

24. SUMMARY OF EXTERNAL-STORE DRAG

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SUMMARY

The drag problems associated with the addition of external stores to airplanes are reviewed. Current analytic techniques for estimating drag penalties associated with the addition of stores in both subsonic and supersonic flight are discussed. In subsonic flight, the drag penalty caused by the addition of external stores is shown to be a function of the type of store installation. In supersonic flight, the drag is shown to be a function of the type of store installation and also of the location of the store installation with respect to the rest of the airplane components. Special store arrangements and attention to the design of the store itself can reduce the drag penalty of the store installation.

INTRODUCTION

The current trend in military airplanes is toward carrying a large variety of external stores in the form of bombs, rockets, rocket launchers, and fuel tanks. The essence of the problem associated with these external stores is that the aerodynamicist designs the airplane to be essentially "clean" as shown in figure 1, while the airplane will probably fly in some less clean configuration, as shown in figure 2. The addition of external stores in various combinations and by various methods of attachment can lead to precipitous increases in drag and perhaps compromise the mission of the airplane. In figure 2 are shown only a few of the possible arrangements of stores - it has been estimated that there are roughly 17 million store combinations possible on one currently operational Navy airplane.

A great quantity of data on external stores has been published in the past 15 years by the NACA, the NASA, and other research organizations. A rather extensive bibliography which covers such problem areas as store effects on performance, store characteristics, and configuration and interference effects is included herein. A parallel bibliography, covering store separation characteristics and store loads, is contained in paper no. 8 by McKinney and Polhamus.

The present paper is concerned with the drag characteristics of the store-airplane configuration. Selected data from some of the reports in the bibliography are presented and some general conclusions regarding store drag are made. A directory of the bibliography is included in table I as a convenience to the reader in locating specific information.

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SYMBOLS

C_D	drag coefficient
D	diameter of store
M	Mach number
r	store nose radius
Δ	increment

Subscripts:

lp	last pair
meas	measured
min	minimum
o	zero lift
store	isolated store

DISCUSSION OF ANALYTIC TECHNIQUES

The discussion of analytic techniques is limited to some of the fundamental problems associated with the drag of external stores or of the store-airplane combination. The basic factors which must be considered in estimating the zero-lift drag of the airplane with external stores in the subsonic region are skin-friction drag, base drag, form drag, and interference drag. Estimates can be readily made for the skin-friction drag, base drag, and form drag by using well-documented techniques, as all these drag components are essentially the drag components of the isolated store. Interference effects, particularly store-store interference where stores are mounted in close proximity, may lead to a significant drag increase. Some limited data on these effects exist and are included in the bibliography.

Factors to be evaluated in the supersonic region are skin-friction drag, base drag, asymmetry and interference drag, and wave drag. Skin-friction and base drag can be estimated by using well-known techniques, asymmetry drag and interference effects can be estimated by using techniques described in paper no. 26 by Carlson and McLean, and the wave drag, which must be estimated for the store and airplane in combination, can be calculated by using a method programed for an electronic computer. This zero-lift wave-drag program is described in part in paper no. 27 by Harris.

It should be pointed out that, although great quantities of wind-tunnel external-store data exist, in many cases insufficient knowledge of the nature of the boundary layer leads to inaccuracies in skin-friction estimation and extrapolation to full-scale values.

Within the supersonic region, the accuracy of the drag estimates also depends on how closely the configuration satisfies the assumptions of linearized theory upon which the computer programs are based. Numerous close correlations have been made by using these estimating techniques on various versions of supersonic transport configurations. These designs are generally long and slender with thin wing sections and with all components integrated to produce a low-drag configuration. The average fighter airplane, however, is not likely to be slender; the wing elements may be relatively thick; and, the external stores may be added with little regard to favorable interference effects. Figure 3 shows the correlation between theory and experiment obtained for a current fighter airplane in the transonic and supersonic flight regimes. Zero-lift drag is plotted against Mach number. The configuration is a variable-sweep airplane with the wings swept fully aft. The experimental data are from references 1 and 2. The stores are pylon mounted beneath the wing - four stores for the transonic region and two stores for the supersonic region. The level of drag for the stores-off configuration is predicted very well in the subcritical Mach number range, and the increment due to the addition of stores is also predicted very closely.

In the supersonic region, the estimated drag for the stores-off configuration is less than that for the experiment. The increment between the stores-on data and stores-off data is predicted reasonably well by the analytic methods. It appears that some further refinement of the analytic techniques would be useful in making more accurate quantitative estimates of the drag characteristics of configurations such as this.

