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EXTERNAL STORE AIRLOADS PREDICTION TECHNIQUE

VOLUME II. DETAILED DATA

BOOK 1. INITIAL AIRLOADS PREDICTION

VOUGHT SYSTEMS DIVISION
LTV AEROSPACE CORPORATION
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JULY 1975

FINAL REPORT: JANUARY 1973 - JUNE 1975

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Presented is an empirical method to compute six-component captive store airloads for single and multiple carriage store configurations for an arbitrary aircraft. The method has the capability for computing the basic airload and the incremental airloads due to aircraft yaw and adjacent store interference. The single carriage method was developed for the Mach range 0.5 to 2.0 while the multiple carriage method is valid for the Mach range 0.5 to 1.6. Both single and multiple carriage methods were developed for the angle of attack range -4 to +12 degrees,

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and the aircraft yaw angle range -8 + 8 degrees. Comparisons between predicted and experimental data show generally good agreement. The report is presented in two volumes. Volume I is the technical summary report describing the program and approach used to develop the prediction technique. Volume II, the user's manual, consists of five books.

SUMMARY

This report (Volume II) presents in handbook form a method to predict six-component captive store airloads for both single and multiple carriage configurations including the basic airload and the incremental airloads due to aircraft yaw and adjacent store interference.

The approach used to develop the prediction technique was an empirical correlation of a large experimentally derived data base and is discussed in detail in the technical summary report, Volume I of this document.

The handbook is organized as follows:

Initial Airloads Prediction-Section II	(Volume 2, Book 1)
Single Carriage-Section III	(Volume 2, Books 1-2)
MER Carriage-Section IV	(Volume 2, Books 3-5)
TER Carriage-Section V	(Volume 2, Book 5)
Other Configurations-Section VI	(Volume 2, Book 5)

Section II outlines the initial airloads prediction procedure for both single and multiple carriage configurations. Final captive store airloads predictions for single, MER, and TER configurations are presented in Sections III, IV, and V, respectively. Section VI contains recommendations for applying the results contained in this handbook to configurations for which the prediction methods do not directly apply and to configurations that may arise in the future due to new carriage rack designs.

The ranges of Mach numbers, angles of attack, and aircraft yaw angles over which the method is applicable are as follows.

	Mach number	α, degrees	ψ, degrees
Single Carriage	0.5 - 2.0	-4/12	-8/8
Multiple Carriage	0.5 - 1.6	-4/12	-8/8

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PREFACE

This report was prepared under the sponsorship of the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida, under Contract Number F08635-73-C-0070 (Project No. FY7621-72-2G001). The cognizant Air Force technical monitors on the program were Messrs. Robert A. Hume Jr. and Charlie D. Turner, Jr. The work was performed by Vought Systems Division of LTV Aerospace Corporation, P. O. Box 5907, Dallas, Texas 75222. Principal investigator for this program was R. D. Callaher. Principal technical personnel were: A. R. Rudnicki, Jr, E. G. Waggoner, Jr., and C. T. Alexander. This effort was conducted during the periods from 8 January 1973 to 30 June 1975.

This report consists of two volumes. Volume I, the technical summary, describes the program and approach used to develop the prediction technique. Volume II, the user's manual, consists of five books. This is Volume II.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

WILLIAM F. BROCKMAN, Colonel, USAF
Chief, Munitions Division

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SECTION I

INTRODUCTION

The purpose of this handbook is to provide the aerodynamicist, the armament design engineer, and others associated with aircraft/stores compatibility problems a technique for calculating captive airloads for individual stores carried singularly or in multiple arrangements over a broad range of flight conditions for a generalized aircraft/store configuration.

Because there are many parameters that affect captive store loads, any prediction technique capable of including even the dominant factors will be lengthy. The technique presented here provides data to include these dominant factors, but the procedure is outlined in a systematic manner to facilitate a simple step-by-step approach to predicting captive store airloads. A description of the derivation of this method is given in the technical summary report, Volume I.

The developed prediction method for single carriage configurations is valid over the Mach number range 0.5 to 2.0 while the method for multiple carriage covers the Mach number range 0.5 to 1.6. Both single and multiple carriage techniques apply over an angle of attack range of -4 to 12 degrees and for an aircraft yaw angle range of ±8 degrees. Provisions are included in the prediction techniques for both single and multiple carriage stores to encompass the effects of store spanwise, chordwise, and vertical position beneath the subject aircraft wing. Parameters are also included to account for aircraft wing sweep angle (quarter-chord sweep angles of 30 to 60 degrees) and the interference effect of the aircraft fuselage for high wing aircraft. The single carriage prediction technique has been developed for wing-mounted stores due to the absence of sufficient single carriage data for fuselage-mounted stores; however, Section VI contains some suggestions for predicting the single carriage fuselage centerline case. The MER/TER prediction technique is based on a fully loaded rack for similar reasons. Suggestions for predicting the airloads on other multiple configurations are included in Section VI. The techniques were developed predominately from a finned store data base and a degradation in accuracy for unfinned stores can be expected, particularly when computing moment terms.

Development of the prediction technique was approached as an empirical correlation of existing individual store airloads data combined with parametric-type wind tunnel data obtained through a test program specifically designed to compliment the existing airloads data. The data were combined to form the basis for the empirical correlation. The data forming the empirical base for the prediction technique were obtained with the stores in a 2° nose down attitude with respect to the aircraft wing chord plane. The accuracy of the predictions contained in this handbook will be affected if the store/wing relationship is significantly different (2° or more). Predictions contained in this handbook are based on aircraft waterline angle of attack.

Analysis of the data base indicated that each component could be satisfactorily approximated by a linear curve over a large range of aircraft angle of attack and yaw angle. As a result, the data base was linearized so that each airload component could be expressed as a slope (force or moment as a function of angle of attack) and an intercept at zero angle of attack. As a result of the linearized data base, all predictions are accomplished in the form of a predicted slope and intercept for each of the airload components. Because of increasing non-linearity at the larger aircraft angles of attack and yaw angles, significant errors are likely outside the range of applicability indicated for these variables.

The basic approach involves the concept that captive store airloads are the result of exposure to a flow field represented by free stream conditions plus the interference effect of the aircraft, suspension equipment, and other stores. In this way, work that has been previously accomplished in the area of free stream aerodynamic predictions can be used as a base upon which to relate captive store aerodynamics. This permits the prediction procedure to be a summation process as indicated below.

Captive Store Airloads = Isolated Store Airloads + Interference Effects

In order to predict the captive airloads on the aircraft/store configuration, a starting point is required. The starting point is called the initial prediction. It is so called because it involves assuming the store is in the flow-field of a base wing (45° sweep) configuration at a specific spanwise, chordwise, and vertical location. The final prediction then applies empirical corrections to the initial prediction to compensate for differences between the subject aircraft configuration on the base wing as well as to account for the effect of the store being in the spanwise, chordwise, and vertical location of interest. Figure 1 illustrates this approach.

The initial prediction of the captive airload is always made at M = 0.5 by assuming the store is inserted into the flow-field of the base wing (45° sweep). The initial predictions of the slope for side force, yawing moment, normal force and pitching moment at M = 0.5 are the result of a summation procedure along the store length when placed in the wing flow-field. The details of this initial prediction procedure are presented in Section II. The axial force and rolling moment initial predictions are made using a different approach which is also discussed in Section II.

The summation procedure is used to make the initial prediction for the basic airload case (i.e., the captive store airload generated by a zero-yaw pitch excursion of the parent aircraft). The incremental captive airloads due to aircraft yaw and the effects of adjacent store interference are predicted as increments to be added to the basic airload. The effects of Mach number are treated as an increment to be added to the prediction at

M = 0.5. At a particular Mach number the total captive airload experienced by a store can be obtained from the following generalized coefficient expression:

$$C_{x_{TOTAL}} = C_{x_{BASIC}} + \Delta C_{x_\beta} \cdot \beta + \Delta C_{x_{INTF}}$$

where:

x - y, n, N, m, A, ℓ representing side force, yawing moment, normal force, pitching moment, axial force, and rolling moment, respectively.

$C_{x_{BASIC}}$ - Basic captive airload generated by a zero yaw pitch excursion of the parent aircraft.

C_{x_β} - Incremental airload due to aircraft yaw per degree store yaw angle, β.

β - Store yaw angle equal to $\psi_{A/C}$ for a right wing store installation and $-\psi_{A/C}$ for a left wing store installation.

$\Delta C_{x_{INTF}}$ - Incremental airload due to the effects of adjacent store interference.

Empirical corrections have been derived from the data base to account for the effects of spanwise, chordwise, and vertical position of the captive store. Corrections are also included for other variables. The final predictions resulting from the combination of the initial predictions (Section II) with the empirical corrections are presented in the sections listed below.

Single Carriage - Section III
MER Carriage - Section IV
TER Carriage - Section V.

Additionally, recommendations for treatment of configurations not conforming directly to the single/MER/TER rack designs outlined in detail in this handbook are presented in Section VI to provide additional versatility.

Figure 2 presents a guide in flow chart form which is to be followed when performing a computation for a desired store loading type.

