24. SUMMARY OF EXTERNAL-STORE DRAG

By Barrett L. Shrout and Thomas C. Kelly
NASA Langley Research Center

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.

24

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.

Preceding page blank

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.

REFERENCES

1. Ayers, Theodore G.: Transonic Aerodynamic Characteristics of a Variable-Wing-Sweep Tactical Fighter Model - Phase 4. NASA TM X-1237, 1966.

2. Shaw, David S.; and Babb, C. Donald: Supersonic Investigation of the Static Stability, Performance, and Control of a Variable-Sweep Tactical Fighter Model - Phase 4. NASA TM X-1143, 1965.

3. Wainwright, John B.; and Rubinstein, Marvin: Report on the Aerodynamic Effects of External Stores on a Wind Tunnel Model XF8U-1 Airplane in the Mach Number Range 0.8 to 1.4. USCEC Rept. 32-1-5, Aerodyn. Test Div., NAMTC, Univ. of Southern California, Apr. 28, 1955.

4. Ferris, James C.: Effects of External Stores on Performance and Stability of a Supersonic Fighter-Bomber Airplane. NASA TM X-1218, 1966.

BIBLIOGRAPHY

1. Silvers, H. Norman; and Vogler, Raymond D.: Résumé of Wind-Tunnel Data on the Effect of External Stores on Stability of Models of Military Airplanes. NACA RM L6K08, 1946.

2. Boddy, Lee E.; and Morrill, Charles P., Jr.: The Aerodynamic Effects of Rockets and Fuel Tanks Mounted Under the Swept-Back Wing of an Airplane Model. NACA RM A7J03, 1948.

3. Silvers, H. Norman; and Spreemann, Kenneth P.: Correlation of Wind-Tunnel and Flight Determinations of the Buffet Speed of an Airplane Equipped With External Stores. NACA RM L7E20, 1948.

4. Silvers, H. Norman; and Spreemann, Kenneth P.: Wind-Tunnel Investigation of a Wing-Fuselage Combination With External Stores. NACA RM L7K20, 1948.

5. Hart, Roger G.; and Katz, Ellis R.: Flight Investigations at High-Subsonic, Transonic, and Supersonic Speeds To Determine Zero-Lift Drag of Fin-Stabilized Bodies of Revolution Having Fineness Ratios of 12.5, 8.91, and 6.04 and Varying Positions of Maximum Diameter. NACA RM L9I30, 1949.

6. Silvers, H. Norman; and Spreemann, Kenneth P.: Effect of Airfoil Section and Tip Tanks on the Aerodynamic Characteristics at High Subsonic Speeds of an Unswept Wing of Aspect Ratio 5.16 and Taper Ratio 0.61. NACA RM L9J04, 1949.

7. Spreemann, Kenneth P.; and Silvers, H. Norman: Experimental Investigation of Various Wing-Mounted External Stores on a Wing-Fuselage Combination Having a Sweptback Wing of Inverse Taper Ratio. NACA RM L9J06, 1950.

8. Silvers, H. Norman; and Spreemann, Kenneth P.: Experimental Investigation of Various External-Store Configurations on a Model of a Tailless Airplane With a Sweptback Wing. NACA RM L9K25, 1950.

9. Welsh, Clement J.; and Morrow, John D.: Effect of Wing-Tank Location on the Drag and Trim of a Swept-Wing Model as Measured in Flight at Transonic Speeds. NACA RM L50A19, 1950.

10. May, Ellery B.; Jr.: Investigation of the Aerodynamic Effects of an External Store in Combination With 60° Delta and Low-Aspect-Ratio Tapered Wings at a Mach Number of 1.9. NACA RM L50K03, 1951.

11. Spreemann, Kenneth P.; and Alford, William J., Jr.: Investigation of the Effects of Geometric Changes in an Underwing Pylon-Suspended External-Store Installation on the Aerodynamic Characteristics of a 45° Sweptback Wing at High Subsonic Speeds. NACA RM L50L12, 1951.

12. Hoffman, Sherwood: Comparison of Zero-Lift Drag Determined by Flight Tests at Transonic Speeds of Pylon, Underslung, and Symmetrically Mounted Nacelles at 40 Percent Semispan of a 45° Sweptback Wing and Body Combination. NACA RM L51D26, 1951.

13. Pepper, William B., Jr.; and Hoffman, Sherwood: Comparison of Zero-Lift Drags Determined by Flight Tests at Transonic Speeds of Symmetrically Mounted Nacelles in Various Chordwise Positions at the Wing Tip of a 45° Sweptback Wing and Body Combination. NACA RM L51F13, 1951.

14. Silvers, H. Norman; King, Thomas J., Jr.; and Pasteur, Thomas B., Jr.: Investigation of the Effect of a Nacelle at Various Chordwise and Vertical Positions on the Aerodynamic Characteristics at High Subsonic Speeds of a 45° Sweptback Wing With and Without a Fuselage. NACA RM L51H16, 1951.

15. Dugan, James C.: External Store Development. Mem. Rept. No. WCNSR-43019-1-1, Wright Air Develop. Center, U.S. Air Force, Aug. 13, 1951.

16. Tamburello, V.; and Burgan, Elmer: Exploratory Wind-Tunnel Tests of External Stores Mounted in Various Locations on the Wing of a 0.17-Scale Model Jet-Fighter Type Airplane. Rept. C-453 Aero 806, David W. Taylor Model Basin, Navy Dept., Sept. 1951.

17. Hasel, Lowell E.; and Sevier, John R., Jr.: Aerodynamic Characteristics at Supersonic Speeds of a Series of Wing-Body Combinations Having Cambered Wings With an Aspect Ratio of 3.5 and a Taper Ratio of 0.2 - Effect at $M = 1.60$ of Nacelle Shape and Position on the Aerodynamic Characteristics in Pitch of Two Wing-Body Combinations with 47° Sweptback Wings. NACA RM L51K14a, 1952.

18. Kremzier, Emil J.; and Dryer, Murray: Aerodynamic Interference Effects on Normal and Axial Force Coefficients of Several Engine-Strut-Body Configurations at Mach Numbers of 1.8 and 2.0. NACA RM E52B21, 1952.