DISCUSSION OF EXPERIMENTAL DATA

The remainder of this paper is concerned with a number of particular store installations. Most of these store arrangements are typical of those found on current fighter airplanes.

Analysis of the data in figure 4 gives an idea of the subsonic drag penalty associated with several types of store installations. The data in figures 4 and 5 were taken from a number of the reports in the bibliography. The ordinate is the increment in experimental zero-lift drag due to the addition of the store or stores. The abscissa is the drag of the isolated store multiplied by the number of stores in the installation. All coefficients are based on the wing area of the particular configuration. No attempt was made to predict the drag increment of the store support system; thus, the experimental value is the total drag penalty of the store and installation. The solid line represents equality between the experimental drag increment and the isolated store drag. Examples of the more common installations are the pylon-mounted single store, the pylon-mounted multiple rack, and the tangent-mounted store,

where the store is mounted flush with the aircraft surface. Less common perhaps is the semisubmerged installation. It is not surprising that this semisubmerged installation shows low values of measured drag compared with the isolated store drag since roughly half the wetted area is submerged within the airplane.

In general, for stores carried completely external to the aircraft, the tangent mount and the pylon-mounted single store lead to only small drag penalties, while the pylon-mounted multiple-rack installation causes a fairly sizable drag penalty.

Figure 5 illustrates the same type of analysis for the supersonic Mach number range. Again, the total measured increase in zero-lift drag due to the installation of the store or stores is plotted against a simple multiple of the isolated-store drag. Here again the coefficients are based on the wing area for the particular configuration. The Mach number range is from about 1.4 to 2.5. Figure 6 shows sketches of the various installations keyed to the data points in figure 5. Data point ① is for a model of a current fighter airplane with four Falcon missiles. The increment of installation drag is due in part to the skin friction of the rather large end-plate installation. It should be noted that some decrease in the store drag increment occurred at lift. Data point ② represents the same type of configuration but with two Falcon missiles. The deviation from the line of equality is somewhat less for this installation than for installation ①. However the decrease in the drag increment at lift for installation ② is negligible. Installation ③ is a rather unique mounting system; that is, the six missiles were sting mounted on the leading edge of the wing. A portion of the drag reduction is undoubtedly due to the elimination of missile base drag by the support system. Installation ④ is for the underwing installation of the same six missiles. A significant increase in drag over that for the leading-edge installation is apparent; however the departure from the line of equality can be attributed in part to the increased skin-friction drag of the pylon installations.

Installations ⑤ and ⑥, for a research model, indicate the large influence of store location on drag. In this particular case, the forward location led to a very high drag level compared with that for the rearward location. Installations ⑦ to ⑩ are for a model of a current fighter airplane with a variety of Sparrow installations. The two fuselage mounts (⑦ and ⑩) show considerably less drag penalty than the corresponding store wing mounts ⑧ and ⑨, respectively. Installations ⑪ and ⑫ are pylon mounts on the engine nacelles and on the fuselage. The fuselage mount ⑫ shows an appreciably smaller drag penalty than the nacelle mount ⑪.

It can be seen that, for the supersonic range in particular, not only the type of installation but also its location on the aircraft can considerably affect the magnitude of the drag. For the supersonic range, consideration of the store in the design of the aircraft using area-rule techniques would certainly be of benefit.

Some of the installations mentioned are perhaps worthy of further comment. Figure 7 presents experimental results for a tangent-mounted store installation and a pylon-mounted installation. The increment of drag for the tangent-mounted store is approximately the estimated amount for skin-friction and base drag. The added increment for the pylon is, however, considerably more than can be attributed to skin-friction drag. The reason for these phenomena is, at present, unknown, although it is probably associated with the amount of the store submerged within the boundary layer.

Figure 8 shows data from reference 3 for a current fighter airplane with a large store semisubmerged in the fuselage. Data are presented for the clean configuration, that is, with the cavity faired, for the configuration with the store installed, and for the configuration with the open cavity after ejection of the store. Of particular interest is the drag of the cavity with the store removed. For this particular installation, in the high subsonic and low supersonic speed ranges, the cavity drag penalty is as much or more than that for the installed store. Although this is not always the case, it is a point to be evaluated when considering a store installation of this type.

Figure 9 presents data for a tandem store installation consisting of two rows of three tandem-mounted stores. On the left side of the figure is shown the gross drag increment for the one, two, and three store pair installations over the Mach number range from 0.6 to 0.9. On the right side of the figure is shown the increment in drag due to the addition of the last store pair for various Mach numbers. It can be seen that the increment in drag for each additional pair decreases. For a blunt-nosed, blunt-based store, this type of installation should be of considerable benefit.