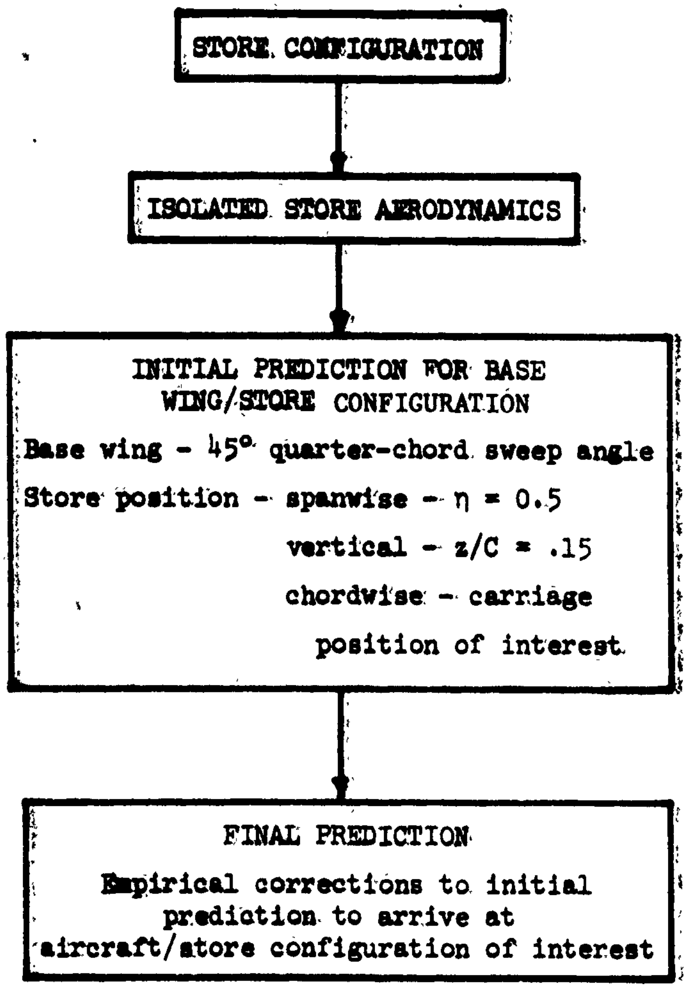


Figure 1. Captive Airloads Prediction Procedure

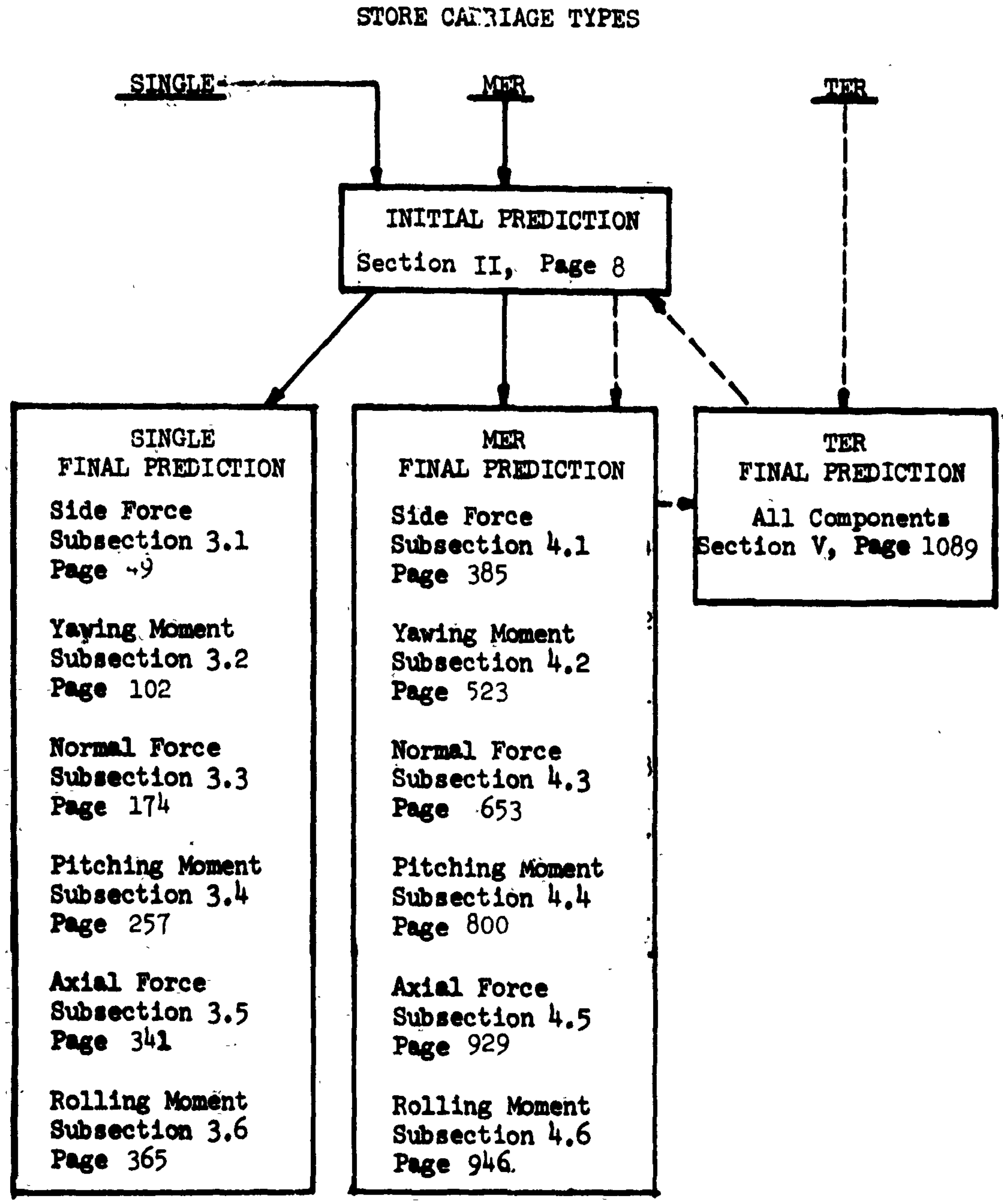


Figure 2. Flowchart for Captive Airloads Prediction

SECTION II

INITIAL AIRLOADS PREDICTION

The basic technique used in the prediction of individual store captive airloads involves an initial captive airloads prediction for the subject store. This initial prediction is then corrected for the influencing parameters of the store/aircraft configuration by various factors and increments, yielding the final airloads prediction. Detailed descriptions of the initial airloads prediction methods are included within this section.

The methods used for the initial predictions of the force and moment components acting on an installed store can be separated into three categories depending on the airload component being considered. These categories result because of the different basic approaches used in the correlation development for the initial airload predictions. The principal category encompasses the approach used for prediction of the variation in normal force, side force, pitching moment, and yawing moment with angle of attack. The two remaining categories include the separate approaches to the initial prediction of axial force and rolling moment components. Included in this section is a thorough discussion of each approach; however, an overview of each approach is presented before the technical details are discussed.

Initial predictions for captive normal force, side force, pitching moment, and yawing moment use isolated store characteristics as a base. These are predicted using Reference 1. This prediction method accurately predicts lift characteristics of wing/body combinations. Through this method, the aerodynamic characteristics of the individual components (wing, body, nose) of the store are predicted, including the mutual interference effects. Hence, it is possible to determine the relative lifting effectiveness of the store components as well as the lift characteristics of the total store in a uniform flow-field.

Once the isolated characteristics and relative lifting effectiveness of the store system have been determined, the initial captive airloads can be predicted. The subject store is then assumed to be immersed in the flow-field of the base wing (45° sweep) at the mid-semispan location. Longitudinally, the store is placed in the same location as the actual captive store and the local wing chord is assumed to be the same length as the chord at the captive position. Knowing the flow-field characteristics of the base wing presented in Reference 4, and the relative lift effectiveness of the store components, a quasi-integration yields the initial prediction.

Throughout this report fin and wing are used interchangeably in reference to store lifting surfaces. When referring to aircraft wings, an attempt has been made to adequately distinguish the aircraft wing to avoid confusion.

Included in Reference 2 is a method which is used to predict isolated store drag characteristics. Through estimating store skin friction drag, wave drag, and base pressure drag a prediction of store axial force at zero store lift is made. Skin friction drag is estimated as a function of Mach number, Reynolds number, and store wetted area. Using the skin friction drag and the ratio of base diameter to maximum body diameter, an estimate of the base pressure drag is made. Body shape and Mach number are used to estimate wave drag. This prediction for the isolated store is used along with an interference increment due to installing the store in the captive location as an initial prediction of installed store axial force at $\alpha=0$.

Isolated store data are not used in the prediction of captive store rolling moment. Detailed examination of available captive store airloads data showed that captive rolling moment was primarily a function of the total fin area of the subject store. A technique was developed to initially predict rolling moment variation with angle of attack and the value at $\alpha=0$ using only fin area of the installed store.

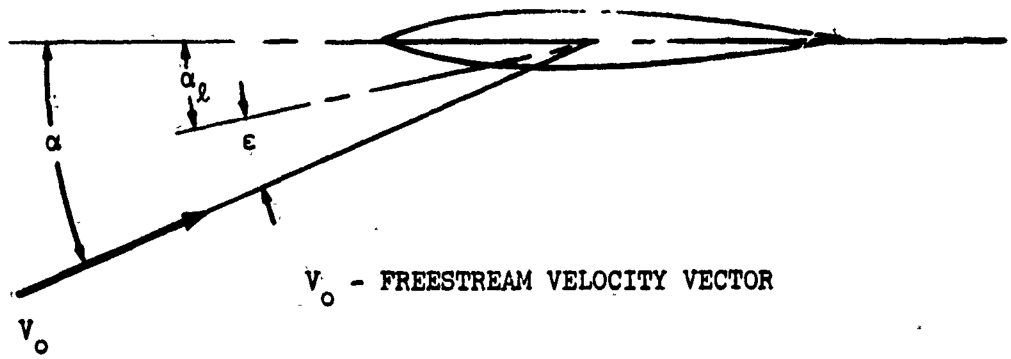
The following subsections delineate each of the parameters used in making the initial predictions for the force and moment components acting on an installed store. These include aircraft flow-field information, isolated store characteristics and geometric considerations, and the detailed force and moment calculation procedures.

2.1 AIRCRAFT FLOW-FIELD CHARACTERISTICS

The aircraft flow-field data used in the initial force and moment prediction were obtained from Reference 4. Experimental sidewash and downwash data at various angles of attack are presented as a function of chordwise position at constant spanwise locations and distances below the 45° swept wing. Before proceeding further, definitions of sidewash and local angle of attack, which are the primary flow ungularity terms used in the prediction method, are necessary. Sidewash, σ, is defined as the difference between local sidewash angle, β_ℓ, and sideslip angle, β, positive for outboard flow. Local angle of attack, α_ℓ, is defined as the difference between wing geometric angle of attack, α, and local downwash, ε, positive for the wing chord plane leading edge deflected upward relative to the resultant flow angularity α_ℓ (see Figure 3).