19. Silvers, H. Norman; and King, Thomas J., Jr.: A Small-Scale Investigation of the Effect of Spanwise and Chordwise Positioning of an Ogive-Cylinder Underwing Nacelle on the High-Speed Aerodynamic Characteristics of a 45° Sweptback Tapered-in-Thickness Wing of Aspect Ratio 6. NACA RM L52J22, 1952.

20. Hoffman, Sherwood: Transonic Flight Tests To Compare the Zero-Lift Drags of Underslung Nacelles Varied Spanwise on a 45° Sweptback Wing and Body Combination. NACA RM L52D04a, 1952.

21. Driver, Cornelius: Aerodynamic Characteristics at Supersonic Speeds of a Series of Wing-Body Combinations Having Cambered Wings With an Aspect Ratio of 3.5 and a Taper Ratio of 0.2 - Effect at $M = 2.01$ of Nacelle Shape and Position on the Aerodynamic Characteristics in Pitch of Two Wing-Body Combinations With 47° Sweptback Wings. NACA RM L52F03, 1952.

22. Scallion, William I.: Low-Speed Investigation of the Effects of Nacelles on the Longitudinal Aerodynamic Characteristics of a 60° Sweptback Delta-Wing—Fuselage Combination With NACA 65A003 Airfoil Sections. NACA RM L52F04, 1952.

23. Jacobsen, Carl R.: Effects of Systematically Varying the Spanwise and Vertical Location of an External Store on the Aerodynamic Characteristics of an Unswept Tapered Wing of Aspect Ratio 4 at Mach Numbers of 1.41, 1.62, and 1.96. NACA RM L52F13, 1952.

24. Bielat, Ralph P.; and Harrison, Daniel E.: A Transonic Wind-Tunnel Investigation of the Effects of Nacelle Shape and Position on the Aerodynamic Characteristics of Two 47° Sweptback Wing-Body Configurations. NACA RM L52G02, 1952.

25. Jacobsen, Carl R.: Effects of the Spanwise, Chordwise, and Vertical Location of an External Store on the Aerodynamic Characteristics of a 60° Delta Wing at Mach Numbers of 1.41, 1.62, and 1.96. NACA RM L52H29, 1952.

26. Silvers, H. Norman; and King, Thomas J., Jr.: Investigation at High Subsonic Speeds of Bodies Mounted From the Wing of an Unswept-Wing—Fuselage Model, Including Measurements of Body Loads. NACA RM L52J08, 1952.

27. Smith, Willard G.: Wind-Tunnel Investigation at Subsonic and Supersonic Speeds of a Model of a Tailless Fighter Airplane Employing a Low-Aspect-Ratio Swept-Back Wing - Effects of External Fuel Tanks and Rocket Packets on the Drag Characteristics. NACA RM A52J31, 1953.

28. Jacobsen, Carl R.: Effects of the Spanwise, Chordwise, and Vertical Location of an External Store on the Aerodynamic Characteristics of a 45° Sweptback Tapered Wing of Aspect Ratio 4 at Mach Numbers of 1.41, 1.62, and 1.96. NACA RM L52J27, 1953.

29. Jacobsen, Carl R.: Effects of Size of External Stores on the Aerodynamic Characteristics of an Unswept and a 45° Sweptback Wing of Aspect Ratio 4 and a 60° Delta Wing at Mach Numbers of 1.41, 1.62, and 1.96. NACA RM L52K20a, 1953.

30. Mitcham, Grady L.; and Blanchard, Willard S., Jr.: Low-Lift Drag and Stability Data From Rocket Models of a Modified-Delta-Wing Airplane With and Without External Stores at Mach Numbers From 0.8 to 1.36. NACA RM L53A27, 1953.

31. Wallskog, Harvey A.; and Hart, Roger G.: Investigation of the Drag of Blunt-Nosed Bodies of Revolution in Free Flight at Mach Numbers From 0.6 to 2.3. NACA RM L53D14a, 1953.

32. Rainey, Robert W.: Effect of Variations in Reynolds Number on the Aerodynamic Characteristics of Three Bomb or Store Shapes at a Mach Number of 1.62 With and Without Fins. NACA RM L53D27, 1953.

33. Carmel, Melvin M.; and Fischetti, Thomas L.: A Transonic Wind-Tunnel Investigation of the Effects of Nacelles on the Aerodynamic Characteristics of a Complete Model Configuration. NACA RM L53F22a, 1953.

34. Mason, Homer P.: Effects of External Store Mounting on the Buffet, Trim, and Drag Characteristics of Rocket-Powered Fuselage and Store Combinations Between Mach Numbers of 0.7 and 1.4. NACA RM L53J22, 1953.

35. Alexander, S. R.: The Influence of External and Internal Stowage of Sparrow II on the Performance of a Transonic Day Fighter Configuration. NAVAER Rept. No. DR-1484, Bur. Aeron., Aug. 1953.

36. Judd, Joseph H.: Flight Investigation of Engine Nacelles and Wing Vertical Position on the Drag of a Delta-Wing Airplane Configuration From Mach Number 0.8 to 2.0. NACA RM L53L21, 1954.

37. Silvers, H. Norman; King, Thomas J., Jr.; and Alford, William J., Jr.: Wind-Tunnel Investigation at High Subsonic Speeds of the Effects of Wing-Mounted External Stores on the Loading and Aerodynamic Characteristics in Pitch of a 45° Sweptback Wing Combined With a Fuselage. NACA RM L54A21, 1954.

38. Alford, William J., Jr.; and Silvers, H. Norman: Investigation at High Subsonic Speeds of Finned and Unfinned Bodies Mounted at Various Locations From the Wings of Unswept- and Swept-Wing—Fuselage Models, Including Measurements of Body Loads. NACA RM L54B18, 1954.

39. Henning, Allen B.: The Effects of Wing Mounted External Stores on the Trim, Buffet, and Drag Characteristics of a Rocket-Propelled Model Having a 45° Sweptback Wing. NACA RM L54B19, 1954.

40. Hoffman, Sherwood; and Wolff, Austin L.: Effect on Drag of Longitudinal Positioning of Half-Submerged and Pylon-Mounted Douglas Aircraft Stores on a Fuselage With and Without Cavities Between Mach Numbers of 0.9 and 1.8. NACA RM L54E26, 1954.