Figure 10 is concerned more with individual stores than with store installations. The data are from reference 4. The installation consists of 16 stores, 9 in the free stream and 7 tandem mounted. The drag increment of the installation is quite large; however, a significant increase is noted for a change in corner radius of the stores. This increment remained relatively constant over the Mach number range of the tests.

This figure illustrates the basis of the store drag problem, that is, if it is necessary to hang a multitude of stores from the aircraft, then a large drag penalty will likely exist. In this case, the drag of the configuration was more than doubled by the addition of stores.

CONCLUDING REMARKS

Analytic methods have been shown to give a reasonably good estimate of the drag increment due to the addition of external stores. The drag penalty due to the addition of stores in the subsonic speed range has been shown to depend in part on the type of installation; the lowest drag penalty is associated with a semisubmerged installation and the largest drag penalty with a multiple-rack installation. At supersonic speeds, the drag of the store depends not only on the type of installation but also on the store location. Use of the analytic methods through area-rule considerations offers promise of drag reduction in the supersonic flight regime. Other factors to be considered in the reduction of store drag are tandem store arrangements and the effects of the shape of the store itself.

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TABLE I.- BIBLIOGRAPHY CROSS-REFERENCE

Bibliography number containing results related to -				
Effects of variations in store location	Various stores in combination; multiple installations	Partially-submerged store installations	Isolated-store characteristics	Store-configuration variations; interference effects
3	2	4	5	18
7	27	17	14	31
8	30	21	18	40
9	39	34	30	41
10	40	40	31	52
11	57	57	32	53
13	60	68	34	55
14	63	74	39	56
16	72	79	40	58
17	82	89	42	59
19	86		45	62
20	93		46	71
21	97		47	91
22	103		50	92
23	107		51	109
25	108		64	111
26	109		66	112
28			67	
29			77	
34			80	
35			84	
36			95	
37			96	
38			102	
40				
42				
47				
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54				
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66				
72				
75				
81				
97				
100				
104				
107				
108				
109				

