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A PARAMETRIC STUDY OF PLANFORM AND AEROELASTIC EFFECTS ON AERODYNAMIC CENTER, $\dot{\alpha}$- AND q-STABILITY DERIVATIVES

Summary Report

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16. Abstract

The report summarizes the aerodynamic center, α- and q- aeroelastic effects on fighter-type aircraft in the 18,700 N gross weight range. The results indicate that with proper tailoring of planform (fixed or variable sweep), stiffness and elastic axis location it is possible to minimize trim requirements between selected extreme conditions. The inertial effects were found to be small for this class of aircraft.

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CONTENTS

TABLES

Tables		Page

Tables | Page

FIGURES

Figures | Page

1. SUMMARY

This report presents the results of a parametric study made to determine the effects of planform shape, Mach number and dynamic pressure on the aerodynamic center, α - and q- stability derivatives of elastic airplanes. The study was addressed to fighter type wing planforms for airplanes in the 40,000 lbs (178,000 N) gross weight range and designed for 7.33 limit load.

Results indicate that there are very significant zero-mass steady state aeroelastic effects on aerodynamic center location as well as on the α - and q- stability derivatives, whereas, the inertially induced steady state aeroelastic effects are small. It is shown that by careful selection of planform (fixed or variable sweep), stiffness and elastic axis location it is possible to minimize trim requirements between selected extreme conditions.

2. INTRODUCTION

Steady state aeroelastic effects on stability characteristics of airplanes have become increasingly important as the performance envelopes of airplanes expanded in terms of attainable Mach numbers and dynamic pressures. A thorough study of methods to be used in the flight path stability analysis of elastic airplanes was reported in References 1 - 4.

This report presents results of a parametric study of the effects of (steady state) aeroelasticity on several longitudinal stability characteristics of airplanes, conducted using the methodology developed in the cited references. The scope of the investigation included wing planforms with the geometric characteristics of Table 1. Ranges of Mach number and altitude within which the investigation was conducted are .25 to 2.5 and sea level to 60,000 ft. (18,288 m.) respectively. Stability characteristics studied in this report include: aerodynamic center location, α- and q- stability derivatives and the inertial stability derivatives (that is, the effects of mass and its distribution). The study was conducted in three phases:

1. Preparation of Computer Routines
2. Calculation of Planform Effects
3. Calculation of the Effect of Stiffness Magnitude and Elastic Axis Location

Results from phases 2 and 3 are presented in this report. The work done under phase 1 is presented in separate Appendix Reports: References 5 through 9. In References 5 through 9, and consequently in this report, the structural representations are all based on beam theory, and the aerodynamic representations are based on the finite element method of Woodward which is developed in Reference 10.

In discussing numerical examples of stability and control characteristics of elastic airplanes, five additional factors arise which do not have similar significance for rigid airplanes. These factors are: total mass, mass distribution, total stiffness, stiffness distribution (related to load-factor to which airplane has been designed) and flight dynamic pressure.

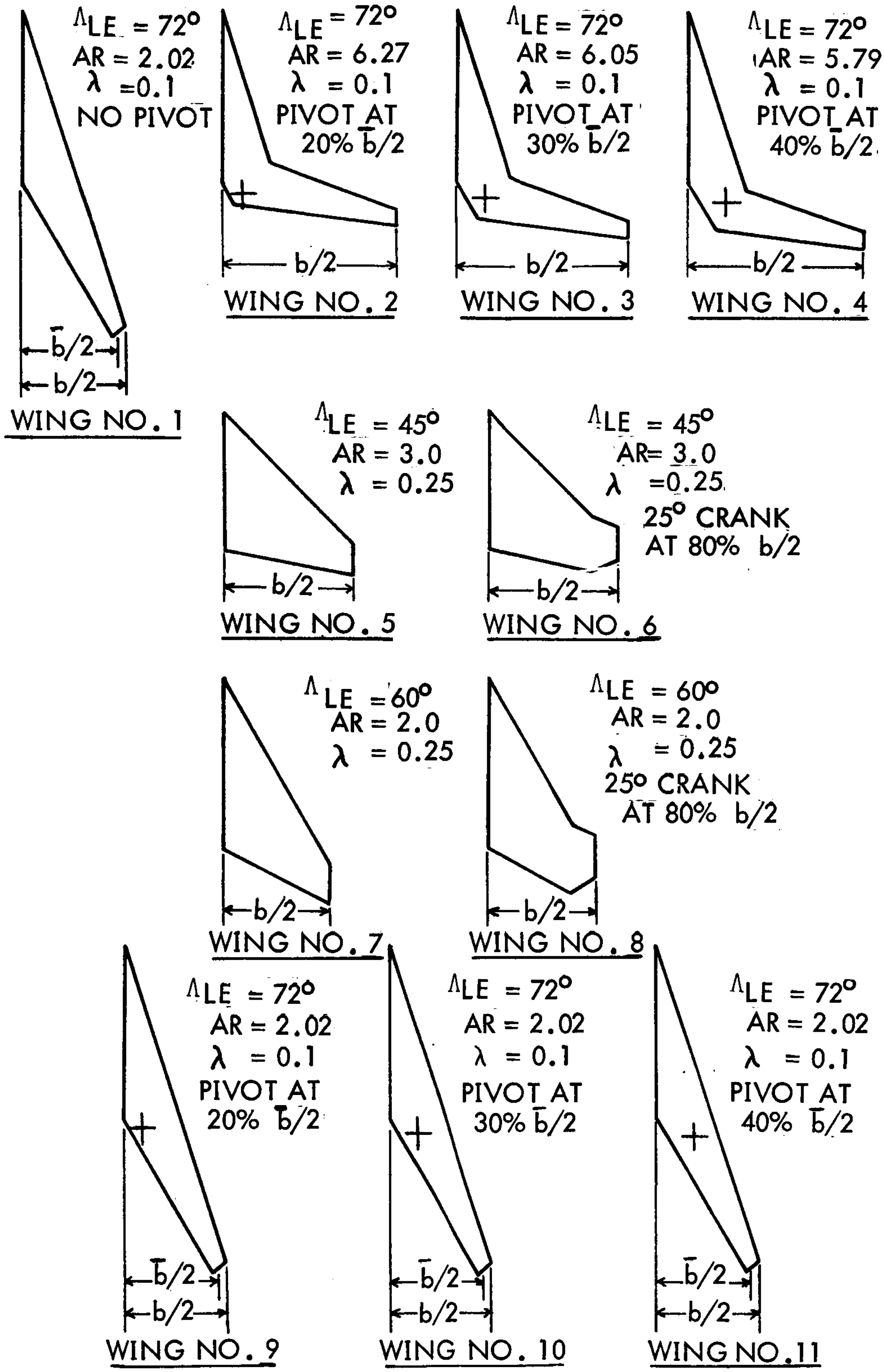
Normally in stability and control problems, only the effects of angle of attack and Mach number must be considered (sometimes Reynolds number is also important). It can be seen that the addition of these five factors complicates any parametric study to a considerable extent. The engineer, in studying elastic airplane stability and control is forced to focus his attention on a specific airplane configuration with specific structural characteristics before any significant calculations can be made. Generalizations are difficult and often impossible to make!

The parametric study reported herein is no different. Before anything could be parameterized it was necessary to further limit the scope of the study to a class of specific airplanes. Wings of typical fighter airplanes with a weight of 40,000 lbs (178,000 Newtons) and wing structures designed to withstand a limit load of 7.33 g's were selected as vehicles for the study. The results are therefore limited in validity to that class of airplanes.

A complete description of the computational methodology used in computing geometric, mass, aerodynamic and structural characteristics is presented in accompanying documents: References 5 through 9. Reference 5 also contains a user's manual for the computer programs developed for use on the CDC 6600 series computers located at the NASA Langley Research Center.

The elastic airplane stability derivatives used in this report differ from conventional rigid airplane derivatives in several important ways. A derivation of these deriva-

Table 1 Geometric Characteristics of Planforms



tives and a description of their tie-in with conventional rigid airplane derivatives is considered beyond the scope of this report. References 1 through 4 and Reference 11 contain detailed discussions of the derivation and application of elastic airplane derivatives.

Symbols used in this report are defined in Chapter 3. Results of the parametric study of planform effects, Mach number effects and dynamic pressure effects on aerodynamic center location as well as on the α - and q- stability derivatives are presented in Chapter 4. Chapter 5 contains the results of a brief investigation into the effect of stiffness magnitudes and elastic axis locations on the longiutdinal stability characteristics of one of the studied planforms integrated into a complete airplane configuration. Chapter 6 contains the results of a study of aeroelastic effects on induced drag. Conclusions and recommendations follow in Chapter 7.

All computer programs, methods, and procedures used to generate the results contained in this Summary Report are contained in five independent appendices, as follows:

Appendix A (Ref. 5) presents the computer program developed for calculating the α- and q- stability derivatives and induced drag for thin elastic airplanes at subsonic and supersonic speeds.

Appendix B (Ref. 6) develops the method used for computing the structural influence coefficient matrix of nonplanar wing-body-tail configurations.

Appendix C (Ref. 7) develops the method used for computing the aerodynamic influence coefficient matrix of nonplanar wing-body-tail configurations.

Appendix D (Ref. 8) presents the procedures used to determine the mass distribution for idealized low-aspect-ratio two spar fighter wings.

Appendix E (Ref. 9) presents the procedures used to determine the structural representation for idealized low-aspect-ratio two spar fighter wings.

3. SYMBOLS

The units used for the physical quantities defined in this paper are given both in the International System of Units (SI) and the U.S. Customary Units. This list is only for symbols used in the Summary Report. Symbols used in the Appendices are defined there.

Readers who are not familiar with the definition or use of elastic airplane stability derivatives are referred to Reference 5, Table 1 and to Reference 11, Chapter 8.

