8. A SUMMARY OF NASA DATA RELATIVE TO EXTERNAL-STORE SEPARATION CHARACTERISTICS

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SUMMARY

The available NACA and NASA data relating to the carriage and separation characteristics of external stores are summarized, and some typical aerodynamic characteristics of stores in the carriage position are presented. Some of the subsonic interference origins and methods of combining experimental flow fields with theory to predict store forces and moments are illustrated by a comparison of calculated and measured store normal force and pitching moment. The effects of various combinations of speed, dive angle, airplane load factor, and store density on the separation characteristics are illustrated by using calculated store trajectories. This paper includes a bibliography of NACA and NASA reports relative to the release of stores from airplanes.

INTRODUCTION

Operational experience by the military services during the past year has focused attention on problems associated with the release of various types of external stores. While a considerable amount of research relative to the carriage and release of external stores was done by the NACA in the past, research on stores during the last 10 years has been concentrated primarily in the area of the release characteristics of internally carried stores and the effect of external stores on aircraft stability and performance, with some related work on the separation characteristics of lifting reentry research vehicles from a carrier airplane. However, in view of the current interest in the carriage and release characteristics of external stores, it was believed that a summary of the available NACA and NASA data would be useful to those engaged in developing and evaluating analytical methods of studying these problems.

The purpose of this paper is to describe the configurations which have been studied and the range of variables covered, to present some typical aerodynamic characteristics of stores in the carriage position, and to illustrate the effect of these characteristics on the separation characteristics of a store under various delivery conditions. A bibliography of NACA and NASA reports related to the release of stores from airplanes is also included.

SYMBOLS

A	wing aspect ratio
a_y	lateral acceleration, feet/second^2
a_z	vertical acceleration, feet/second^2
b	wing span, feet
c	local wing chord, feet
$\bar{c}$	wing mean aerodynamic chord, feet
C_m	store pitching-moment coefficient referred to $0.462l$, $\frac{\text{Store pitching moment}}{qS_s l}$
C_N	store normal-force coefficient, $\frac{\text{Store normal force}}{qS_s}$
C_n	store yawing-moment coefficient referred to $0.462l$, $\frac{\text{Store yawing moment}}{qS_s l}$
C_p	pressure coefficient
C_Y	store side-force coefficient, $\frac{\text{Store side force}}{qS_s}$
EAS	equivalent airspeed, knots
i_s	store incidence angle relative to wing reference line, degrees
l	store length, feet
M	Mach number
Δn	airplane incremental load factor, referred to steady equilibrium flight conditions
q	dynamic pressure, pounds/foot^2
S	airplane wing area, feet^2
S_s	store reference area, maximum frontal area of body, feet^2
t/c	wing thickness ratio
W	airplane weight, pounds

W_s	store weight, pounds
W/S	airplane wing loading, pounds/foot^2
α_w	angle of attack of airplane wing, degrees
γ	dive (flight-path) angle, degrees
λ	taper ratio
$\Lambda_{c/4}$	wing sweep of quarter-chord line, degrees

CONFIGURATIONS STUDIED

The major portion of the wind-tunnel studies for wing-pylon-store configurations which are applicable to the current problem area utilized one of the two test methods shown in figure 1. The top sketch illustrates the method in which the aerodynamic forces and moments of the store in the carriage position are measured by means of a strain-gage balance mounted within the store and attached to the wing pylon. Data obtained by this method can be used to determine the store carriage loads and the initial separation characteristics of the store. The lower sketch illustrates the method in which the store is supported by a sting through an internal strain-gage balance. In addition to providing carriage loads, the sting-support method allows the store to be tested at various positions and attitudes relative to the airplane and thereby provides store aerodynamic data which can be used to compute both the release and the trajectory characteristics of the store.

Comparisons between computed trajectories using aerodynamic data obtained by this technique and trajectory measurements made in flight and with free-fall techniques are given in references 1 and 2, respectively, and indicate a satisfactory agreement.

