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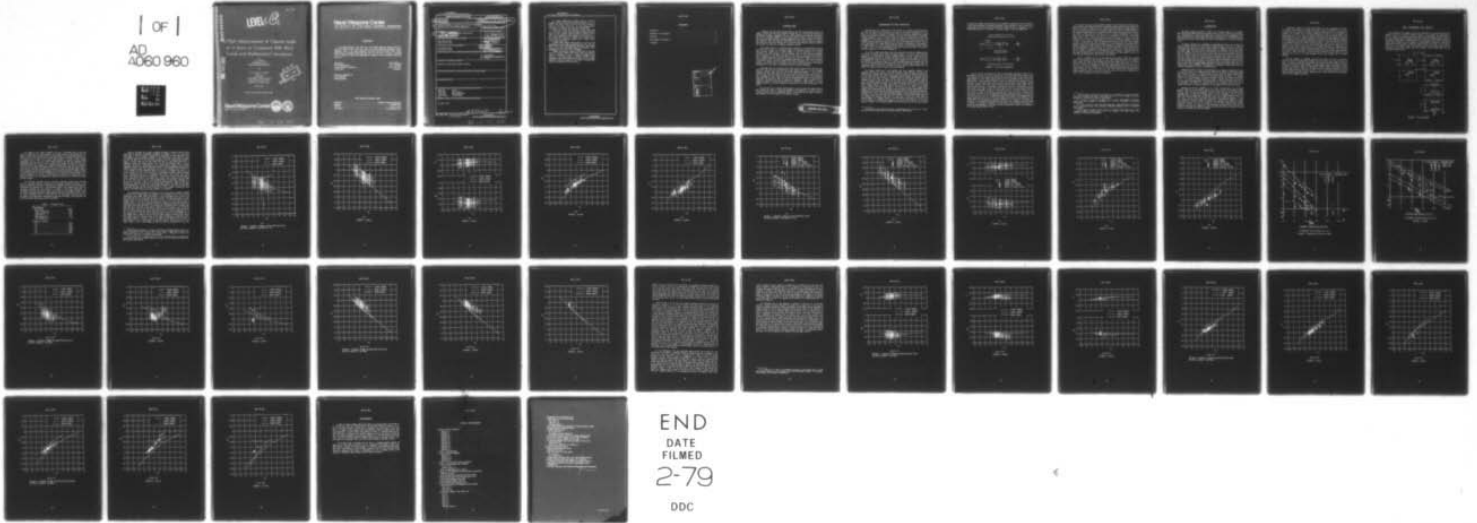
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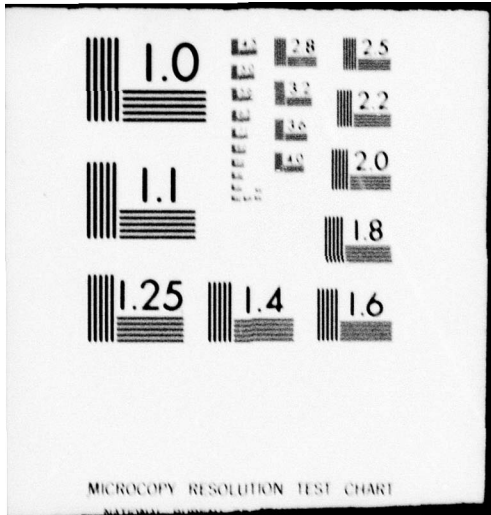
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# In-Flight Measurements of Captive Loads on a Store as Compared With Wind Tunnel and Mathematical Simulations

by  
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and

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## Naval Weapons Center

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# Naval Weapons Center

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## FOREWORD

The research described in this report was a joint program under the direction of the Navy with Naval Weapons Center, China Lake, Calif., and Arnold Engineering Development Center, Tullahoma, Tenn., as the main participants. The Navy portion was funded under AirTask WF32-323-202 and performed during fiscal years 1976, 1977 and 1977. It is part of a continuing effort to evaluate and improve the methodology of assessing the result of launching a store from an aircraft.

Approved by  
M. M. ROGERS, *Head*  
*Systems Development Department*  
6 April 1978

Under authority of  
W. L. HARRIS  
RAdm., U.S. Navy  
*Commander*

Released for publication by  
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(U) *In-Flight Measurements of Captive Loads on a Store as Compared With Wind Tunnel and Mathematical Simulations*, by A. R. Maddox, Naval Weapons Center, and R. E. Dix and G. R. Mattasits, Arnold Air Force Station, China Lake, Calif., Naval Weapons Center, April 1978. 42 pp. (NWC TP 6026, publication UNCLASSIFIED.)

(U) A series of flight tests were made to acquire captive loads data on a store to compare with corresponding data from several wind tunnel tests with conditions matched as closely as possible as well as with the best mathematical models available. The store consisted of a Mk 83 bomb shape mounted on a triple-ejector rack (TER) on an F-4 aircraft which was instrumented complete with a standard research boom mounted on the nose.

(U) The flight conditions spanned Mach 0.6 to 0.9 in both maneuvering and steady flight. Corresponding wind tunnel tests were made at 5% at both Arnold Engineering Development Center (AEDC) and the David Taylor Naval Ship Research and Development Center (DTNSRDC), as well as tests at 10% at DTNSRDC.

(U) The data show good correlation between flight test and wind tunnel for moderate subsonic Mach numbers when good geometric similarity is maintained, but there is a pronounced divergence in this agreement as the Mach number is increased. Correlation between mathematical models of this problem and the flight test show the same magnitude in loads and moments, but the trends do not always agree. This is most pronounced in the pitch plane.

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## INTRODUCTION

A persistent, and often heated, technical debate in the area of store separation concerns the validity of wind tunnel data when compared with flight test, not to mention the effectiveness of mathematical simulations. Investigators from the various disciplines have frequently cited favorite sets of data to establish credibility, but this has done little to settle the issue since comparisons have been made despite improperly matched configurations and/or flight conditions. The result is that simulations, both wind tunnel and mathematical, have been used most often in a qualitative sense and not in their most effective role to uncover the most hazardous separation conditions and to reduce the overall cost of qualifying a separation condition.

This document reports on a research program to obtain a set of measurements both in the wind tunnel and in flight on an instrumented aircraft with conditions matched as well as possible. This first phase consisted only of captive loading on a Mk 83 bomb shape on a standard triple-ejector rack (TER) mounted on an F-4 Phantom. Drop tests with this same configuration will be conducted in a later phase. The flight test, taken with an instrumented aircraft complete with a standard research boom mounted on the nose, is expected to supply a set of data for direct comparisons with wind tunnel and mathematical simulations over a wide range of conditions. It should also supply a data base against which future improvements can be compared. The selection of the Mk 83 store for this series was the result of several compromises, but it appears representative of a wide variety of configurations and thus of general applicability.

These flight tests were conducted at the Naval Air Test Center (NATC), Patuxent River, through the joint efforts of the Naval Weapons Center (NWC), China Lake, Air Force Armament Laboratory (AFATL), Eglin AFB, and the Arnold Engineering Development Center (AEDC), Tullahoma. The basic wind tunnel data base was the result of numerous wind tunnel tests at 5% scale at AEDC with some testing at the David Taylor Naval Ship Research and Development Center (DTNSRDC) at both 5 and 10% scale. The existing flight-rated store and airborne balance combination was supplied by NWC and adapted and calibrated by AEDC. A special TER was supplied by AFATL. It should also be noted that on all flights, a similar balance for a similar program conducted by the United Kingdom was being flown on the right inboard pylon of the aircraft.

The data show good correlation between flight test and wind tunnel for moderate subsonic Mach numbers, but there is a pronounced divergence in this agreement as the Mach number is increased. Correlation between mathematical models of this problem and the flight test show the same magnitude in loads and moments, but trends do not agree.

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## DESCRIPTION OF TEST APPARATUS

The flight tests were conducted with an F-4J aircraft, but a number of special precautions were taken to enhance both the validity of the data for the present comparisons and in the future as a data base for refinement of simulations. First, the aircraft was equipped with a typical research boom mounted on the nose and coupled to the aircraft recording system for measurement of flight parameters. Second, in order to match the large wind tunnel data base that had accumulated up to this time, an Air Force pylon was mounted on the left inboard station. The centerline and outer pylons were mounted, but not used. An interesting feature, however, was that on the Navy pylon on the right inboard station was mounted a triple-ejector rack and adapter of the United Kingdom. As a result of joint cooperative efforts, a United Kingdom airborne balance in a Mk 10 store was flown simultaneously on the right wing, but the results of this separate correlation program are to be reported independently.

An Air Force TER was mounted on the left inboard pylon, and the two shoulder positions were fitted with dummy Mk 83 bombs. The center position of the TER at the bottom was occupied by a conventional Mk 83 body modified internally to accept a flight-rated balance. Special precautions were taken to determine the attitude of the stores with respect to the aircraft by establishing the aircraft on jacks with the ordnance reference lines level. The store axes were then checked. The instrumented store, as a result of machining and special handling, was quite true, but the shoulder-mounted stores showed the effects of manufacturing tolerances. There was considerable camber in the axis of the inboard store, but both were leveled to within about 1/2 degree in the mean by means of lug and sway brace adjustment.

The airborne balance was of the Pastushin type more completely described in the publication referenced in Footnote 1. This device consisted of large rigid upper and lower plates interconnected by linkages with ball-joint ends so that force would be transmitted only along one axis. The upper plate was the inert or mechanically grounded element, and protruded through cut-outs in the store shell as necessary to provide surfaces for attaching the suspension lugs and accepting the contact of the sway braces. The lower plate was the "active" element to which the store was attached. Normal and side forces were derived from measurements of pitching and yawing moments; therefore the balance was considered a moment balance. Axial force was sensed with a separate element, but rolling moment was derived from the outputs of two parallel elements mounted in the lateral-vertical plane of the store that were also used in sensing pitching moment. Three accelerometers were mounted on the lower plate to provide measurements of store accelerations in the three body-axis coordinate directions. The Mk 83 store shape was originally a standard Mk 83, but the center section had been hollowed out and machined internally to accept the balance. The center section had been further modified to provide isolation gaps around the inert elements with which the hooks and sway braces were in contact. All internal wiring was bundled together in an umbilical, fastened to the inert element, and brought out an extra hole in the top element. The umbilical was attached to the rack and then connected to the aircraft system. In addition to the normally detachable tail cone, the nose cone was also made removable

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<sup>1</sup> Naval Weapons Center. *Measured Air Loads for a Free-Fall Weapon on an A-4 Aircraft*, by R. E. Smith. China Lake, Calif., NWC, October 1968. (NWC TP 4804, publication UNCLASSIFIED.)

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for access to the balance. Since the tail cone was removable, an alternate tail cone was fabricated at AEDC which duplicated the modification necessary to the store shape in order to mount it on a sting during wind tunnel testing. The standard store shape, referred to as afterbody 1, and the modified shape, referred to as afterbody 2, are shown in Figure 1. Both were flight-tested.

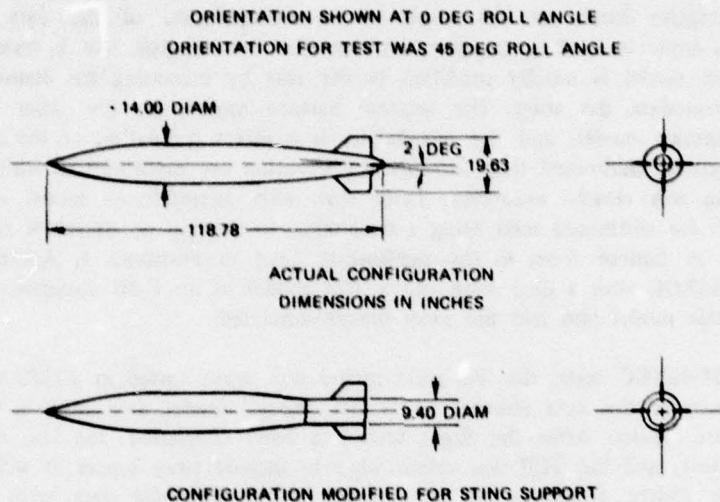


FIGURE 1. Mk 83 Test Configurations.

The F-4J aircraft was equipped with special instrumentation subsystems for flight test. A signal-condition subsystem served as an interface box for all signal wiring and provided the means of conditioning the output signals from the airborne balance. The balance output signals required bridge balance circuits; low level amplifiers; 6-pole, 6-Hz, low-pass Butterworth filters; 1-pole, 2-Hz, high-pass filters; voltage substitution calibration circuits; and differential input amplifiers with gain and offset for the bridge voltage monitor circuits. The accelerometer output signals required differential amplifiers and 4-pole, 10-Hz, low-pass Butterworth filters. Output signals from the boom subsystem required no conditioning for sensing static pressure, total temperature, airspeed, altitude, and aircraft angle of attack and sideslip angle. All data were synchronized through the time correlation subsystem consisting of a time code generator, a cockpit time display, a pilot's event mark, an aircraft bomb button firing pulse, and a UHF radio link to synchronize the aircraft time with NATC time. The pulse code modulation subsystem consisted of a vector DAS 507 PCM unit, and a bit rate of 88,000/second was selected allowing 100 samples/second and ensuring data reconstruction up to 20 Hz. All channels were filtered to remain within this limit. Output signals from the pulse code modulation subsystem were recorded by the magnetic tape subsystem, a 14-track MARS 2000 intermediate band recorder with a maximum frequency response of 250 Hz at 60 inches of tape/second. A record speed of 30 inches/second was selected to handle the data bandwidth for this test. All aircraft instrumentation systems were calibrated by the Technical Support Division of NATC.

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Wind tunnel data used in the comparisons consisted of several large blocks of data taken in different modes with limited differences in configuration during the several tunnel entries. The initial data was taken at AEDC at 5% scale with an F-4C model using a dual-sting technique as well as an internal balance model for the captive loading and is reported in AEDC TR-76-122.<sup>2</sup> The dual-sting technique employs one sting for the aircraft model and a separate sting to hold the store model. In this manner, the store model is free to be moved independently of the aircraft model, and the captive loads are the result of an extrapolation of the data to the captive position. There is never a hard connection between the two models. As a result of this sting mounting, the store model is usually modified in the rear by increasing the diameter of the base in order to accommodate the sting. The internal balance model, on the other hand, is rigidly mounted to the aircraft model, and the installation is a direct simulation of the airborne balance flight-test configuration. Additional data for this configuration are reported<sup>2</sup> in which the effect of the sting mounting was closely examined. Later this same aircraft/store model combination was used at DTNSRDC for additional tests using a dual sting to develop an extensive force grid. These data are reported in limited form in the publication cited in Footnote 3. Additional data were also taken at DTNSRDC with a dual sting and a 10% model of an F-4B modified to look like an F-4C. This 10% scale model also had the sway braces simulated.

After the DTNSRDC tests, the 5% scale model was again tested at AEDC with an internal balance. This constitutes the data referred to as the "early" model data used in the comparisons with the flight test results. After the flight tests had been concluded, the fins of the 5% scale model were reworked, and the TER was refabricated to include sway braces as well as cutouts on the rack to more nearly duplicate the real article. Again additional data were taken with an internal balance. These data, referred to as the "final" model data, are documented in the reports noted in Footnotes 4 and 5. Thus, three sets of data were obtained with two generations of models through this period but, except for the sway braces and cutouts, the differences were minor both in the geometry as well as the resulting data.

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<sup>2</sup> Arnold Engineering Development Center. *Comparison of Two Methods Used To Measure Aerodynamic Loads Acting on Captive Store Models in Wind Tunnel Tests*, by R. E. Dix. Tullahoma, Tenn., AEDC, September 1976. (AEDC-TR-76-122, publication UNCLASSIFIED.)

<sup>3</sup> G. F. Cooper, A. R. Maddox, J. R. Marshall, and E. F. McCabe. "Store Separation. State-of-the-Art Review," *Tenth Navy Symposium on Aeroballistics, 15-17 July 1975*. Fredericksburg, Va. (Publication UNCLASSIFIED.)

<sup>4</sup> R. E. Dix. "Simulation of Sway Braces and Mounting Gaps on Small Scale Models for Wind Tunnel Tests," in *Proceedings of Fourth JTCG Aircraft/Stores Compatibility Symposium, October 1977*. (Publication UNCLASSIFIED.)

<sup>5</sup> Arnold Engineering Development Center. *Influences of Sway Braces and Mounting Gaps on the Static Aerodynamic Loading of External Stores*, by R. E. Dix. Tullahoma, Tenn., AEDC, February 1978. (AEDC-TR-77-117, publication UNCLASSIFIED.)

## CALIBRATION

The balance calibration was done at AEDC by the Instrument Branch of the Propulsion Wind Tunnel Facility (PWT). Although it had been stored out of use for several years, the balance was in surprisingly good condition and required only a moderate amount of refurbishment to the gage, wiring, flexures, etc. Minor changes were made to the electronics, but the largest change was to eliminate the internal recording system and mate the instrumentation to the aircraft recording system.