Symbol	Definition	Dimension
A or AR	Aspect ratio	
a.c.	Aerodynamic center	
b	(Wing) span	ft (m)
$\bar{b}$	Span (distance between midpoints of non-streamwise tip chords)	ft (m)
$C_{D_i} = \frac{\text{Induced drag}}{\bar{q}\,S}$	Induced drag coefficient	
c_{d_i}	Sectional induced drag coefficient	
$C_L = \frac{\text{Lift}}{\bar{q}\,S}$	Lift coefficient (airplane)	
c_l	Sectional lift coefficient	
$C_{L_q} = \frac{\partial C_L}{\partial\left(\frac{q\bar{c}}{2U_1}\right)}$	Variation of lift coefficient with pitch rate	rad^{-1}
$C_{L_{q_E}} = \left.\frac{\partial C_L}{\partial\left(\frac{q\bar{c}}{2U_1}\right)}\right\|_E$	Variation of lift coefficient with pitch rate for the elastic case with zero mass	rad^{-1}
$C_{L_{q_I}} = \left.\frac{\partial C_L}{\partial\left(\frac{q\bar{c}}{2U_1}\right)}\right\|_I$	Inertially induced variation of lift coefficient with pitch rate	rad^{-1}
$C_{L_{\dot{w}_I}} = \left.\frac{\partial C_L}{\partial \dot{w}}\right\|_I$	Inertially induced variation of lift coefficient with rate of downward velocity perturbation	$\text{sec}^2\text{ft}^{-1}$ ($\text{sec}^2\text{m}^{-1}$)

Symbol	Definition	Dimension
$C_{L_\alpha} = \dfrac{\partial C_L}{\partial \alpha}$	Airplane lift curve slope	rad^{-1}
$C_{L_{\alpha_{\bar{E}}}} = \left.\dfrac{\partial C_L}{\partial \alpha}\right\|_{\bar{E}}$	Variation of lift coefficient with angle of attack for the elastic case with zero mass	rad^{-1}
$C_{L_{\alpha_E}} = \left.\dfrac{\partial C_L}{\partial \alpha}\right\|_{E}$	Variation of lift coefficient with angle of attack for the elastic case including mass effect	rad^{-1}
$C_{L_{\ddot{\theta}_I}} = \left.\dfrac{\partial C_L}{\partial \ddot{\theta}}\right\|_{I}$	Inertially induced variation of lift coefficient with pitch angular acceleration	$\text{sec}^2\text{rad}^{-1}$
$C_m = \dfrac{\text{Pitching moment}}{\bar{q}\ S\ \bar{c}}$	Pitching moment coefficient (airplane, planform)	
$C_{m_q} = \dfrac{\partial C_m}{\partial\left(\dfrac{q\bar{c}}{2U_1}\right)}$	Variation of pitching moment coefficient with pitch rate	rad^{-1}
$C_{m_{q_{\bar{E}}}} = \left.\dfrac{\partial C_m}{\partial\left(\dfrac{q\bar{c}}{2U_1}\right)}\right\|_{\bar{E}}$	Variation of pitching moment coefficient with pitch rate for the elastic case with zero mass	rad^{-1}
$C_{m_{q_I}} = \left.\dfrac{\partial C_m}{\partial\left(\dfrac{q\bar{c}}{2U_1}\right)}\right\|_{I}$	Inertially induced variation of pitching moment coefficient with pitch rate	rad^{-1}
$C_{m_{\dot{w}_I}} = \left.\dfrac{\partial C_m}{\partial \dot{w}}\right\|_{I}$	Inertially induced variation of pitching moment coefficient with rate of downward velocity perturbation	$\text{sec}^2\text{ft}^{-1}$ $(\text{sec}^2\text{m}^{-1})$
$C_{m_\alpha} = \dfrac{\partial C_m}{\partial \alpha}$	Variation of pitching moment coefficient with angle of attack (i.e., static longitudinal stability)	rad^{-1}

Symbol	Definition	Dimension
$C_{m_{\alpha_{\bar{E}}}} = \left.\dfrac{\partial C_m}{\partial \alpha}\right\|_{\bar{E}}$	Variation of pitching moment coefficient with angle of attack for the elastic case with zero mass	rad^{-1}
$C_{m_{\alpha_E}} = \left.\dfrac{\partial C_m}{\partial \alpha}\right\|_{E}$	Variation of pitching moment coefficient with angle of attack for elastic case including mass effect	rad^{-1}
$C_{m_{\ddot{\theta}_I}} = \left.\dfrac{\partial C_m}{\partial \theta}\right\|_{I}$	Inertially induced variation of pitching moment coefficient with pitch angular acceleration	$sec^2\, rad^{-1}$
c	Chord	ft (m)
$\bar{c}$	Reference chord	ft (m)
$\dfrac{\partial C_L}{\partial n}$	Variation of lift coefficient with load factor	
$\dfrac{\partial C_m}{\partial n}$	Variation of pitching moment coefficient with load factor	
$\dfrac{dC_m}{dC_L}$	Static margin in fractions of the root chord	
$\Delta \dfrac{dC_m}{dC_L}$	Aerodynamic center shift in fractions of the root chord	
E	Young's Modulus of elasticity	$\dfrac{lbs}{ft^2} \left(\dfrac{N}{m^2}\right)$
G	Shear Modulus of elasticity	$\dfrac{lbs}{ft^2} \left(\dfrac{N}{m^2}\right)$
g	Acceleration of gravity	$\dfrac{ft}{sec^2} \left(\dfrac{m}{sec^2}\right)$
I	Moment of inertia	slug ft^2 (kg m^2)

Symbol	Definition	Dimension
J	Polar moment of inertia	slug ft^2 (kg m^2)
M	Mach number	
n	Load factor	
q	Perturbed pitch rate	$\frac{rad}{sec}$
$\bar{q}$	Dynamic pressure	$\frac{lbs}{ft^2}\left(\frac{N}{m^2}\right)$
S	Reference area	ft^2 (m^2)
U_1	Free stream velocity	$\frac{ft}{sec}\left(\frac{m}{sec}\right)$
W	Weight	lbs (N)
$\dot{w}$	Perturbed downward acceleration	$\frac{ft}{sec^2}\left(\frac{m}{sec^2}\right)$
X, Y	Coordinate axes located at wing apex (see Figure 1 for positive directions)	ft (m)
$\ddot{\theta}$	Pitch attitude angle acceleration (total)	$\frac{rad}{sec^2}$
Λ	Sweep angle	deg
λ	Taper ratio	

Subscripts:

Symbol	Definition
c/4	Quarter chord
$\bar{E}$	Elastic, zero mass
E	Elastic, corrected for mass
I	Inertial
LE	Leading edge
r	Root
ref	reference
w	Wing
72	72° Swept wing

4. THE EFFECT OF PLANFORM SHAPE, MACH NUMBER AND DYNAMIC PRESSURE ON LONGITUDINAL STABILITY CHARACTERISTICS

This chapter describes results obtained from a parametric investigation of the following planforms:

4.1 Fixed 72° swept wing and variable sweep wing, $\Lambda = 72^{\circ}$ with the pivot at 20, 30, and 40% of the $\Lambda = 72^{\circ}$ semispan

4.2 Variable sweep wing, $\Lambda = 20^{\circ}$ with the pivot at 20, 30, and 40% of the $\Lambda = 72^{\circ}$ semispan

4.3 45° Swept, aspect ratio 3 wing with and without forward tip crank

4.4 60° Swept, aspect ratio 2 wing with and without forward tip crank

For this investigation, the following longitudinal stability derivatives were computed:

For the Rigid Airplane

$$C_{L_{\alpha}},\ C_{m_{\alpha}},\ C_{m_{\alpha}}/C_{L_{\alpha}} = \text{static margin},\ C_{L_q},\ C_{m_q}$$

For the Elastic Airplane (Zero Mass)

$$C_{L_{\alpha_{\bar{E}}}},\ C_{m_{\alpha_{\bar{E}}}},\ C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}} = \text{static margin},\ C_{L_{q_{\bar{E}}}},\ C_{m_{q_{\bar{E}}}}$$

For the Elastic Airplane (Non-zero Mass)

$$C_{L_{\alpha_E}},\ C_{m_{\dot{\alpha}_E}},\ C_{m_{\alpha_E}}/C_{L_{\alpha_E}} = \text{static margin},\ C_{L_{q_I}},$$

$$C_{m_{q_I}},\ C_{L_{\dot{w}_I}},\ C_{m_{\dot{w}_I}},\ C_{L_{\ddot{\theta}_I}},\ C_{m_{\ddot{\theta}_I}},\ \partial C_L/\partial n,\ \partial C_m/\partial n$$

A complete derivation and description of the use of these derivatives is given in Reference 11. All moments in this chapter are referred to the wing planform apex.

To make realistic calculations of elastic planform derivatives it is necessary to use representative data for wing mass and for wing stiffness distribution. The respective distributions used in this report are described in References 8 and 9.

4.1. Fixed 72° swept wing and variable sweep wing at $\Lambda = 72^\circ$ having pivots at 20, 30, and 40% of the $\Lambda = 72^\circ$ semispan (Wings 1, 9, 10, and 11)

For these wings, longitudinal characteristics were computed for the flight conditions of Table 2.

Figures 1 and 2 show the planform geometry of wings 1, 9, 10, and 11. Observe from Figures 2a through 2c that the elastic axes inboard of the wing pivots are perpendicular to the wing centerline. The reason for this is that in variable sweep wing structures the bending and torque box which connects both pivots generally runs approximately perpendicular to the airplane centerline.

Tabulated results for the stability derivatives of these wings are presented in Table 3 for the rigid wing and in Tables 4 through 7 for the elastic wings. Obviously, for the case of the rigid wing at constant sweep angle, there is no effect of spanwise pivot position on the derivatives. Figures 3 through 6 show the effect of Mach number and dynamic pressure on lift-curve-slope, static margin (i.e., aerodynamic center location) and pitch damping derivative for the zero mass (or constant load-factor) case.

The general effects of elasticity are seen in these Figures to be as expected: a decrease in lift-curve-slope, a forward shift in aerodynamic center and a decrease in pitch damping for increasing dynamic pressure at each Mach number.

A series of crossplots of aerodynamic center location versus dynamic pressure is shown in Figure 7. These data demonstrate the strong effect of elasticity and of pivot location on aerodynamic center location. Because of the shorter outboard elastic axes associated with the more outboard pivot locations, the result is to diminish the aerodynamic center shift due to elasticity. The results of Figures 3 through 7 demonstrate that much design tailoring can be done in terms of adjusting pivot location to keep aerodynamic center shifts within acceptable boundaries from a longitudinal stability and from a trim drag point of view. It may be seen from Figure 7 that there is not much difference in aerodynamic center location when going from a 20% to a 30% pivot location. This is due to the fact that the outboard elastic axes for wings 9 and 10 are virtually identical in location (compare Figures 2a and 2b). Going to the 40% pivot results in a different elastic axis as shown in Figure 2c. This in turn results in a significant aft shift in a.c. as seen in figure 7.

The tabulated derivatives of Tables 4 through 7 suggest that mass (inertial) effects are not very important for the types of airplanes studied here. This conclusion follows from:

1. Comparing E - subscripted derivatives with $\bar{E}$ - subscripted derivatives which show little difference.

2. Comparing $C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$ with $C_{m_{\alpha_E}} / C_{m_{\alpha_E}}$ shows less than 1% difference in aerodynamic center location.

3. The inertia relief effect due to load-factor, $\partial C_L/\partial n$, is only -.05 per unit change in load-factor.

4. The I (inertia) - subscripted derivatives are all very small. The reader may convince himself of this fact by assuming a reasonable value for $\dot{\theta}$, $\dot{w}$, or q and multiplying those values by the appropriate inertial derivative. The result is invariably very small. For example, assume $\dot{w}$ = 10 ft/sec^2 (~ 1/3 g .). This results in

$$\Delta C_{L_{\text{due to } \dot{w}}} = .0162$$ which is indeed small.