The use of free-fall and forced-ejection methods by NASA has been directed primarily toward ejection from bomb bays rather than the release of external stores, and will not be discussed here. However, a bibliography of this work is included. It should also be pointed out that problems associated with scaling (refs. 3 to 6) and simulation of release conditions, such as dive angle, tend to limit the usefulness of the free-fall and forced-ejection methods. The configurations studied by the techniques shown in figure 1 are described in figures 2 and 3. The configurations studied by the pylon-support method are shown in figure 2, and the configurations studied by the sting-support method are shown in figure 3. A bottom view of the airplane is shown and the various stores tested are shown in the carriage position. The alternate location of the store is shown by the dotted outline. The table under the sketches lists some of the pertinent geometric characteristics of the wings, the Mach number ranges of the test, the facility used, the reference containing the data of the more important variables studied, and the type of data obtained.

Wing planforms cover the sweep range from 0° to 47° and include a 60° delta wing. Aspect ratios from 4 to 7.7 were covered. The Mach numbers ranged from approximately 0 to 2.01. Both finned and unfinned stores have been investigated. In general, the configurations studied are representative of rather large stores primarily because the balances required for the smaller stores were not available. Five-component force data are available for configurations 1 to 5; pressure distributions on the stores were measured for configurations 6 to 8; for configuration 8, complete wing pressure distributions were measured without the store and with the store in two vertical locations. Five-component force data have also been obtained on configurations 9 to 12, and for the supersonic studies on configurations 11 and 12 store force data have been obtained for a large number of positions within the shaded area for several vertical store locations. For the subsonic studies (configurations 13 and 14), the local angularities in both the longitudinal and lateral planes and the local flow velocities were measured at various vertical locations beneath the wing and fuselage for the range of spanwise and chordwise locations indicated by the dashed line for the unswept wing and the shaded area for the swept wing. These configurations are similar to two of those used to measure store force data and therefore are useful not only in evaluating flow-field theories but also in evaluating methods of predicting store forces.

TYPICAL AERODYNAMIC CHARACTERISTICS

Inasmuch as the current operational problems are primarily associated with subsonic deliveries, the remainder of this paper will deal with the subsonic case.

Configuration 5 was chosen to illustrate some typical aerodynamic characteristics of a store in the carriage position and to show the effects of delivery conditions on release characteristics and is presented in figure 4. The pertinent geometric characteristics of the wing and the location of the store beneath the wing are indicated. This configuration was selected because of its similarity to configuration 14, for which complete flow-field surveys were available.

Before presenting the various aerodynamic characteristics of the store, a somewhat detailed look at the store normal-force and pitching-moment characteristics will be made to illustrate the order of magnitude of the various flow-field induced effects and to indicate the effectiveness of simplified theory for predicting the store forces and moments. The calculations are based on the application of the measured flow field (ref. 7) to body-fin theory and ignore the mutual interference effects between the wing and store. Figure 5 shows a comparison of the calculated and measured store normal-force coefficient with wing angle of attack for the body, the fins, and the body-fin combination. For the body alone it will be noted that the calculated buoyancy effect (shown by the short-dash line) associated with the wing-body-induced static-pressure gradient is rather large and produces a negative normal-force-curve slope and a large positive normal force at $\alpha_W = 0^{\circ}$. The positive force at $\alpha_W = 0^{\circ}$ is, of course, associated with the wing-thickness-induced buoyancy and will increase with increasing wing thickness ratio. The wing for this case was 6 percent thick. The effect of the flow angularity on the body (indicated as the local α effect) includes both the induced-angle-of-attack and induced-camber effects determined by the method of reference 8 with the crossflow-separation effects accounted for by the method of reference 9. The sum of the buoyancy and local α effects shown by the solid line indicates a positive value of normal force at $\alpha_w = 0^\circ$ and is in fairly good agreement with the experimental data. The estimate of the fin increment accounting for the local angle-of-attack distribution, shown by the solid line in the lower left of figure 5, indicates a slope of about one-half of that predicted for the isolated fins and reasonably good agreement with experiment. The reduction in slope is, of course, associated with the wing-lift-induced downwash characteristics while the positive normal force at $\alpha_w = 0^\circ$ is due to the thickness-induced upwash. The results for the body-fin combination, shown at the lower right of figure 5, also indicate fairly good agreement with the experiment.