The balance calibration was accomplished by suspending the balance from the PWT large balance calibration rig with the upper balance platform attached to the rig by means of conventional bomb lugs and four sway brace pads. During the calibration procedure, the balance was installed inside the bomb midsection, which served as a calibration body to which known loads were applied. Load points on the bomb midsection were at known positions so that the effect of incremental loads on the balance outputs could accurately be determined. The balance calibration followed normal wind tunnel practice and consisted of three load cycles. During each load cycle, balance outputs for incremental loads were obtained and recorded for both positive and negative loadings along each of the three primary body-axis (balance-axis) system directions. After an incremental load was applied or removed, the balance was leveled in pitch and roll to ensure that the load was properly applied. All calibration data were recorded using the force and moment readout system (FAMROS). The FAMROS is a multichannel, parallel, readout system for measuring and digitizing the output of strain-gage balances.

Although the electrical output of any good balance as a function of applied load is linear in nature, the linearity in one loading sense may differ from the linearity in the opposite loading sense. Therefore, the bilinear or two-slope method was used to reduce the balance calibration data. Slopes were determined by the method of least squares which was applied to all digitized calibration data in determining the final balance calibration constants. The constants were defined in two  $6 \times 6$  balance coefficient matrixes, one matrix for positive strain-gage outputs and the other for negative strain-gage outputs. The diagonal terms of each matrix are large in relation to the off-diagonal terms, which are commonly referred to as interaction terms. They are, for example, the output of the side-force gage due to a load applied in the normal force direction.

Although the laboratory FAMROS and the aircraft recording systems were electrically equivalent, differences in the length or gage of circuit wiring can affect the magnitude of these electrical outputs and hence the calibration. Therefore, a shunt ratio was used to relate in-flight strain-gage outputs to laboratory strain-gage outputs. The basic assumption is that the ratio of flight-to-laboratory strain-gage output is equivalent to the ratio of flight-to-laboratory shunts (the shunt ratio). During the laboratory calibration, the balance power supply was adjusted to 11 volts, direct current, and the balance gages were allowed time to reach thermal equilibrium. A shunt box, consisting of calibration resistors and switches, was assembled for the flight test program. During the calibration, the box was attached so that the shunt resistors could be placed sequentially across the four elements of each strain gage. The absolute values from the four elements of each gage were averaged and recorded, and six shunt values were obtained. The same procedure was followed before each day's flights.

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Accelerometer calibrations, both static and dynamic, were also accomplished at the AEDC. Four Statham accelerometers were installed, three inside the Mk 83 bomb shape, and one used as a backup. The static calibration was made by rolling the accelerometer from 0 to 180 degrees, in increments of 10 degrees, and the dynamic calibrations were made at 50 cycles/second. The average sensitivity for the static and dynamic calibrations were approximately equal. These accelerometers were used in conjunction with the Mk 83 bomb shape mass properties to determine the components of force and moment measurements attributable to inertial loading. Mass properties of the instrumented bomb shape were determined by means of a static tare calibration. The bomb was completely assembled and suspended from the calibration rig where balance output data were obtained at roll orientations of  $0 \pm 90$  and 180 degrees with pitch equal to 0 degree. Data were obtained at various pitch attitudes with roll set to 0 degree. These data were reduced using the balance coefficient matrixes obtained during the balance calibration. The results were three values of the bomb weight as measured by the balance gages in the three primary balance directions. The location of the bomb center of gravity was also determined by this procedure. Static tare calibrations were done for the bomb configured with first the standard, then the modified afterbody.

Numerous preflight and postflight procedures were utilized to ensure the operational reliability of the Mk 83 instrumentation package. A shunt calibration using the same shunt box as used in the laboratory calibration was performed before and after each day's flights as a means of setting and checking the required reading at the gage amplifier outputs. This procedure provided the means of correlating balance and accelerometer outputs obtained during flight to outputs obtained during laboratory calibrations. The holes that had been drilled and tapped into the Mk 83 shell along the body-axis pitch and yaw planes to serve as load points during the laboratory balance calibration also served to hold a weight pan used for quick field checks of the calibration. These holes were plugged during flight.

DATA ACQUISITION AND RESULTS

Data acquisition, both straight and level and maneuvering, was concentrated around Mach numbers of 0.6, 0.7, 0.8, and 0.9 at angles of attack of -4 to 6 degrees. The final selection of data to be reduced for comparison with wind tunnel data at similar Mach numbers was made on the basis of Mach number by scanning the data with an IBM 370 interactive graphics system for data intervals during which the Mach number fell on the desired values within a tolerance of  $\pm 0.005$ . Shown in Figure 2 is a data sample for a nominal Mach 0.8 condition for a time interval during which the Mach number is within the specified limits, but the angle of attack seems to have taken on two different values. In such cases, the time interval was broken down into subintervals of shorter data samples. Other data anomalies, such as random spikes, were also eliminated during this process.

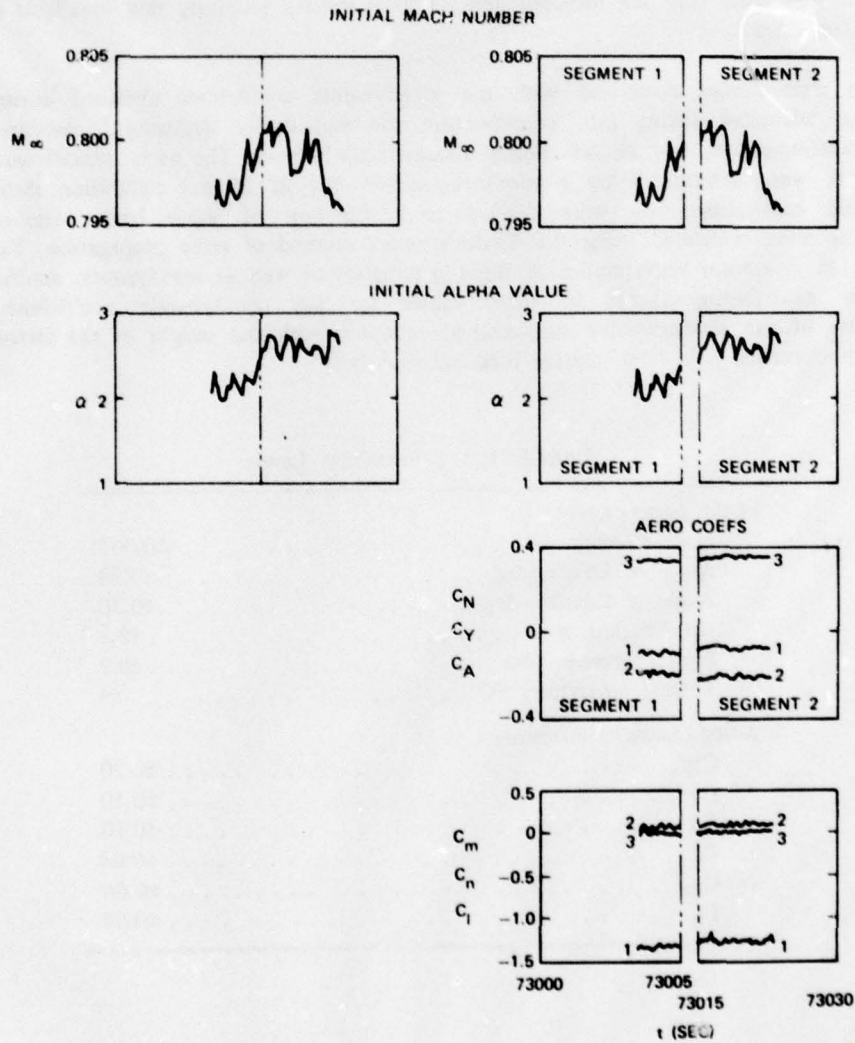


FIGURE 2. Test Data Samples.

The number of data samples (recorded at the rate of 10/second) within a given data interval or subinterval was a direct function of the flight maneuver. During straight and level flight, the Mach number remained within the  $\pm 0.005$  tolerance for several seconds, generally 5 to 10 and as long as 25. During the more transient flight maneuvers, the Mach number was within the tolerance for as little as 0.4 second. Each parameter of interest was then averaged arithmetically over the same time interval. Analysis indicated that first-order expressions would satisfactorily describe the data in any time interval. Data averaged over intervals of less than 1 second (less than 10 data samples) were considered statistically weak. These data were reexamined after data from all flights were tabulated. Data at the same Mach number and aircraft angle of attack (plus or minus the uncertainty) were compared for steady and nonsteady flight maneuvers. These comparisons showed that the magnitudes of the calculated aerodynamic coefficients obtained at aircraft pitch rates of less than 0.6 degree/second were consistently the same; therefore, on the basis of repeatability, data obtained at aircraft pitch rates greater than 0.6 degree/second can be disregarded. However, they are included here to illustrate the relatively few unreliable data samples that were obtained.

The uncertainties associated with the aerodynamic coefficients obtained during the flight tests were calculated taking into consideration the statistically determined inaccuracies of the balance, accelerometers, and aircraft boom measurement systems. The basic aircraft instrumentation uncertainties were determined by a root-mean-square analysis of the calibration data. Since the aerodynamic coefficient data were derived as a function of those basic measurements, the uncertainties were calculated using the Taylor's series method of error propagation. Table 1 shows the estimated maximum uncertainties of flight parameters as well as aerodynamic coefficients where the major contributing factor to these values for the aerodynamic coefficients were the uncertainties of the accelerometer measurements coupled with the weight of the instrumented test store. Both elements yield large inertial load uncertainties.

TABLE 1. Uncertainty Levels.

Flight parameters:	
Mach number	$\pm 0.005$
Angle of attack, deg	$\pm 0.30$
Angle of sideslip, deg	$\pm 0.30$
Acceleration, g	$\pm 0.1$
Static pressure, psia	$\pm 0.2$
Total temperature, °C	$\pm 4$
Aerodynamic coefficients:	
C <sub>N</sub>	$\pm 0.20$
C <sub>Y</sub>	$\pm 0.10$
C <sub>A</sub>	$\pm 0.10$
C <sub>l</sub>	$\pm 0.08$
C <sub>m</sub>	$\pm 0.06$
C <sub>n</sub>	$\pm 0.04$

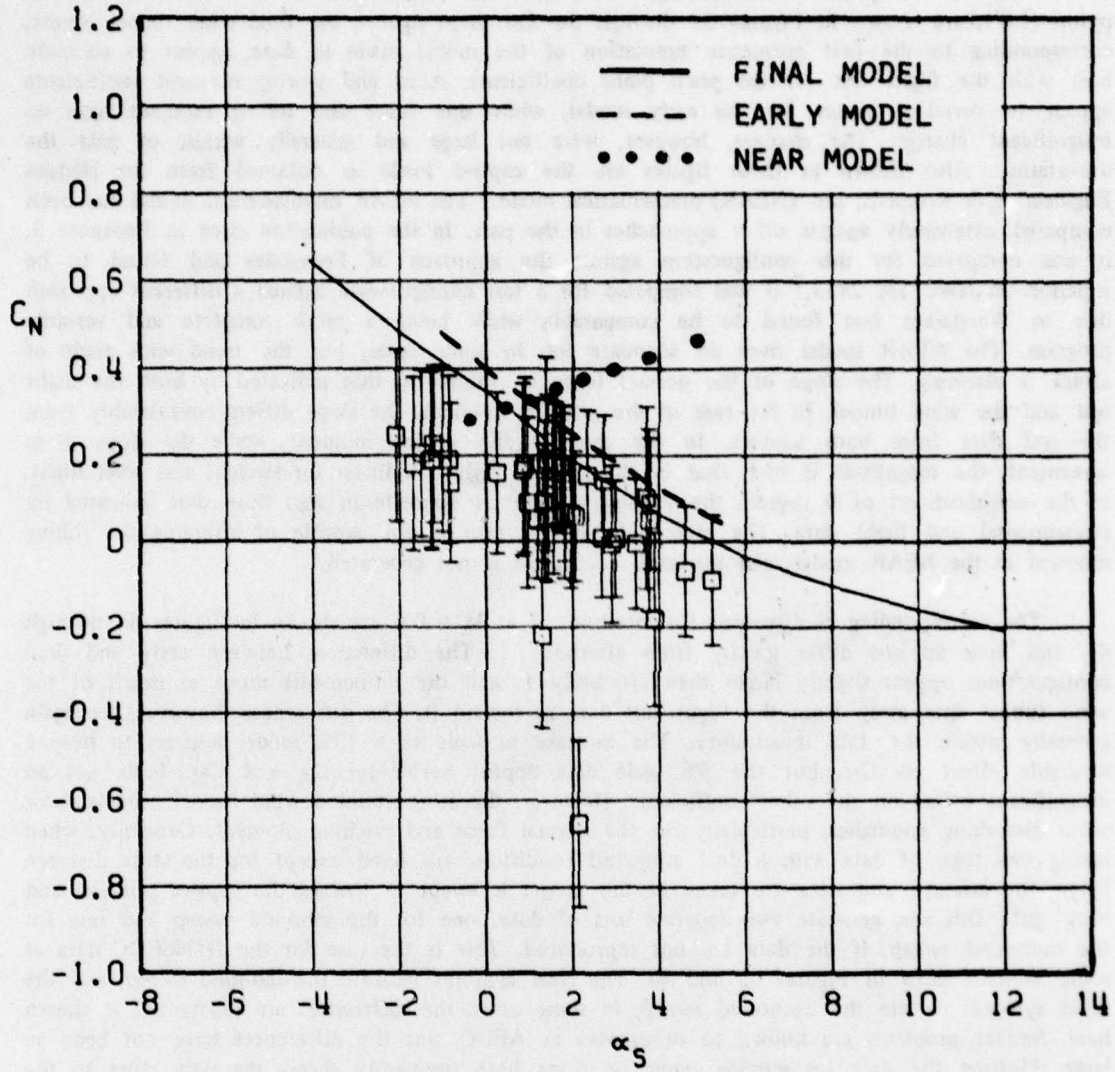
Results of the flight tests are shown in Figures 3a through 7c, along with the various wind tunnel data for comparison. Aerodynamic coefficients for afterbody 1 at  $M = 0.6$ , left inboard pylon (LIP), are shown in Figures 3a through 3e. On these figures, the final wind tunnel results, corresponding to the best geometric simulation of the model made to date, appear to compare best with the flight test for the pitch plane coefficients. Axial and yawing moment coefficients appear to correlate better for the early model, while side force and rolling moment have an insignificant change. The changes, however, were not large and generally within or near the uncertainty. Also shown in these figures are the captive loads as obtained from the Nielsen Engineering & Research, Inc. (NEAR) mathematical mode.<sup>6</sup> The NEAR mathematical model has been compared extensively against other approaches in the past. In the publication cited in Footnote 3, it was compared for this configuration against the approach of Fernandes and found to be superior. In NWC TM 2853,<sup>7</sup> it was compared for a test configuration against a different approach due to Woodward and found to be comparable while being a more complete and versatile program. The NEAR model does an adequate job in some cases, but the trend with angle of attack is alarming. The slope of the normal force is counter to that indicated by both the flight test and the wind tunnel. In the case of the pitching moment, the slope differs considerably from the test data from both sources. In the case of the yawing moment, while the slope is in agreement, the magnitude is such that in the normal flight condition for straight and level flight, in the neighborhood of 0 degree, the yawing moment is opposite in sign from that indicated by experimental and flight data. The effect of the fin cant is not capable of affecting the rolling moment in the NEAR model, and the axial coefficient is not generated.