Table 2 Flight Conditions for Wings 1, 9, 10 and 11

WING NUMBER	WING TYPE	MACH NUMBER	RIGID	ELASTIC Sealevel	ELASTIC 35,000 ft. (10,668 m)	ELASTIC 60,000 ft. (18,288 m)
1	A=2	.25	x	x		
	$\Lambda_{LE}=72^{\circ}$	.50	x	x		
	No Pivot	.80	x	x	x	x
		1.25	x			
		1.50	x	x	x	x
		1.75	x			
		2.00	x		x	x
		2.25	x			
		2.50	x		x	x
9	A=2	.25	x	x		
	$\Lambda_{LE}=72^{\circ}$	.50	x	x		
	Pivot at	.80	x	x	x	x
	$.20\ b_{72}/2$	1.25	x			
		1.50	x	x	x	x
		1.75	x			
		2.00	x	x	x	x
		2.50	x		x	x
10	A=2	.25	x	x		
	$\Lambda_{LE}=72^{\circ}$	.50	x	x		
	Pivot at	.80	x	x	x	x
	$.30\ b_{72}/2$	1.25	x			
		1.50	x	x	x	x
		1.75	x			
		2.00	x	x	x	x
		2.50	x		x	x
11	A=2	.25	x	x		
	$\Lambda_{LE}=72^{\circ}$	.50	x	x		
	Pivot at	.80	x	x	x	x
	$.40\ b_{72}/2$	1.25	x			
		1.50	x	x	x	x
		1.75	x			
		2.00	x	x	x	x
		2.50	x		x	x

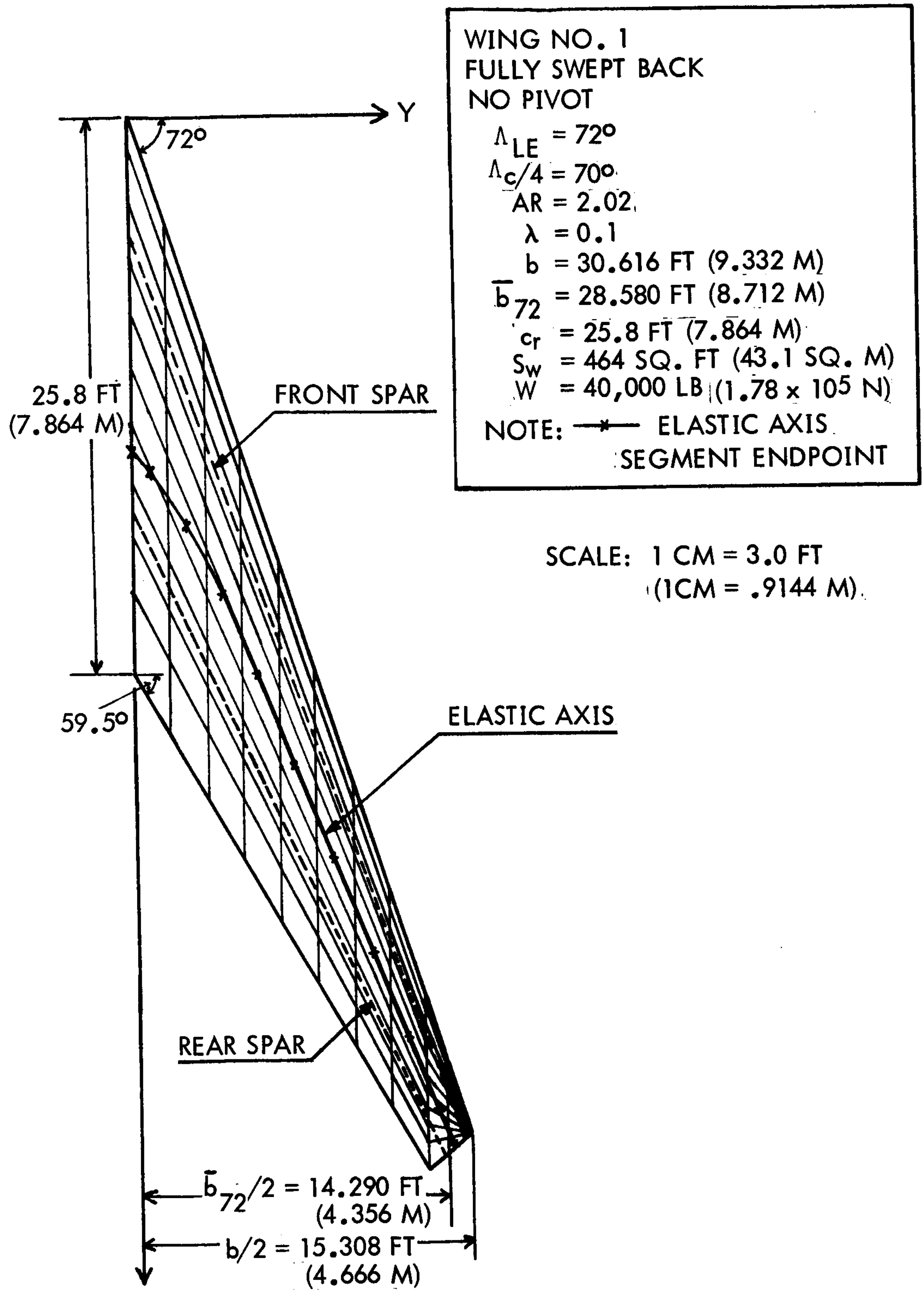


Figure 1. Planform Definition for Wing No. 1

WING NO. 9

FULLY SWEPT BACK

PIVOT AT 20% of $\bar{b}_{72}/2$

$\Lambda_{LE} = 72°$

$\Lambda_{c/4} = 70°$

$AR = 2.02$

$\lambda = 0.1$

$b = 30.616$ FT (9.332 M)

$\bar{b}_{72} = 28.580$ FT (8.712 M)

$c_r = 25.8$ FT (7.864 M)

$S_w = 464$ SQ FT (43.1 SQ M)

$W = 40{,}000$ LB (1.78×10^5 N)

$X_{PIVOT} = 27.348$ FT (8.336 M)

$Y_{PIVOT} = 2.838$ FT (.865 M)

NOTE: —×— ELASTIC AXIS SEGMENT ENDPOINT

SCALE: 1 CM = 3.0 FT
(1 CM = .9144 M)