41. Smith, Norman F.: Exploratory Investigation of External Stores on the Aerodynamic Characteristics of a 1/16-Scale Model of the Douglas D-558-II Research Airplane at a Mach Number of 2.01. NACA RM L54F02, 1954.

42. Mason, Homer P..; and Henning, Allen B.: Effects of Some External-Store Mounting Arrangements and Store Shapes on the Buffet and Drag Characteristics of Wingless Rocket-Powered Models at Mach Numbers From 0.7 to 1.4. NACA RM L54I20a, 1954.

43. Gapcynski, John P.; and Carlson, Harry W.: A Pressure-Distribution Investigation of the Aerodynamic Characteristics of a Body of Revolution in the Vicinity of a Reflection Plane at Mach Numbers of 1.41 and 2.01. NACA RM L54J29, 1955.

44. Ballentine, Donald C.: Wind-Tunnel Investigation of a 0.15-Scale Model F3H-2N Airplane Equipped With an Adjustable Leading-Edge Slot and Various External Stores. Aero Rept. 871, David W. Taylor Model Basin, Navy Dept., Oct. 1954.

45. Alford, William J., Jr.; Silvers, H. Norman; and King, Thomas J., Jr.: Experimental Aerodynamic Forces and Moments at Low Speed of a Missile Model During Simulated Launching From the Midsemispan Location of a 45° Sweptback Wing-Fuselage Combination. NACA RM L54K11a, 1955.

46. Alford, William J., Jr.: Experimental Static Aerodynamic Forces and Moments at Low Speed on a Canard Missile During Simulated Launching From the Midsemispan and Wing-Tip Locations of a 45° Sweptback Wing-Fuselage Combination. NACA RM L55A12, 1955.

47. Smith, Norman F.; and Carlson, Harry W.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces on Several Wing-Fuselage-Store Configurations. I.- Swept-Wing Heavy-Bomber Configuration With Large Store (Nacelle). Lift and Drag; Mach Number, 1.61. NACA RM L55A13a, 1955.

48. Sleeman, William C., Jr.; and Alford, William J., Jr.: Low-Speed Investigation of the Effects of Wing Tanks and Speed Brakes on the Static Stability of a Model Having a 40° Swept Wing. NACA RM L55C17, 1955.

49. Silvers, H. Norman; and King, Thomas J., Jr.: Investigation at High Subsonic Speeds of the Effects of Various Underwing External-Store Arrangements on the Aerodynamic Characteristics of a 1/16-Scale Model of the Douglas D-558-II Research Airplane. NACA RM L55D11, 1955.

50. Alford, William J., Jr.; Silvers, H. Norman; and King, Thomas J., Jr.: Experimental Static Aerodynamic Forces and Moments at Low Speed on a Missile Model During Simulated Launching From the 25-Percent-Semispan and Wing-Tip Locations of a 45° Sweptback Wing-Fuselage Combination. NACA RM L55D20, 1955.

51. Mason, Homer P.: Effects of Wing-Mounted Tank-Type Stores on the Low-Lift Buffeting and Drag of a Swept-Wing Airplane Configuration Between Mach Numbers of 0.8 and 1.3. NACA RM L55D27, 1955.

52. Smith, Norman F.; and Carlson, Harry W.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces On Several Wing-Fuselage-Store Configurations. II.- Swept-Wing Heavy-Bomber Configuration With Large Store (Nacelle). Lateral Forces and Pitching Moments; Mach Number, 1.61. NACA RM L55E26a, 1955.

53. Smith, Norman F.; and Carlson, Harry W.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces on Several Wing-Fuselage-Store Configurations. III.- Swept-Wing Fighter-Bomber Configuration With Large and Small Stores. Mach Number, 1.61. NACA RM L55H01, 1955.

54. Kelly, Thomas C.: Transonic Wind-Tunnel Investigation of the Effects of External Stores and Store Position on the Aerodynamic Characteristics of a 1/16-Scale Model of the Douglas D-558-II Research Airplane. NACA RM L55I07, 1955.

55. Morris, Odell A.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces on Several Wing-Fuselage-Store Configurations. IV.- Delta-Wing Heavy-Bomber Configuration With Large Store. Mach Number, 1.61. NACA RM L55I27a, 1955.

56. Hart, Roger G.: Flight Investigation at Mach Numbers From 0.8 to 1.5 To Determine the Effects of Nose Bluntness on the Total Drag of Two Fin-Stabilized Bodies of Revolution. NACA TN 3549, 1955. (Supersedes NACA RM L50I08a.)

57. Wainwright, John B.; and Rubinstein, Marvin: Report on the Aerodynamic Effects of External Stores on a Wind Tunnel Model XF8U-1 Airplane in the Mach Number Range 0.8 to 1.4. USCEC Rept. 32-1-5, Aerodyn. Test Div., NAMTC., Univ. of Southern California, Apr. 28, 1955.

58. Carlson, Harry W.; and Geier, Douglas J.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces on Several Wing-Fuselage-Store Configurations. V.- Swept-Wing Heavy-Bomber Configuration With Large Store (Nacelle). Mach Number 2.01. NACA RM L55K15, 1956.

59. Smith, Norman F.: The Origin and Distribution of Supersonic Store Interference From Measurement of Individual Forces on Several Wing-Fuselage-Store Configurations. VI.- Swept-Wing Heavy-Bomber Configuration With Stores of Different Sizes and Shapes. NACA RM L55L08, 1956.

60. Robinson, Ross B.: Longitudinal Characteristics of an Unswept-Wing Fighter-Type Model With External Stores at a Mach Number of 1.82 and Some Effects of Horizontal-Tail and Yaw-Damper Deflection on the Sideslip Derivatives. NACA RM L55L26, 1956.

61. Hallisy, Joseph M., Jr.; and Kudlacik, Louis: A Transonic Wind-Tunnel Investigation of Store and Horizontal-Tail Loads and Some Effects of Fuselage-Afterbody Modifications on a Swept-Wing Fighter Airplane. NACA RM L56A26, 1956.