The corresponding comparisons for afterbody 2 at  $M = 0.6$  are shown in Figures 4a through 4e, and they do not differ greatly from afterbody 1. The differences between early and final configurations appear slightly larger than afterbody 1, and the refinements move as much of the wind tunnel data away from the flight test data as toward it. The differences, however, are again generally within the data uncertainty. The increase in scale to a 10% model appears to have a favorable effect on  $C_N$ , but the 5% scale data appear better for  $C_A$  and  $C_M$ . Scale has an insignificant effect on the other coefficients. However, the sting-mounted wind tunnel models show some disturbing anomalies, particularly for the normal force and pitching moment. Generally, when taking this type of data with a dual sting, all conditions are fixed except for the store distance below the aircraft, and data are taken as the model is swept in toward the captive position and back out. This can generate two separate sets of data, one for the inbound sweep and one for the outbound sweep, if the data are not reproduced. This is the case for the DTNSRDC data as some samples show in Figures 5a and 5b. The clear symbols indicate the inbound sweep, and the filled symbols denote the outbound sweep. In some cases, the differences are substantial as shown here. Similar problems are known to occur also at AEDC, but the differences have not been so large. Plotting the data on semilog paper as done here frequently shows the data close to the captive position to form a nearly straight line which can easily be extrapolated into the captive

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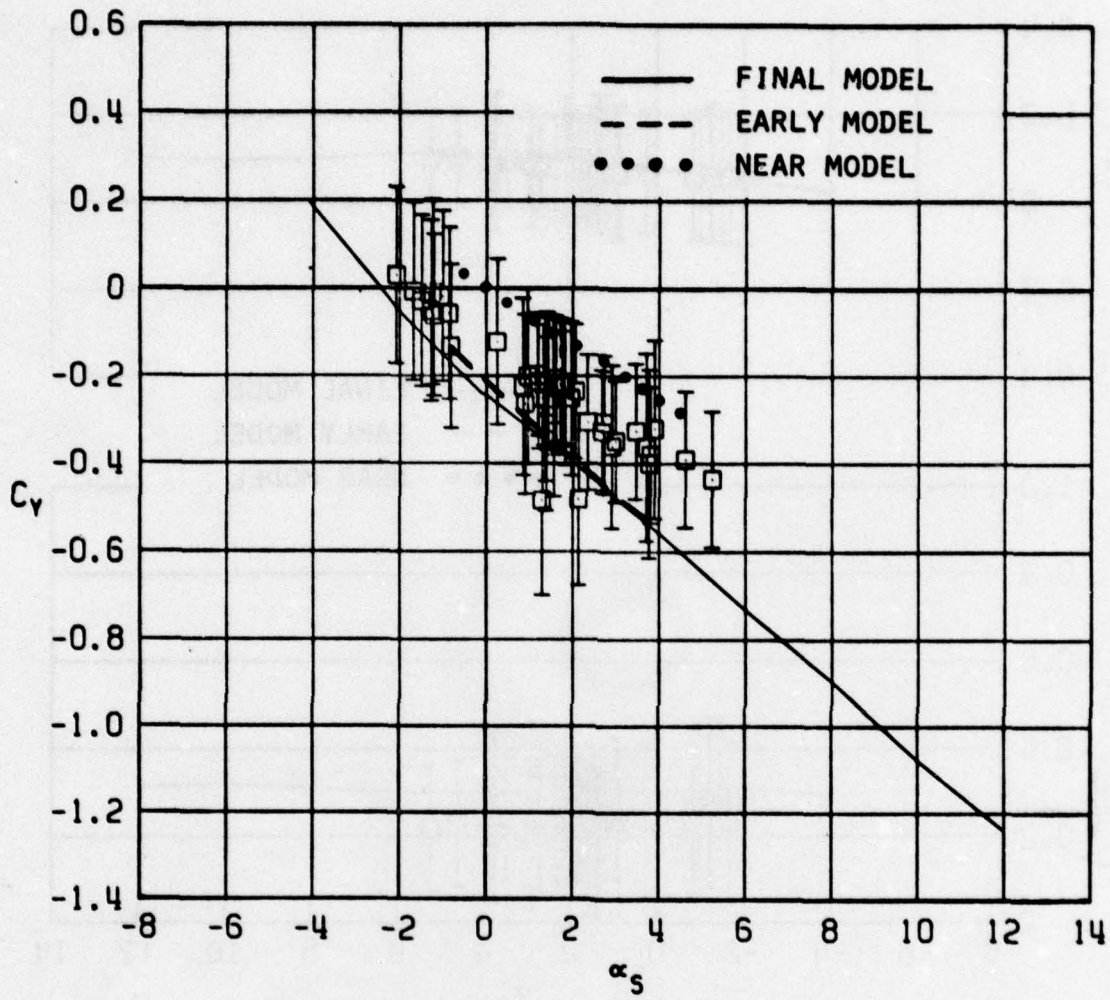
<sup>6</sup> Nielsen Engineering & Research Inc. *Extension of the Method for Predicting Six-Degree-of-Freedom Store Separation Trajectories at Speeds Up to the Critical Speed to Include a Fuselage With Non-Circular Cross Section—Volumes I and II*, by F. K. Goodwin, M. F. E. Dillertus, and J. N. Nielsen. Palo Alto, Calif., NEAR, November 1974. (AFFDL-TR-74-130, publication UNCLASSIFIED.)

<sup>7</sup> Naval Weapons Center. *A Comparison Between the Nielsen and Woodward Programs in Predicting Flow Fields and Store Loads*, by R. M. Rogers. China Lake, Calif., NWC, July 1977. (NWC Technical Memorandum 2853, publication UNCLASSIFIED.)



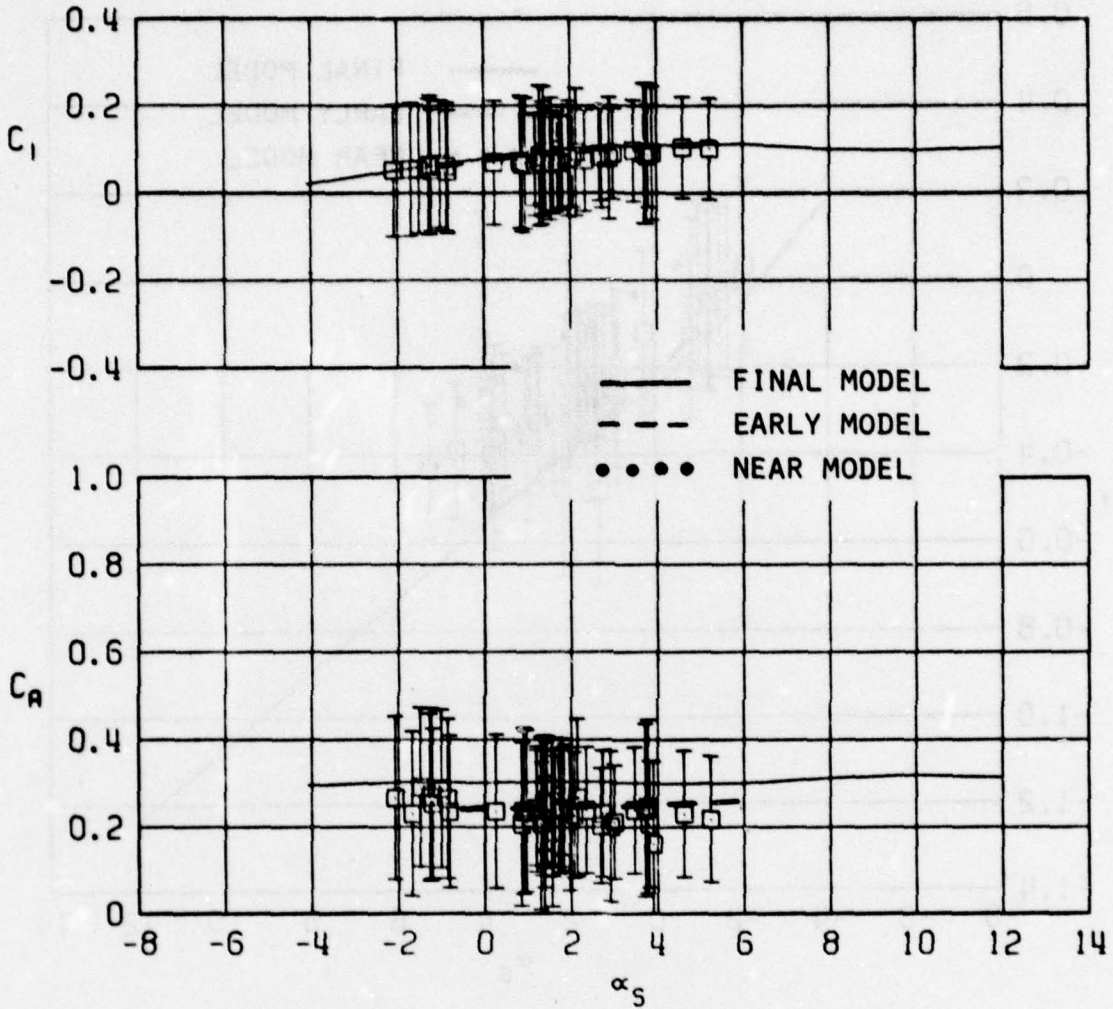
(a)

FIGURE 3. Comparison of Flight Test Results With Wind Tunnel;  
Mk 83/F-4, Afterbody 1, LIP, TER-1,  $M = 0.6$ .



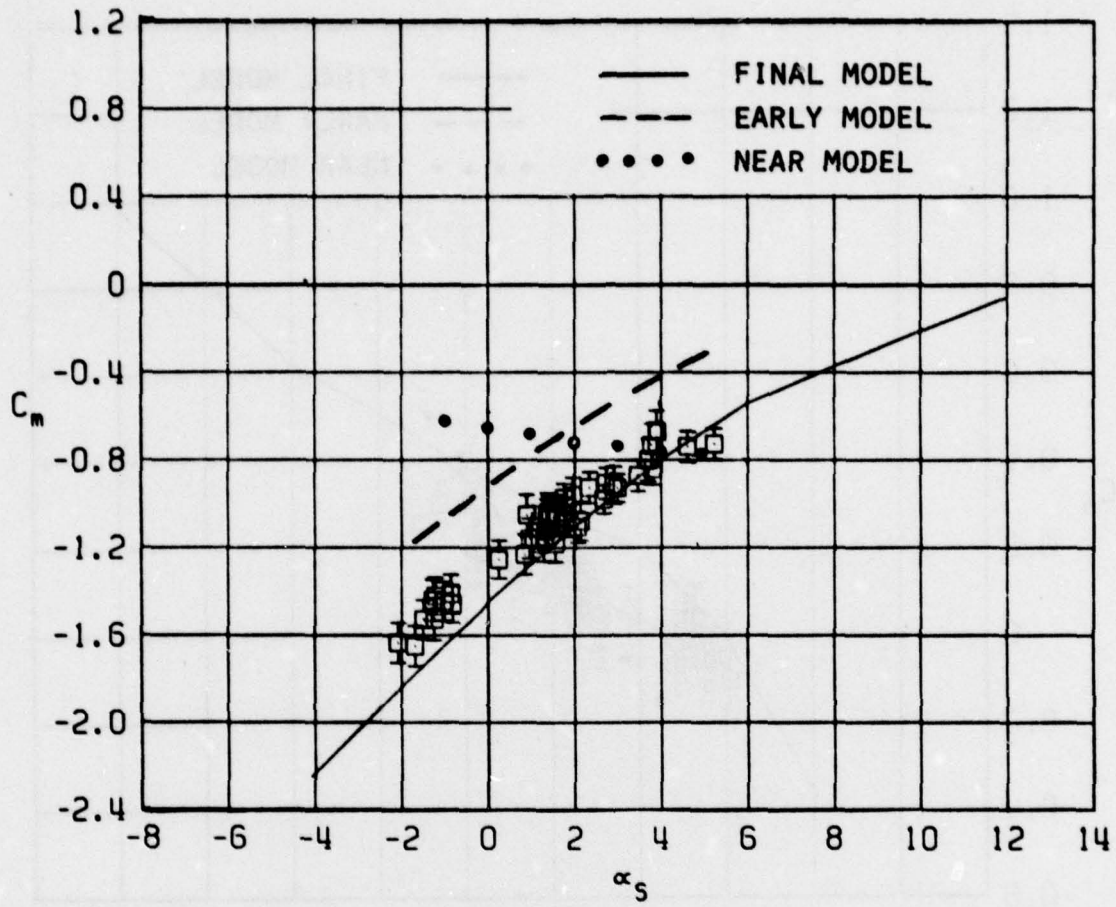
(b)

FIGURE 3. (Contd.)



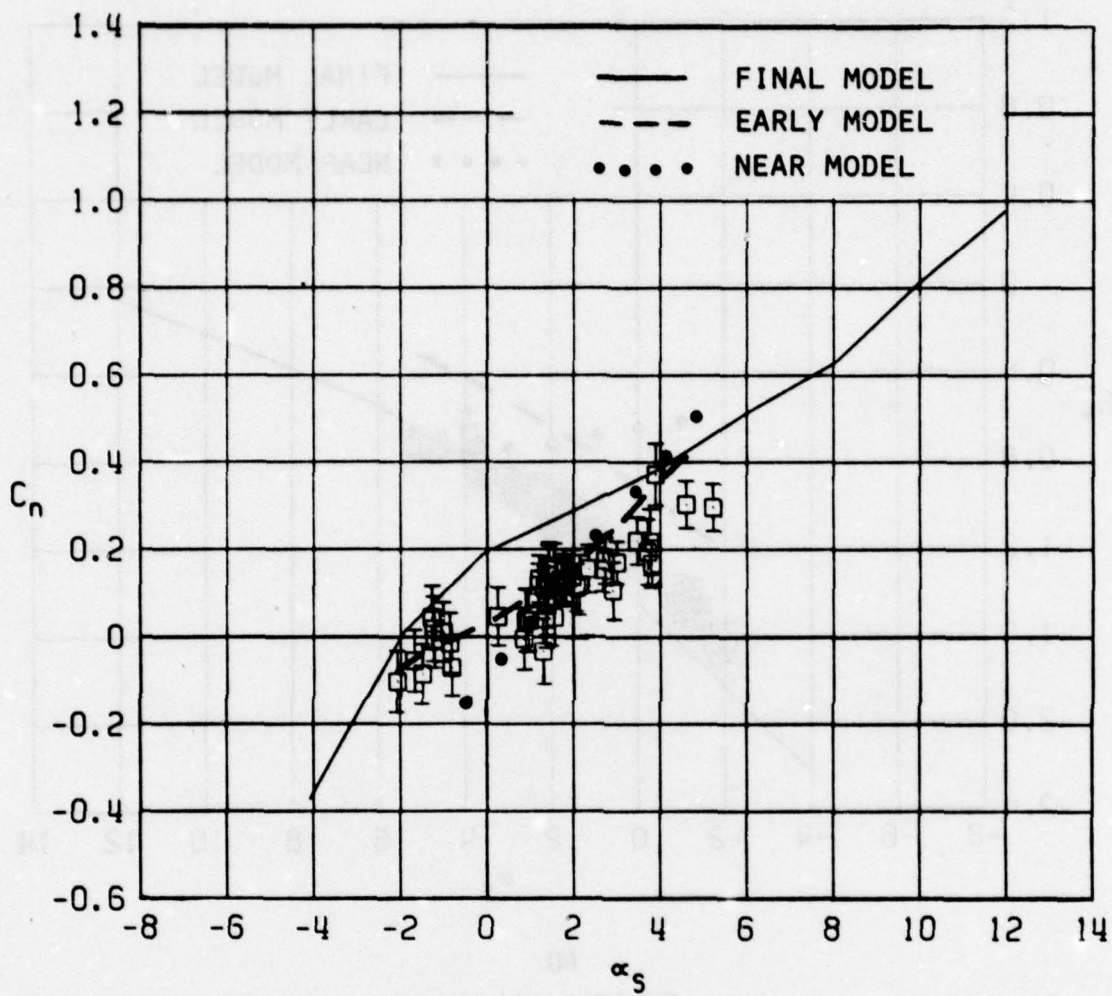
(c)

FIGURE 3. (Contd.)



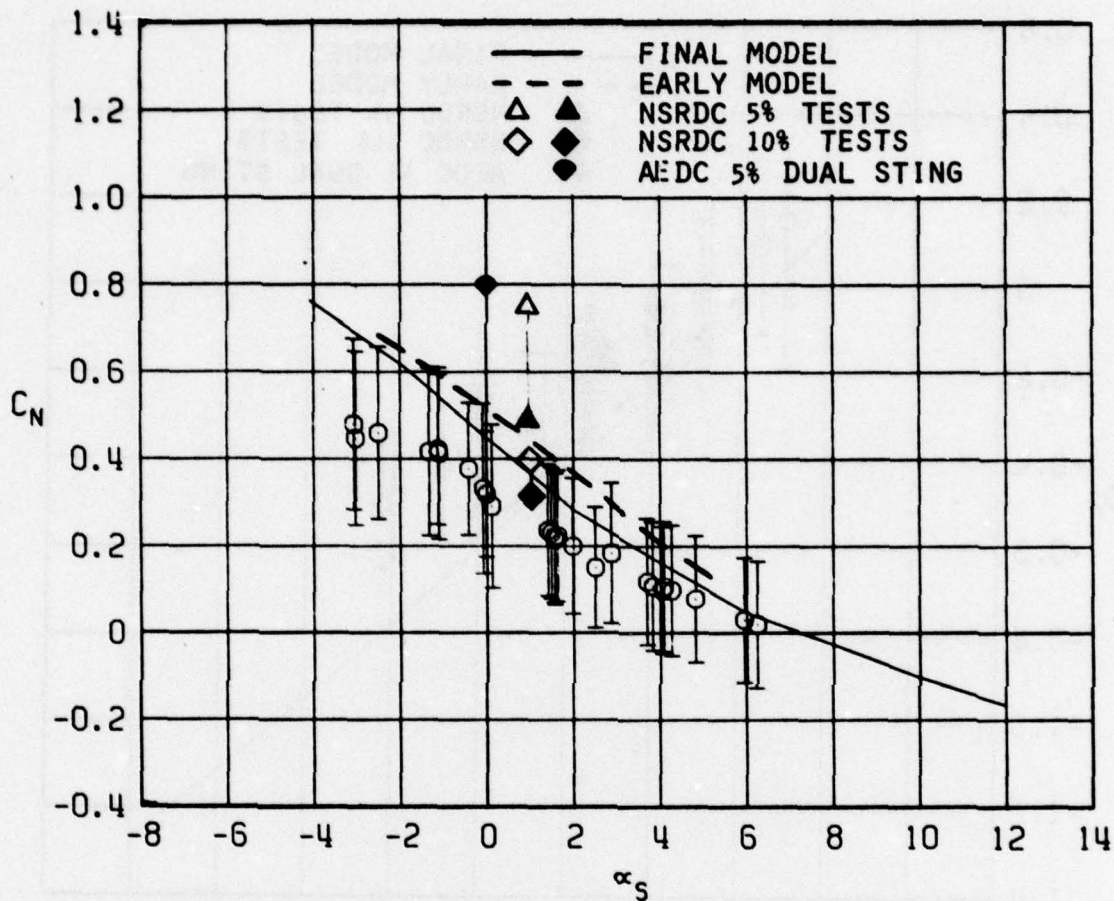
(d)

FIGURE 3. (Contd.)