CLEAN CONFIGURATION

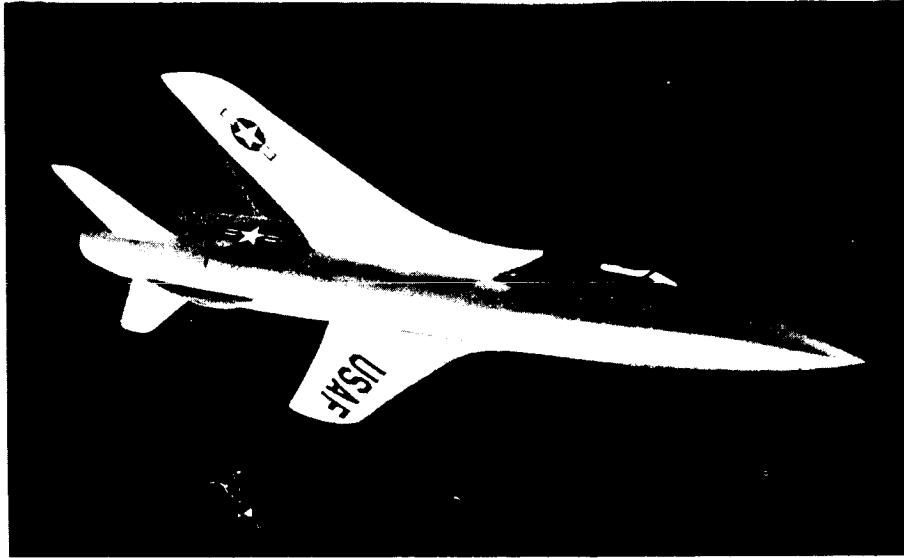


Figure 1

L-2694-1

CONFIGURATION WITH STORES

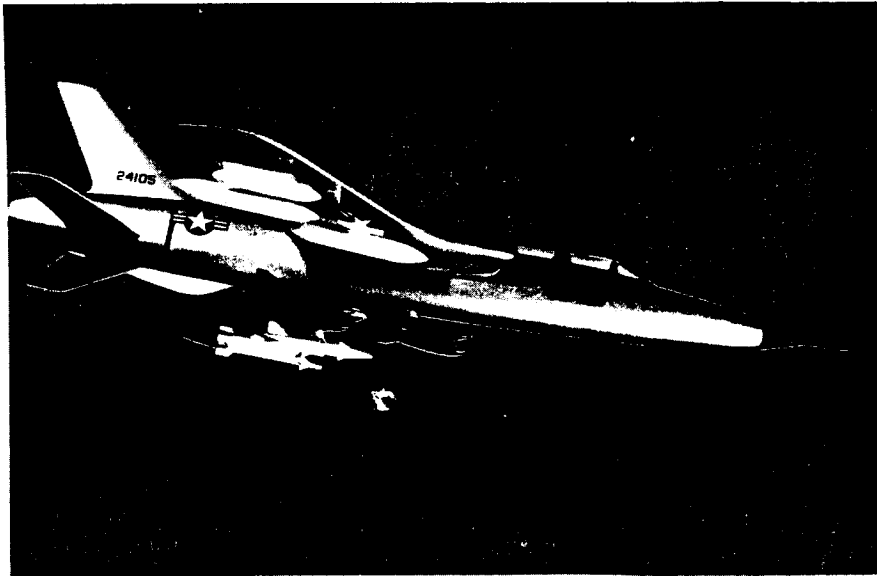


Figure 2

L-2694-8

ANALYSIS AND CORRELATION

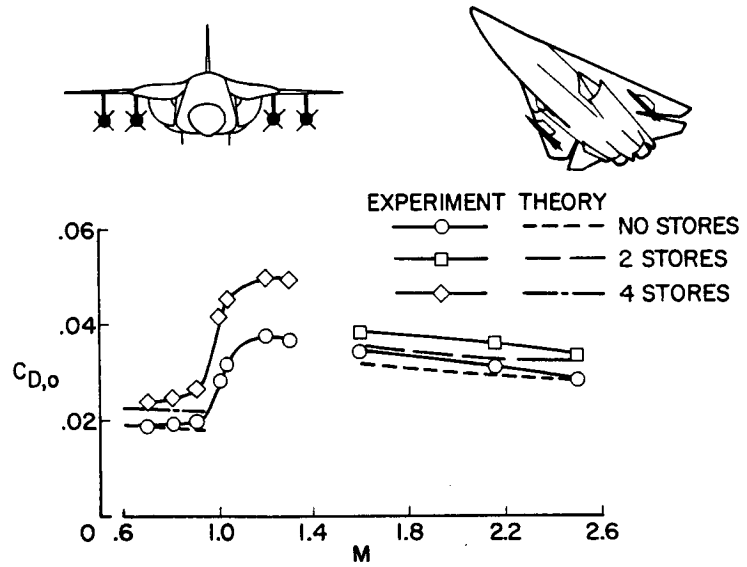


Figure 3