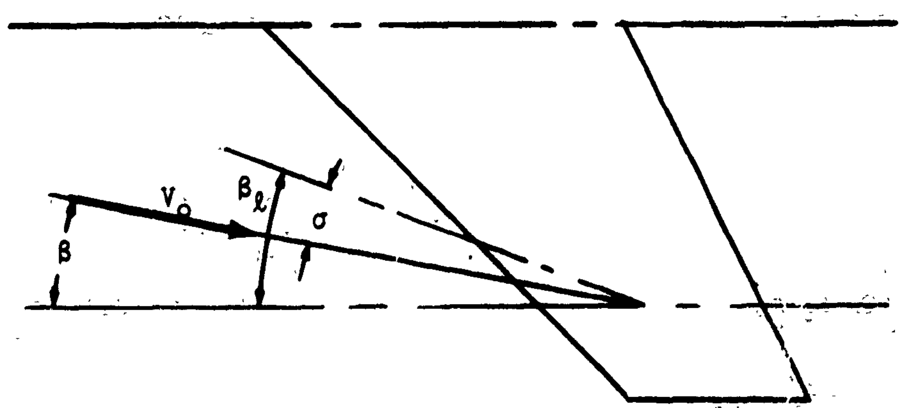
The data from Reference 4 were analyzed to determine the variation of α_ℓ and σ with angle of attack. These data are presented as a function of local chord in Figures 4 and 5. Subsection 2.3 shows the manner in which these terms are used in the initial predictions. As these angularity data were used as a base for all the correlations, for consistency these data should also be used when attempting to use the method although more definitive data on the subject aircraft flow-field may be available.

WING LONGITUDINAL PLANE



V_o - FREESTREAM VELOCITY VECTOR

WING LATERAL PLANE



V_o - FREESTREAM VELOCITY VECTOR

Figure 3. Flow Angularity Definitions for an Aircraft/Store Combination

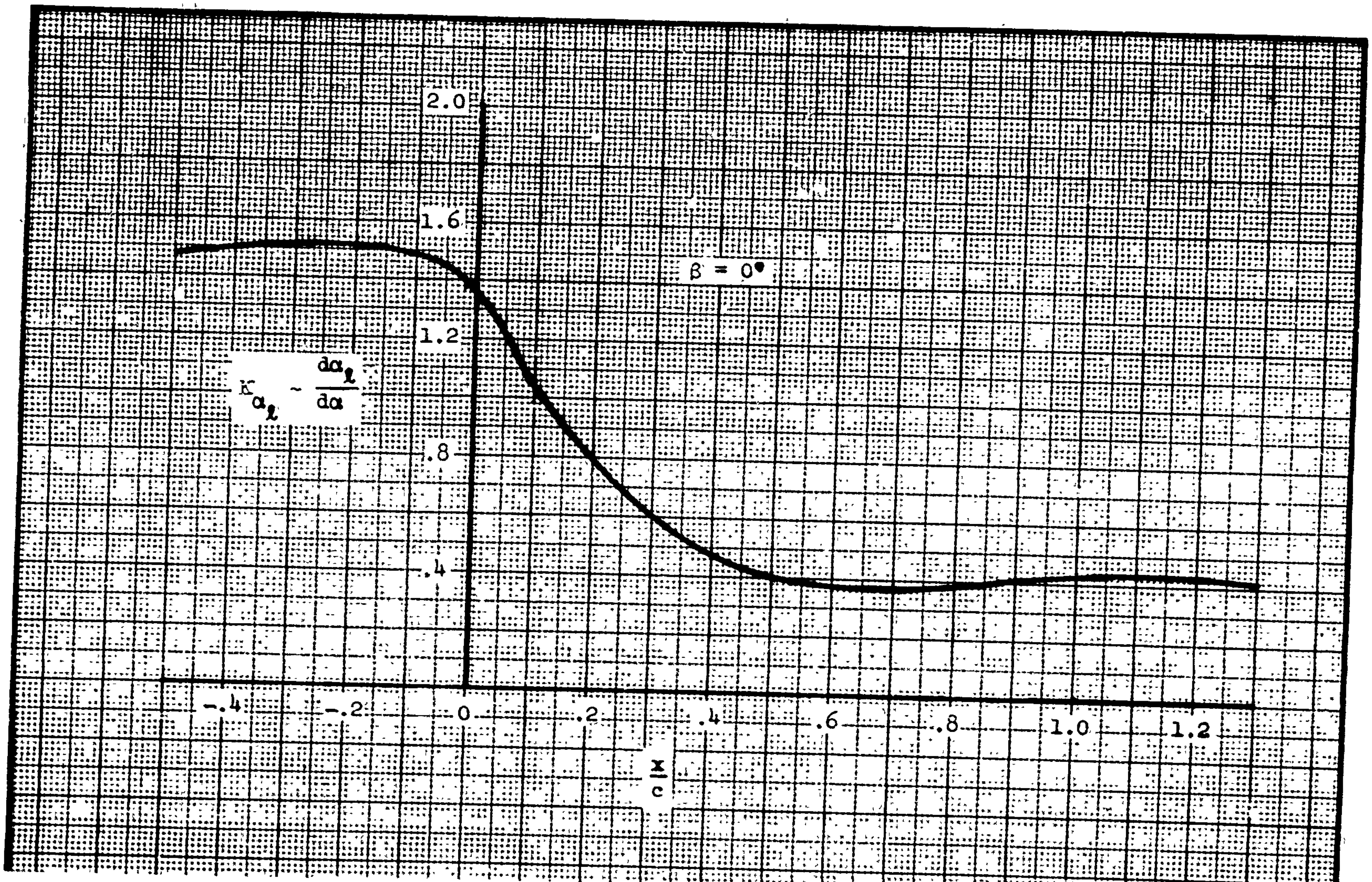


Figure 4. Variation of α_ℓ with α for a 45° Swept Wing

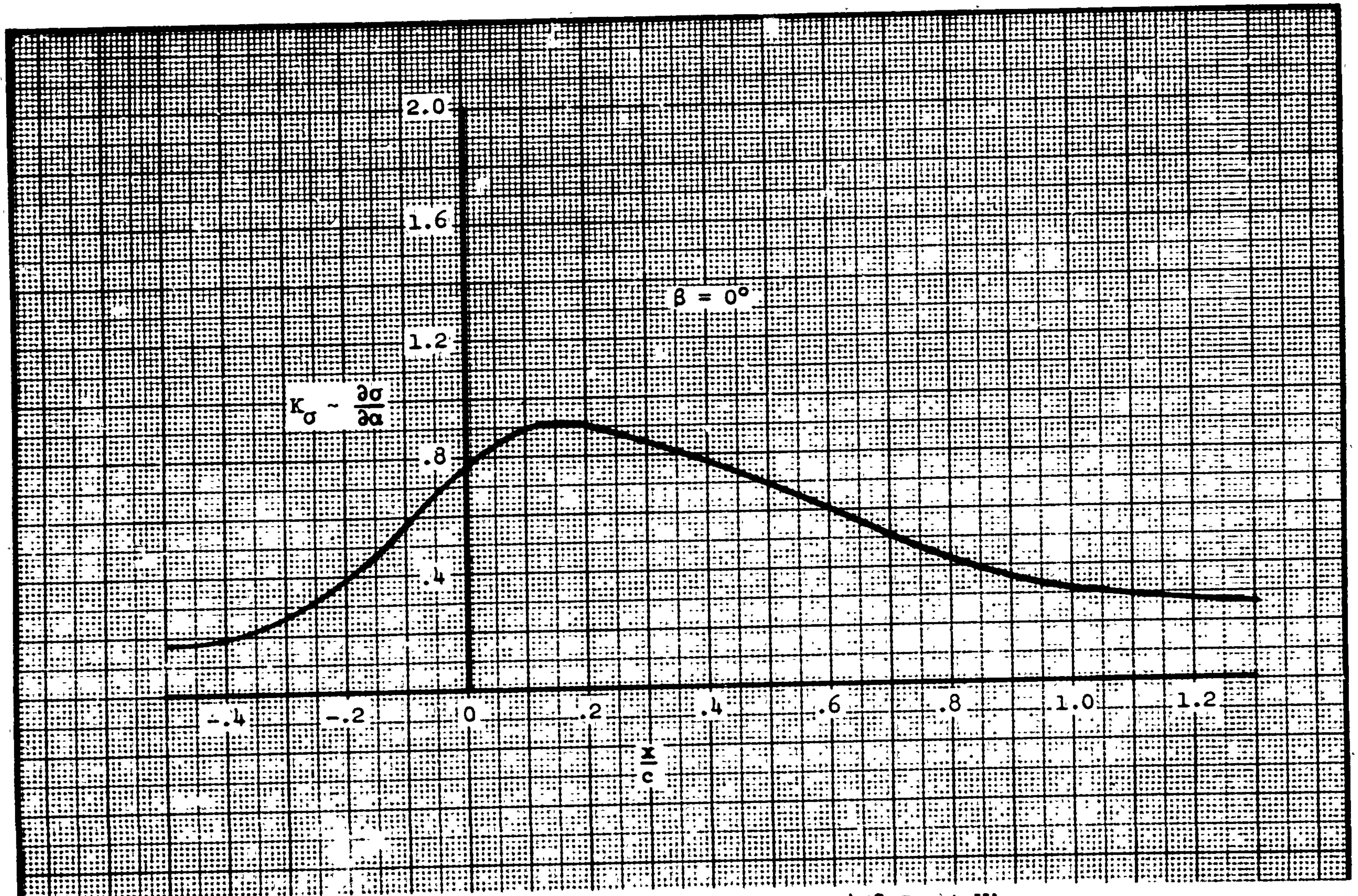


Figure 5. Variation of σ with α for a 45° Swept Wing

2.2 STORE CHARACTERISTICS

2.2.1 Isolated Store Airloads Prediction

Initial prediction of the captive store force and moment components are based on two isolated store airloads prediction techniques, Reference 1 and Reference 2. Although various isolated store prediction techniques are available, these two define parameters within the computational procedure which lend themselves to the calculation of store airloads in a non-uniform flow-field. The initial prediction of captive store, normal store, side force, pitching moment, and yawing moment is based on the isolated store airload prediction technique presented in Reference 1. Included in Reference 2 is a technique to predict drag at zero lift for an isolated store. This estimate is then used in the initial prediction of captive store axial force at $\alpha=0$. Each isolated store prediction technique is discussed in this section; however, a more detailed description of each method is included in References 1 and 2. The application of each of these methods to the initial prediction is presented in Subsection 2.3.