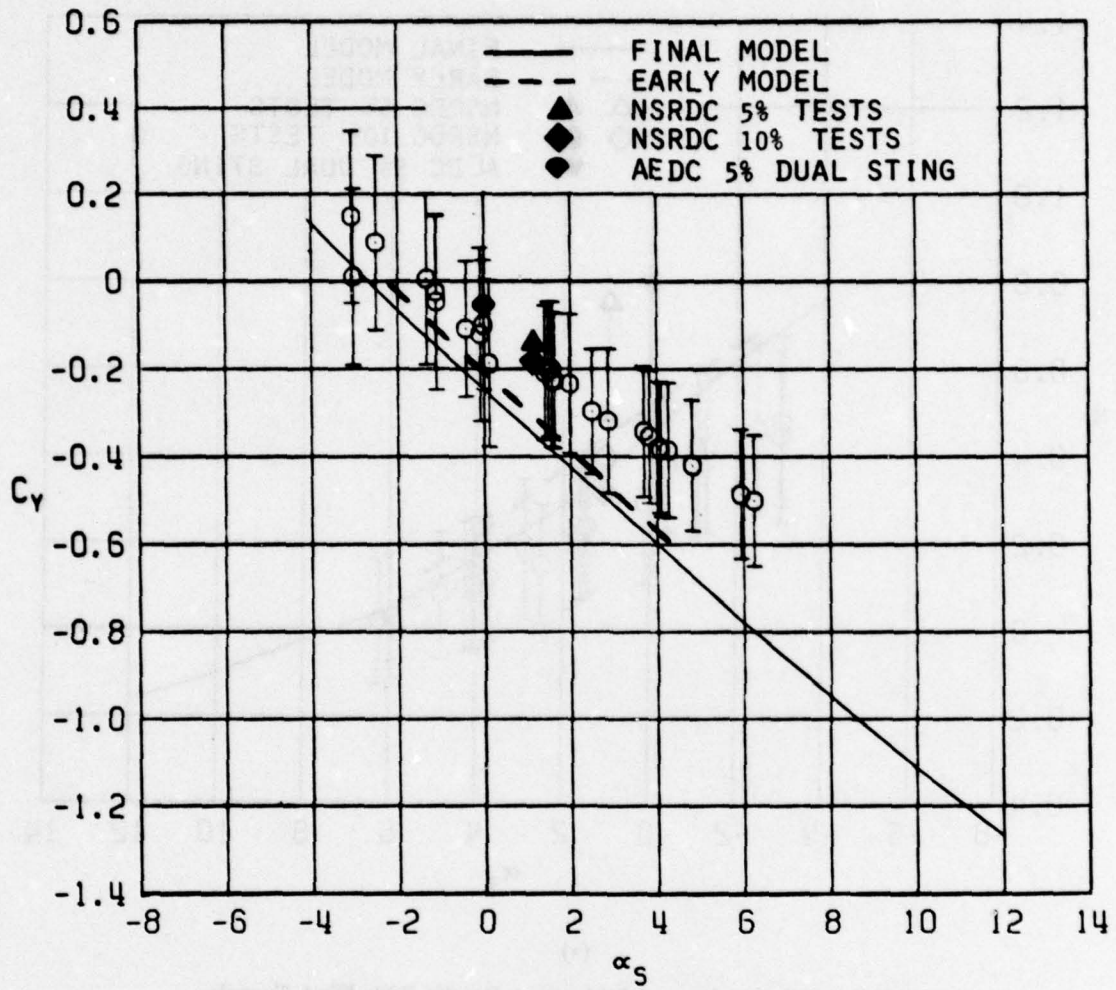
(e)

FIGURE 3. (Contd.)



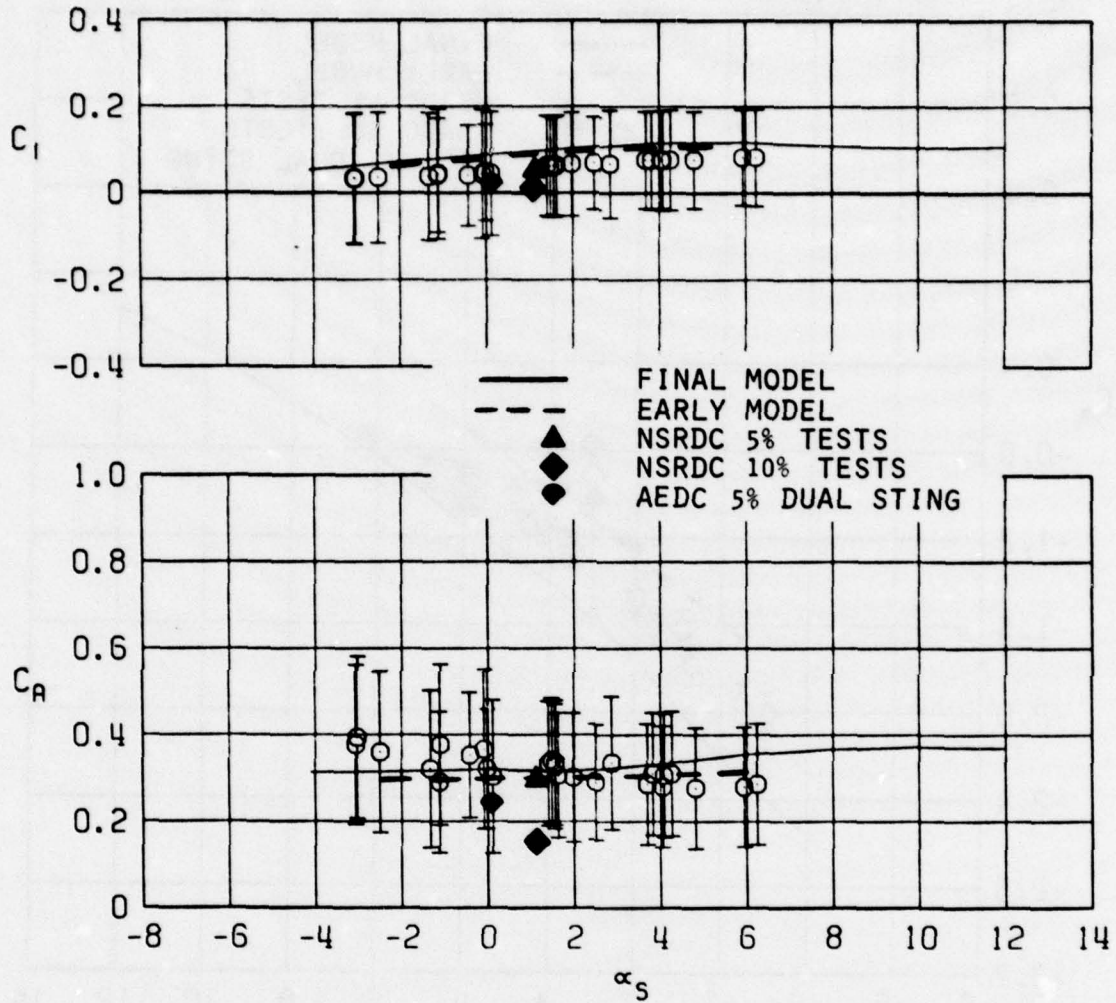
(a)

FIGURE 4. Comparison of Flight Test Results With Wind Tunnel;  
Mk 83/F-4, Afterbody 2, LIP, TER-1, M = 0.6.



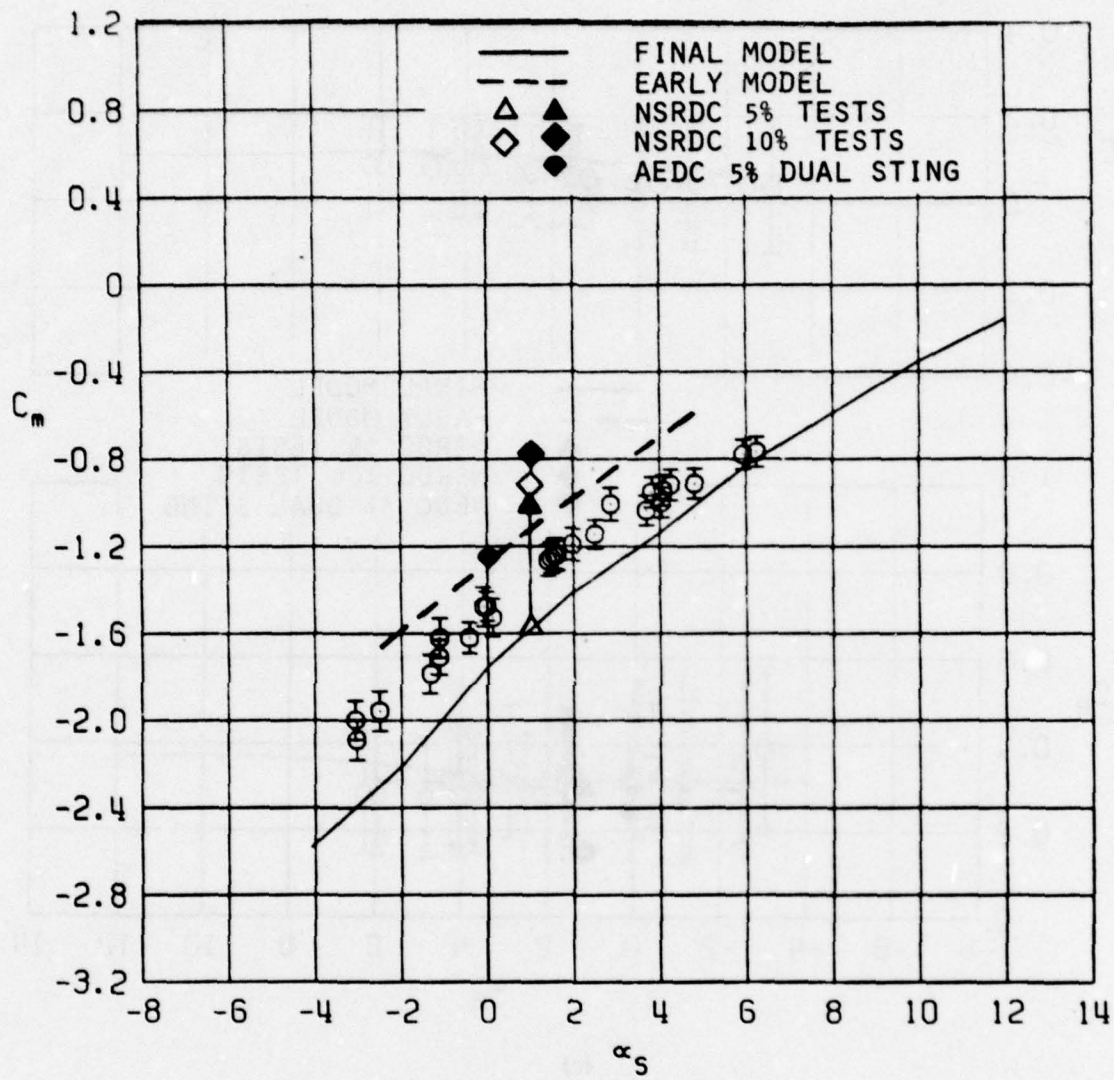
(b)

FIGURE 4. (Contd.)



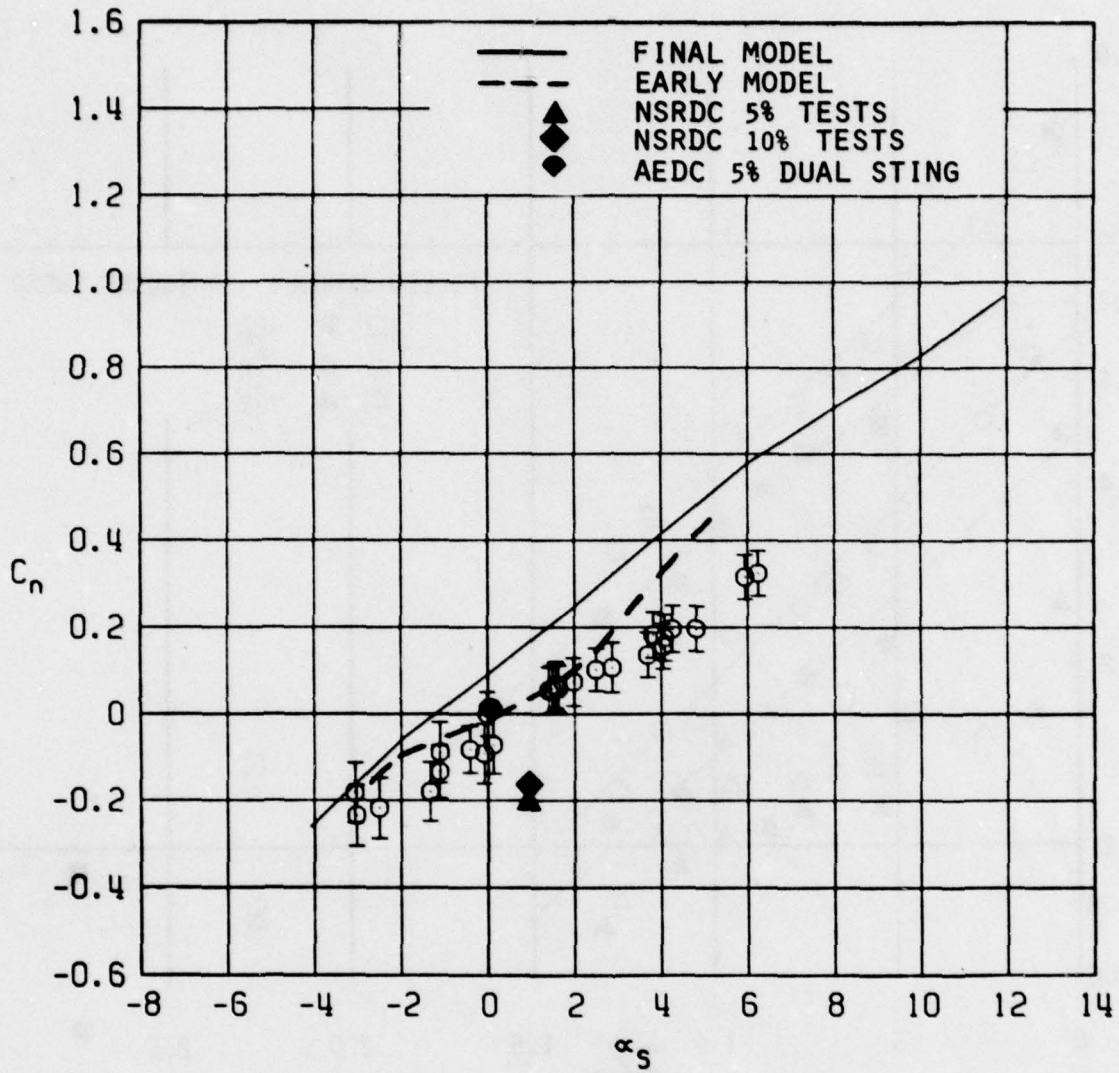
(c)

FIGURE 4. (Contd.)