62. Foster, Gerald V.; and Driver, Cornelius: Effects of External Stores on the Static Longitudinal and Lateral Aerodynamic Characteristics of a Model of a 45° Swept-Wing Fighter Airplane at Mach Numbers of 1.61 and 2.01. NACA RM L56F15a, 1956.

63. Spearman, M. Leroy; and Driver, Cornelius: Longitudinal and Lateral Stability Characteristics of a Low-Aspect-Ratio Unswept-Wing Airplane Model at Mach Numbers of 1.82 and 2.01. NACA RM L56H06, 1957.

64. Morris, Odell A.: Aerodynamic Forces and Moments on a Large Ogive-Cylinder Store at Various Locations Below the Fuselage Center Line of a Swept-Wing Bomber Configuration at a Mach Number of 1.61. NACA RM L56I25, 1957.

65. Alford, William J., Jr.; and King, Thomas J., Jr.: Experimental Static Aerodynamic Forces and Moments at High Subsonic Speeds on a Missile Model During Simulated Launching From the Midsemispan Location of a 45° Sweptback Wing-Fuselage-Pylon Combination. NACA RM L56J05, 1957.

66. Hill, P. R.; and Hoffman, S.: Preliminary Evaluation of the Wing Leading Edge as a Missile-Mounting Location. NACA RM L56J12, 1957.

67. Geier, Douglas J.; and Carlson, Harry W.: Measurement of Static Forces on Externally Carried Bombs of Fineness Ratios 7.1 and 10.5 in the Flow Field of a Swept-Wing Fighter-Bomber Configuration at a Mach Number of 1.6. NACA RM L56K30, 1957.

68. Hoffman, Sherwood: Zero-Lift Drag of a Large Fuselage Cavity and a Partially Submerged Store on a 52.5° Sweptback-Wing—Body Configuration as Determined From Free-Flight Tests at Mach Numbers of 0.7 to 1.53. NACA RM L56L21, 1957.

69. Nugent, Jack: Effect of Wing-Mounted External Stores on the Lift and Drag of the Douglas D-558-II Research Airplane at Transonic Speeds. NACA RM H57E15a, 1957.

70. Gapcynski, John P.; and Carlson, Harry W.: The Aerodynamic Characteristics of a Body in the Two-Dimensional Flow Field of a Circular-Arc Wing at a Mach Number of 2.01. NACA RM L57E14, 1957.

71. Polhamus, Edward C.: Effect of Nose Shape on Subsonic Aerodynamic Characteristics of a Body of Revolution Having a Fineness Ratio of 10.94. NACA RM L57F25, 1957.

72. Pearson, Albin O.: Transonic Investigation of Effects of Spanwise and Chordwise External Store Location and Body Contouring on Aerodynamic Characteristics of 45° Sweptback Wing-Body Configurations. NACA RM L57G17, 1957.

73. Hoffman, Sherwood: Free-Flight Investigation of the Drag of a Model of a 60° Delta-Wing Bomber With Strut-Mounted Siamese Nacelles and Indented Fuselage at Mach Numbers From 0.80 to 1.35. NACA RM L57G29, 1957.

74. Church, James D.: Effects of Components and Various Modifications on the Drag and the Static Stability and Control Characteristics of a 42° Swept-Wing Fighter-Airplane Model at Mach Numbers of 1.60 to 2.50. NACA RM L57K01, 1957.

75. Geier, Douglas J.: An Investigation of Supersonic Store Interference in the Vicinity of a 22° Swept-Wing—Fuselage Configuration at Mach Numbers of 1.61 and 2.01. NACA RM L57L18, 1957.

76. Cook, Martin L.: Static Longitudinal Characteristics of a Semispan Delta-Wing Airplane Model With a Pylon-Mounted 0.500-Scale Model XASM-N-8 Corvus Missile. Aero Rept. 920, David W. Taylor Model Basin, Navy Dept., June 1957.

77. Brindle, C. Carl: Longitudinal Characteristics at Supersonic Speeds of a Winged and a Wingless 0.08-Scale Half Model Sparrow I Missile at Angles of Attack up to 180°. Aero Rept. 931, David W. Taylor Model Basin, Navy Dept., Dec. 1957.

78. Reese, David E., Jr.: A Wind-Tunnel Investigation of Several Wingless Missile Configurations at Supersonic Speeds. NACA RM A57J22, 1958.

79. Gnos, A. Vernon; and Kurkowski, Richard L.: Static Longitudinal and Lateral Stability and Control Characteristics of a Model of a Swept-Wing Fighter-Bomber-Type Airplane With a Top Inlet at Mach Numbers From 1.6 to 2.35. NACA RM A57K20, 1958.

80. Hoffman, Sherwood: Free-Flight Investigation at Mach Numbers From 0.8 to 1.5 of the Effect of a Fuselage Indentation on the Zero-Lift Drag of a 52.5° Sweptback-Wing—Body Configuration With Symmetrically Mounted Stores on the Fuselage. NACA RM L57L04, 1958.

81. Morris, Odell A.: Effects of External Store-Pylon Configuration and Position on the Aerodynamic Characteristics of a 45° Swept Wing-Fuselage Combination at a Mach Number of 1.61. NACA RM L58C13, 1958.

82. Oehman, Waldo I.; and Turner, Kenneth L.: Aerodynamic Characteristics of a 45° Swept-Wing Fighter Airplane Model and Aerodynamic Loads on Adjacent Stores and Missiles at Mach Numbers of 1.57, 1.87, 2.16, and 2.53. NACA RM L58C17, 1958.

83. Robinson, Robert C.: The Effect of Lower Surface Spoilers on the Transonic Trim Change of a Wind-Tunnel Model of a Fighter Airplane Having a Modified Delta Wing. NASA MEMO 12-27-58a, 1959.

84. Hoffman, Sherwood: Free-Flight Investigation of the Drag of a 60° Delta-Wing Configuration With Large Stores Mounted Below the Indented Fuselage at Mach Numbers Between 0.8 and 1.6. NASA MEMO 10-9-58L, 1958.

85. Margolis, Kenneth; Malvestuto, Frank S., Jr.; and Maxie, Peter J., Jr.: Theoretical Calculations of Supersonic Wave Drag at Zero Lift for a Particular Store Arrangement. NACA TN 4120, 1958.