Presented in Reference 1 is a method for calculating lift and center of pressure characteristics of circular cylindrical bodies in combination with triangular, rectangular, or trapezoidal wings and/or tails. The method is valid through the subsonic, transonic, and supersonic speed ranges. Detailed geometric data and wing/fin lift characteristics are necessary inputs. For consistency, Reference 3 should be used to provide the isolated wing aerodynamic data inputs to Reference 1. The geometry of the wings for which Reference 3 is applicable is limited only to the extent that they must be symmetric about the root chord, have a straight quarter chord over the semispan and have no discontinuities in twist. Within Reference 1, factors are defined which are ratios of the lift of the various components of the store system (wing, body, nose) to the lift of the wing alone. These ratios, obtained primarily by slender-body theory, are used in establishing the wing-body interference. A method is also provided to account for wing-tail interference. A simplified version of the total calculation procedure is presented in chart form in the referenced report which reduces the calculation to routine procedures. Experimental isolated store data may be used when available and are advisable when the store geometry differs considerably from geometry for which the calculation method was developed.

Reference 2 presents a method which may be used to calculate axial force at zero lift for a wing-body combination. This is basically a simplified method consisting of a summation of the individual drag contributions of the body, wings, and tails. Each drag contribution is composed of skin friction drag and wave drag. In addition, a term is added to account for base pressure drag on the body. Acceptable correlations of predicted data have been achieved for the Mach range over which this method is valid. However, isolated store experimental data are recommended for use if such data are available.

2.2.2 Store Planform Projected Area

The calculation procedure for determining the initial airloads acting on the captive store incorporates store area distribution as a primary factor. Definition of the store area distribution influence is achieved through a summation procedure in which the store is divided into various segments of constant length and the area distributions of these segments are calculated. In addition, the areas are separated into nose, body, and wing components. A sketch identifying the typical segmentation of a 300-gallon tank is shown in Figure 6, along with designations of the various area components. The calculation procedure is performed for the area distribution in one of two planes according to the airload component in question. The paragraphs below describe the area distribution calculation for single and multiple carriage in each of the two planes.

Plan projected area (PPA) is defined as the planform area of the installed store projected into the X_B, Y_B plane. In the initial prediction of both normal force and pitching moment, plan projected area is used in the summation procedure. It merits mentioning at this point that for stores whose wings are in an 'X' configuration some of the body area is shadowed or blocked out by the wings and should not be included. Both multiple and single carriage stores are calculated in a similar manner. Table 1 presents data on a 300-gallon tank installed on the A-7 center pylon. Note that the projected areas of each component (nose, body, wing) are calculated individually. These data are for area segments which are a constant 25 inches in length, as shown in Figure 6. Detailed information concerning the segmentation is provided in Subsection 2.3.2.

Side projected area (SPA) is defined as the planform area of the installed store projected into the X_B, Z_B plane. In the initial prediction of both side force and yawing moment, side projected area is used in the summation procedure. As in the case for plan projected area, some of the body area is shadowed when the store is installed with wings in an 'X' configuration. For multiple stores, the rack centerline stores are used for the initial prediction for both centerline and shoulder stores. In this case, the exposed side projected area is used in the calculation. This area is defined as that part of the centerline store not shadowed in the X_B, Z_B plane by another store on the multiple installation (see Figure 7). A comparison of the side projected area and exposed side projected area for a M117 carried on a MER centerline position is presented in Table 2.

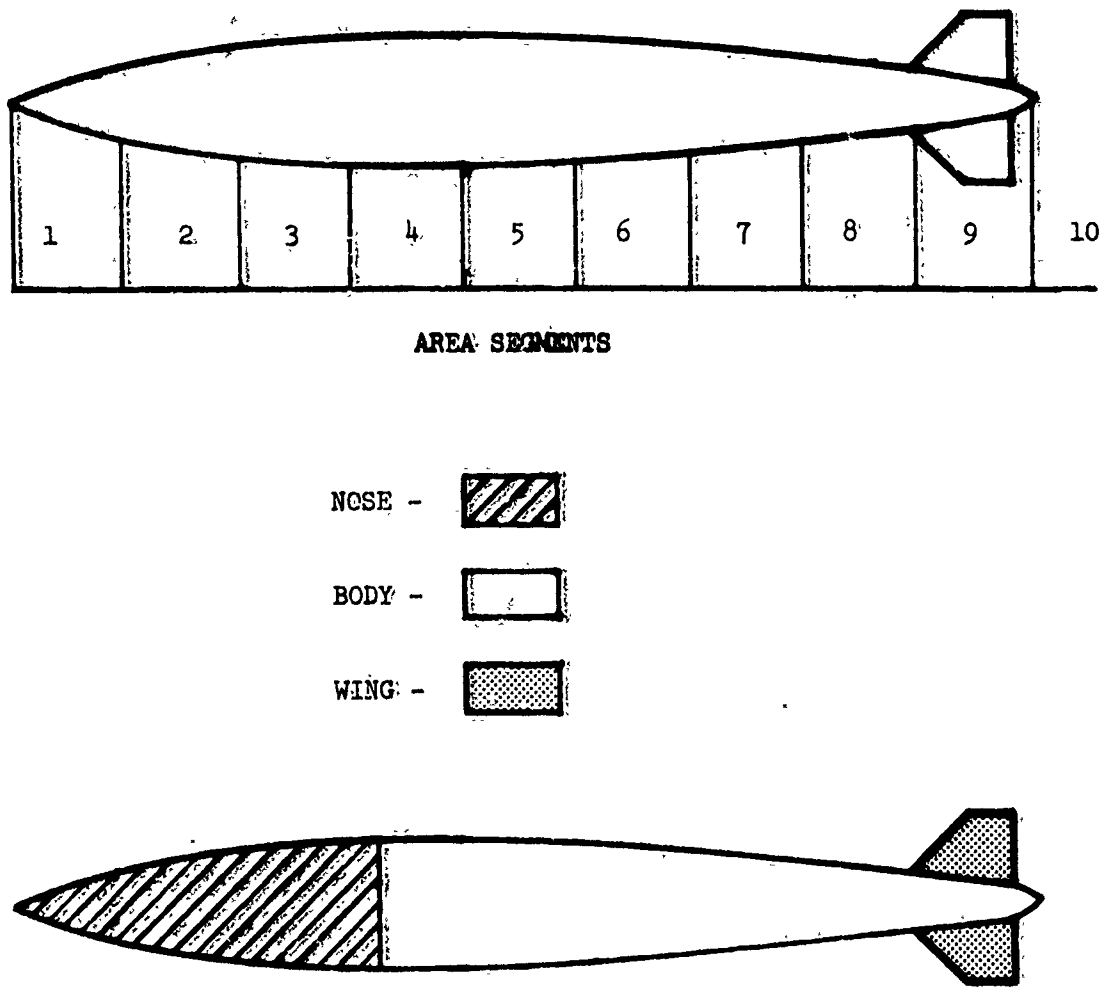


Figure 6. Area Segments for a Typical Store

TABLE 1. AREA SEGMENTATION FOR A 300-GALLON TANK

AREA SEGMENT	PPA or SPA (in.^{2})
1N	292.0
2N	548.0
3N	648.0
4N	142.0
4B	520.0
5B	662.0
6B	620.0
7B	531.0
8B	393.0
8W	4.5
9B	203.0
9W	443.0
10B	0.6
TOTAL	5007.1

Note: For symmetric single carried stores, PPA = SPA.

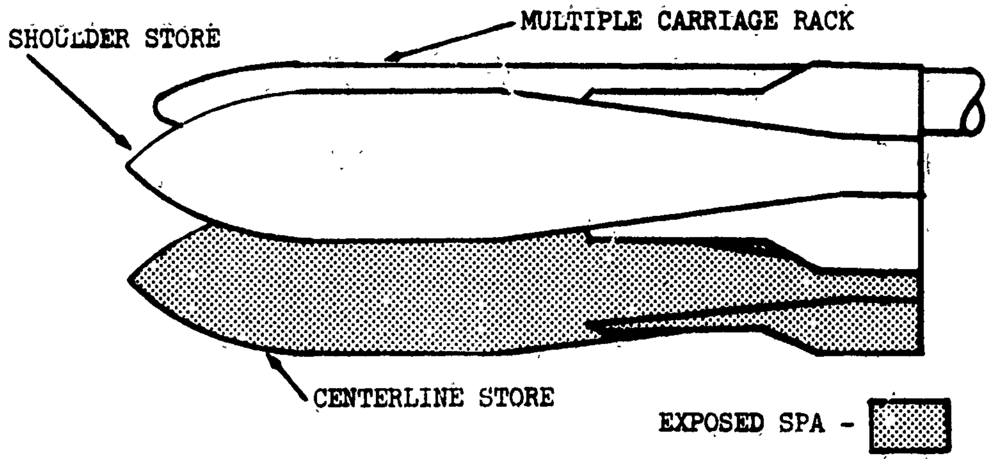


Figure 7. **Exposed Side Projected Area for a Multiply Carried M117 Store**

TABLE 2. SPA AND EXPOSED SPA FOR AN M117 STORE CARRIED ON A MULTIPLE RACK CENTERLINE POSITION

AREA SEGMENT	SPA-in^2	EXPOSED SPA-in^2
1N	209.3	181.8
2B	322.6	230.6
3B	272.2	221.4
3W	21.	10.5
4B	119.6	114.6
4W	134.8	69.8
5B	22.3	13.5
5W	98.5	49.3
TOTAL	1200.3	891.5

N - Nose

B - Body

W - Wing/Fin

Note: Area Segments are 20 inches in length.