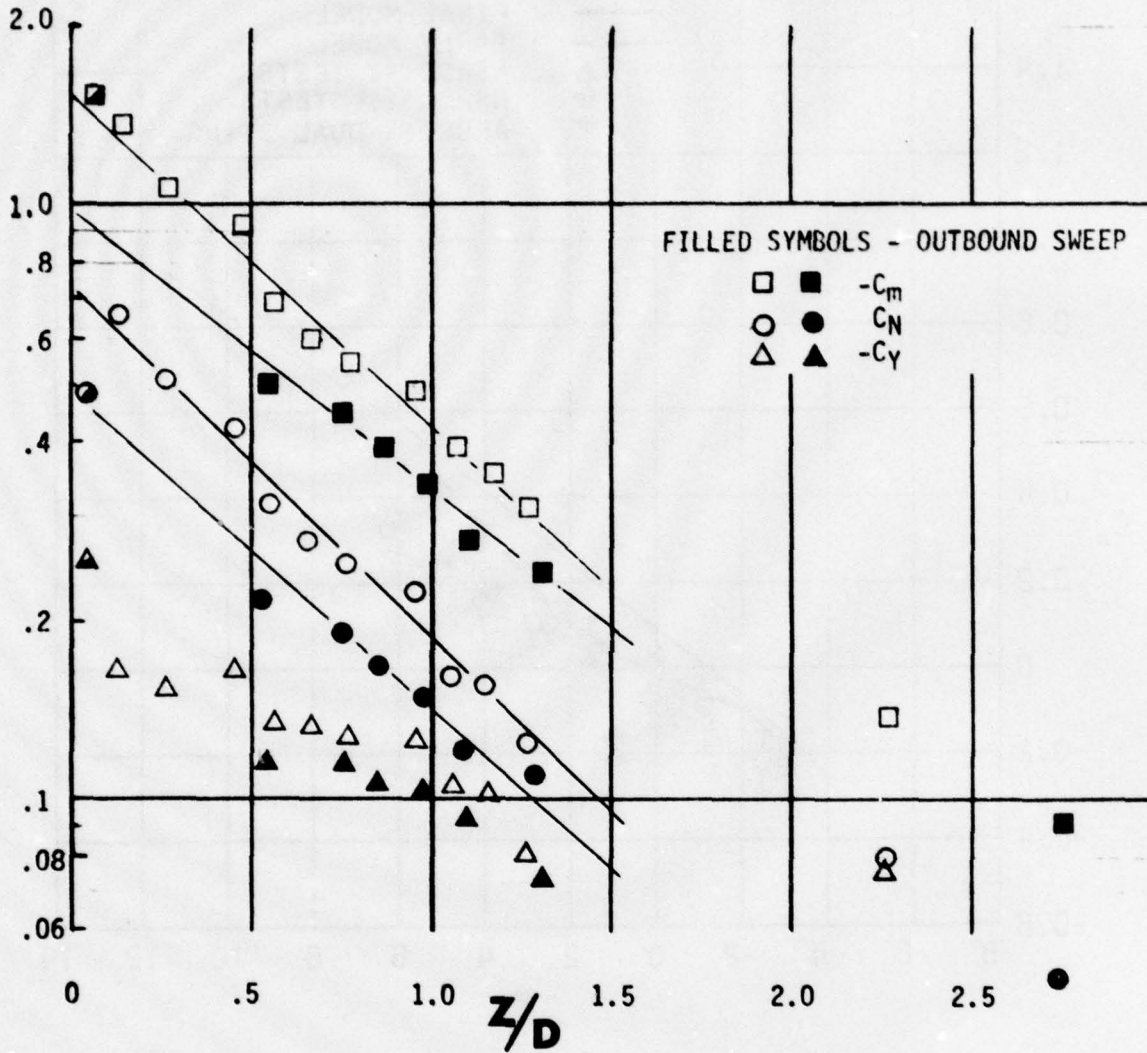
(d)

FIGURE 4. (Contd.)



(e)

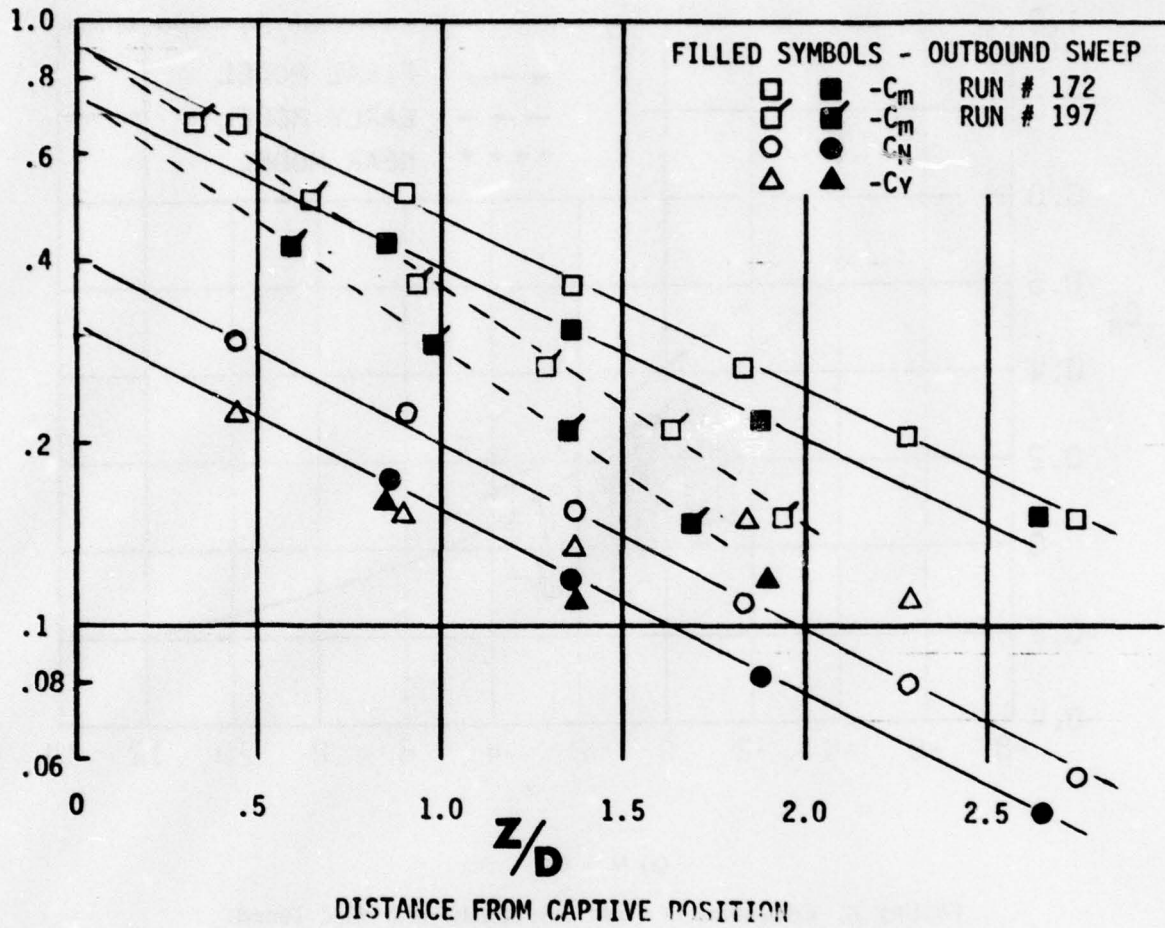
FIGURE 4. (Contd.)



DISTANCE FROM CAPTIVE POSITION

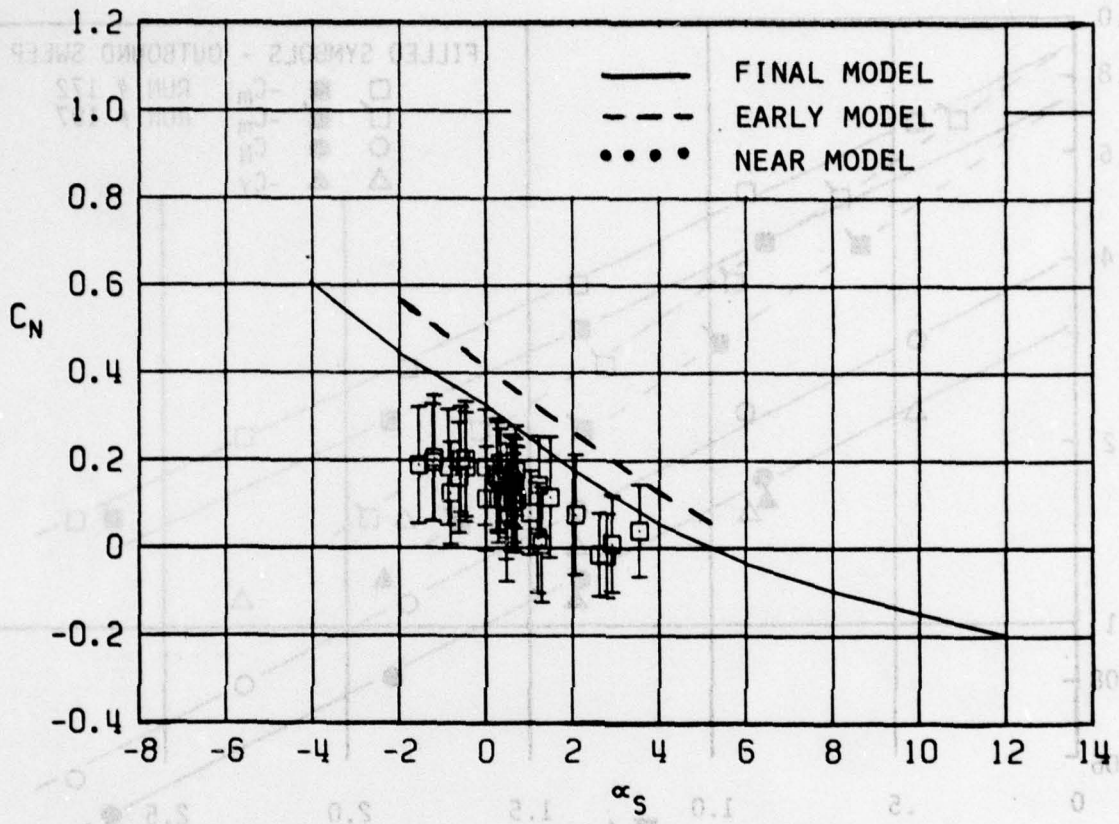
(a) DTNSRDC 5% scale, F-4/Mk 83, M = 0.6.

FIGURE 5. Dual-Sting Wind Tunnel Store Loads.



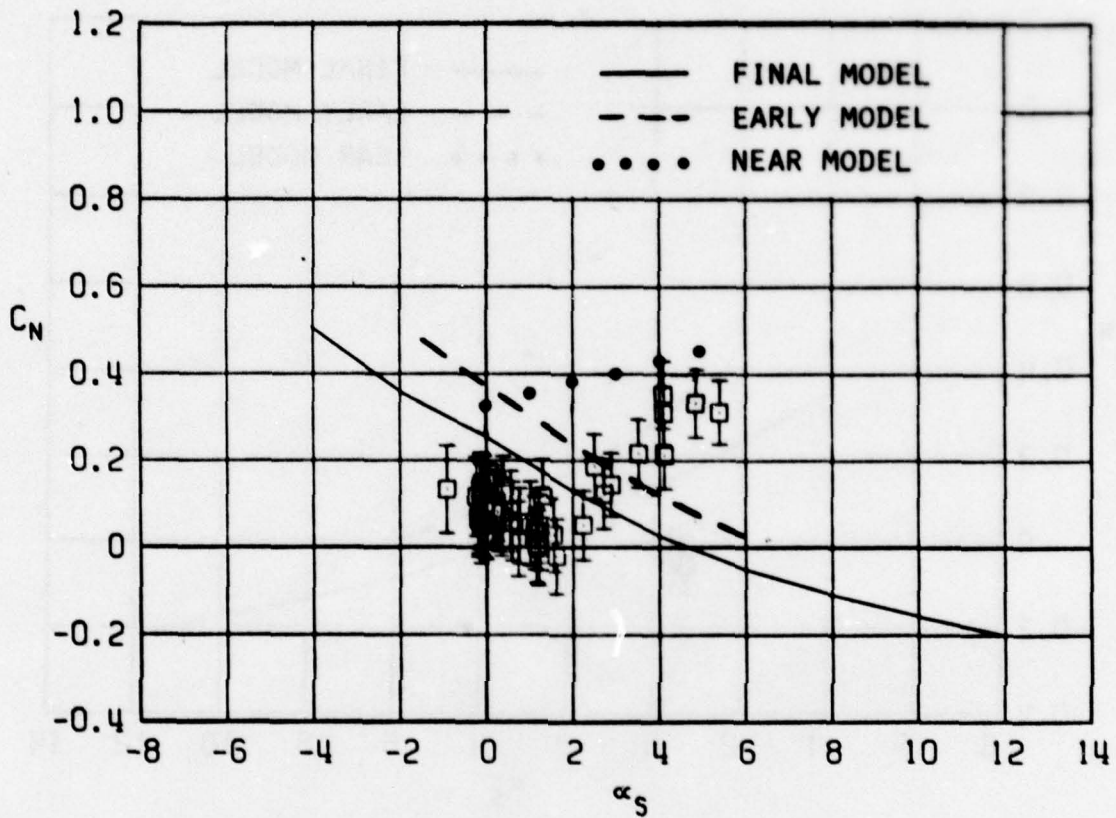
(b) DTNSRDC 10% Scale, F-4/Mk 83, M = 0.6.

FIGURE 5. (Contd.)



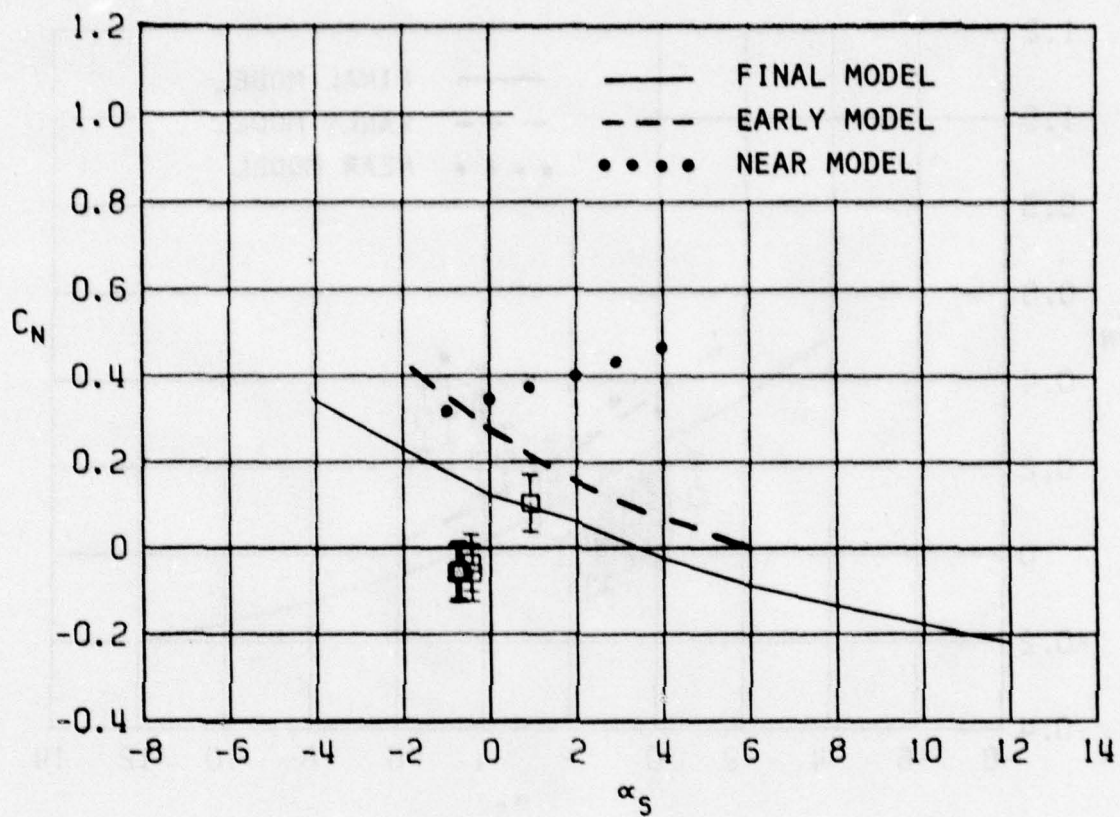
(a)  $M = 0.7$ .

FIGURE 6. Comparison of Flight Test Results With Wind Tunnel; Mk 83/F4, Afterbody 1, LIP, TER-1.