86. Appich, W. H., Jr.; Oehman, Waldo I.; and Gregory, Donald T.: Aerodynamic Characteristics of Three Versions of a Supersonic Airplane Model With a 45° Sweptback Midwing at Mach Numbers of 1.57 and 2.01. NASA MEMO 12-6-58L, 1959.

87. Bielat, Ralph P.: A Transonic Wind-Tunnel Investigation of the Performance and of the Static Stability and Control Characteristics of a Model of a Fighter-Type Airplane Which Embodies Partial Body Indentation. NASA MEMO 12-13-58L, 1959.

88, White. Maurice D.; and Innis, Robert C.: A Flight Investigation of the Low-Speed Handling Qualities of a Tailless Delta-Wing Fighter Airplane. NASA MEMO 4-15-59A, 1959.

89. Carmel, Melvin M.; and Gregory, Donald T.: Preliminary Investigation of the Static Longitudinal and Lateral Stability Characteristics of a Model of a 45° Swept Wing Airplane at Mach Numbers of 1.59, 1.89, and 2.09. NASA MEMO 3-30-59L, 1959.

90. Wornom, Dewey E.: Transonic Aerodynamic Characteristics of a 45° Swept-Wing—Fuselage Model With a Finned and Unfinned Body Pylon-Mounted Beneath the Fuselage or Wing, Including Measurements of Body Loads. NASA MEMO 4-20-59L, 1959.

91. Drougge, Georg (with appendix by Sune B. Berndt and Lars O. A. Hilding): An Experimental Investigation of the Interference Between Bodies of Revolution at Transonic Speeds With Special Reference to the Sonic and Supersonic Area Rules. FFA Rept. 83, Aeron. Res. Inst. Swed., 1959.

92. Pitts, William C.; and Wiggins, Lyle E.: Axial-Force Reduction by Interference Between Jet and Neighboring Afterbody. NASA TN D-332, 1960.

93. Fischetti, Thomas L.; and Eaton, Peter T.: Investigation of the Effects of the Corvus Missile on the A4D-2 Airplane at High Subsonic Speeds. Aero Rept. 987, David W. Taylor Model Basin, Navy Dept, July 1960.

94. Anon.: Aircraft Bombs, Fuzes and Associated Components. NAVWEPS OP 2216, Vol. 1, Dept. Navy, Aug. 1, 1960.

95. Pivirotto, Thomas J.: Aerodynamic Test of the 0.16-Scale Model of the Hughes Model 50 Missile. WT 20-355, Jet Propulsion Lab., California Inst. Technol., Aug. 21, 1960.

96. Brown, A. E.; deLancey, L. M.; and Meeker, R. E.: Studies of the Sidewinder 1C Aeromechanics - Part 1. Aerodynamics NAVWEPS Rept. 6596, Pt. 1, U.S. Naval Ord. Test Station, Oct. 24, 1960.

97. Fischetti, Thomas L.; and Eaton, Peter T.: Wind-Tunnel Investigation of the Effects of Externally Installed Missiles on an Aircraft Configuration at High Subsonic Speeds. Aero Rept. 995, David W. Taylor Model Basin, Navy Dept., Dec. 1960.

98. Luoma, Arvo A.: Transonic Wind-Tunnel Investigation of the Static Longitudinal Stability and Performance Characteristics of a Supersonic Fighter-Bomber Airplane. NASA TM X-513, 1961.

99. Robinson, Ross B.; and Spearman, M. Leroy: Static Lateral and Directional Stability and Control Characteristics of a 1/40-Scale Model of a 60° Delta Wing Bomber Configuration at a Mach Number of 1.99. NASA TM X-537, 1961.

100. Bielat, Ralph P.; and Robins, A. Warner: Stability and Control Characteristics at Transonic Speeds of Two Variable-Sweep Airplane Configurations Differing in Wing-Pivot Locations. NASA TM X-559, 1961.

101. Luoma, Arvo A.: Transonic Wind-Tunnel Investigation of the Static Stability and Control Characteristics of a Supersonic Fighter-Bomber Airplane. NASA TM X-591, 1961.

102. Brindle, C. Carl: Wind-Tunnel Investigation of the Drag Characteristics of a Pylon-Mounted Missile. Aero Rept. 1010, David W. Taylor Model Basin, Navy Dept., June 1961.

103. Eaton, Peter T.: Wind-Tunnel Investigation of the Effects of Multiple External Stores on the Longitudinal Aerodynamic Characteristics of the Douglas A4D Airplane. Aero Rept. 1009, David W. Taylor Model Basin, Navy Dept., Sept. 1961.

104. Brindle, C. Carl: Wind-Tunnel Investigation of External Store Arrangements To Reduce Wave Drag. Aero Rept. 1016, David W. Taylor Model Basin, Navy Dept., Nov. 1961.

105. Landrum, Emma Jean: Static Lateral and Directional Stability and Control Characteristics of a 1/40-Scale Model of a 60° Delta Wing Bomber Configuration at a Mach Number of 1.61. NASA TM X-748, 1963.

106. Foster, Gerald V.; and Kyle, Robert G.: Aerodynamic Characteristics of a 1/22-Scale Model of a Fighter Airplane With an Extended Forebody and Other Modifications at Mach Numbers of 1.57 and 2.01. NASA TM X-833, 1963.

107. Eaton, Peter T.; and Swinney, Charles S.: Incremental Lift and Drag of an External Aircraft Store - Phase I. Test Rept. AL 20, David Taylor Model Basin, Dept. Navy, July 1965.

108. Shaw, David S.; and Babb, C. Donald: Supersonic Investigation of the Static Stability, Performance, and Control of a Variable-Sweep Tactical Fighter Model - Phase 4. NASA TM X-1143, 1966.

109. Ferris, James C.: Effects of External Stores on Performance and Stability of a Supersonic Fighter-Bomber Airplane. NASA TM X-1218, 1966.

110. Ayers, Theodore G.: Transonic Aerodynamic Characteristics of a Variable-Wing-Sweep Tactical Fighter Model - Phase 4. NASA TM X-1237, 1966.

111. Landrum, Emma Jean: Effect of Nacelle Orientation on the Aerodynamic Characteristics of an Arrow Wing-Body Configuration at Mach Number 2.03. NASA TN D-3284, 1966.