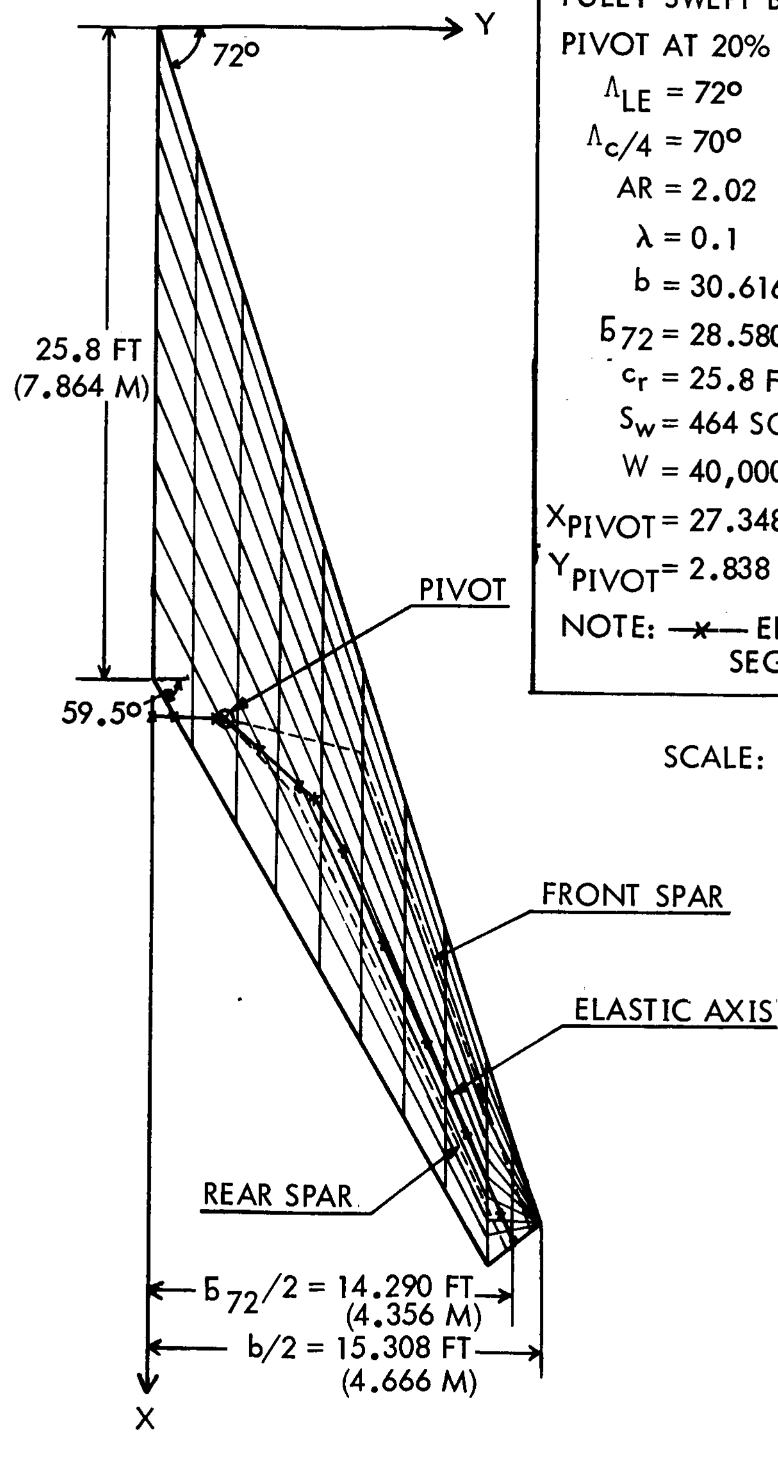


Figure 2.a Planform Definition for Wing No. 9

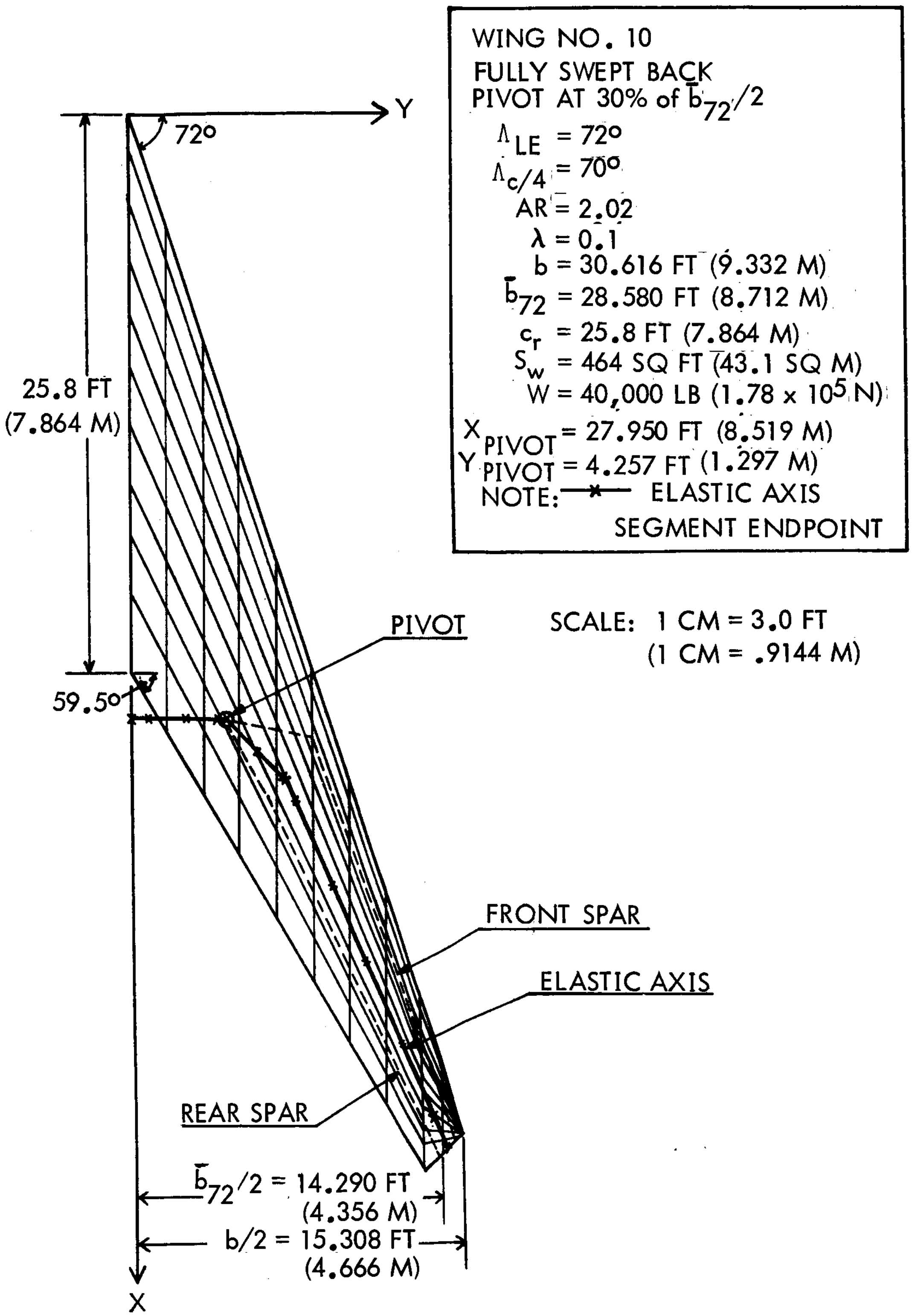


Figure 2.b Planform Definition for Wing No. 10

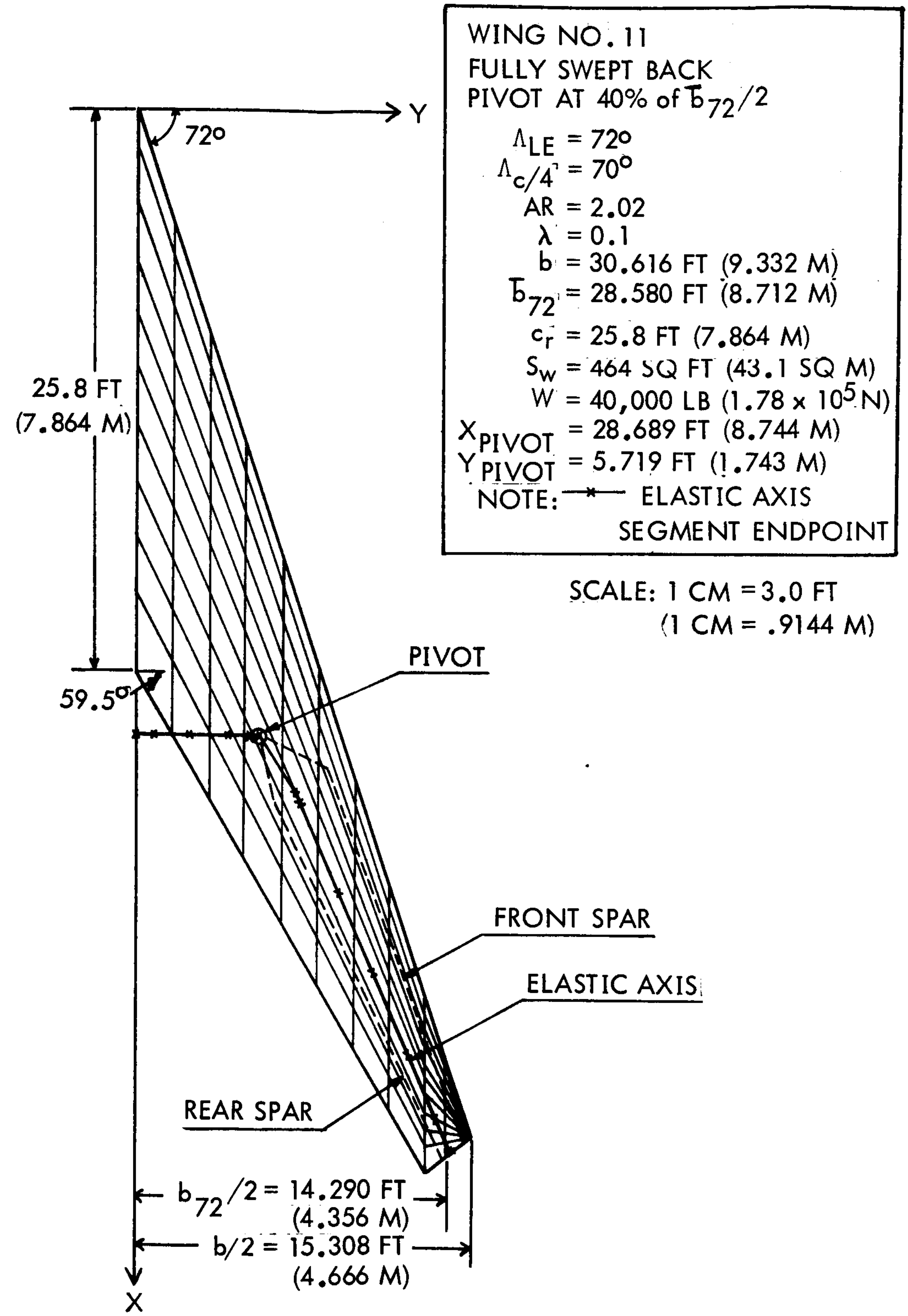


Figure 2.c Planform Definition for Wing No. 11

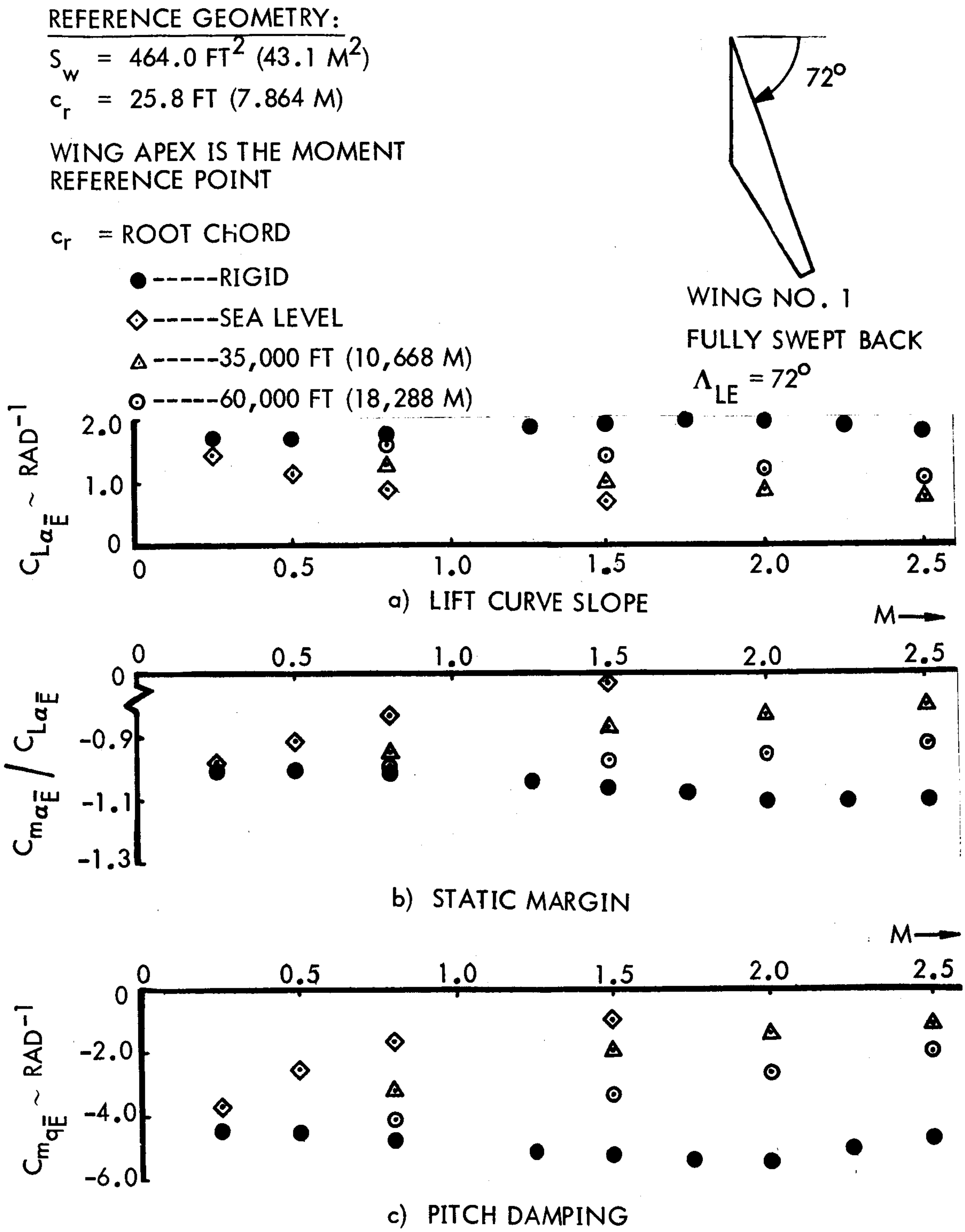


Figure 3. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 1.