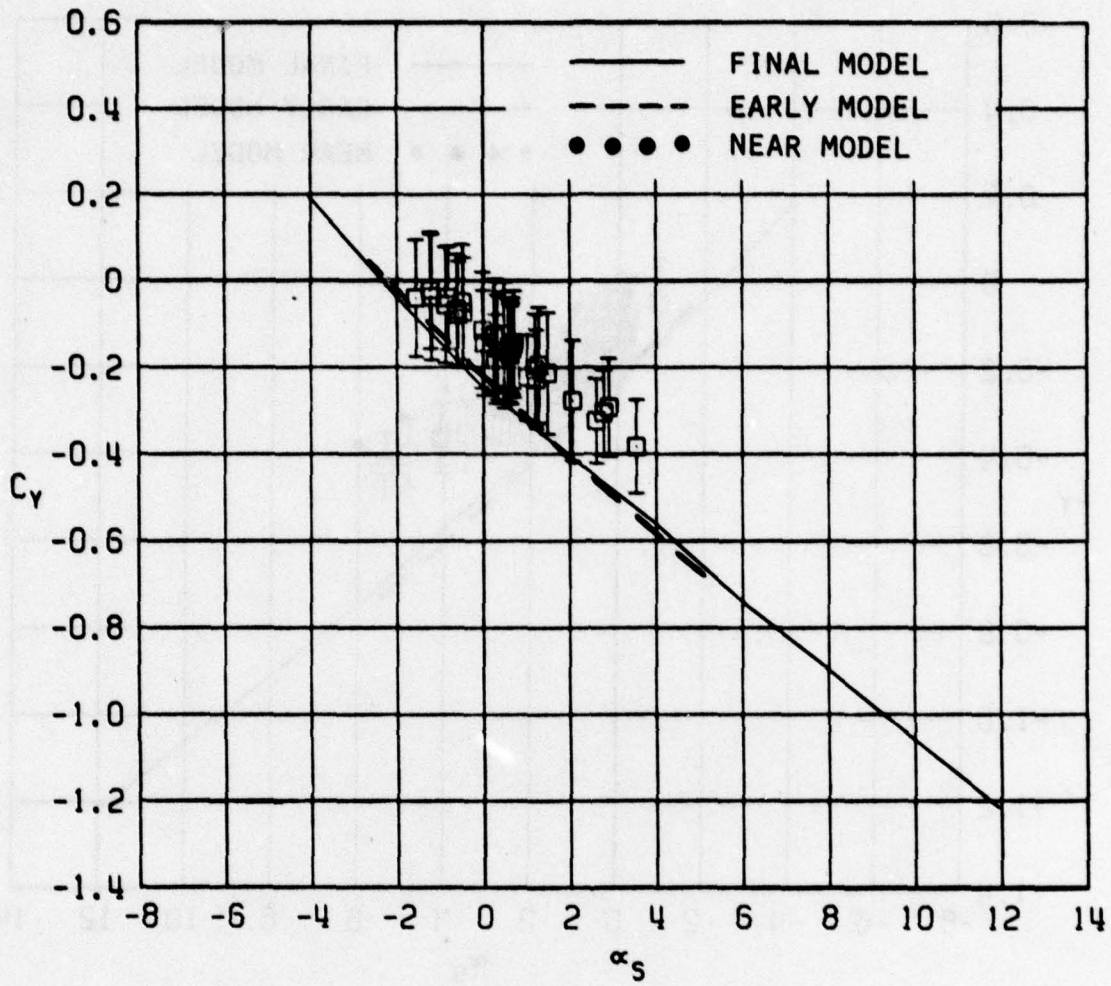
(b)  $M = 0.8$ .

FIGURE 6. (Contd.)



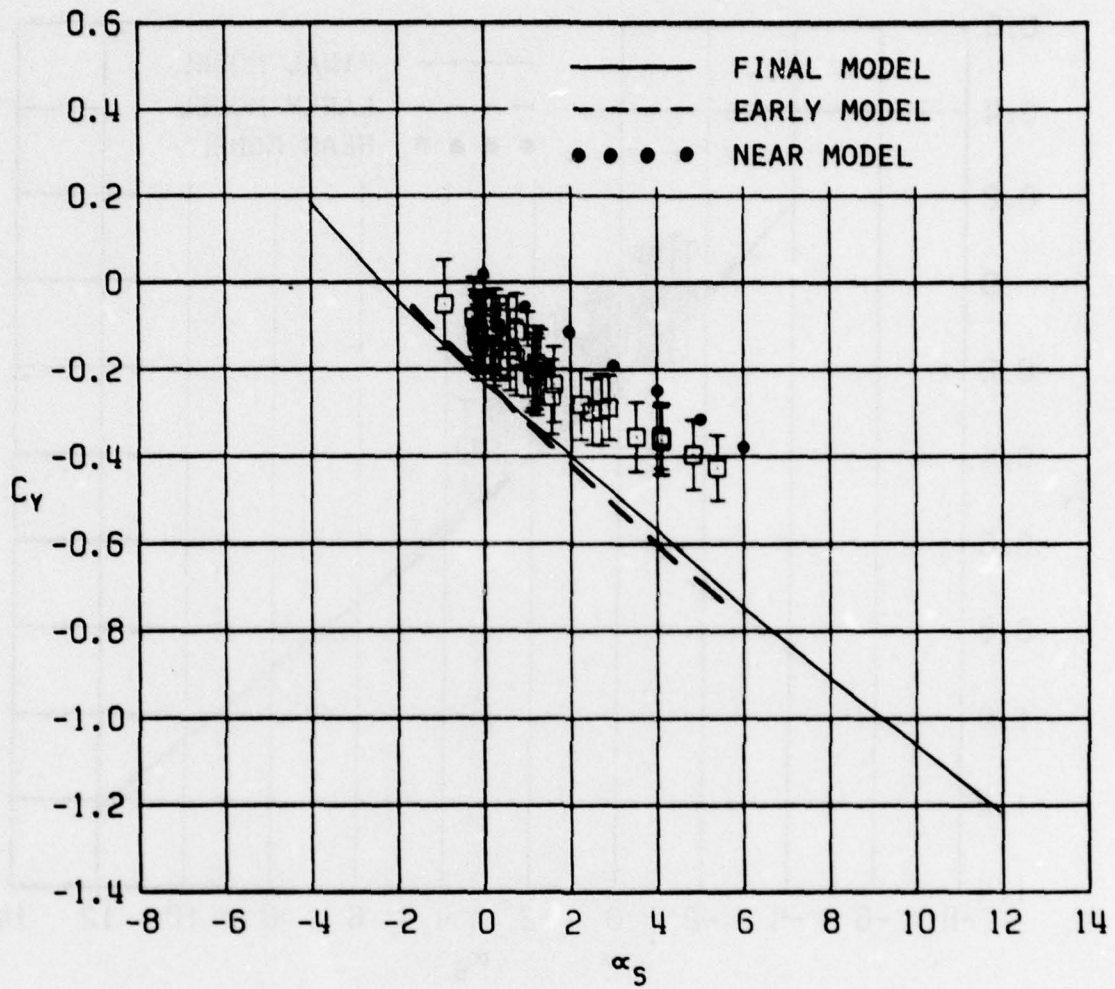
(c)  $M = 0.9$ .

FIGURE 6. (Contd.)



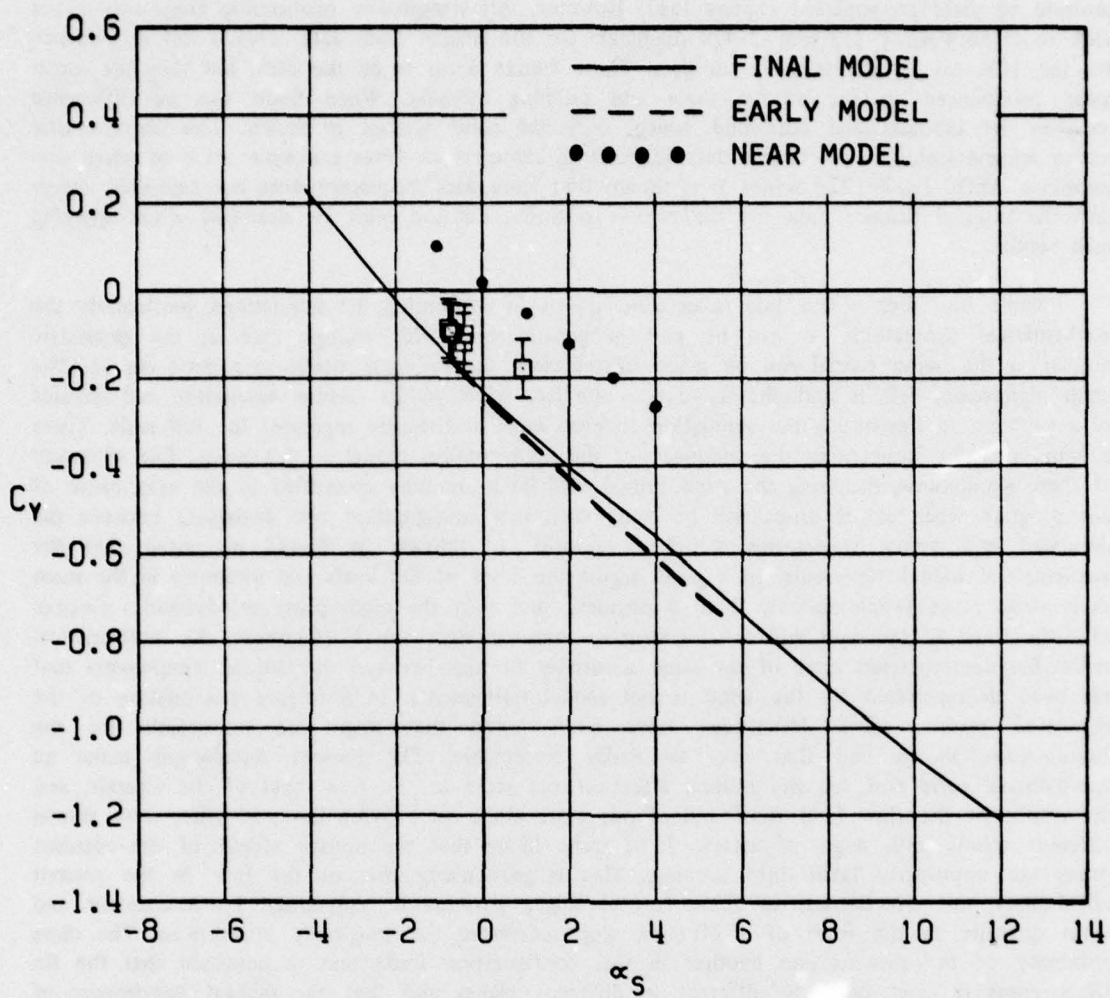
(a)  $M = 0.7$ .

FIGURE 7. Comparison of Flight Test Results With Wind Tunnel;  
Mk 83/F-4, Afterbody 1, LIP, TER-1.



(b)  $M = 0.8$ .

FIGURE 7. (Contd.)



(c)  $M = 0.9$ .

FIGURE 7. (Contd.)

position to yield an apparent captive load. However, this straight-line relationship frequently has a kink in it between 1 1/2 and 2 1/2 diameters for the smaller scale data. This is not in evidence for the 10% data which is more uniform. These trends occur in all the data, but they are much more pronounced in the normal force and pitching moment. When there was no difference between the inbound and outbound sweep, only the solid symbol is shown. This characteristic makes sting-mounted, wind tunnel data difficult to interpret at times and even more so when one examines AEDC-TR-76-122<sup>2</sup> where it is shown that sting data frequently does not smoothly merge into the internal balance data for the captive position. Caution must be exercised when applying such results.

While the Mach = 0.6 data raises some questions concerning the simulations, particularly the mathematical simulations, it can be said in general that with enough care in the geometric simulation the wind tunnel can be made to represent the full-scale article to a good degree. The small discrepancy left is undoubtedly due to the lack of Reynolds number simulation and remains as a problem in fine-tuning the simulation to even more realistically represent the full scale. There is some question concerning the adequacy of the mathematical model at this point. The adequacy of these simulations, including the wind tunnel, will be more fully quantified in the next phase of this program when actual drops will be made with this configuration and deviations between the simulated and actual trajectories will be examined. In fairness, it should be noted that the mathematical model represents, to a good degree, the level of the loads and moments in the most likely drop range (approximately 2 to 3 degrees), and only the pitch plane aerodynamics disagree with the trend of the data into the transient or maneuvering range. Furthermore, the mathematical model has demonstrated some of the same sensitivity to gaps between the various components that has been demonstrated by the wind tunnel model refinements. In a further examination of the calculated results, some deficiencies have been noted that might be responsible for the discrepancies shown and that may be easily correctable. The present calculations make an approximate correction for the mutual effect of the store in the flow field of the aircraft, and the results of the flow field itself and of one store alone on a pylon have, in other tests, shown different trends with angle of attack. It is quite likely that the mutual effects of the adjacent stores are improperly taken into account. This is particularly true of the fins. In the present calculations, the effectiveness of these fins as lifting surfaces is represented by a constant and input quantity in the form of a lift-curve slope corrected for wing-body interactions. The close proximity of the fins to one another in this configuration leads one to conclude that the fin effectiveness is most probably different in different planes and that the mutual interference of these lifting surfaces is most significant.

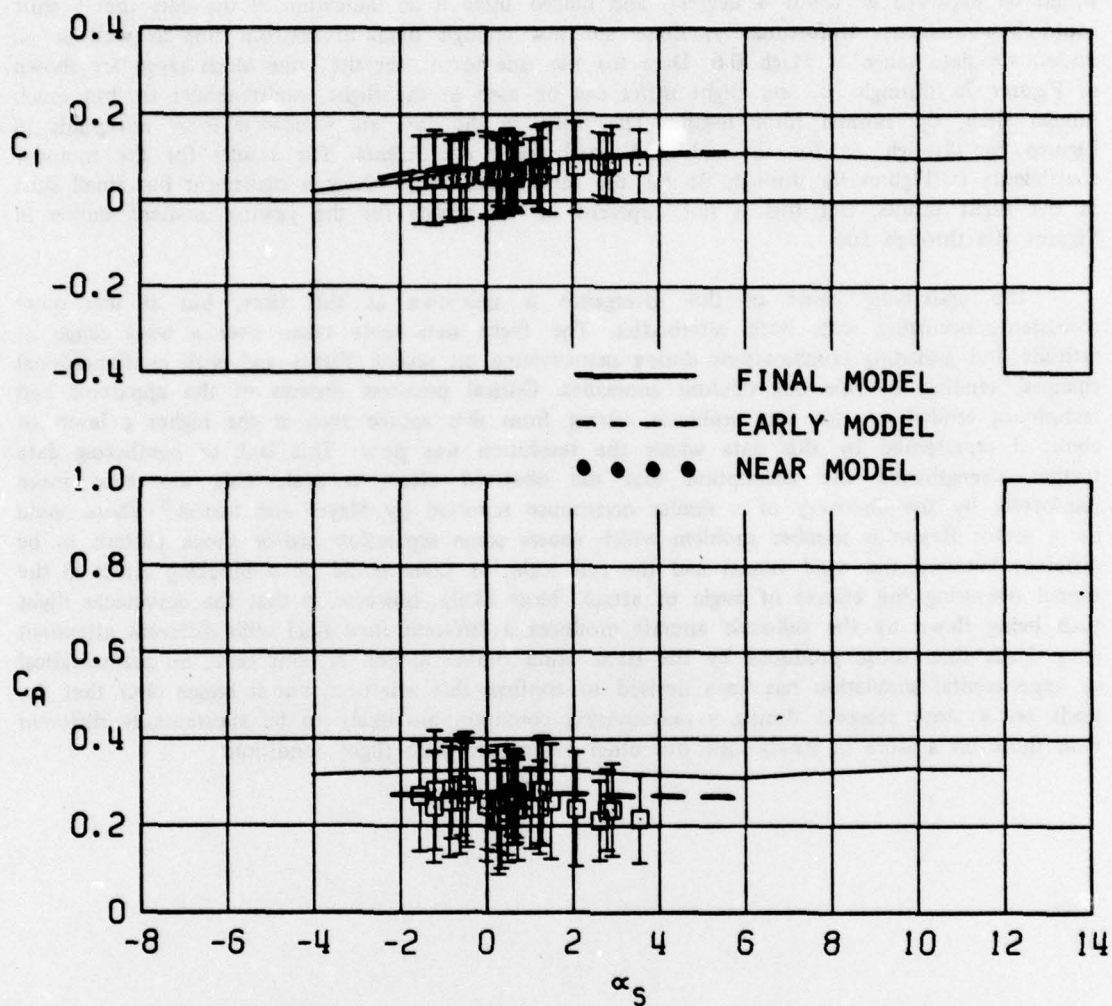
It is the development of the data with Mach number, however, that introduces the most uncertainty into the problem of simulation. Figures 6a through 6c show the development of the normal force with Mach number from 0.7 through 0.9. At Mach 0.7, there were limited simulations, and this condition is shown for completeness. It is at Mach 0.8 that a surprising divergence takes place. At approximately 2 degrees angle of attack of the store (3 degrees for the aircraft), the flight data appear to shift rather quickly to a different level and possibly resume the original trend with angle of attack, but there are inadequate data to definitely conclude the return to the original trend. In the particular region of the shift, the NEAR model seems to have the appropriate trend and more nearly represents the flight test than the wind tunnel. This may be fortuitous, however. At Mach 0.9, the same trend is still in evidence, but the data are quite limited. An interesting point to observe is that the shift occurs at about 0 degree at Mach 0.9 and about 2 degrees at Mach 0.8. If one extrapolates this trend to the Mach 0.7 data, a shift

would be expected at about 4 degrees, and indeed there is an indication in the data that a shift could be imminent. Unfortunately, there are not enough data to confirm this as well as an inadequate data range at Mach 0.6. Data for the side force over the same Mach range are shown in Figures 7a through 7c, and slight shifts can be seen in the flight results similar to, but much smaller than, the normal force results. The shifts in the data are somewhat more noticeable in Figures 8a through 8c for the roll and axial force coefficients. The results for the moment coefficients in Figures 9a through 9c for the same Mach range show a significant but small shift in the flight results, but this is not apparent in the results for the yawing moment shown in Figures 10a through 10c.