112. Norris, John D.; and McGhee, Robert J.: Effects of Bluntness on the Subsonic Drag of an Elliptical Forebody. NASA TN D-3388, 1966.

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				
53				
54				
57				
66				
72				
75				
81				
97				
100				
104				
107				
108				
109				

CLEAN CONFIGURATION

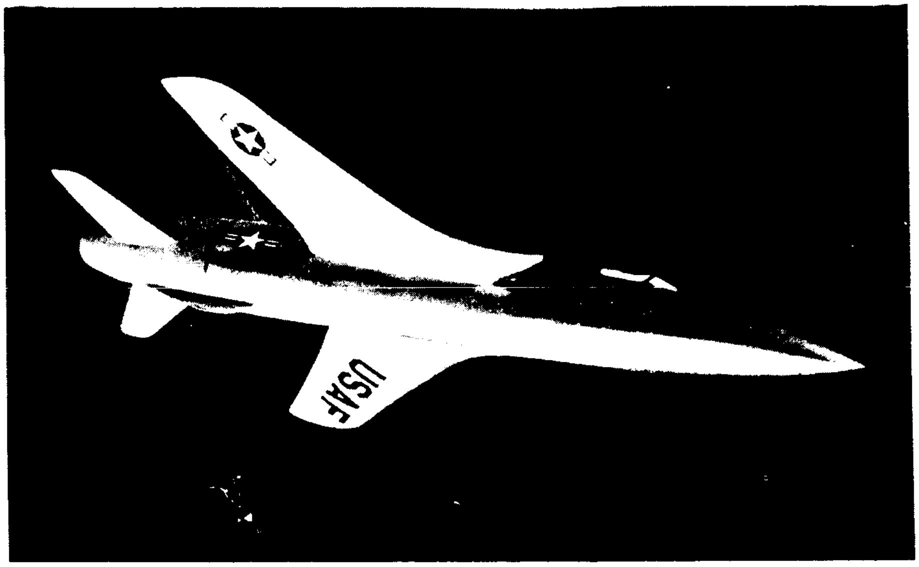

Figure 1 L-2694-1

CONFIGURATION WITH STORES

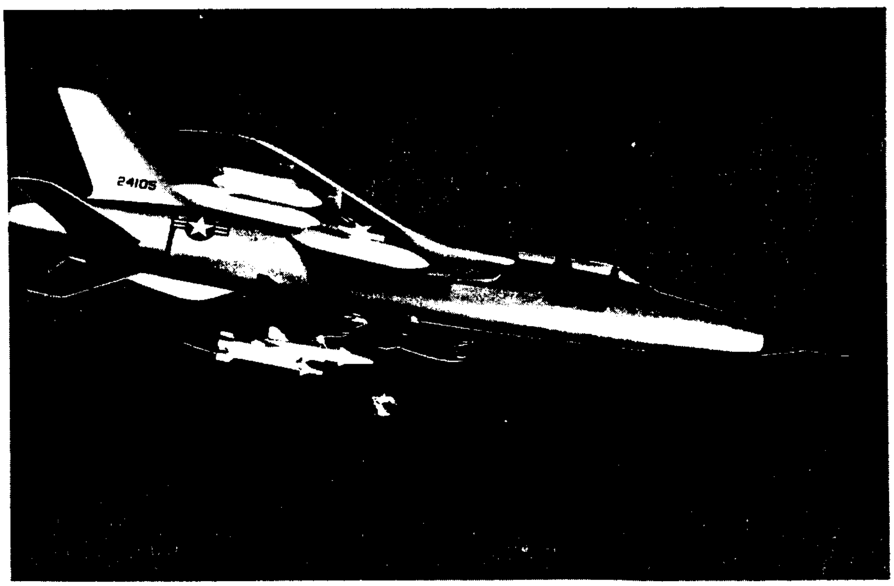

Figure 2 L-2694-8

ANALYSIS AND CORRELATION

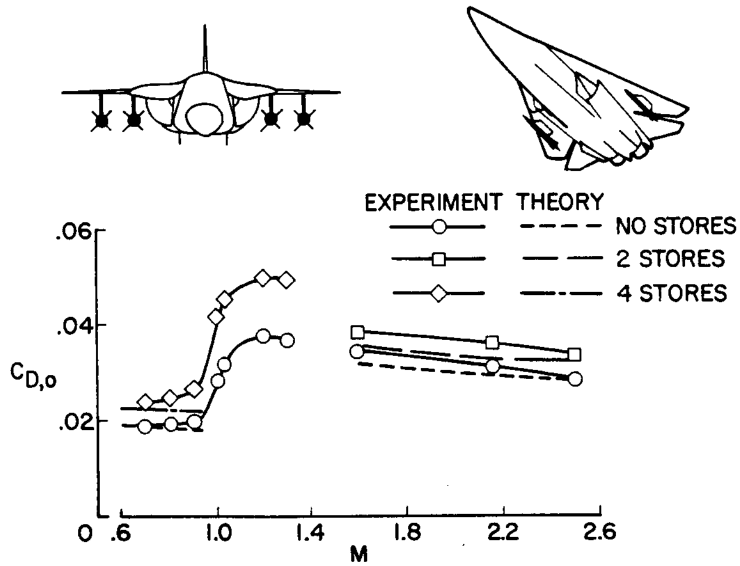

Figure 3

INCREMENTAL STORE-INSTALLATION DRAG
SUBSONIC

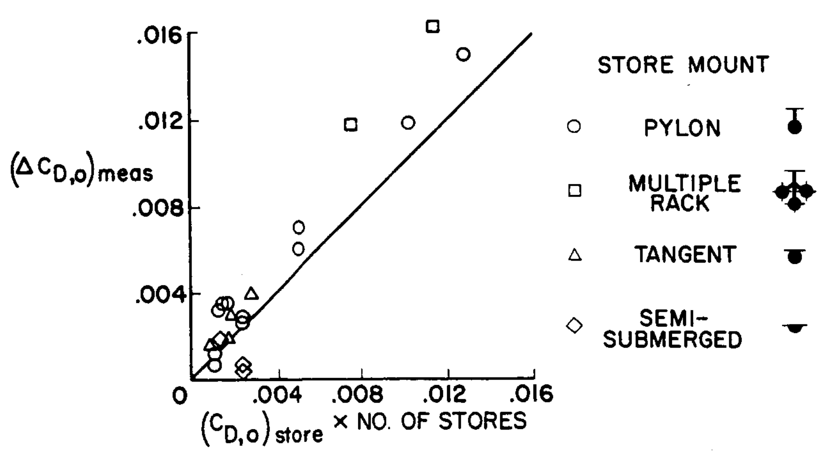

Figure 4

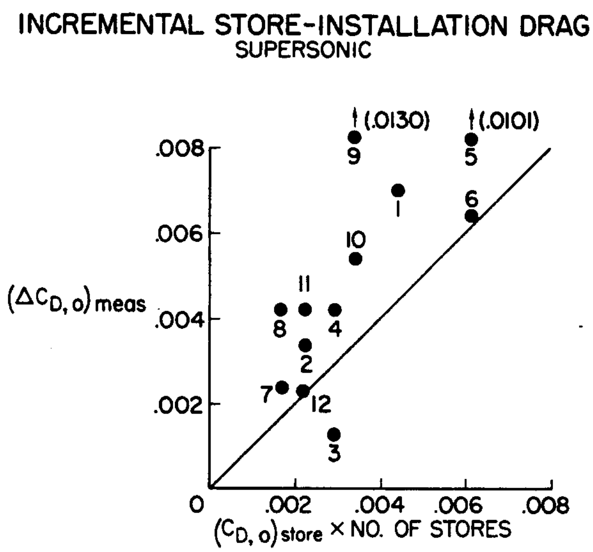