The calculated and measured pitching-moment coefficients for the body, the fins, and the body-fin combination are shown in figure 6 as functions of wing angle of attack. The methods used were the same as those previously described in connection with the normal force. For the body alone, the buoyancy effect gives a stabilizing moment whereas the local angle-of-attack effect calculated by the methods of reference 4 gives an unstable slope. The sum of the buoyancy and local-angle-of-attack effect is shown by the solid line and indicates the same slope as the experiment over most of the angle-of-attack range; however, the magnitude of body pitching moment predicted is considerably higher. The estimate for the fin accounting for the local-angle-of-attack effect and shown on the lower left of figure 6 shows reasonable agreement at the lower values of α_w; however, at the higher value of α_w this agreement deteriorates. The discrepancies between the calculated and experimental values of pitching-moment coefficient for both the body and the fin are additive so that the estimate for the body-fin combination gives, in general, poor agreement with the experiment. This figure serves to point out the need for more sophisticated theories to predict the store pitching-moment characteristics in the interference flow field.

Experimentally obtained aerodynamic characteristics for the example configuration (configuration 5) at a Mach number of 0.50 are shown in figure 7. The normal-force and pitching-moment curves are the same curves that were discussed on the two preceding figures and are presented here for completeness.

In the lateral plane, a positive value of side-force coefficient (C_Y), indicating a force toward the fuselage, is obtained at $\alpha_w = 0^\circ$. As α_w is increased, a change in sign of C_Y occurs. The significant point to be noted about the yawing moment is that the lateral center of pressure lies ahead of the store center of gravity for the complete wing angle-of-attack range shown, and, as a result, the nose of the store will be yawed in the direction of the side force. Figure 8 further illustrates the change in sign of side force with angle of attack and shows the experimental store pressure distributions measured on configuration 8 at $\alpha_w = 0^\circ$ and $\alpha_w = 8^\circ$. The pressure distribution on the isolated store is also shown for reference. Note that at $\alpha_w = 0^\circ$ high negative pressures are acting on the inboard side of the store whereas at $\alpha_w = 8^\circ$ high positive pressures are obtained on the inboard side of the store.

SEPARATION CHARACTERISTICS

Since all the curves shown in figure 7 are displaced at $\alpha_w = 0^\circ$ and in the lateral case change sign with wing angle of attack, airspeed would be expected to have a large influence on the forces developed on the store at release. To illustrate the order of magnitude of this effect on the initial store trajectory, the linear accelerations acting on the store at release are shown in figure 9 for the example configuration.

On the left of figure 9, the effect of equivalent airspeed on the vertical acceleration at the store fin for a store at $i_s = 0^\circ$ relative to the wing chord line, is shown for store weights of 180 and 960 pounds. The vertical acceleration at the store nose at $i_s = -5^\circ$ is also shown as a function of airspeed for store weights of 180 and 960 pounds. As indicated by the arrows, positive acceleration is toward the airplane wing. The points on the store for which the acceleration is shown are the most critical points from contact consideration when both the store normal force and pitching moment are accounted for. The weights were taken to represent near minimum and maximum weights for this class of store. The wing angle-of-attack variation used in the calculation corresponds to the angle of attack required for steady level flight of the carrier airplane at a wing loading of 100 lb/ft^2 over the speed range and therefore decreases with increasing speed. For a wing loading of 100 lb/ft^2 this configuration gives an airplane weight of 18 650 pounds. For the lightweight store at $i_s = 0^\circ$ the fin accelerates toward the wing and this acceleration increases rapidly with airspeed, and results, of course, from the buoyancy effect at $\alpha_w = 0^\circ$. When the store is mounted with -5° incidence relative to the wing, the normal force at $\alpha_w = 0^\circ$ is negative and this trend is reversed; that is, as speed is increased and store weight reduced, the store is accelerated away from the wing at a faster rate.

The curves on the right of the figure show that, as speed is increased, the lateral acceleration changes from an acceleration away from the fuselage to an acceleration toward the fuselage, as indicated by the variation of C_Y and C_n with wing angle of attack in figure 7.

To account for the effect of dive angle on the store separation characteristics, a three-degree-of-freedom system of motion equations was used to calculate store trajectories in the longitudinal plane. This effect of dive angle is illustrated in figure 10 for a 960-pound store released at 530 knots.

On the left of figure 10 calculated trajectories are shown at a dive angle γ of 0° for initial store incidence angles of 0° and -5°, and on the right of the figure at a dive angle of 75° also for initial store incidence angles of 0° and -5°.