INCREMENTAL STORE-INSTALLATION DRAG SUBSONIC



Figure 4

INCREMENTAL STORE-INSTALLATION DRAG
SUPERSONIC

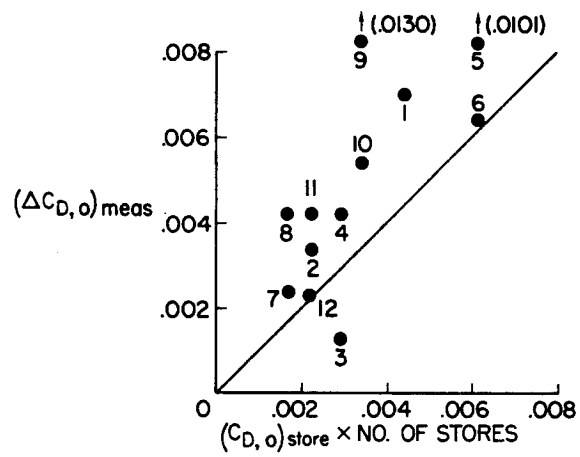


Figure 5

STORE INSTALLATIONS

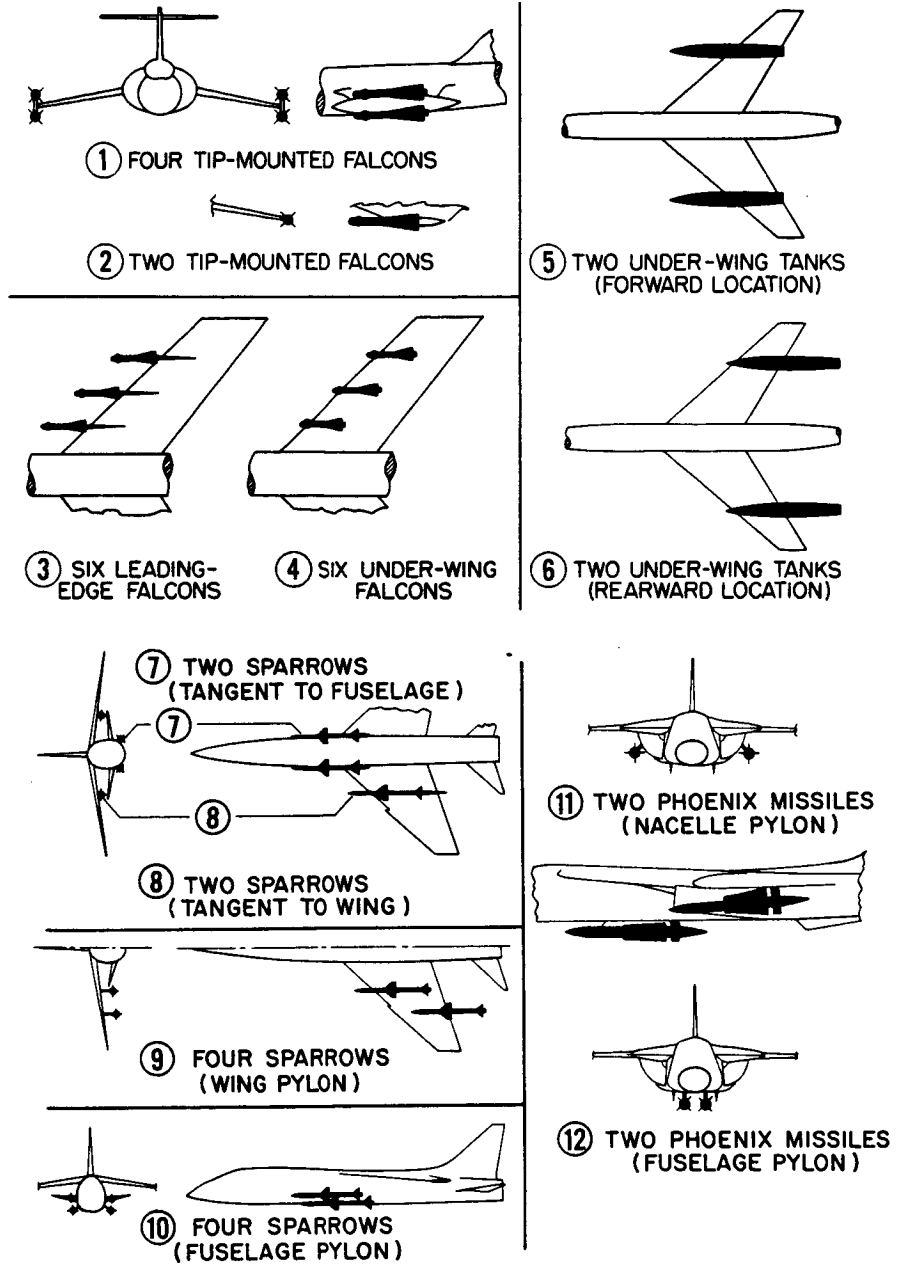


Figure 6

TANGENT AND PYLON INSTALLATIONS

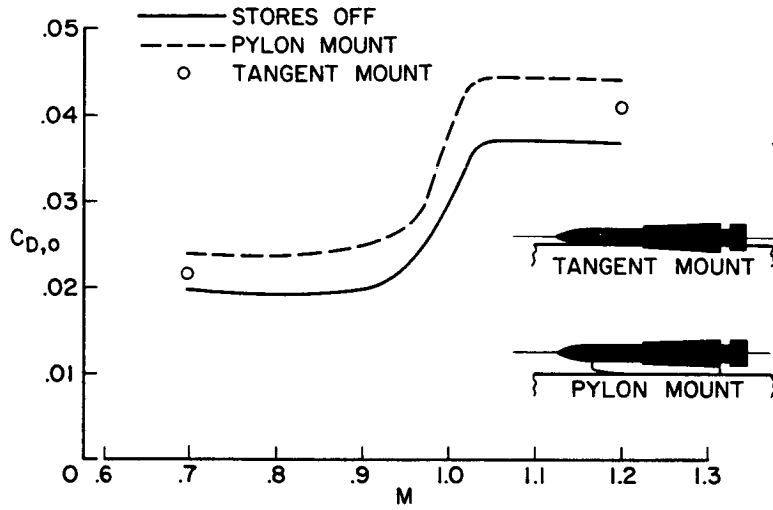