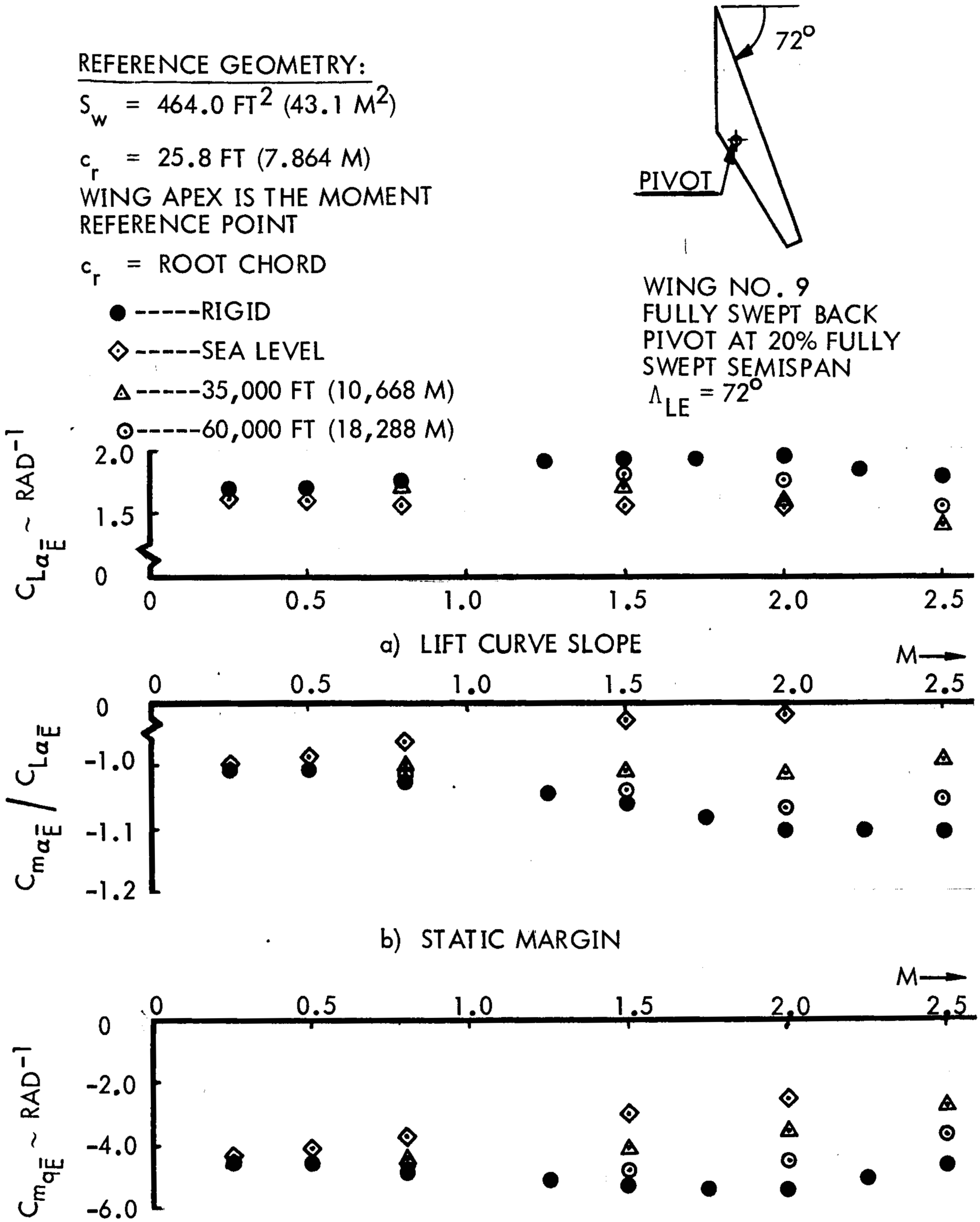


Figure 4. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 9.

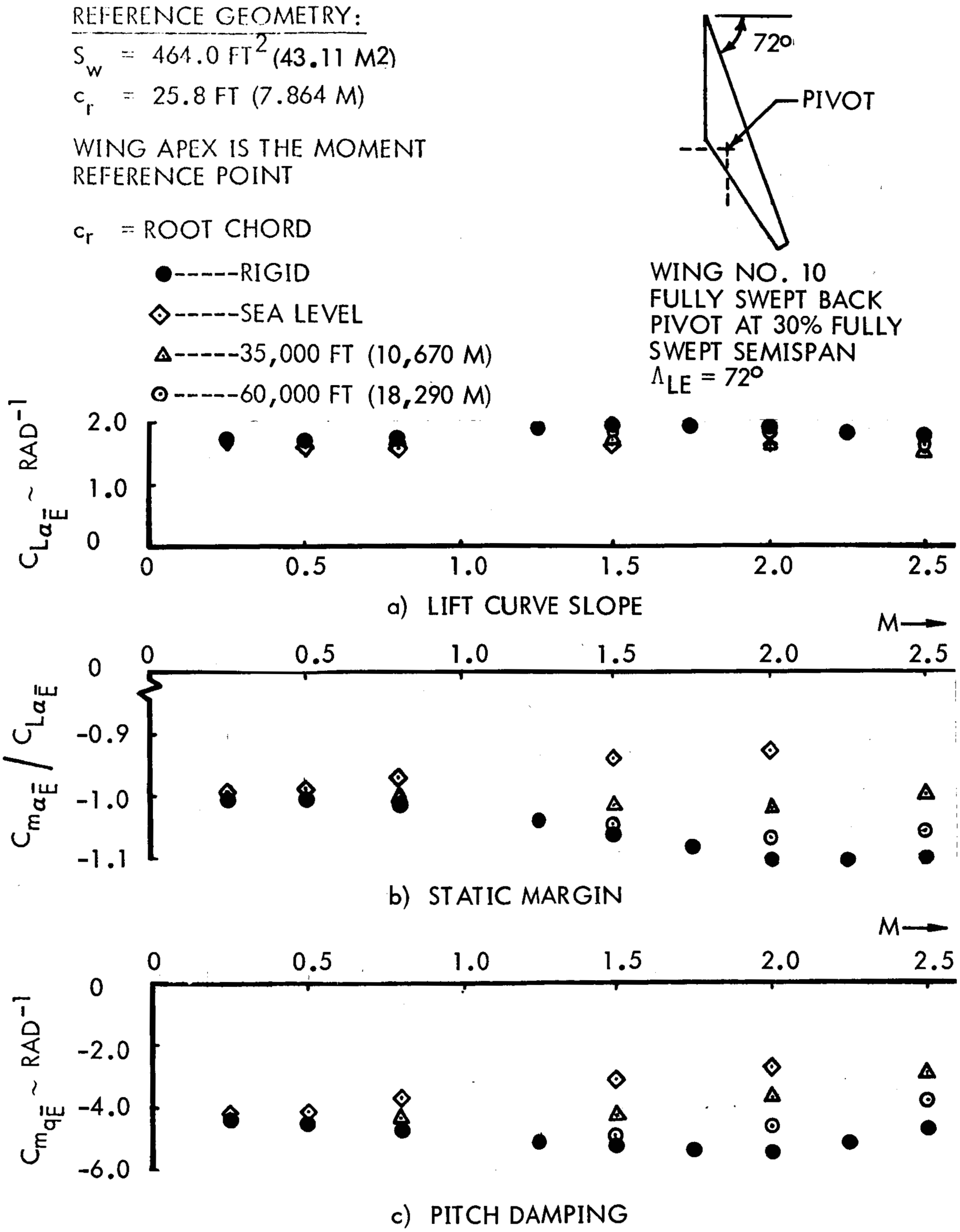


Figure 5. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 10.

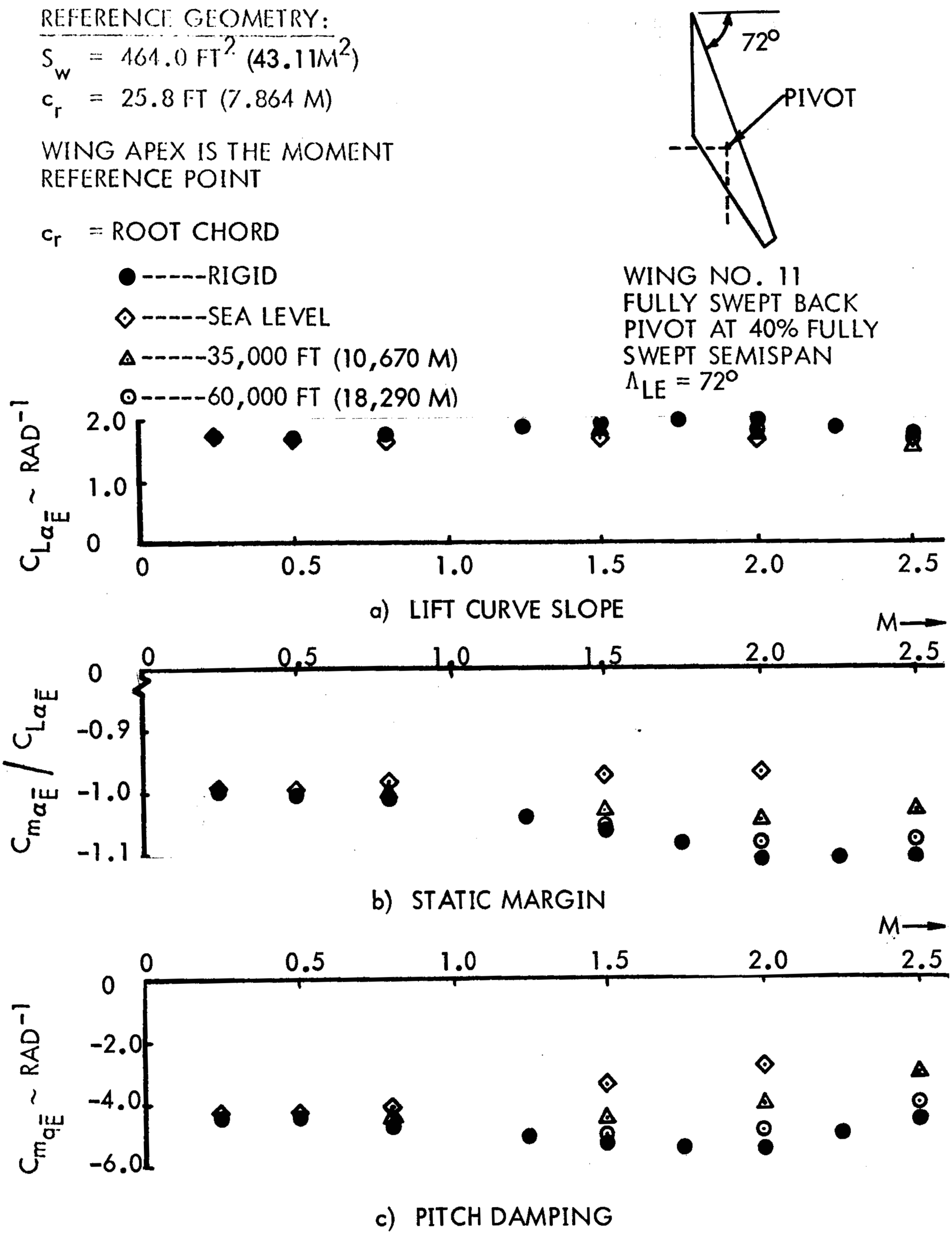


Figure 6. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 11.