At zero dive angle the weight of the store is essentially normal to the aircraft reference and the initial acceleration corresponds to that shown in figure 9 by the dashed line at 530 knots. When the store is released contact does not occur. For a dive angle of approximately 75° the normal weight component is reduced by the cosine of the dive angle and a component of the weight goes into thrust which accelerates the store relative to the carrier airplane. Since the store normal-force curves are displaced at $\alpha_w = 0^\circ$, the reduction in store normal force resulting from the change in α_w required to maintain steady flight on the 75° flight path is insignificant relative to the reduction of the gravity component. As a result, for $i_s = 0^\circ$, the store normal force approximately equals its normal weight component and the nose-down pitch rotation combined with the forward acceleration of the store relative to the airplane causes the store fin to contact the trailing edge of the wing. However, at $i_s = -5^\circ$, contact is not indicated. Although the dive angle at which contact is shown for this store is large, a store having larger fins or located beneath a thicker wing section, where the buoyancy effect would be greater, would be expected to contact the wing at lower dive angles. The results of the calculated trajectories for the example configuration at $i_s = 0^\circ$ are summarized in figure 11.

The lines or boundaries on the left of the figure represent the maximum dive angle for release of a 960-pound store without contact between the fin and airplane wing as a function of equivalent airspeed, under conditions of steady flight and imposed incremental load factors of -0.25 and -0.5. Contact is indicated on the hatched side of the boundary. The dashed line shows the boundary obtained if compressibility effects are neglected. (The compressibility effects are based on sea-level conditions.) For the store-airplane configuration illustrated here the reduction in store normal force and increase in drag associated with the higher Mach numbers opens the boundaries at the higher airspeeds. Data obtained on airplanes during attack missions indicate that at the instant of ordnance release the airplane is quite often in a pushover. For certain delivery techniques, a pushover is required to offset the horizontal drift associated with increases in speed during a dive. Figure 11 indicates that severe penalties in both maximum permissible dive angle and flight speed may be encountered if the store is released during a pushover.

On the right of the figure the effect of store weight on contact at release is shown as a function of equivalent airspeed for flight-path angles of 0° and 60°. The boundaries indicate the minimum weight at which the store can be released without contact over the speed range for the two dive angles. In this figure contact is indicated below the boundary.

CONCLUDING REMARKS

The available NACA and NASA data relating to the carriage and separation characteristics of external stores have been summarized. A comparison of calculated and measured store normal force and pitching moment has been presented to illustrate some of the subsonic interference origins and methods of combining experimental flow fields with theory to predict store forces and moments. This comparison indicates that additional work is required to develop completely satisfactory analytical methods of obtaining store moments in the interference flow field. Therefore, at present it appears that the best method is to measure the store characteristics in the wind tunnel. When the aerodynamic characteristics of a store in the wing flow field are known, the store trajectories can be calculated with reasonable accuracy. The effects of various combinations of speed, dive angle, airplane load factor, and store density on the separation characteristics are illustrated by using calculated store trajectories.

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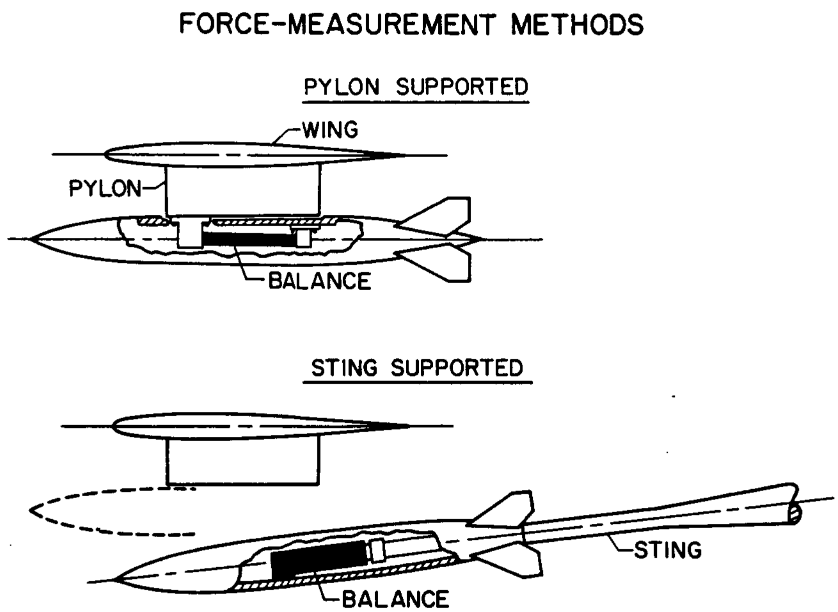
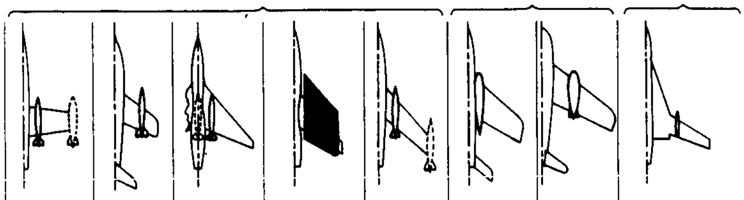