2.3 AIRCRAFT-STORE COMBINATION

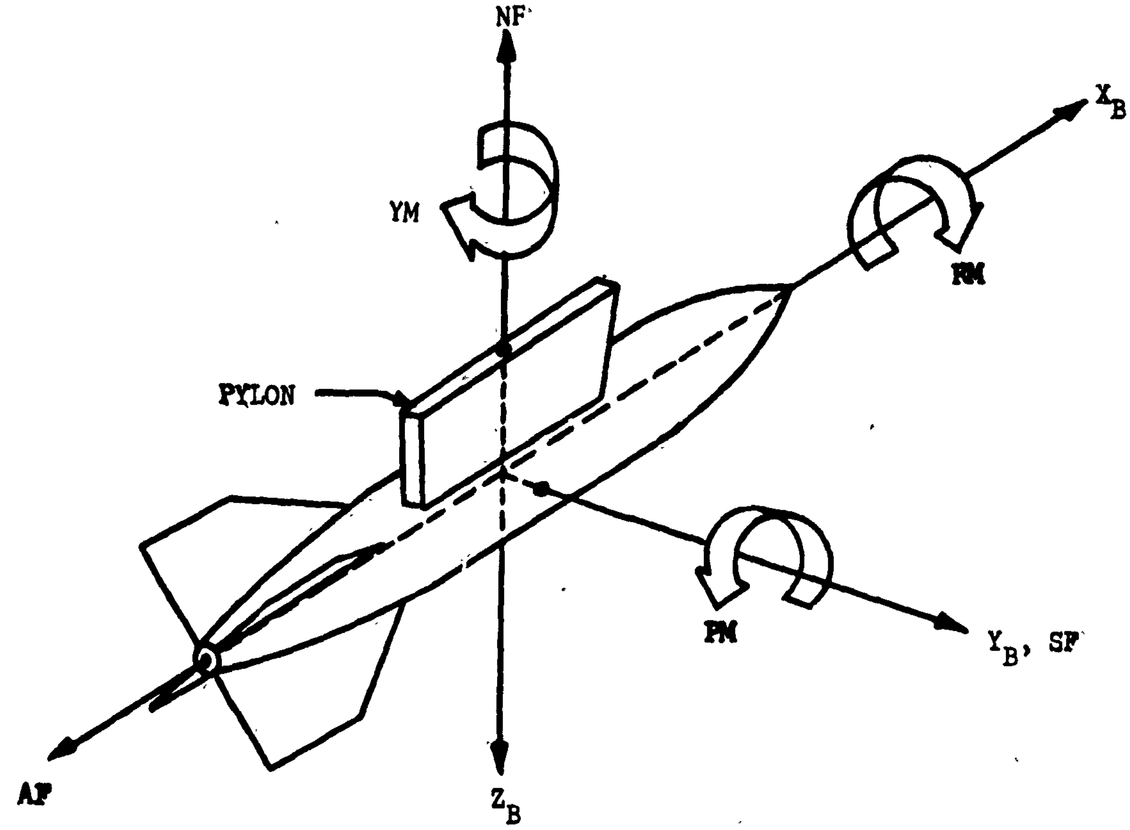
Prediction of the base aerodynamic loads experienced by a store due to installation on an aircraft is discussed in this section. After having developed the isolated store airloads through the procedures identified in Subsection 2.2, the base installed store airloads (initial prediction) can be determined by application of the general procedures outlined here. Final adjustment of the base installed store airloads to compensate for the precise flight conditions and loading arrangements desired are presented in detail in Sections III, IV, and V.

The primary information presented in this section includes the force and moment coordinate systems and the initial prediction force and moment calculation procedures. Example calculations are also included to improve understanding of the computation procedures. Procedures for predicting single and multiple store airloads are presented separately to simplify the procedure complexity.

2.3.1 Store Airloads Coordinate Systems

2.3.1.1 Single Carriage

The single carriage coordinate system and sign convention is presented in Figure 8. The system shown is a right-hand coordinate system with the positive sense of the moments being defined by the right-hand rule. The store coordinate system y body axis remains parallel to the aircraft y body axis regardless of the orientation of the wing pylon. All force and moment predictions contained in this handbook are referenced to this system. The airloads predictions contained herein assume that the subject wing-mounted store is carried on the right wing of the aircraft. To apply the predicted forces and moments to a left wing store installation, a similar but mirrow-image system must be established. This will establish a left-hand coordinate system for the left wing with positive sense of the moments determined by the left-hand rule. By defining a left-hand coordinate system for a left aircraft wing store installation, it is possible to apply the results of computation from this handbook without changing the sign of any force or moment.

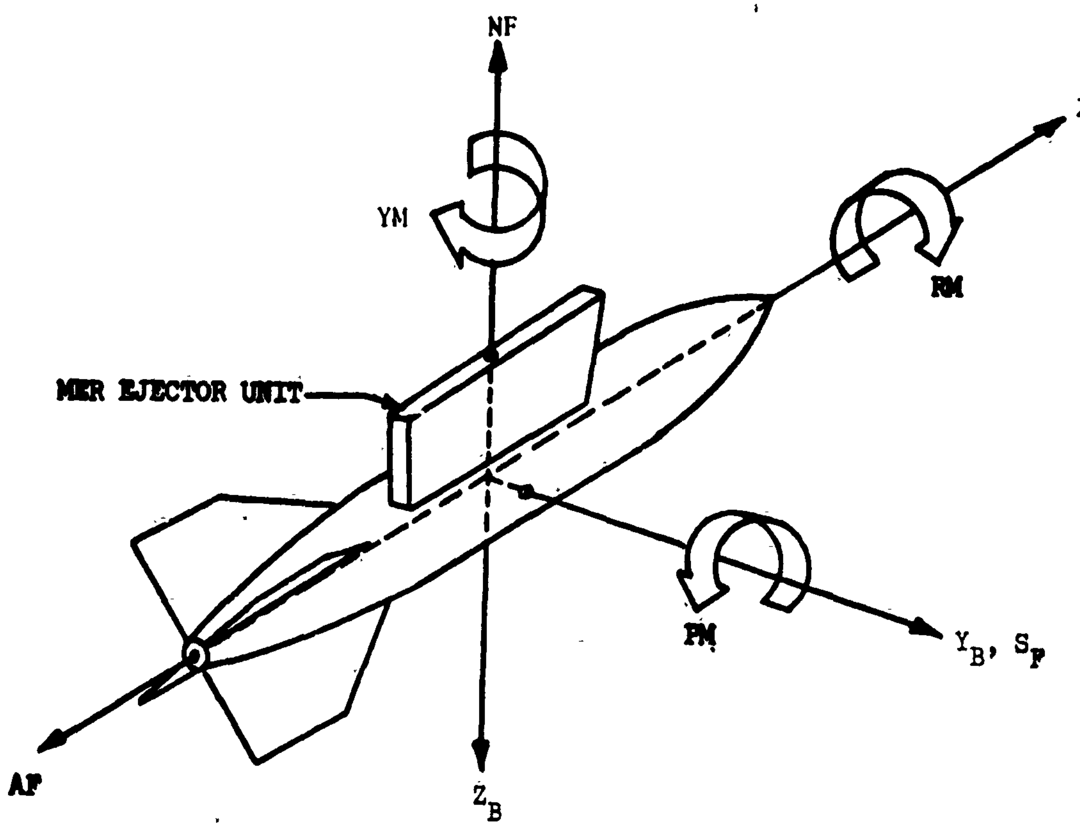


Note: Moment reference point is on the store longitudinal axis at the mid-lug point.

Figure 8. Single Carriage Store Airloads Coordinate System

2.3.1.2 Multiple Carriage

The coordinate system and sign convention for multiple carriage configurations is illustrated in Figure 9. Figure 9 depicts the coordinate system for multiple carriage centerline racks (MER STA 1, 2 or TER STA 1). The coordinate systems for shoulder stations are rotated so that they are parallel to the multiple rack centerline stations. This produces a system of parallel coordinate systems for all multiple stations as illustrated in Figure 10. As with the single carriage coordinate system, the multiple carriage system y-axis remains parallel to aircraft y-body axis regardless of the orientation of the wing pylon. The multiple carriage coordinate system is a set of right-hand coordinate systems with the positive sense of moments determined by the right-hand rule. Predictions contained in this handbook assume a right-wing installation for multiple carriage configurations. To apply the results obtained herein to a left-wing installation, a similar but mirror-image set of coordinate systems should be established for the left wing in the manner described in Subsection 2.3.1.1.

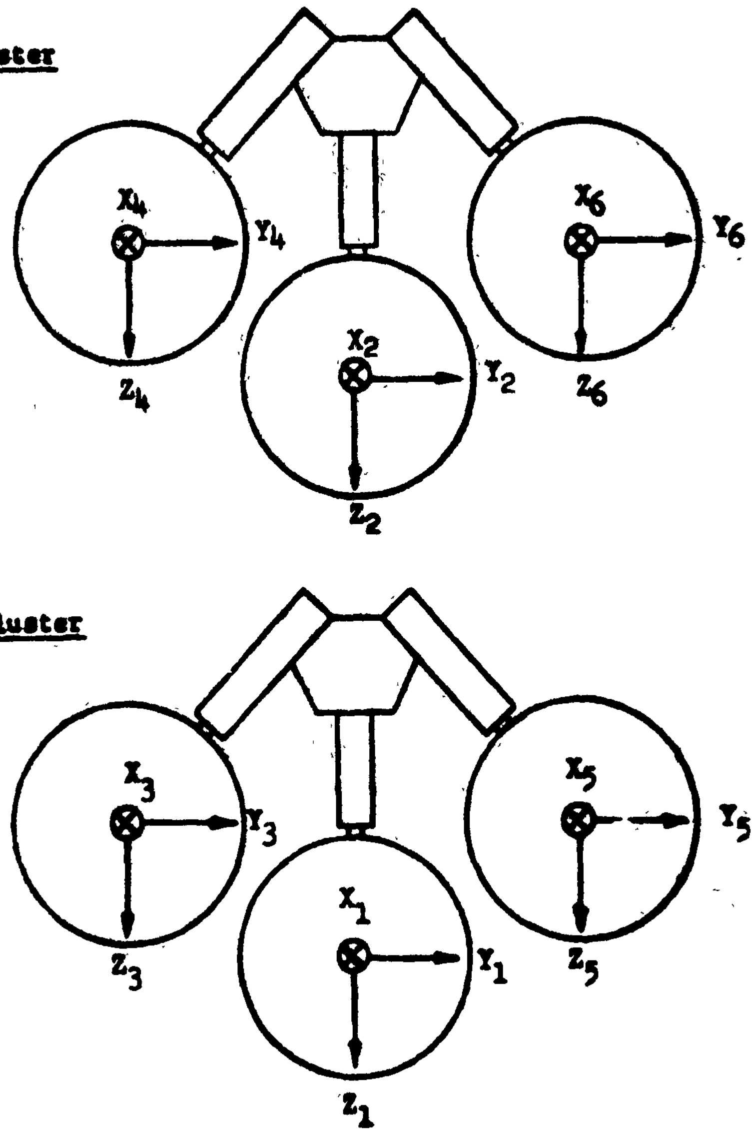


Note: Moment reference point is on the store longitudinal axis at the mid-lug point.

