shapes with experimental data and/or Euler solver results is recommended. Although not discussed in this paper to any great extent, verification and possible improvement of the wing-tail interference models is also suggested. For the 1986 NEAR code, it is recommended that the omission of parent aircraft and image store effects in the submunition pressure calculation, originally based on data comparisons,[10] be re-evaluated. Recent data comparisons for submunition/dispenser configurations indicate that the inclusion of these effects, which are related to buoyancy, may improve predicted results. The resulting updated program(s) should be of great value in engineering-level studies of submunition aerodynamics and trajectory analysis during dispense.

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