FORCE-MEASUREMENT METHODS
PYLON SUPPORTED
WING
PYLON
BALANCE
STING SUPPORTED
STING
BALANCE

Figure 1

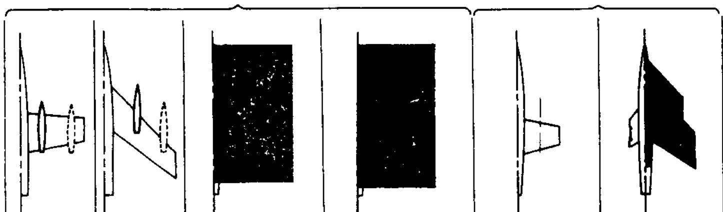
CONFIGURATIONS STUDIED
PYLON SUPPORTED



	FORCE DATA					PRESSURE DISTRIBUTION		WING AND STORE PRESS. DIST.
CONFIGURATION	1	2	3	4	5	6	7	8
$\Lambda_{c/4}$	4°	36°	45°	45°	47°	40°	35°	27.5°
A	4.0	3.6	4.0	4.0	4.0	3.4	5.2	7.7
t/c	0.06	0.10	TAPERED 0.06—0.03	0.06	0.06	0.10	TAPERED 0.12 → 0.11	TAPERED 0.10 → 0.06
M	0.50→0.91	0.66→1.03	0.80→1.45	1.61	0.50→0.91	0.80→1.03	0.55→1.03	0.23
VARIABLE	SPANWISE POSITION	———	SPANWISE POSITION	SPANWISE & CORDWISE LOCATION	SPANWISE POSITION	———	———	VERTICAL POSITION
REFERENCE	10	11	12	13	10	14	15 AND 16	LANGLEY (UNPUBLISHED)
FACILITY	HS 7'×10'	FLIGHT	8' TPT	4' SPT	HS 7'×10'	16' TT	FLIGHT	HS 7'×10'

Figure 2

CONFIGURATIONS STUDIED
STING SUPPORTED



	FORCE DATA				FLOW-FIELD SURVEY	
CONFIGURATION	9	10	11	12	13	14
$\Lambda_{c/4}$	0°	45°	45°	60°	6°	45°
A	4.0	4.0	4.0	2.31	3.0	4.0
t/c	0.04	0.06	0.06	0.04	0.04	0.06
M	0.75 — 1.96	0.70 — 1.96	1.61 — 2.01	1.61	≈ 0	≈ 0
VARIABLE	STORE SPANWISE AND VERTICAL LOCATION		STORE SIZE AND LOCATION	STORE LOCATION	LONG. AND VERTICAL SURVEY	COMPLETE SURVEY
REFERENCE	17	18	19, 20, 21, 22	23	7	7 AND 24
FACILITY	9"×12" BDT	9"×12" BDT	4' SPT	4' SPT	300 MPH 7'×10'	300 MPH 7'×10'