Figure 9. Multiple Carriage Store Airloads Coordinate System for Rack Centerline Stores

Fwd Cluster

Aft Cluster



Notes: 1. View shown with observer viewing from downstream.

2. Coordinate systems are numbered according to MER station location.

Figure 10. Multiple Carriage Store Airloads Coordinate System

2.3.2 Force Calculation Procedure

The initial prediction for the side force and normal force variation with angle of attack is presented in this section. The axial force prediction follows a different approach and requires only the isolated store prediction discussed in Subsection 2.2.1 along with the remainder of the prediction technique presented in Subsection 3.5. The rolling moment prediction is totally contained in Subsection 3.6.

The initial captive side force and normal force slope calculations begin by assuming the store is inserted into the flow-field of the base wing (45° sweep) at the mid-semispan ($\eta = 0.5$) position. Longitudinally the store is placed at the true captive position, and the local wing chord is assumed to be the same as the captive position for the subject aircraft wing. Procedures for side force and normal force slope calculations are the same; hence, the side force component will be discussed in detail.

The store is positioned in the aircraft flow-field as shown in Figure 11 . The sidewash characteristics of the base wing are known from an analysis of flow-field data as discussed in Subsection 2.1. The wing flow-field term used in the initial side force slope prediction is $\frac{d\sigma}{d\alpha}$, the rate of change of sidewash angle, σ, with respect to angle of attack α. The term $\frac{d\sigma}{d\alpha}$ is known as a function of x/c for the base wing (Figure 5, Subsection 2.1). With a knowledge of the store geometric and isolated aerodynamic characteristics, a summation procedure is performed along the store in the aircraft flow-field to obtain an initial prediction of side force slope.

In order to perform the summation procedure, several definitions concerning the store geometric and aerodynamic characteristics must be made. Several of the required geometric definitions were made in Subsection 2.2.2 but will be restated here for clarity. The reader is referred to Figure 6 for the following discussion.

The total store planform area is divided into nose area, body area, and wing area. The distinction in planform areas is required since aerodynamically, the nose and wing are more efficient producing lift than the store body. Because of this efficiency distinction, factors have been defined using Reference 1 for the store nose, K_{NOSE}, and wing(s), K_{WING}, to weight their respective planform areas in relation to the store body planform area. The weighting factors are defined for three store types by the following relationships.

Case 1. Store with Wing at Aft End of Body:

$$K_{NOSE} = K_{N/B}\left(\frac{\text{BODY AREA}}{\text{NOSE AREA}}\right)$$

where:

$$K_{N/B} = \frac{K_N}{K_{B(W)}}$$

K_N - Ratio of lift of body nose to lift of wing alone. See line 80, Table 1, page 38 of Reference 1.

$K_{B(W)}$ - Ratio of the body lift in the presence of the wing to lift of wing alone. See line 48, Table 1, page 38 of Reference 1.

BODY AREA - Body planform area, in^2., Subsection 2.2.2.

NOSE AREA - Nose planform area, in^2., Subsection 2.2.2.

$$K_{WING} = K_{W/B}\left(\frac{\text{BODY AREA + NOSE AREA}}{\text{WING AREA}}\right)$$

where,

$$K_{W/B} = \frac{K_{W(B)}}{K_{B(W)} + K_N}$$

$K_{W_{(B)}}$ - Ratio of lift of wing in the presence of the body to lift of wing alone. See line 47, Table 1, page 38 of Reference 1.

WING AREA - Wing planform area, in^2., Subsection 2.2.2.

Case 2. <u>Store with Wing on Forward Body and Tail at Aft End</u>

$$K_{NOSE} = K_{N/B} \frac{\text{BODY AREA}}{\text{NOSE AREA}}$$

where:

$$K_{N/B} = \frac{K_N C_{L_{\alpha(W)}}}{K_{B_{(W)}} C_{L_{\alpha(W)}} + K_{B_{(T)}} C_{L_{\alpha(T)}}}$$

$$K_{TAIL} = K_{T/B} \frac{\text{BODY AREA + NOSE AREA}}{\text{TAIL AREA}}$$

where:

TAIL AREA - Tail planform area, in^2., defined identical to wing area, Subsection 2.2.2.

$$K_{T/B} = \frac{K_{T_{(B)}} C_{L_{\alpha(T)}}}{(K_{B_{(W)}} + K_N) C_{L_{\alpha(W)}} + K_{B_{(T)}} C_{L_{\alpha(T)}}}$$

where:

$K_{T_{(B)}}$ - Ratio of lift of tail in the presence of the body to lift of tail alone. See line 63, Table 1, page 38 of Reference 1.

$C_{L_{\alpha(T)}}$ - Isolated tail lift curve slope as determined by the methods outlined in Subsection 2.2.1.

$K_{B_{(W)}}$ - Ratio of the lift of the body in the presence of the wing to lift of wing alone. See line 48, Table 1, page 38 of Reference 1.

K_N - Ratio of lift of body nose to lift of wing alone. See line 80, Table 1, page 38 of Reference 1.

$C_{L_{\alpha(W)}}$ - Isolated wing lift curve slope as determined by the methods outlined in Subsection 2.2.1.

$K_{B_{(T)}}$ - Ratio of the lift of the body in the presence of the tail to lift of tail alone. See line 64, Table 1, page 38 of Reference 1.

$$K_{WING} = K_{W/B}\left(\frac{\text{BODY AREA + NOSE AREA}}{\text{WING AREA}}\right)$$

where:

$$K_{W/B} = \frac{K_{W_{(B)}} C_{L_{\alpha(W)}}}{(K_{B_{(W)}} + K_N) C_{L_{\alpha(W)}} + K_{B_{(T)}} C_{L_{\alpha(T)}}}$$

$K_{W_{(B)}}$ - Ratio of the lift of the wing in the presence of the body to lift of wing alone. See line 47, Table 1, page 38 of Reference 1.

For this case, a factor has been defined to account for the interference effect of the wing on the tail lift. This factor should be multiplied times K_{TAIL} (defined above) and is given by the following relationship:

$$K = 1 - \frac{C_{L_{\alpha(WBT)_{INTF}}} - C_{L_{\alpha(WBT)_{W/O\ INTF}}}}{C_{L_{\alpha(T)}}}$$

where:

$C_{L_{\alpha(WBT)_{INTF}}}$ - Lift curve slope of wing/body/tail accounting for interference of wing on tail. See line 88, Table 1, page 38 of Reference 1.

$C_{L_{\alpha(WBT)_{W/O\ INTF}}}$ - Lift curve slope of wing/body/tail without interference effect of wing on tail. See line 124, Table 1, page 38 of Reference 1.

Case 3: <u>Unfinned Store</u>

For an unfinned store, K_{NOSE} is the only additional parameter which must be defined.

$$K_{NOSE} = 2.0$$

The planform area of the store is projected into the X_B, Z_B plane and is defined as side projected area, SPA. The store is divided into constant length segments from nose to tail. The SPA is computed for each of the segments with distinction made as to nose, body, or wing areas. The area segments for a 300-gallon tank are tabulated in Table 1 and will be referred to in the example to follow in Subsection 2.3.2.1. With the segmented side projected areas defined and the store inserted into flow-field of the base wing, the summation procedure is given by the following relationship.

$$\text{ADJUSTED SPA} = \sum_{n=1}^{m} K_{\sigma_n} K_{NOSE_n} K_{\substack{WING\\(TAIL)}_n} K_{INTF_n} SPA_n$$

where:

m - Number of constant length area segments as computed from store nose to tail.

K_σ - Rate of sidewash variation with angle of attack, $\frac{d\sigma}{d\alpha}$, Figure 5.

K_{NOSE} - Store nose lift effectiveness as defined by Case 1, 2, or 3 equations presented above.

$K_{\substack{WING\\(TAIL)}}$ - Store wing or tail lift effectiveness as defined by Case 1, 2, or 3 equations presented above.

K_{INTF} - Tail lift interference factor. Applicable only to Case 2 above. All other cases, $K_{INTF} = 1$.

SPA - Store side projected area, in^2.

then:

$$K_{C_{SF}} = \frac{\text{ADJUSTED SPA}}{SPA_{TOTAL}}$$

where:

ADJUSTED SPA - Adjusted side projected area of the store as given by the summation equation above.

SPA_{TOTAL} - Total side projected area of the store. The sum of nose, body, and wing side projected areas.

The initial side force slope prediction is given by the following equation.

$$\frac{d\left(\frac{SF}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED.}} = K_{C_{SF}} \frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$$

where:

$\frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$ = Isolated aerodynamic characteristics of the subject store. Equal to $C_{L_{\alpha_{ISO}}} S_{REF}, \frac{ft^2}{deg}$. Computed from the method of Reference 1.

It should be noted that if experimental isolated store characteristics are used in the above equation, the user must still perform most of the computations of Reference 1 since many of the terms of the computation are used in defining the store nose and wing weighting factors presented in Cases 1 and 2 previously discussed.

The initial normal force slope prediction follows a similar procedure and is given by the following relationships.

$$\text{ADJUSTED PPA} = \sum_{n=1}^{m} K_{\alpha_{\ell_n}} K_{NOSE_n} K_{WING_{(FIN)^n}} K_{INTF_n} PPA_n$$

where

K_{α_ℓ} - Rate of local angle of attack variation with aircraft angle of attack, $\frac{d\alpha_\ell}{d\alpha}$, Figure 4.

PPA - Store planform projected area, in^2. (Same as SPA for a symmetrical store.)

$$K_{C_{NF}} = \frac{\text{ADJUSTED PPA}}{PPA_{TOT}}$$

where ADJUSTED PPA - Adjusted planform projected area of the store as given by the summation equation above.

PPA_{TOTAL} - Total planform projected area of the store. The sum of nose, body, and wing planform projected areas.

$$\frac{d\left(\frac{NF}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED}} = K_{C_{NF}} \frac{d\left(\frac{NF}{q}\right)}{d\alpha}_{ISO}$$

where

$\frac{d\left(\frac{NF}{q}\right)}{d\alpha}_{ISO}$ - Isolated aerodynamic characteristics of the subject store. Equal to $C_{L_{\alpha_{ISO}}} \cdot S_{REF}$, $\frac{ft^2}{deg}$. Computed from the method of Reference 1.