The underlying cause of this divergence is unknown at this time, but it was quite consistent, occurring with both afterbodies. The flight data were taken over a wide range of attitude and  $g$ -loading combinations during maneuvering on several flights and with configurational changes, tending to rule out random anomalies. Critical post-test reviews of the apparatus and techniques tended to rule out problems arising from this source even at the higher  $g$  levels of about 3 represented by this data where the resolution was poor. This lack of conflicting data further strengthened the assumption that the observed effect is real. This was even more reinforced by the discovery of a similar occurrence reported by Meyer and Sisson.<sup>8</sup> There could be a severe Reynolds number problem which causes some separation and/or shock pattern to be different between the wind tunnel and the full scale, or there could be a blocking effect in the tunnel obscuring the effects of angle of attack. More likely, however, is that the curvilinear flight path being flown by the full-scale aircraft produces a different flow field with different attendant store loads than those produced by the static wind tunnel model. At this time, no mathematical or experimental simulation has been devised to confirm this assertion, but it seems clear that the loads on a store released during a maneuvering condition are likely to be substantially different than those on a store in steady-state but otherwise at the same flight conditions.

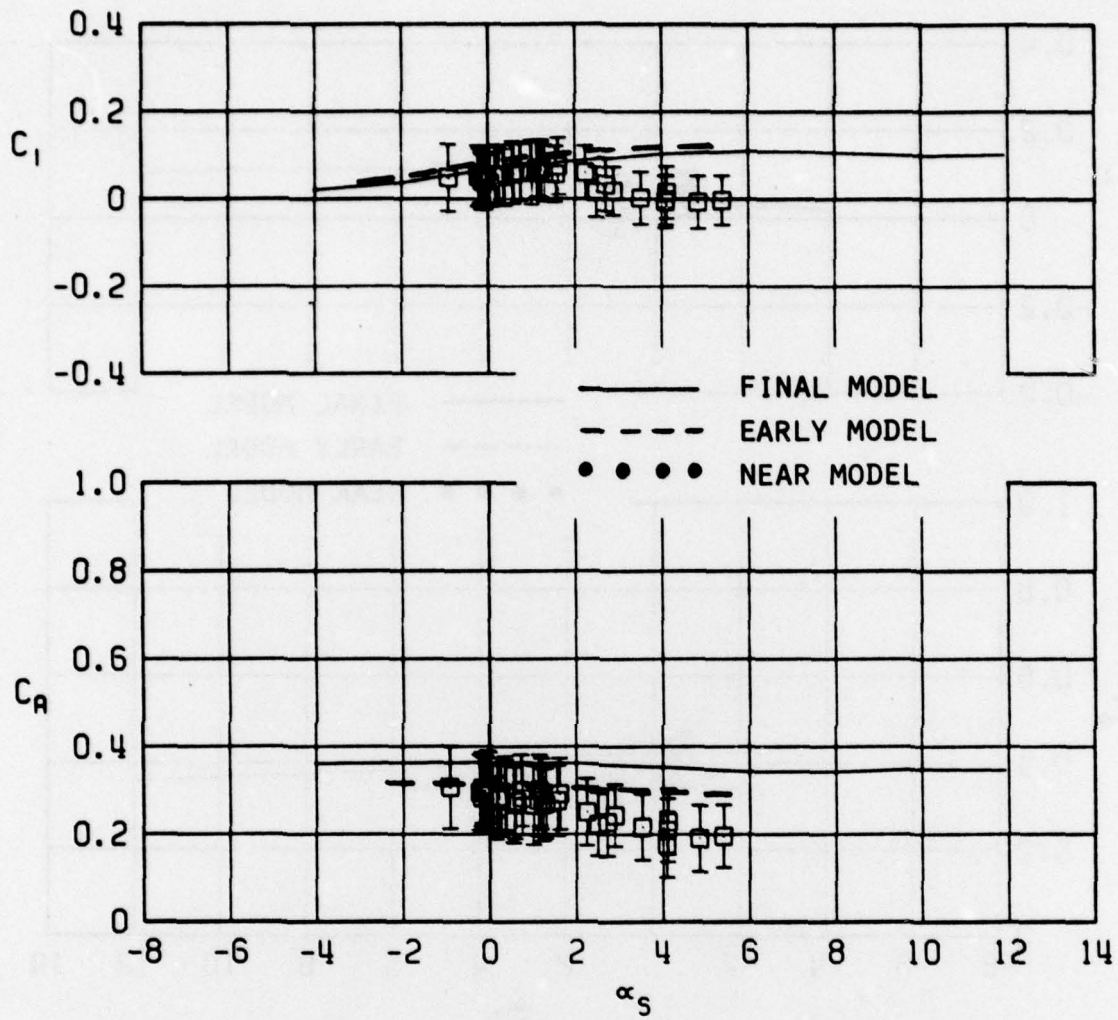
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<sup>8</sup> S. D. Meyer and C. E. Sisson. "An Experimental Investigation of Captive Flight Loads on a Bomb During External Carriage on the F-111 Aircraft," *Aircraft Stores Compatibility Symposium, 18-20 September 1973*. Sacramento, Calif. (Publication UNCLASSIFIED.)



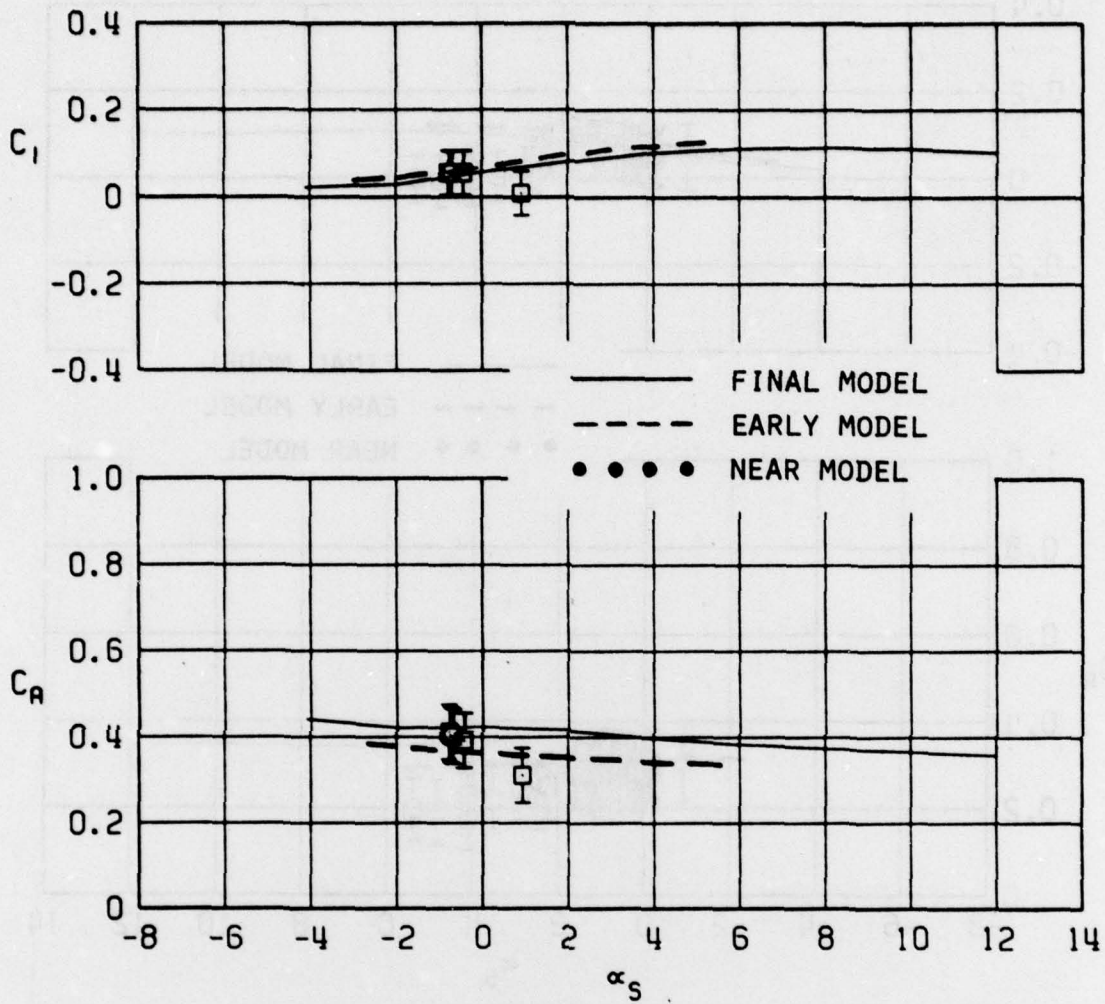
(a)  $M = 0.7$ .

FIGURE 8. Comparison of Flight Test Results With Wind Tunnel;  
Mk 83/F-4, Afterbody 1, LIP, TER-1.



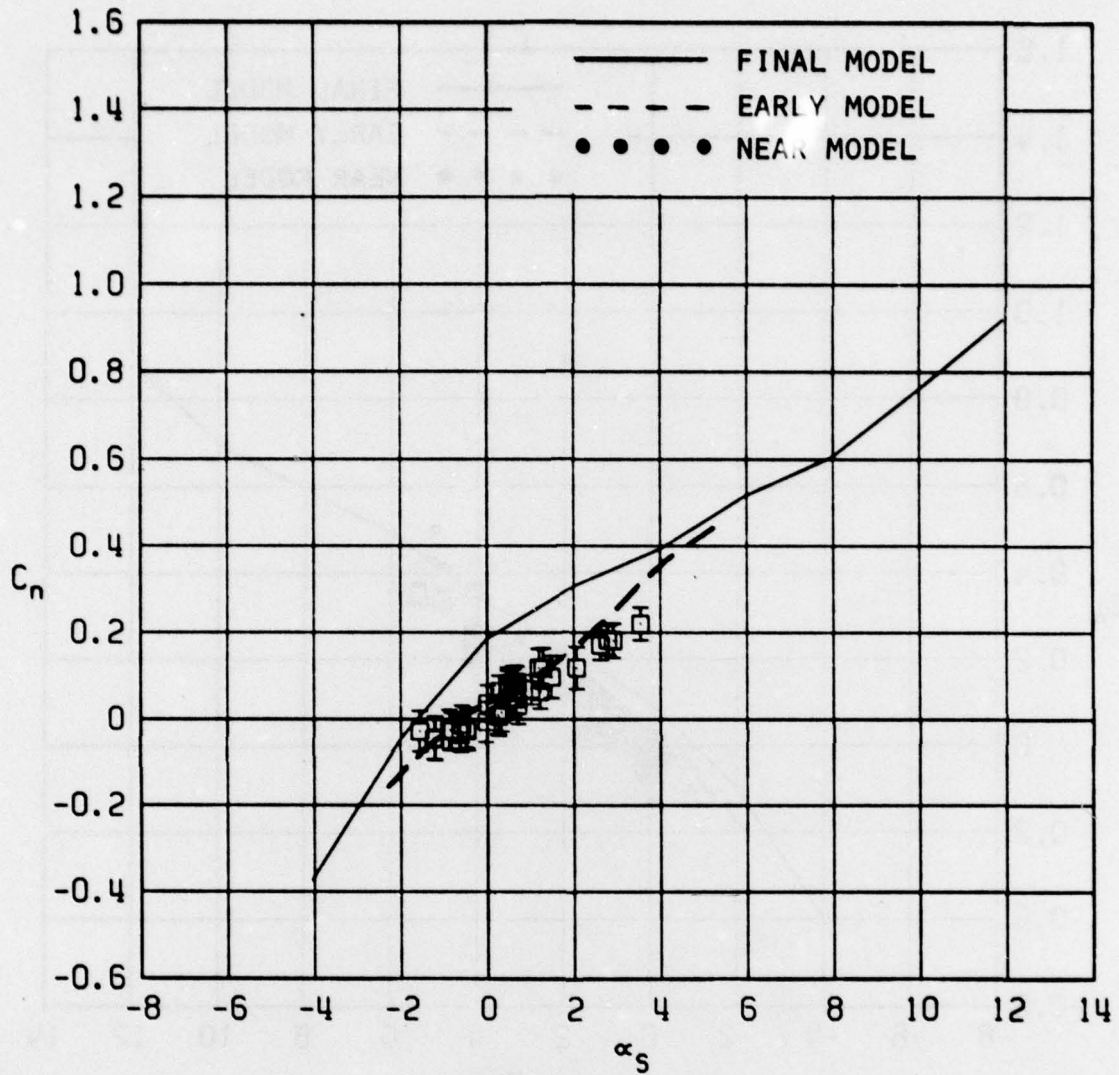
(b)  $M = 0.8$ .

FIGURE 8. (Contd.)



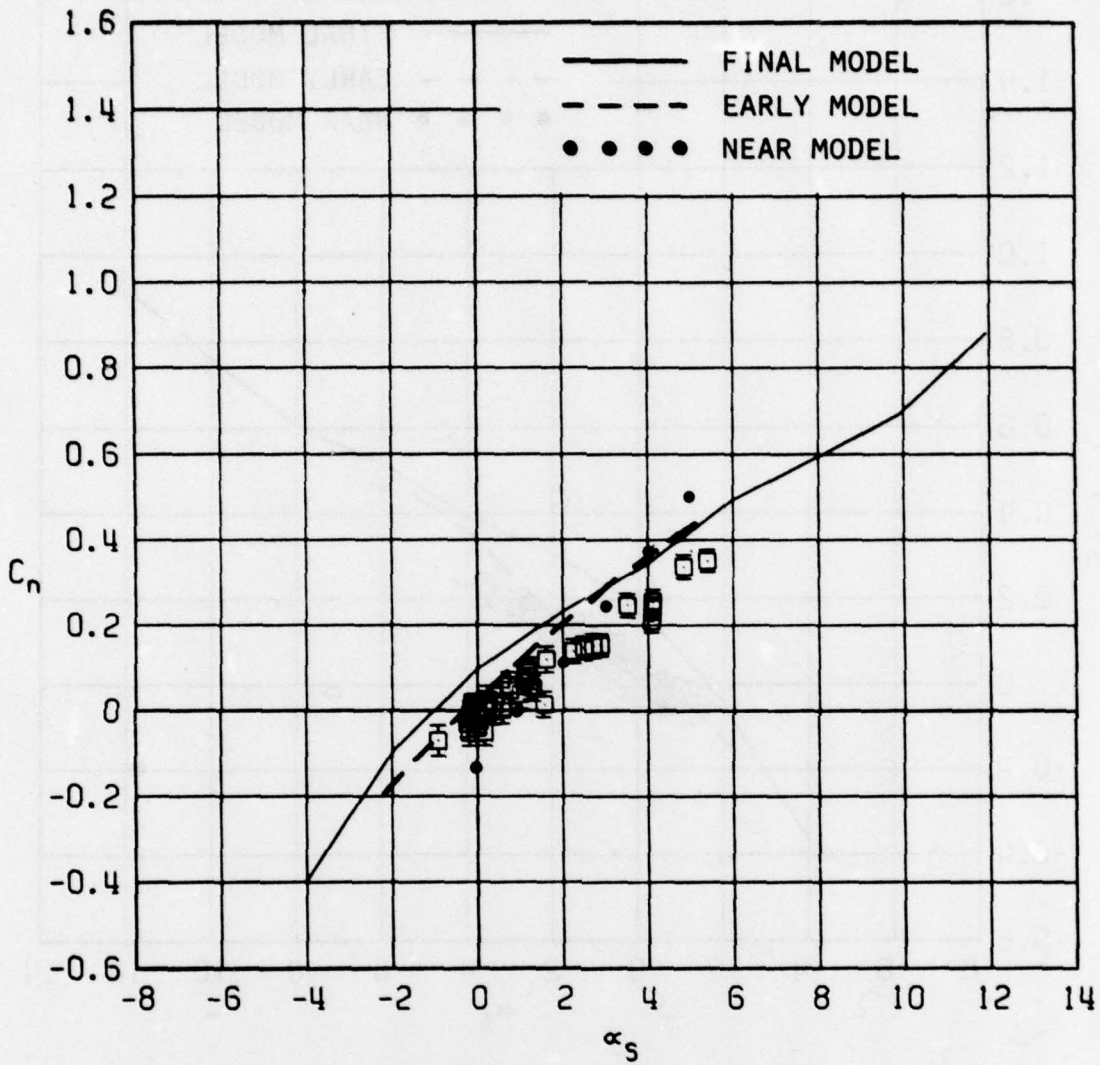
(c)  $M = 0.9$ .