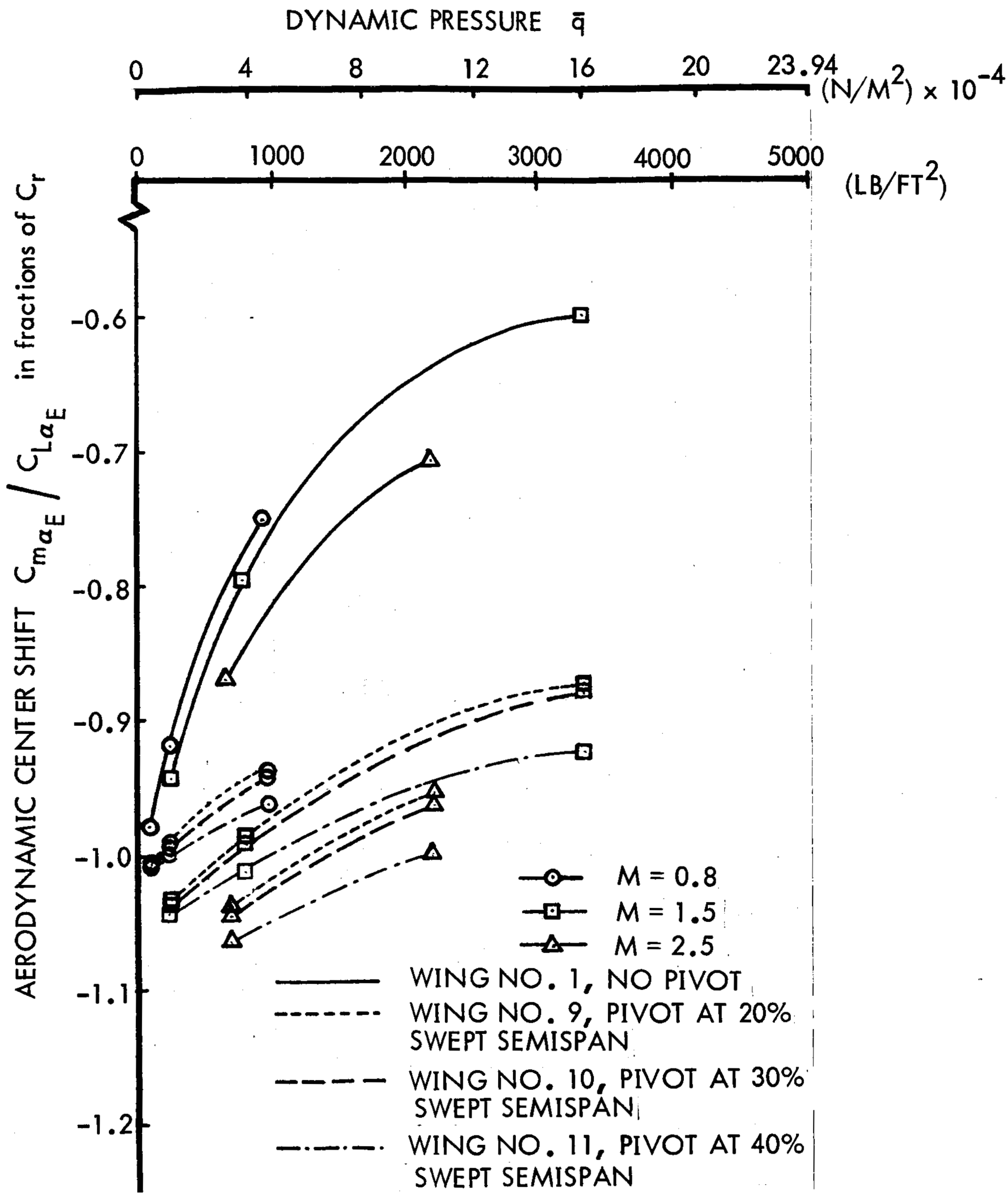


Figure 7 Aerodynamic Center Shift versus Dynamic Pressure for Three Mach Numbers and Four Pivot Locations

Table 3 Stability Derivatives for the Rigid 72° Swept Back Wing (Wing 1)

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha}/C_{L_\alpha}$
0.25	1.6823	-1.6862	+4.0314	-4.4486	-1.00232
0.50	1.7071	-1.7154	+4.0917	-4.5258	-1.00486
0.80	1.7658	-1.7858	+4.2336	-4.7112	-1.01133
1.25	1.8837	-1.9574	+4.4623	-5.1123	-1.03913
1.50	1.9164	-2.0289	+4.4853	-5.2476	-1.05870
1.75	1.9452	-2.1033	+4.4979	-5.3877	-1.08128
2.00	1.9566	-2.1627	+4.4536	-5.4694	-1.10534
2.25	1.8678	-2.0646	+4.0900	-5.0355	-1.10536
2.50	1.7852	-1.9722	+3.7790	-4.6600	-1.10475

Reference geometry: S_w = 464 ft.^{2}

c_r = 25.8 ft. (root chord)

Moment reference center is wing apex

TABLE 4A STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING (WING 1) AT SEA LEVEL

DERIVATIVES	M = 0.25 $\bar{q}$ = 92.701	0.5 370.80	0.8 949.25	1.5 3337.2
$C_{L_{\alpha_{\bar{E}}}}$	1.4752	1.1535	0.90445	0.71066
$C_{m_{\alpha_{\bar{E}}}}$	-1.4392	-1.0542	-0.75221	-0.51450
$C_{L_{q_{\bar{E}}}}$	3.4120	2.4497	1.7193	1.1115
$C_{m_{q_{\bar{E}}}}$	-3.7066	-2.5519	-1.6638	-0.95367
$C_{L_{q_I}}$	-9.7623	-24.672	-34.548	-42.196
$C_{m_{q_I}}$	11.845	30.188	42.800	52.061
$C_{L_{\dot{w}_I}}$	0.0016153	0.0010205	0.00055823	0.00019393
$C_{m_{\dot{w}_I}}$	-0.0019599	-0.0012487	-0.00069156	-0.00023928
$C_{L_{\ddot{\theta}_I}}$	0.064866	0.040110	0.020942	0.0066752
$C_{m_{\ddot{\theta}_I}}$	-0.079658	-0.050019	-0.026845	-0.0086412
$\partial C_L/\partial n$	-0.052011	-0.032861	-0.017975	-0.0062447
$\partial C_m/\partial n$	0.063110	0.040209	0.022268	0.0077047
$C_{L_{\alpha_E}}$	1.3970	1.0106	0.75501	0.57230
$C_{m_{\alpha_E}}$	-1.3444	-0.87941	-0.56707	-0.34380
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.97513	-0.91393	-0.83167	-0.72398
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.96235	-0.87015	-0.75108	-0.60073

Reference Geometry: $S_w = 464\ ft^2$; c_r=25.8 ft (root chord)
Moment reference center is wing apex

TABLE 4B STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING (WING 1) AT 35,000 FEET (10,668m)

DERIVATIVES	$M = 0.8$ $\bar{q} = 223.26$	1.5 784.91	2.0 1395.4	2.5 2180.3
$C_{L_{\alpha_{\bar{E}}}}$	1.3287	1.0173	0.88145	0.77318
$C_{m_{\alpha_{\bar{E}}}}$	-1.2600	-0.88498	-0.73380	-0.62243
$C_{L_{q_{\bar{E}}}}$	2.9345	1.9026	1.4570	1.1474
$C_{m_{q_{\bar{E}}}}$	-3.1401	-1.9304	-1.4314	-1.0959
$C_{L_{q_I}}$	-60.894	-98.554	-104.50	-109.26
$C_{m_{q_I}}$	74.757	127.27	137.25	143.03
$C_{L_{\dot{w}_I}}$	0.0012957	0.00059650	0.00035577	0.00023806
$C_{m_{\dot{w}_I}}$	-0.0015907	-0.00077029	-0.00046728	-0.00031165
$C_{L_{\ddot{\theta}_I}}$	0.051406	0.022462	0.013058	0.0086148
$C_{m_{\ddot{\theta}_I}}$	-0.064105	-0.029869	-0.017740	-0.011696
$\partial C_L/\partial n$	-0.041722	-0.019207	-0.011456	-0.0076657
$\partial C_m/\partial n$	0.051221	0.024803	0.015047	0.010035
$C_{L_{\alpha_E}}$	1.1991	0.86588	0.74357	0.64762
$C_{m_{\alpha_E}}$	-1.1009	-0.68944	-0.55270	-0.45806
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.94831	-0.86992	-0.83250	-0.80502
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.91813	-0.79622	-0.74331	-0.70729

Reference Geometry: $S_w = 464$ ft^2; $c_r = 25.8$ ft (root chord)

Moment Reference center is wing apex

TABLE 4C STABILITY DERIVATIVES FOR THE ELASTIC 72°SWEPT BACK WING (WING 1) AT 60,000 FEET (18,288m)

DERIVATIVES	$M = 0.8$ $\bar{q} = 67.155$	1.5 236.09	2.0 419.72	2.5 655.81
$C_{L_{\alpha_{\bar{E}}}}$	1.5903	1.3883	1.2061	1.0431
$C_{m_{\alpha_{\bar{E}}}}$	-1.5746	-1.3542	-1.1533	-0.96783
$C_{L_{q_{\bar{E}}}}$	3.7096	2.9448	2.3106	1.7957
$C_{m_{q_{\bar{E}}}}$	-4.0779	-3.2679	-2.5628	-1.9490
$C_{L_{q_I}}$	-82.201	-197.34	-237.94	-258.01
$C_{m_{q_I}}$	100.54	255.27	319.61	347.96
$C_{L_{\dot{w}_I}}$	0.0017665	0.0012063	0.00081815	0.00056778
$C_{m_{\dot{w}_I}}$	-0.0021607	-0.0015604	-0.0010990	-0.00076573
$C_{L_{\ddot{\theta}_I}}$	0.070967	0.047485	0.031760	0.021845
$C_{m_{\ddot{\theta}_I}}$	-0.087815	-0.062430	-0.043486	-0.030111
$\partial C_L / \partial n$	-0.056882	-0.038843	-0.026344	-0.018282
$\partial C_m / \partial n$	0.069575	0.050245	0.035387	0.024657
$C_{L_{\alpha_E}}$	1.5228	1.2548	1.0690	0.91574
$C_{m_{\alpha_E}}$	-1.4920	-1.1815	-0.96914	-0.79606
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.99011	-0.97544	-0.95625	-0.92783
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.97979	-0.94160	-0.90662	-0.86931

Reference Geometry: $S_w = 464$ ft^2; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 5 A STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 20% SWEPT SEMISPAN (WING 9) AT SEALEVEL