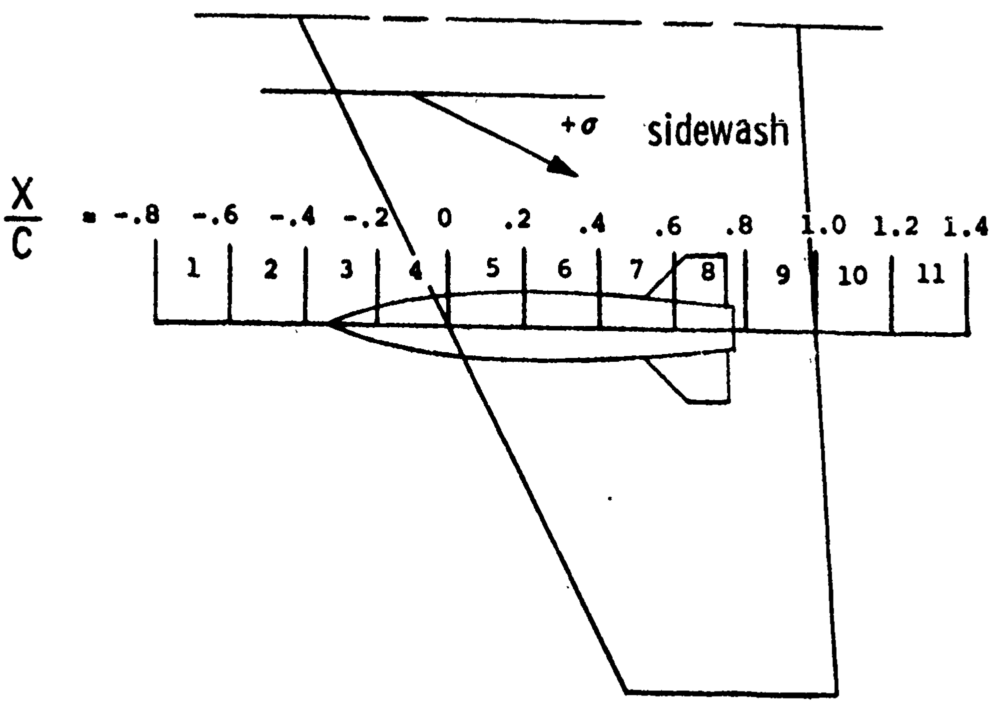


Figure 11. Typical Store Immersed in Aircraft Flow-Field

2.3.2.1 Computational Example-Single Carriage

Application of the prediction equations in Section 2.3.2 is illustrated by initial prediction of side force variation with angle of attack, $\left(\frac{SF}{q}\right)_{\alpha_{INITIAL\ PRED}}$, for a 300-gallon tank on the A-7 center pylon at M = 0.5.

Required for Computation:

C_{LOCAL} = 127.6 in.

ℓ_{LE} = 75.1 in.

K_σ from Figure 5

K_{WING} = 7.12, Case 1 computation, Subsection 2.3.2.

K_{NOSE} = 4.46, Case 1 computation, Subsection 2.3.2.

K_{INTF} = 1.0, Case 2 for definition, Subsection 2.3.2.

SPA from Table 1 (in 25-in. segments)

$$\frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO} = .262\ \frac{ft^2}{deg}$$

Table 3 is used to demonstrate the computation as shown below where N represents nose SPA, B body SPA, and W wing SPA. The control point for applying the sidewash term, K_σ, is the midpoint of each 25-in. length segment.

The store nose/wing leading edge relationship is given by

$$X_{NOSE} = -\ell_{LE} = -75.1 \text{ in.}$$

The first control point for the store is

$$X_{MID-POINT} = X_{NOSE} + \frac{25}{2} = -75.1 + 12.5 = -62.6 \text{ in.}$$

TABLE 3. INITIAL SIDE FORCE SLOPE PREDICTION CALCULATION FOR A 300-GALLON TANK ON THE A-7 CENTER PYLON

AREA SEG.	X_{MID} POINT in.	X/C_{MID} POINT	K_σ	K_{WING}	K_{NOSE}	SPA_{TOT} in^2.	ADJ.SPA in^2.
1N	-62.6	-.491	0.175	1.0	4.46	292	228
2N	-37.6	-.295	0.275	1.0	4.46	548	672
3N	-12.6	-.099	0.57	1.0	4.46	648	1647
4N	12.4	.097	0.89	1.0	4.46	142	565
4B	12.4	.097	0.89	1.0	1.0	520	463
5B	37.4	.293	0.84	1.0	1.0	662	558
6B	62.4	.489	0.69	1.0	1.0	620	428
7B	87.4	.685	0.52	1.0	1.0	531	276
8B	112.4	.881	0.38	1.0	1.0	393	149
8W	112.4	.881	0.38	7.12	1.0	4.5	12.2
9B	137.4	1.077	0.31	1.0	1.0	203	63.1
9W	137.4	1.077	0.31	7.12	1.0	443	978
10B	162.4	1.273	0.265	1.0	1.0	.6	.2
						5007.1	6039.5

$$K_{C_{SF}} = \frac{ADJ.SPA}{SPA_{TOT.}} = \frac{6039.5}{5007.1} = 1.206$$

$$\left.\frac{d\left(\frac{SF}{q}\right)}{d\alpha}\right|_{\substack{INITIAL\\PRED.}} = K_{C_{SF}} \left.\frac{d\left(\frac{SF}{q}\right)}{d\psi}\right|_{ISO}$$

$$= 1.206(.262)$$

$$= .316 \frac{ft^2}{deg}$$

2.3.2.2 Example Computation-Multiple Carriage

This section presents an example computation illustrating the application of the prediction equations developed in Subsection 2.3.2. The initial prediction equations are similar to those presented in Subsection 2.3.2 but due to slight differences in the definition of certain terms, they are presented again below for the multiple case initial side force slope prediction.

$$\text{ADJUSTED SPA} = \sum_{n=1}^{m} K_{\sigma_n} K_{NOSE_n} K_{\binom{WING}{TAIL}_n} K_{INTF_n} SPA_n$$

This summation equation is applied only to the two MER centerline rack stations (MER STATIONS 1, 2). The shoulder stations are predicted as an increment added to MER STATIONS 1 and 2. The only difference in the above equation and the one presented in the previous section is the interpretation of the side projected area term, SPA, for the initial side force slope prediction. The store side projected area used in the computation of ADJUSTED SPA is the exposed side projected area as defined in Subsection 2.2.2.

$$K_{C_{SF}} = \frac{\text{ADJUSTED SPA}}{SPA_{TOTAL}}$$

where

ADJUSTED SPA - Adjusted side projected area given by the above equation, in^2.

SPA_{TOTAL} - Total store side projected area (not the exposed SPA), in^2.

The initial side force slope prediction is given by the following equation.

$$\left.\frac{d\left(\frac{SF}{q}\right)}{d\alpha}\right|_{\substack{INITIAL\\PRED.}} = K_{C_{SF}} \left.\frac{d\left(\frac{SF}{q}\right)}{d\psi}\right|_{ISO}$$

where

$$\frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$$ – Isolated aerodynamic characteristics of the subject store. Equal to $C_{L_{\alpha_{ISO}}} \cdot S_{REF}, \frac{ft^2}{deg}$

Computed from Reference 1.

The normal force initial slope prediction makes use of the same set of equations presented above except that side projected area is replaced by planform projected area, PPA, and K_σ is replaced by K_{α_ℓ}. It should be noted that the exposed PPA is the same as the total PPA.

The nose and wing lift efficiency factors should be computed in the manner described in Subsection 2.3.2 for Cases 1, 2, or 3. The nose lift efficiency factor, K_{NOSE}, is set equal to 1.0 for all store types on the MER aft centerline station (MER STATION 1) due to the blockage effect of the MER forward cluster.

Example: Compute the initial prediction of side force variation with angle of attack, $\left(\frac{SF}{q}\right)_{\alpha_{\text{INITIAL PRED.}}}$, for an M117 store on MER STATION 2 (forward centerline) of a fully loaded MER on the A-7 center pylon at M = 0.5.

Required for Computation:

C_{LOCAL} = 127.6 in.

ℓ_{LE} = 59.3 in.

K_σ from Figure 5.

K_{WING} = 2.98; Case 1 Computation, Subsection 2.3.2.

K_{NOSE} = 13.25; Case 1 Computation, Subsection 2.3.2.

K_{INTF} = 1.0; See Case 2 definition; Subsection 2.3.2.

SPA from Table 2 (in 20-in. segments)

$$SPA_{TOTAL} = 1200 \text{ in}^2.$$

$$\frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO} = .114 \frac{ft^2}{deg}$$

Table 4 demonstrates the computation as shown below where N represents nose SPA, B body SPA, and W wing SPA. The control point for applying the sidewash term, K_σ, is the mid-point of each 20-in. length area segment.

The store nose/wing leading edge relationship is given by

$$X_{NOSE} = -\ell_{LE} = -59.3 \text{ in.}$$

The first control point for the store is

$$X_{MID\text{-}POINT} = X_{NOSE} + \frac{20}{2} = -59.3 + 10 = -49.3 \text{ in.}$$

TABLE 4. INITIAL SIDE FORCE SLOPE PREDICTION CALCULATION FOR AN M117 AT MER STATION 2 ON THE A-7 CENTER PYLON

AREA SEG.	X_{MID} POINT in.	X/C_{MID} POINT	K_σ	K_{WING}	K_{NOSE}	SPA (EXPOSED) in.^{2}	ADJ.SPA in.^{2}
1N	-49.3	-.387	0.21	1.0	13.25	181.8	505.5
2B	-29.3	-.23	0.33	1.0	1.0	230.6	75.6
3B	- 9.3	-.071	0.66	1.0	1.0	221.4	146.4
3W	- 9.3	-.071	0.66	2.98	1.0	10.5	[illegible]
4B	10.7	.084	0.89	1.0	1.0	114.6	101.5
4W	10.7	.084	0.89	2.98	1.0	69.8	185.0
5B	30.7	.241	0.865	1.0	1.0	13.5	11.4
5W	30.7	.241	0.865	2.98	1.0	49.3	127.0
							1172.8

$$K_{C_{SF}} = \frac{ADJ.SPA}{SPA_{TOT.}} = \frac{1172.8}{1200} = .976$$

$$\frac{d\left(\frac{SF}{q}\right)}{d\alpha_{\substack{INITIAL\\PRED}}}' = K_{C_{SF}} \frac{d\left(\frac{SF}{q}\right)}{d\psi_{ISO}}$$

$$= (.976)(.114) = .111 \frac{ft^2}{deg}$$

2.3.3 Moment Calculation Procedure

The initial moment calculation follows essentially the same procedure outlined in Subsection 2.3.2 for the initial force calculation. The only difference is that a moment arm term has been added to the equation for adjusted side projected area to weight each area segment according to its distance from the store moment reference point (MRP). The moment arm used is the distance from the store MRP to the mid-point of each respective area segment. The store MRP for all computations from this handbook is located on the store longitudinal axis at the mid-lug point. The moment arm definition is illustrated in Figure 12. An equation is included in the figure for computing the moment arms.