Figure 7

SEMISUBMERGED STORE INSTALLATION

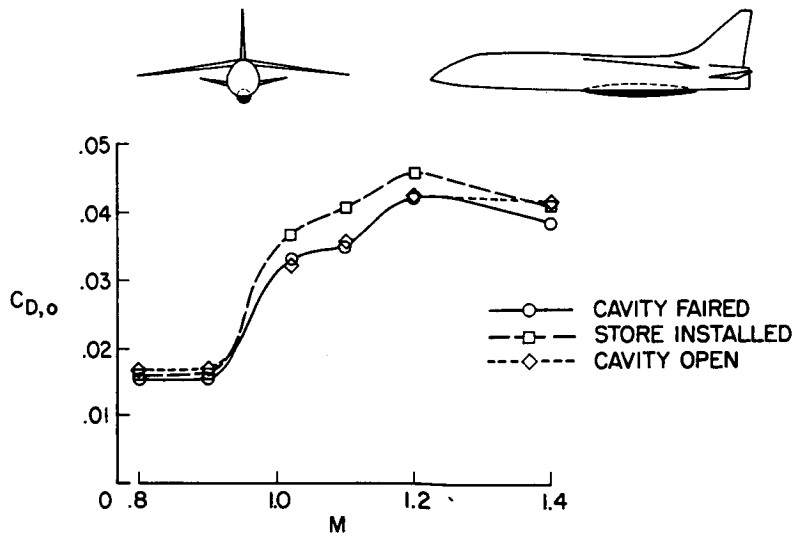


Figure 8

TANDEM STORE INSTALLATION

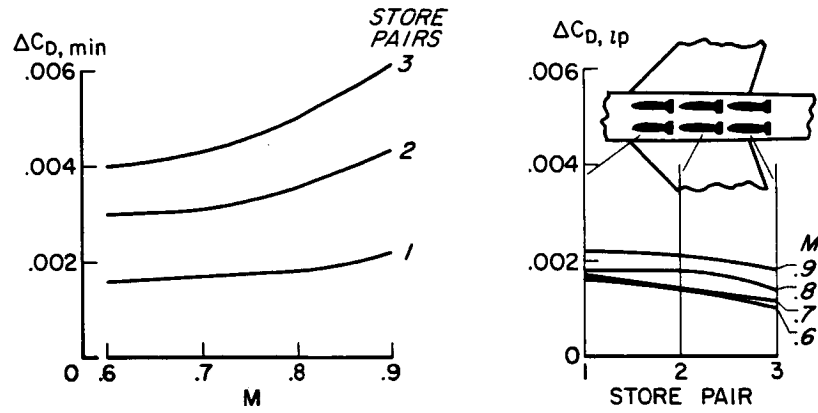


Figure 9

EFFECTS OF STORE CORNER RADIUS

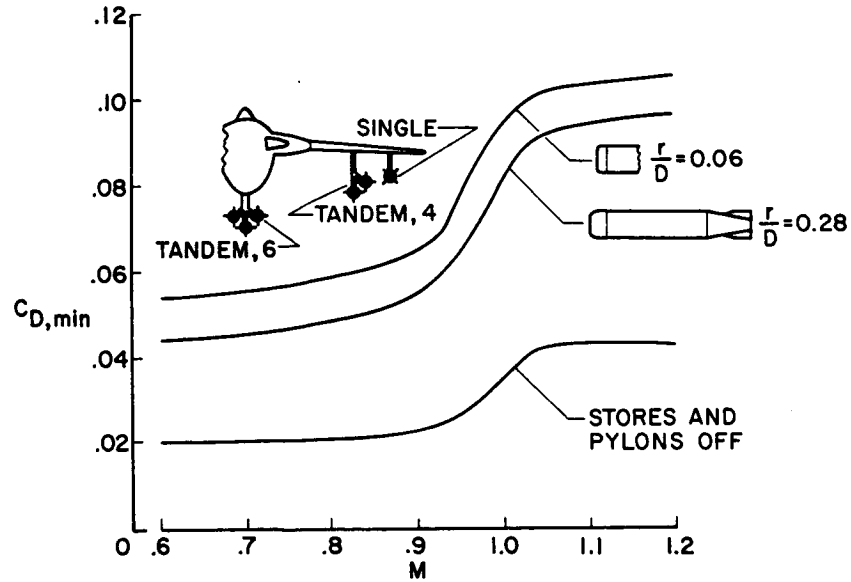


Figure 10