INCREMENTAL STORE-INSTALLATION DRAG
SUPERSONIC
(.0130)
(.0101)
.008
.006
.004
.002
0
.002
.004
.006
.008
$(\Delta C_{D,o})_{meas}$
$(C_{D,o})_{store}$ × NO. OF STORES
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5

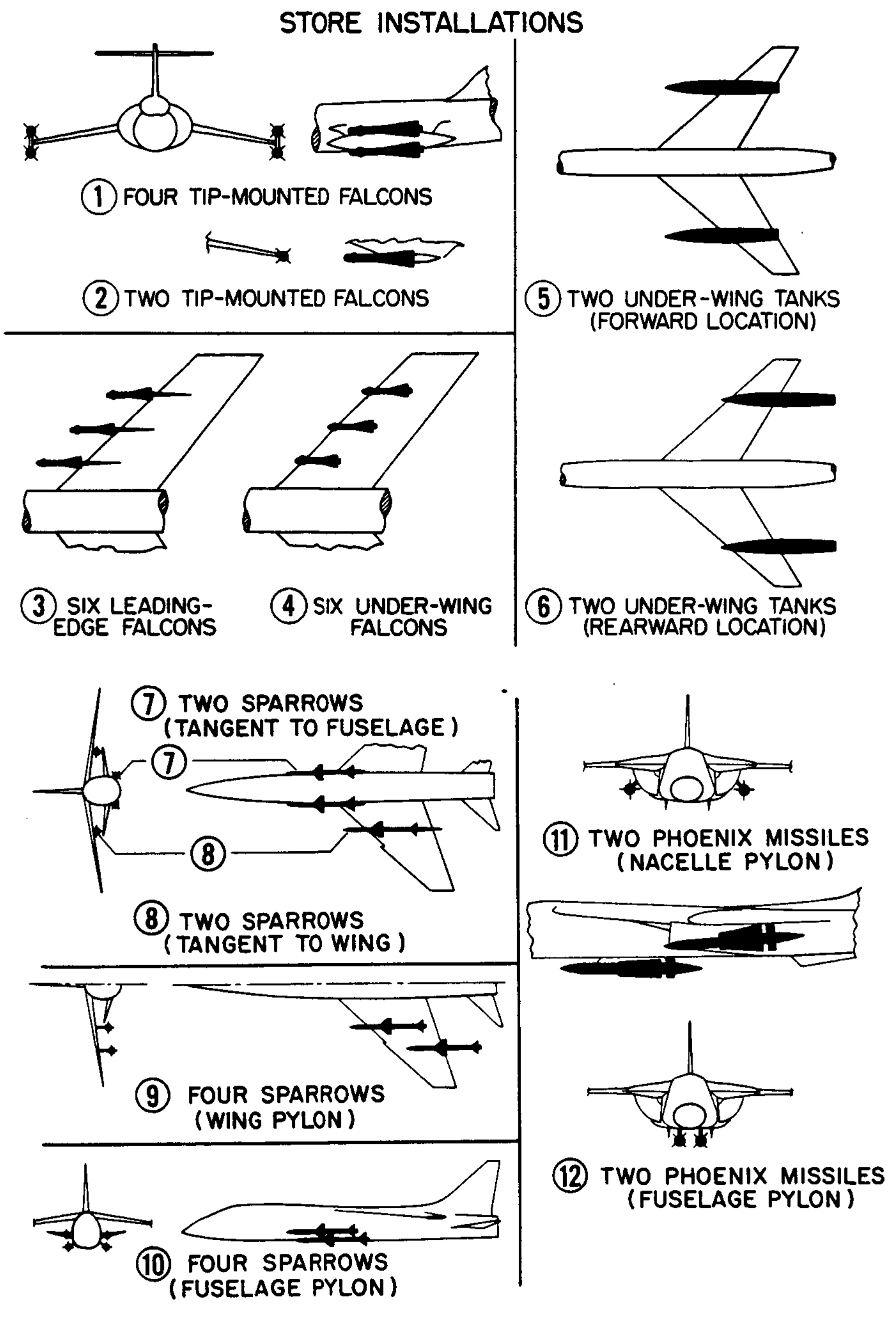
STORE INSTALLATIONS
1 FOUR TIP-MOUNTED FALCONS
2 TWO TIP-MOUNTED FALCONS
5 TWO UNDER-WING TANKS (FORWARD LOCATION)
3 SIX LEADING-EDGE FALCONS
4 SIX UNDER-WING FALCONS
6 TWO UNDER-WING TANKS (REARWARD LOCATION)
7 TWO SPARROWS (TANGENT TO FUSELAGE)
7
8
8 TWO SPARROWS (TANGENT TO WING)
11 TWO PHOENIX MISSILES (NACELLE PYLON)
9 FOUR SPARROWS (WING PYLON)
12 TWO PHOENIX MISSILES (FUSELAGE PYLON)
10 FOUR SPARROWS (FUSELAGE PYLON)