The equation for computing the initial prediction of yawing moment slope is presented below.

$$\frac{d\left(\frac{YM}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED}} = K_{C_{YM}} \frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$$

where

$$K_{C_{YM}} = \frac{\sum_{n=1}^{m} \left[(ADJ.SPA)_n X_{MOM_n} - (WING\ ADJ.SPA)_n X_{MOM_n} \right]}{SPA_{TOTAL}}$$

where

m	- Number of constant length area segments as computed from store nose to tail.
$(ADJ.SPA)_n$	- Adjusted side projected area of area segment n, in^2.
X_{MOM_n}	- Distance from store MRP to area segment n mid-point, ft., see Figure 12.
(WING ADJ.SPA)	- Adjusted store wing side projected area, in^2. (for wing at aft end of store only).
SPA_{TOTAL}	- Defined in Subsection 2.3.2.
$\frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$	- Defined in Subsection 2.3.2.

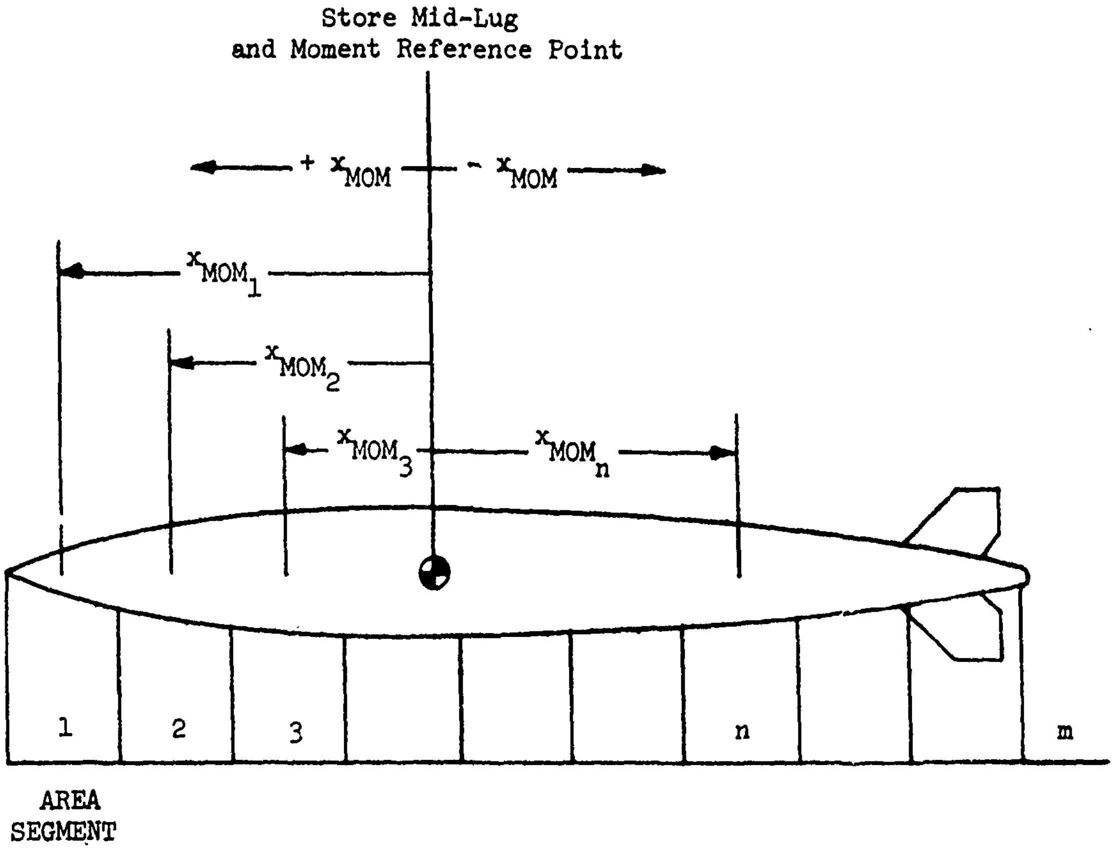
The equation for computing the initial prediction of pitching moment slope is presented below.

$$\frac{d\left(\frac{PM}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED.}} = K_{C_{PM}} \frac{d\left(\frac{NF}{q}\right)}{d\alpha}_{ISO}$$

where

$$K_{C_{PM}} = \frac{\sum_{n=1}^{m} (ADJ.PPA)_n X_{MOM_n}}{PPA_{TOTAL}}$$

where all terms are defined above or in Subsection 2.3.2.



$$x_{MOM_n} = x_{M.L.} \quad 5x_{\substack{SEGMENT\\LENGTH}} - x_{\substack{SEGMENT\\LENGTH}} (n-1)$$

where:

$n = 1, 2, 3, ---, m$ segments

$x_{M.L.}$ - Distance from store nose to mid-lug point (positive)

$x_{\substack{SEGMENT\\LENGTH}}$ - Constant length of each area segment measured along the store longitudinal axis (positive). Assigned by the user.

Figure 12. Moment Arms for Initial Airloads Prediction

2.3.3.1 Example Computation-Single Carriage

Application of the prediction equations in Subsection 2.3.3 is illustrated by the initial prediction of yawing moment variation with angle of attack, $\left(\frac{YM}{q}\right)_{\alpha_{\substack{INITIAL\\PRED.}}}$, for a 300-gallon tank on the A-7 center pylon at M = 0.5.

Given: All items given in the example of Subsection 2.3.2.1.

Store mid-lug = 95.5 in. aft of store nose

The initial moment arm is

$$X_{MOM_1} = X_{M.L.} - \frac{25}{2} \text{ (for 25 in. area segments)}$$

$$= \frac{95.5 - 12.5}{12} = 6.91 \text{ ft.}$$

Each successive moment arm is 25 in. aft of the previous one from area segment 1 through the total number of segments. For this example the values of X_{MOM} are tabulated below in Table 5.

Table 5 is used to present the example summation. Values of ADJ. SPA in the table are extracted from Table 3 in Subsection 2.3.2.1.

TABLE 5. **INITIAL YAWING MOMENT SLOPE PREDICTION CALCULATION FOR A 300-GALLON TANK ON THE A-7 CENTER PYLON**

AREA SEG.	ADJ. SPA in^2	X_{MOM} ft.	(ADJ. SPA)X_{MOM} in^2.-ft.
1N	228	6.91	1572
2N	672	4.83	3250
3N	1647	2.75	4530
4N	565	.67	379
4B	463	.67	310
5B	558	-1.42	-790
6B	428	-3.5	-1500
7B	276	-5.58	-1540
8B	149	-7.66	-1143
8W	12.2	-7.66	-94
9B	63.1	-9.76	-615
9W	978	-9.76	-9540
10B	.2	-11.84	-2
			-5183

$$K_{C_{YM}} = \frac{\sum_{n=1}^{m} \left[(ADJ.SPA)_n X_{MOM_n} - (WING\ ADJ.SPA)_n X_{MOM_n} \right]}{SPA_{TOTAL}}$$

$$K_{C_{YM}} = \frac{-5183 - (-94 - 9540)}{5007.1}$$

$$= .889 \text{ ft.}$$

then

$$\frac{d\left(\frac{YM}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED}} = K_{C_{YM}} \frac{d\left(\frac{SF}{q}\right)}{d\psi_{ISO}}$$

$$= (.889)(.262)$$

$$= .233 \frac{ft^3}{deg}$$

2.3.3.2 Example Computation-Multiple Carriage

The equations of Subsection 2.3.3.1 apply to the multiple carriage case with the exception of $K_{C_{YM}}$ which is redefined below.

$$K_{C_{YM}} = \frac{\sum_{n=1}^{m} (ADJ.SPA)_n X_{MOM_n}}{SPA_{TOTAL}}$$

where all terms have been defined in Subsections 2.3.2 and 2.3.3.

Example: Compute the initial prediction of yawing moment variation with angle of attack, $\left(\frac{YM}{q}\right)_{\alpha_{\text{INITIAL PRED.}}}$, for an M117 store on MER STATION 2 (forward centerline) of a fully loaded MER on the A-7 center pylon at M = 0.5.

Given: All terms and results in the example in Subsection 2.3.3.1. X_{MOM} is defined in the manner discussed in Subsection 2.3.3.1.

The computation is presented in Table 6 below in the same manner as the previous example in Subsection 2.3.3.1.

TABLE 6. INITIAL YAWING MOMENT SLOPE PREDICTION CALCULATION FOR AN M117 AT MER STATION 2 ON THE A-7 CENTER PYLON

AREA SEG	ADJ. SPA in^2.	X_{MOM} ft.	$(ADJ.SPA)X_{MOM}$ in^2.-ft.
1N	582	1.74	879.6
2B	106	.075	5.7
3B	180	-1.59	-232.8
3W	41	-1.59	-32.4
4B	106	-3.26	-330.9
4W	357	-3.26	-603.1
5B	19	-4.42	-50.4
5W	254	-4.42	-561.0
			-925.3

$$K_{C_{YM}} = \frac{\sum_{n=1}^{m} (ADJ.SPA)_n X_{MOM_n}}{SPA_{TOT}}$$

$$\frac{925.3}{1200} = -.771 \text{ ft.}$$

then

$$\frac{d\left(\frac{YM}{q}\right)}{d\alpha}_{\substack{INITIAL\\PRED.}} = K_{C_{YM}} \frac{d\left(\frac{SF}{q}\right)}{d\psi}_{ISO}$$

$$= (-.771)(.114) = -.088 \frac{ft^3}{deg}$$

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