Figure 3

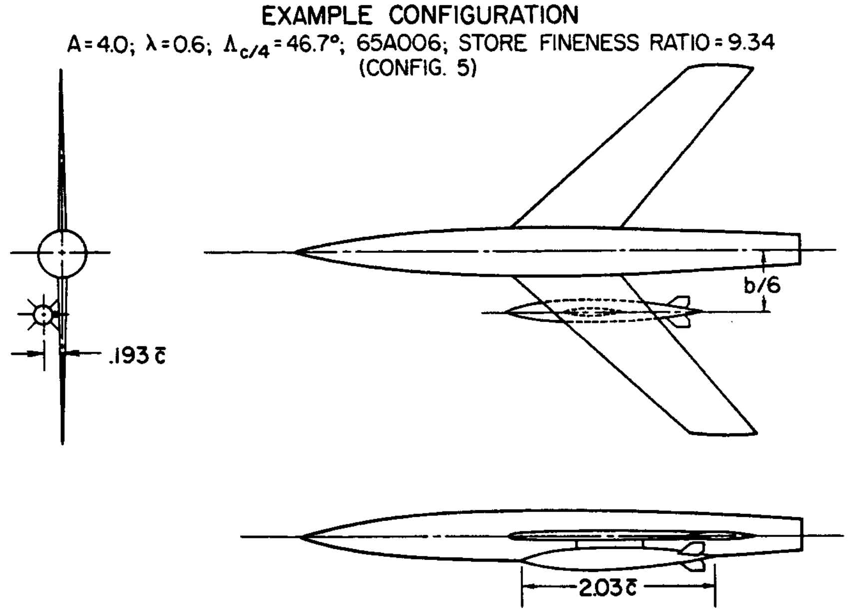


Figure 4

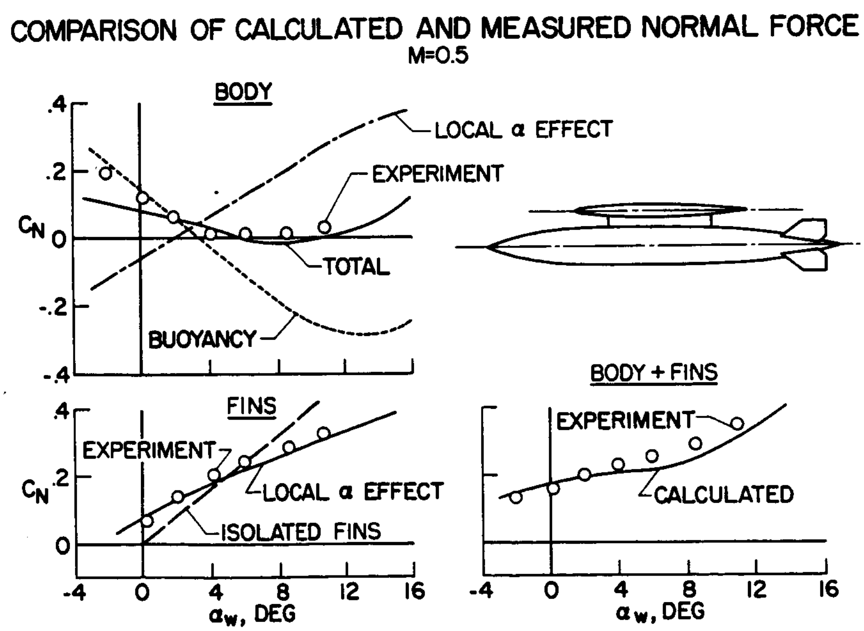


Figure 5

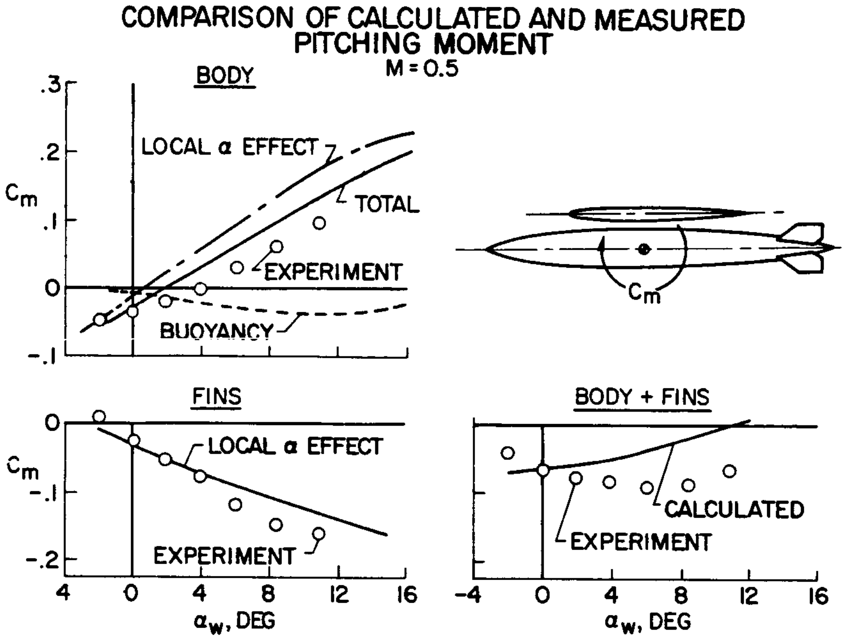