DERIVATIVES	M = 0.25 $\bar{q}$ = 92.701	0.5 370.80	0.8 949.25	1.5 3337.2	2.0 5932.8
$C_{L_{\alpha_{\bar{E}}}}$	1.6563	1.6131	1.5662	1.5627	1.5632
$C_{m_{\alpha_{\bar{E}}}}$	-1.6512	-1.5875	-1.5067	-1.4496	-1.4392
$C_{L_{q_{\bar{E}}}}$	3.9361	3.7438	3.4762	2.9300	2.4838
$C_{m_{q_{\bar{E}}}}$	-4.3247	-4.0712	-3.7072	-3.0260	-2.5502
$C_{L_{q_I}}$	-1.8985	-6.8369	-14.415	-25.858	-29.621
$C_{m_{q_I}}$	2.3958	8.6430	18.314	33.879	38.945
$C_{L_{\dot{w}_I}}$	0.00031411	0.00028280	0.00023292	0.00011885	0.000076580
$C_{m_{\dot{w}_I}}$	-0.00039641	-0.00035752	-0.00029593	-0.00015571	-0.00010068
$C_{L_{\ddot{\theta}_I}}$	0.013284	0.011925	0.0097582	0.0048742	0.0031252
$C_{m_{\ddot{\theta}_I}}$	-0.016835	-0.015147	-0.012471	-0.0064359	-0.0041299
$\partial C_L / \partial n$	-0.010114	-0.0091063	-0.0075000	-0.0038269	-0.0024659
$\partial C_m / \partial n$	0.012764	0.011512	0.0095288	0.0050139	0.0032420
$C_{L_{\alpha_E}}$	1.6384	1.5523	1.4468	1.3611	1.3364
$C_{m_{\alpha_E}}$	-1.6287	-1.5106	-1.3549	-1.1854	-1.1410
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.99694	-0.98416	-0.96199	-0.92762	-0.92066
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.99405	-0.97319	-0.93651	-0.87095	-0.85378

Reference Geometry: S_W = 464 ft^2; c_r= 25.8 ft (root chord)

Moment reference center is wing apex

TABLE 5B. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 20% SWEPT SEMISPAN (WING 9) AT 35,000 FEET (10,668m)

DERIVATIVES	$M = 0.8$ $\bar{q} = 223.26$	1.5 784.91	2.0 1395.4	2.5 2180.3
$C_{L_{\alpha_{\bar{E}}}}$	1.6999	1.6891	1.5734	1.4089
$C_{m_{\alpha_{\bar{E}}}}$	-1.6961	-1.7015	-1.5923	-1.3990
$C_{L_{q_{\bar{E}}}}$	3.9928	3.6657	3.1055	2.4762
$C_{m_{q_{\bar{E}}}}$	-4.3953	-4.1165	-3.5458	-2.7892
$C_{L_{q_I}}$	-14.394	-38.325	-51.064	-59.096
$C_{m_{q_I}}$	18.332	51.104	69.822	80.616
$C_{L_{\dot{w}_I}}$	0.00030629	0.00023196	0.00017385	0.00012876
$C_{m_{\dot{w}_I}}$	-0.00039007	-0.00030931	-0.00023771	-0.00017566
$C_{L_{\ddot{\theta}_I}}$	0.012928	0.0097288	0.0072507	0.0053504
$C_{m_{\ddot{\theta}_I}}$	-0.016540	-0.013093	-0.0099650	-0.0073354
$\partial C_L/\partial n$	-0.0098625	-0.0074693	-0.0055979	-0.0041462
$\partial C_m/\partial n$	0.012560	0.0099597	0.0076543	0.0056561
$C_{L_{\alpha_E}}$	1.6575	1.5815	1.4426	1.2752
$C_{m_{\alpha_E}}$	-1.6422	-1.5581	-1.4136	-1.2166
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_E}}$	-0.99778	-1.0074	-1.0120	-0.99294
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.99074	-0.98518	-0.97985	-0.95402

Reference Geometry: $S_w = 464^2$; $c_r = 45.8$ ft (root chord)
Moment reference center is wing apex

TABLE 5C STABILITY DERIVATIVES FOR THE ELASTIC 72°SWEPT BACK WING WITH PIVOT AT THE 20% SWEPT SEMISPAN (WING 9) AT 60,000FEET (18,288m)

DERIVATIVES	M = 0.8 $\bar{q}$ = 67.155	1.5 236.09	2.0 419.72	2.5 655.81
$C_{L_{\alpha_{\bar{E}}}}$	1.7443	1.8242	1.7673	1.5759
$C_{m_{\alpha_{\bar{E}}}}$	-1.7566	-1.8986	-1.8875	-1.6648
$C_{L_{q_{\bar{E}}}}$	4.1555	4.1623	3.8150	3.1016
$C_{m_{q_{\bar{E}}}}$	-4.6090	-4.8043	-4.5633	-3.6945
$C_{L_{q_I}}$	-15.291	-48.608	-75.701	-94.177
$C_{m_{q_I}}$	19.482	65.009	104.50	130.19
$C_{L_{\dot{w}_I}}$	0.00032860	0.00029713	0.00026029	0.00020725
$C_{m_{\dot{w}_I}}$	-0.00041867	-0.00039738	-0.00035932	-0.00028649
$C_{L_{\ddot{\theta}_I}}$	0.013893	0.012538	0.010959	0.0087089
$C_{m_{\ddot{\theta}_I}}$	-0.017776	-0.016839	-0.015188	-0.012085
$\partial C_L/\partial n$	-0.010581	-0.0095676	-0.0083814	-0.0066733
$\partial C_m/\partial n$	0.013481	0.012796	0.011570	0.0092250
$C_{L_{\alpha_E}}$	1.7300	1.7777	1.6980	1.4998
$C_{m_{\alpha_E}}$	-1.7385	-1.8363	-1.7919	-1.5595
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-1.0071	-1.0407	-1.0680	-1.0564
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-1.0049	-1.0330	-1.0553	-1.0398

Reference Geometry: S_w = 464 ft^2; c_r = 25.8 ft (root chord)
Moment reference center is wing apex

TABLE 6A . STABILITY DERIVATIVES FOR THE ELASTIC 72°SWEPT BACK WING WITH PIVOT AT THE 30% SWEPT SEMISPAN (WING 10) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.5 370.80	0.8 949.25	1.5 3337.2	2.0 5932.8
$C_{L_{\alpha_{\bar{E}}}}$	1.6611	1.6291	1.5953	1.5970	1.5993
$C_{m_{\alpha_E}}$	-1.6574	-1.6084	-1.5450	-1.4964	-1.4880
$C_{L_{q_{\bar{E}}}}$	3.9510	3.7927	3.5642	3.0383	2.6022
$C_{m_{q_{\bar{E}}}}$	-4.3437	-4.1338	-3.8201	-3.1614	-2.6915
$C_{L_{q_I}}$	-1.8025	-6.5642	-14.028	-25.256	-29.011
$C_{m_{q_I}}$	2.2942	8.3797	18.048	33.673	38.726
$C_{L_{\dot{w}_I}}$	0.00029824	0.00027152	0.00022667	0.00011608	0.000075002
$C_{m_{\dot{w}_I}}$	-0.00037959	-0.00034662	-0.00029162	-0.00015476	-0.00010012
$C_{L_{\ddot{\theta}_I}}$	0.012692	0.011529	0.0095745	0.0048217	0.0031131
$C_{m_{\ddot{\theta}_I}}$	-0.016208	-0.014722	-0.012374	-0.0064620	-0.0041608
$\partial C_L / \partial n$	-0.00906032	-0.0087431	-0.0072985	-0.0037377	-0.0024151
$\partial C_m / \partial n$	0.012223	0.011161	0.0093900	0.0049833	0.0032238
$C_{L_{\alpha_E}}$	1.6441	1.5700	1.4766	1.3951	1.3714
$C_{m_{\alpha_E}}$	-1.6358	-1.5330	-1.3923	-1.2273	-1.1837
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.99781	-0.98729	-0.96849	-0.93706	-0.93039
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.99497	-0.97641	-0.94292	-0.87973	-0.86317

Reference Geometry: $S_w = 464$ ft^2; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 6B. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 30% SWEPT SEMISPAN (WING 10) AT 35,000 FEET(10,668m)

DERIVATIVES	M = 0.8 $\bar{q}$ = 223.26	1.5 784.91	2.0 1395.4	2.5 2180.3
$C_{L_{\alpha_{\bar{E}}}}$	1.7114	1.7177	1.6080	1.4405
$C_{m_{\alpha_{\bar{E}}}}$	-1.7112	-1.7408	-1.6404	-1.4433
$C_{L_{q_{\bar{E}}}}$	4.0282	3.7507	3.2061	2.5636
$C_{m_{q_{\bar{E}}}}$	-4.4408	-4.2301	-3.6802	-2.9054
$C_{L_{q_I}}$	-13.734	-37.291	-50.079	-58.063
$C_{m_{q_I}}$	17.654	50.254	69.226	80.121
$C_{L_{\dot{w}_I}}$	0.00029224	0.00022570	0.00017050	0.00012651
$C_{m_{\dot{w}_I}}$	-0.00037566	-0.00030416	-0.00023568	-0.00017458
$C_{L_{\ddot{\theta}_I}}$	0.012418	0.0095444	0.0071779	0.0053127
$C_{m_{\ddot{\theta}_I}}$	-0.016020	-0.012911	-0.0099560	-0.0073531
$\partial C_L / \partial n$	-0.0094100	-0.0072677	-0.0054900	-0.0040737
$\partial C_m / \partial n$	0.012096	0.0097940	0.0075890	0.0056214
$C_{L_{\alpha_E}}$	1.6707	1.6111	1.4767	1.3060
$C_{m_{\alpha_E}}$	-1.6589	-1.5971	-1.4590	-1.2577
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.99988	-1.0134	-1.0202	-1.0020
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.99292	-0.99132	-0.98798	-0.96302

Reference Geometry: S_w = 464 ft^2; c_r = 25.8 ft (root chord)

Moment reference center is wing apex

TABLE 6C. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACKWING WITH PIVOT AT THE 30% SWEPT SEMISPAN (WING 10) AT 60,000 FEET (18,288m)