FIGURE 8. (Contd.)



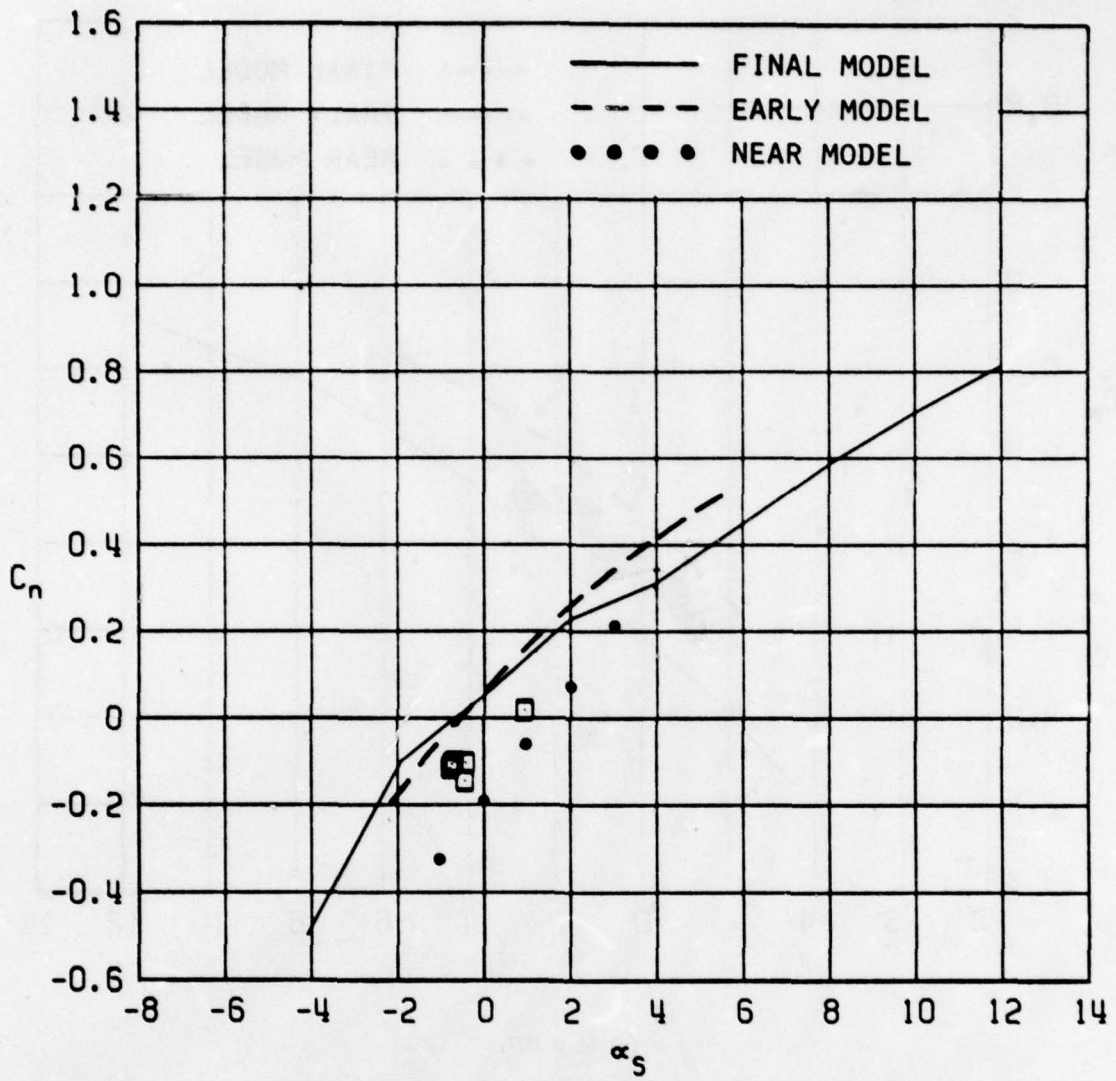
(a)  $M = 0.7$ .

FIGURE 9. Comparison of Flight Test Results With Wind Tunnel;  
Mk 83/F-4, Afterbody 1, LIP, TER-1.



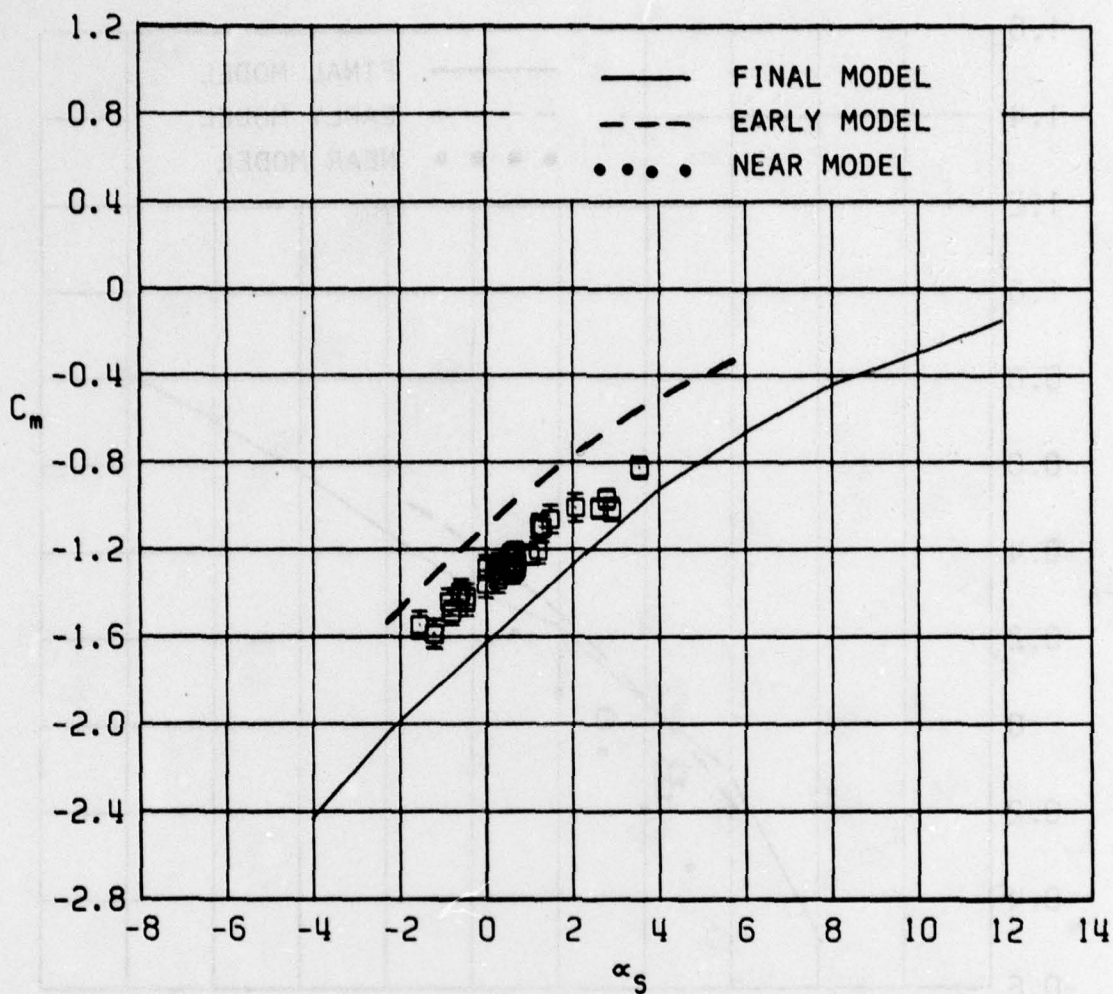
(b)  $M = 0.8$ .

FIGURE 9. (Contd.)



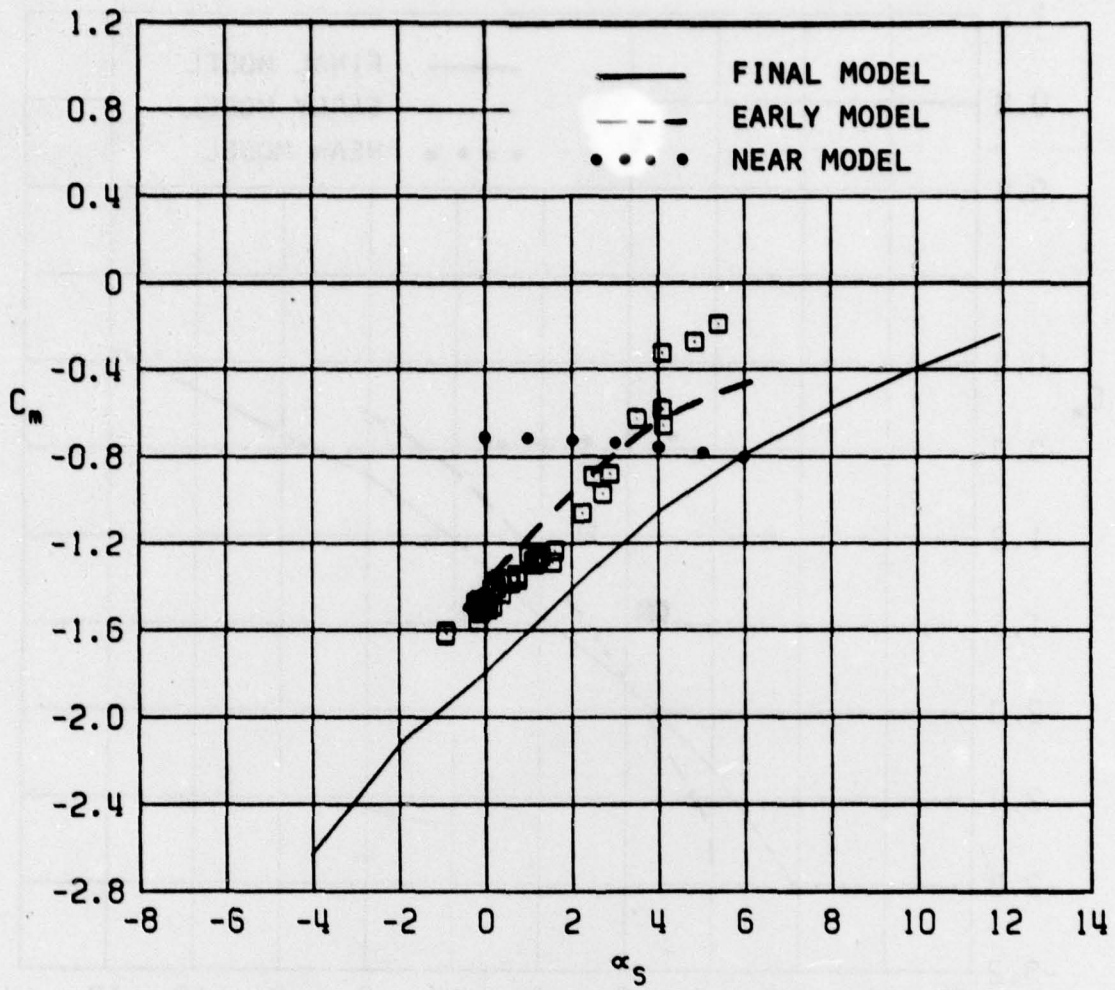
(c)  $M = 0.9$ .

FIGURE 9. (Contd.)



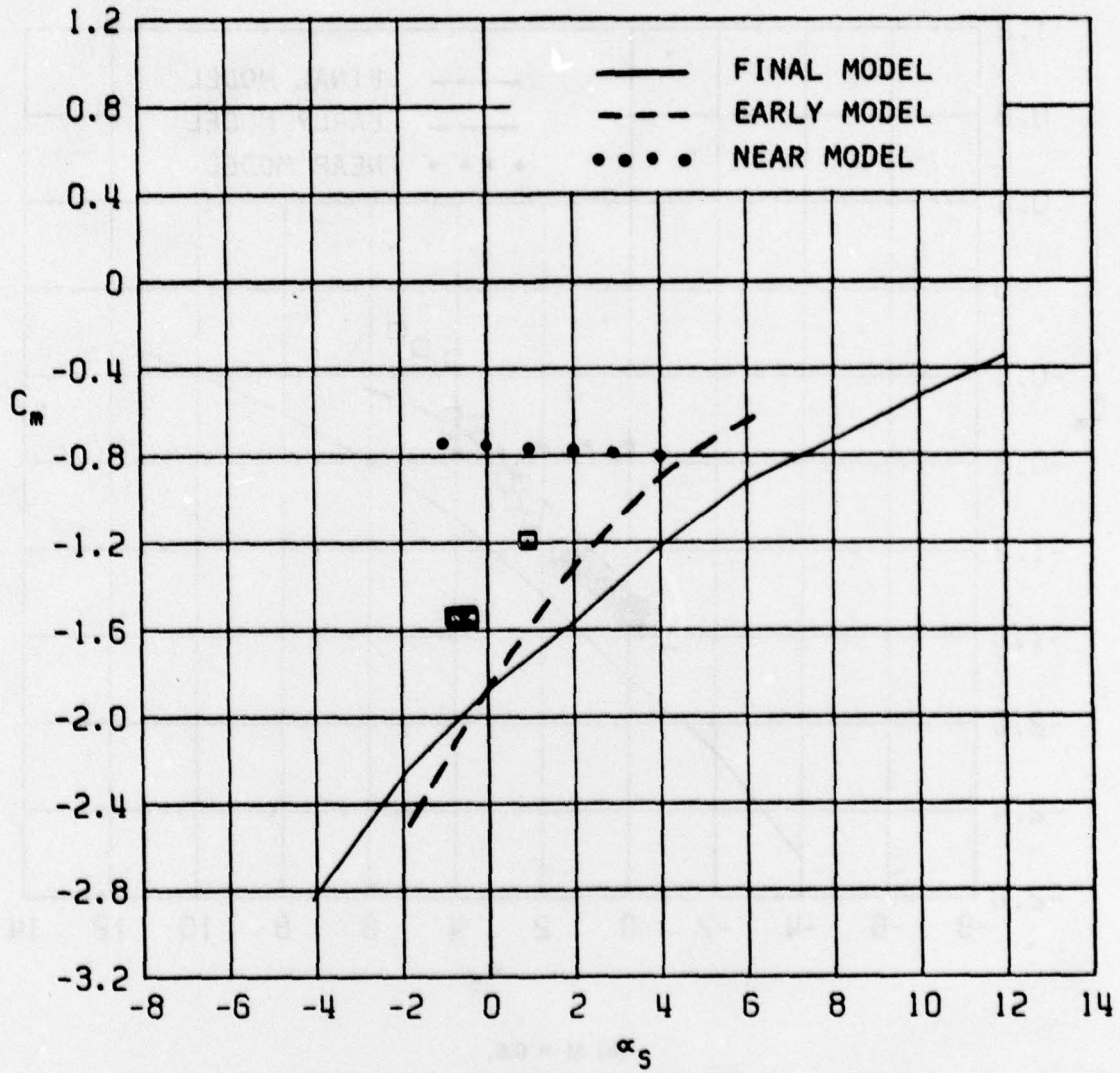
(a)  $M = 0.7$ .

FIGURE 10. Comparison of Flight Test Results With Wind Tunnel; Mk 83/F-4, Afterbody 1, LIP, TER-1.



(b)  $M = 0.8$ .

FIGURE 10. (Contd.)



(c)  $M = 0.9$ .

FIGURE 10. (Contd.)

## CONCLUSIONS

A flight test program utilizing a Mk 83 store shape on an airborne balance and mounted on an F-4J has been flown under well-instrumented and controlled conditions to produce a set of data for correlation purposes on captive loads. A comparison with a large block of wind tunnel data run in support of this program shows general agreement between the flight test and wind tunnel simulations at moderate subsonic Mach numbers, but there is a surprising sensitivity of the wind tunnel data to apparently minor geometric similitude as well as the manner of taking the data. This sensitivity overshadows the remaining uncertainty due to Reynolds number type of scale effect. The best mathematical simulations available generally agree in magnitude with the forces and moments, but occasionally differ in the trend of these coefficients with angle of attack.

As the Mach number is increased from 0.6, there is a surprising divergence between the flight test and wind tunnel results which occurs at progressively lower angles of attack as the Mach number is increased. This sudden change is not reflected in the mathematical models either. The cause of this divergency is very much open to question at this time, but it must be resolved before the simulations, wind tunnel or mathematical, can exert a significant effect on the mechanics of dealing with captive loading and store separation in general.

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