Figure 6

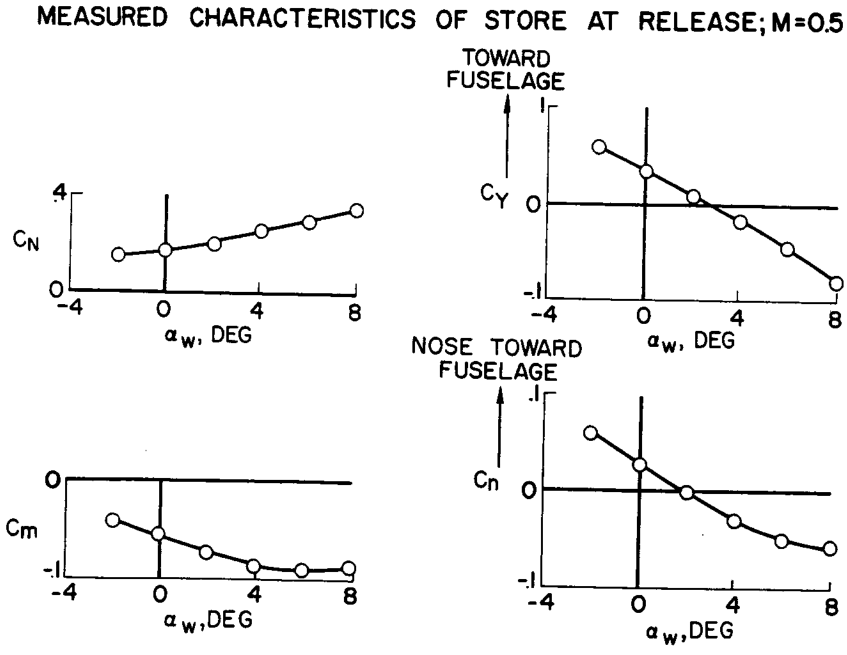


Figure 7

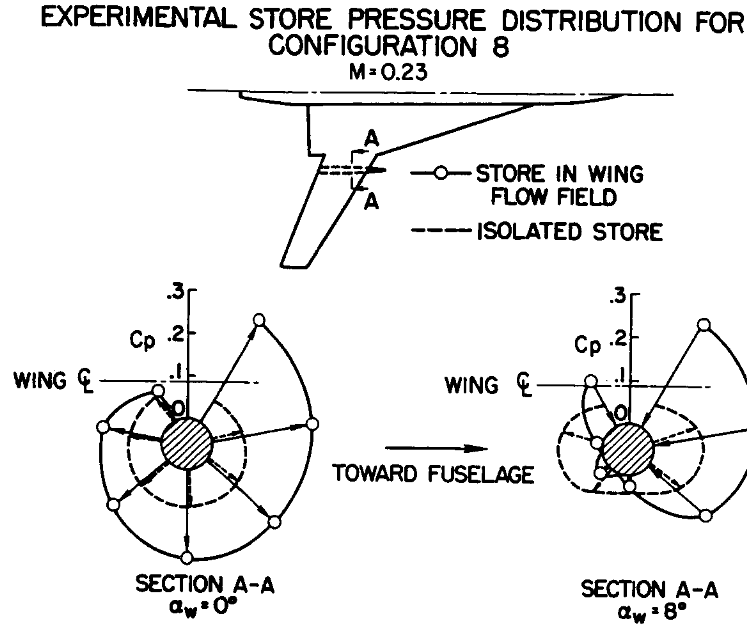


Figure 8