Figure 6

TANGENT AND PYLON INSTALLATIONS

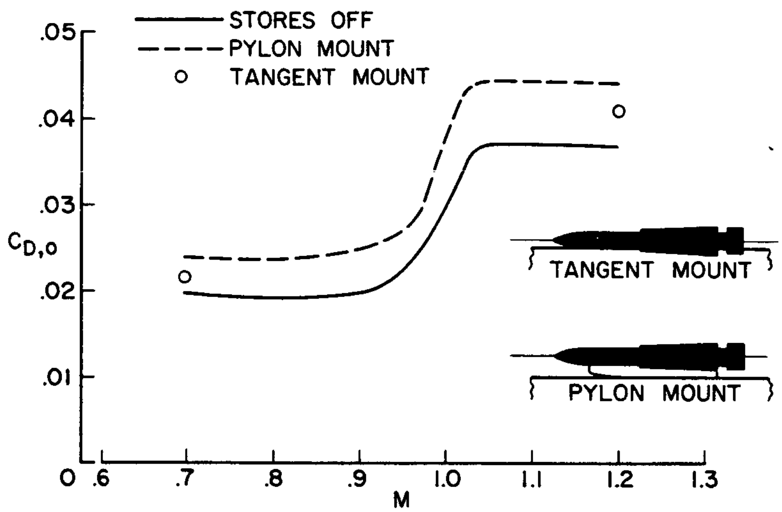

Figure 7

SEMISUBMERGED STORE INSTALLATION

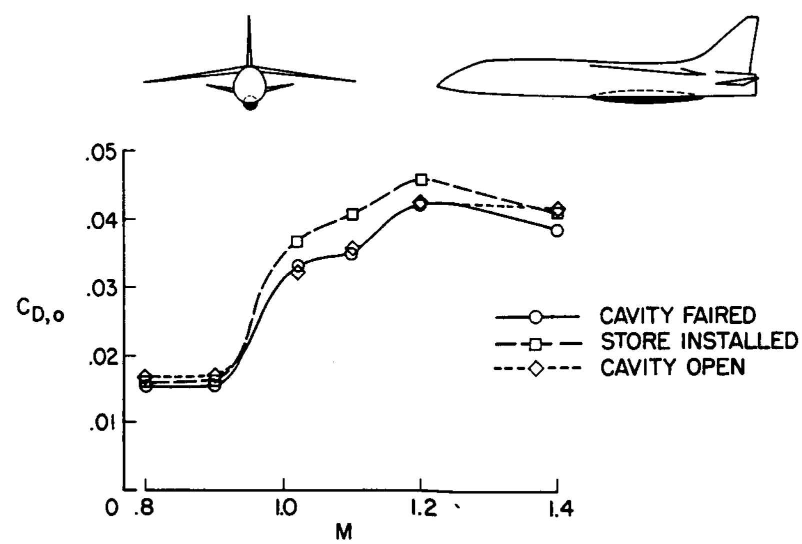

Figure 8

TANDEM STORE INSTALLATION

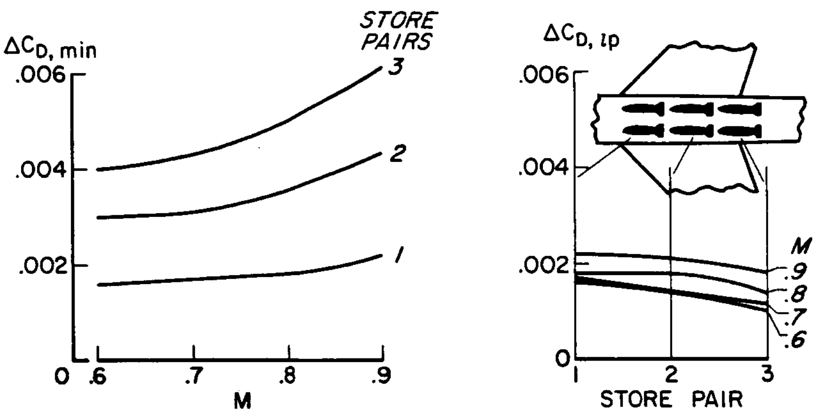

Figure 9

EFFECTS OF STORE CORNER RADIUS

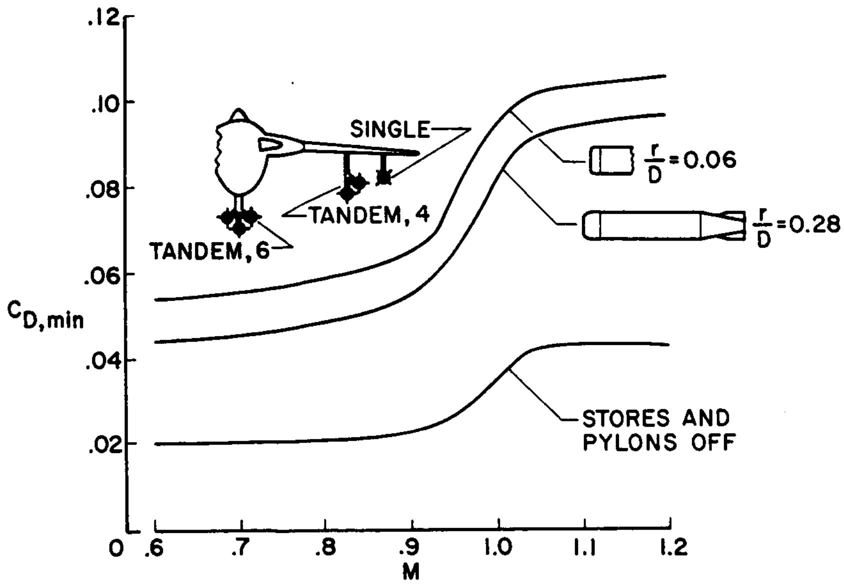

Figure 10