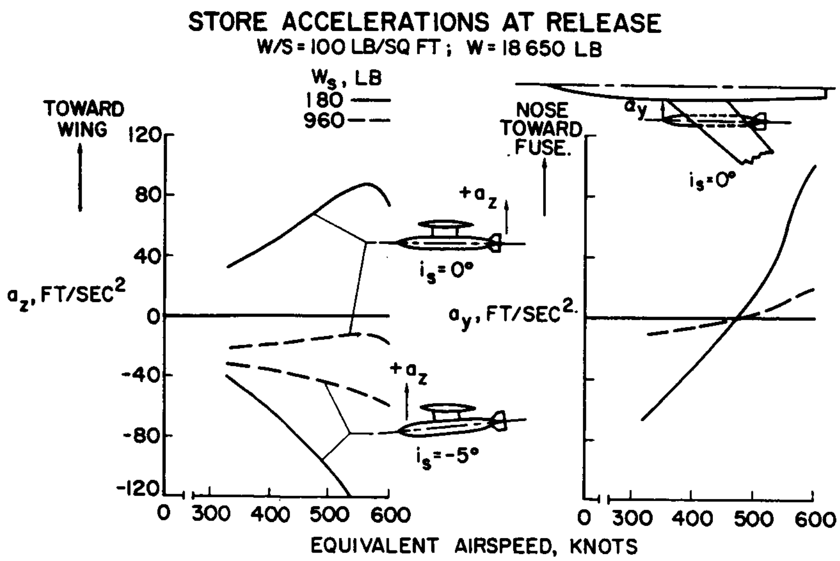


Figure 9

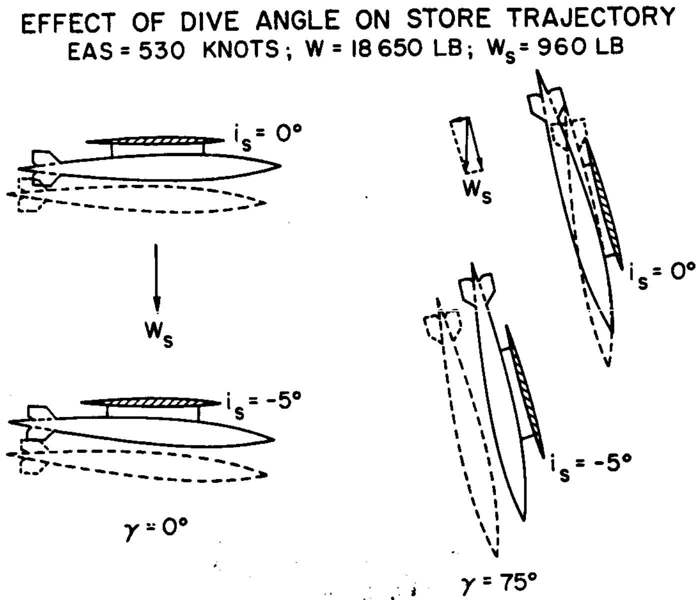


Figure 10

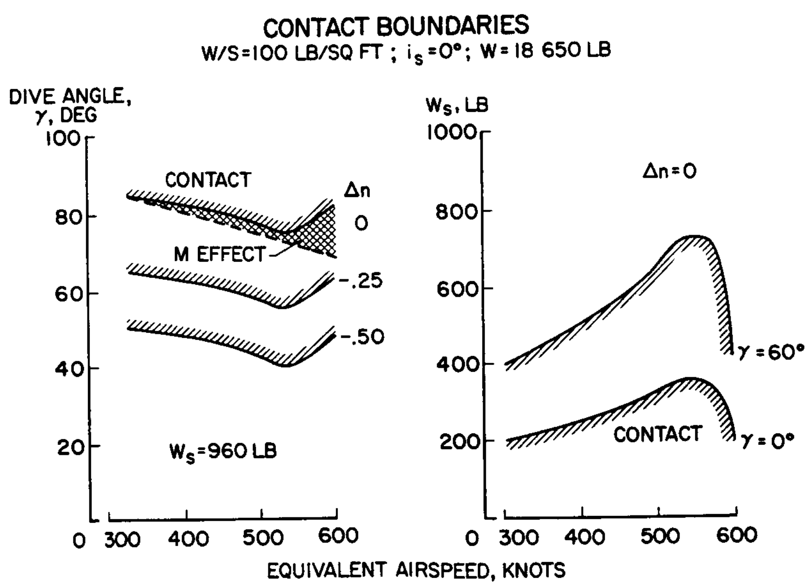


Figure 11