DERIVATIVES	$M = 0.8$ $\bar{q} = 67.155$	1.5 236.09	2.0 417.72	2.5 655.81
$C_{L_{\alpha_{\bar{E}}}}$	1.7482	1.8381	1.7894	1.5996
$C_{m_{\alpha_{\bar{E}}}}$	-1.7618	-1.9175	-1.9183	-1.6982
$C_{L_{q_{\bar{E}}}}$	4.1676	4.2035	3.8791	3.1663
$C_{m_{q_{\bar{E}}}}$	-4.6247	-4.8599	-4.6510	-3.7839
$C_{L_{q_I}}$	-14.483	-46.545	-73.063	-91.091
$C_{m_{q_I}}$	18.612	62.766	101.68	126.89
$C_{L_{\dot{w}_I}}$	0.00031124	0.00028452	0.00025122	0.00020046
$C_{m_{\dot{w}_I}}$	-0.00039997	-0.00038367	-0.00034960	-0.00027924
$C_{L_{\ddot{\theta}_I}}$	0.013243	0.012090	0.010655	0.0084903
$C_{m_{\ddot{\theta}_I}}$	-0.017075	-0.016355	-0.014869	-0.011858
$\partial C_L/\partial n$	-0.010022	-0.0091616	-0.0080893	-0.0064547
$\partial C_m/\partial n$	0.012879	0.012354	0.011257	0.0089915
$C_{L_{\alpha_E}}$	1.7347	1.7931	1.7216	1.5247
$C_{m_{\alpha_E}}$	-1.7444	-1.8568	-1.8240	-1.5939
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-1.0078	-1.0432	-1.0720	-1.0617
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-1.0056	-1.0355	-1.0595	-1.0454

Reference Geometry: $S_W = 464\ ft^2$; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 7A. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 40% SWEPT SEMISPAN (WING 11) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.5 370.80	0.8 949.25	1.5 3337.2	2.0 5932.8
$C_{L_{\alpha_{\bar{E}}}}$	1.6704	1.6621	1.6624	1.6766	1.6468
$C_{m_{\alpha_{\bar{E}}}}$	-1.6697	-1.6523	-1.6363	-1.6289	-1.5912
$C_{L_{q_{\bar{E}}}}$	3.9779	3.8864	3.7454	3.1926	2.6405
$C_{m_{q_{\bar{E}}}}$	-4.3797	-4.2600	-4.0714	-3.4460	-2.8442
$C_{L_{q_I}}$	-1.3682	-5.1644	-11.774	-24.521	-28.422
$C_{m_{q_I}}$	1.6974	6.4211	14.729	31.994	37.730
$C_{L_{\dot{w}_I}}$	0.00022638	0.00021362	0.00019025	0.00011270	0.000073479
$C_{m_{\dot{w}_I}}$	-0.00028085	-0.00026561	-0.00023800	-0.00014705	-0.000097544
$C_{L_{\ddot{\theta}_I}}$	0.0096423	0.0090927	0.0080852	0.0047746	0.0031254
$C_{m_{\ddot{\theta}_I}}$	-0.011970	-0.011313	-0.010122	-0.0062264	-0.0041330
$\partial C_L/\partial n$	-0.0072893	-0.0068786	-0.0061261	-0.0036289	-0.0023660
$\partial C_m/\partial n$	0.0090433	0.0085525	0.0076636	0.0047349	0.0031409
$C_{L_{\alpha_E}}$	1.6574	1.6143	1.5573	1.4701	1.4162
$C_{m_{\alpha_E}}$	-1.6536	-1.5929	-1.5049	-1.3594	-1.2851
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.99959	-0.99409	-0.98431	-0.97154	-0.96623
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.99770	-0.98672	-0.96632	-0.92469	-0.90742

Reference Geometry: $S_W = 464\ ft^2$; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 7B. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 40% SWEEP SEMISPAN (WING 11) AT 35,000 FT (10,668 m)

DERIVATIVES	$M = 0.8$ $\bar{q} = 223.26$	1.5 784.91	2.0 1395.4	2.5 2180.3
$C_{L_{\alpha_{\bar{E}}}}$	1.7342	1.7803	1.6837	1.5054
$C_{m_{\alpha_{\bar{E}}}}$	-1.7417	-1.8328	-1.7614	-1.5512
$C_{L_{q_{\bar{E}}}}$	4.0934	3.9178	3.3927	2.6992
$C_{m_{q_{\bar{E}}}}$	-4.5292	-4.4811	-3.9905	-3.1463
$C_{L_{q_I}}$	-10.643	-31.544	-44.932	-54.026
$C_{m_{q_I}}$	13.320	41.332	60.707	73.034
$C_{L_{\dot{w}_I}}$	0.00022646	0.00019092	0.00015297	0.00011772
$C_{m_{\dot{w}_I}}$	-0.00028343	-0.00025010	-0.00020668	-0.00015913
$C_{L_{\ddot{\theta}_I}}$	0.0096414	0.0081229	0.0065049	0.0050051
$C_{m_{\ddot{\theta}_I}}$	-0.012074	-0.010643	-0.0087853	-0.0067580
$\partial C_L / \partial n$	-0.0072922	-0.0061477	-0.0049257	-0.0037905
$\partial C_m / \partial n$	0.0091263	0.0080532	0.0066550	0.0051241
$C_{L_{\alpha_E}}$	1.7021	1.6859	1.5594	1.3737
$C_{m_{\alpha_E}}$	-1.7015	-1.7091	-1.5934	-1.3731
$C_{m_{\alpha_E}} / C_{L_{\alpha_{\bar{E}}}}$	-1.0043	-1.0295	-1.0461	-1.0304
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.99967	-1.0138	-1.0218	-0.99956

Reference Geometry: $S_w = 464\ ft^2$; $c_r = 25.8$ ft (root chord)

Moment reference center is wing apex

TABLE 7C. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT THE 40 % SWEPT SEMISPAN (WING 11) AT 60,000 FT (18,288 m)

DERIVATIVES	M = 0.8 $\bar{q}$ = 67.155	1.5 236.09	2.0 419.72	2.5 655.81
$C_{L_{\alpha_{\bar{E}}}}$	1.7557	1.8656	1.8374	1.6487
$C_{m_{\alpha_{\bar{E}}}}$	-1.7719	-1.9572	-1.9917	-1.7743
$C_{L_{q_{\bar{E}}}}$	4.1894	4.2811	4.0121	3.2905
$C_{m_{q_{\bar{E}}}}$	-4.6540	-4.9733	-4.8574	-3.9809
$C_{L_{q_I}}$	-10.986	-36.781	-59.709	-77.001
$C_{m_{q_I}}$	13.751	48.205	80.940	104.57
$C_{L_{\dot{w}_I}}$	0.00023610	0.00022484	0.00020531	0.00016945
$C_{m_{\dot{w}_I}}$	-0.00029551	-0.00029466	-0.00027831	-0.00023011
$C_{L_{\ddot{\theta}_I}}$	0.010056	0.0095784	0.0087455	0.0072149
$C_{m_{\ddot{\theta}_I}}$	-0.012594	-0.012557	-0.011854	-0.0097931
$\partial C_L / \partial n$	-0.0076024	-0.0072397	-0.0066109	-0.0054562
$\partial C_m / \partial n$	0.0095153	0.0094882	0.0089615	0.0074096
$C_{L_{\alpha_E}}$	1.7454	1.8293	1.7801	1.5830
$C_{m_{\alpha_E}}$	-1.7589	-1.9096	-1.9140	-1.6851
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-1.0092	-1.0491	-1.0839	-1.0762
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-1.0077	-1.0439	-1.0752	-1.0645

Reference Geometry: S_W=464 ft^2; c_r = 25.8 ft (root chord)
Moment reference center is wing apex

4.2. Variable sweep wing, $\Lambda = 20^\circ$ having pivots at 20, 30, and 40% of the $\Lambda = 72^\circ$ semispan (Wings 2, 3, and 4).

For these wings, longitudinal characteristics were computed for the flight conditions of Table 8.

Table 8. Flight Conditions for Wings 2, 3, and 4

WING NUMBER	WING TYPE	MACH NUMBER	RIGID	ELASTIC		
				Sealevel	35,000 ft. (10,668 m)	60,000 ft. (18,288 m)
2	$A=6.27$ $\Lambda_{LE}=20^\circ$ Pivot at $.20\ b_{72}/2$	.25	x	x	x	
		.50	x	x	x	
		.80	x	x	x	x
3	$A=6.05$ $\Lambda_{LE}=20^\circ$ Pivot at $.30\ b_{72}/2$	.25	x	x	x	
		.50	x	x	x	
		.80	x	x	x	x
4	$A=5.79$ $\Lambda_{LE}=20^\circ$ $.40\ b_{72}/2$	.25	x	x	x	
		.50	x	x	x	
		.80	x	x	x	x

Figures 8, 9, and 10 show the planform geometry of wings 2, 3, and 4. Observe, that the pivots were selected such that the $\Lambda_o = 20^\circ$ spans were the same for the three wings and such that the $\Lambda = 72^\circ$ planforms were all identical. These "rules" for determining the pivot locations led to inconsistent aspect ratios, based upon the conventional definition $A = b^2/S$.

Tabulated results for the derivatives are presented in Tables 9 for the rigid wings 2, 3, and 4 and Tables 10, 11, and 12 for the elastic wings 2, 3, and 4.

Figures 11, 12, and 13 show the effect of Mach number and dynamic pressure on lift-curve-slope, aerodynamic center location and pitch damping derivative for the zero mass (or constant load-factor) case. Figure 11 shows an unusual feature for planforms with low outboard sweep angles: the lift-curve-slope increases with dynamic pressure. This indicates a tendency toward divergence which is usually associated with swept forward wings. It is thought that the cause for this behavior is that part of the elastic axis is swept forward (Figure 8) which would contribute to divergent behavior.

By making the inboard part of the elastic axis stiffer some of the divergent trends would tend to be eliminated.

Note from Figures 12 and 13 that the divergency trend is gone. This is because the elastic axis is straightened out as the wing pivot is moved outboard. This fact may also be seen from Figures 9 and 10.

The data of Figures 11, 12, and 13 indicate the very strong effect of pivot location and elasticity combined on aerodynamic center location. These features present the designer with some tough problems in airplane balance. However, with proper analysis there is much opportunity for tailoring the design to achieve proper balance over a wide spectrum of flight conditions.

For example, comparison of Figures 11 and 13 shows that moving the pivot outboard from 20% to 40% changes the elastic aerodynamic center shifts from 2.3% aft to .6% forward of the respective rigid locations at $M = .8$ and sea level. This is a considerable shift, particularly in view of the fact that the aerodynamic center is taken in relation to the root chord.

Another fact, evident from Figures 11, 12, and 13 is that the overall effect of aeroelasticity is diminished greatly as the pivot is moved outboard. This fact does not necessarily apply to all variable sweep wings. Much depends upon the relative size of the strake and on the chordwise location of the pivot. Table 13 shows a systematic analysis of this effect. In this table, the values of $(dC_m / dC_L)_{\bar{E}}$ (static margin) and $\Delta(dC_m / dC_L)_{\bar{E}}$ (aerodynamic center shift from low sweep, low Mach number to high sweep, high Mach number flight condition) are entered. These data in turn are plotted in Figure 14, which shows that the effect of outboard movement of the pivot lowers the a.c. shift. It is also noted that the effect of elasticity is to lower the a.c. shifts in relationship to those of the corresponding rigid wing.

Inertial effects are again small, as may be seen from Tables 10 through 12 by comparing the E - subscripted quantities with the $\bar{E}$ - subscripted quantities and by checking the magnitudes of the I - subscripted derivatives in the manner suggested in Sec. 4.1.

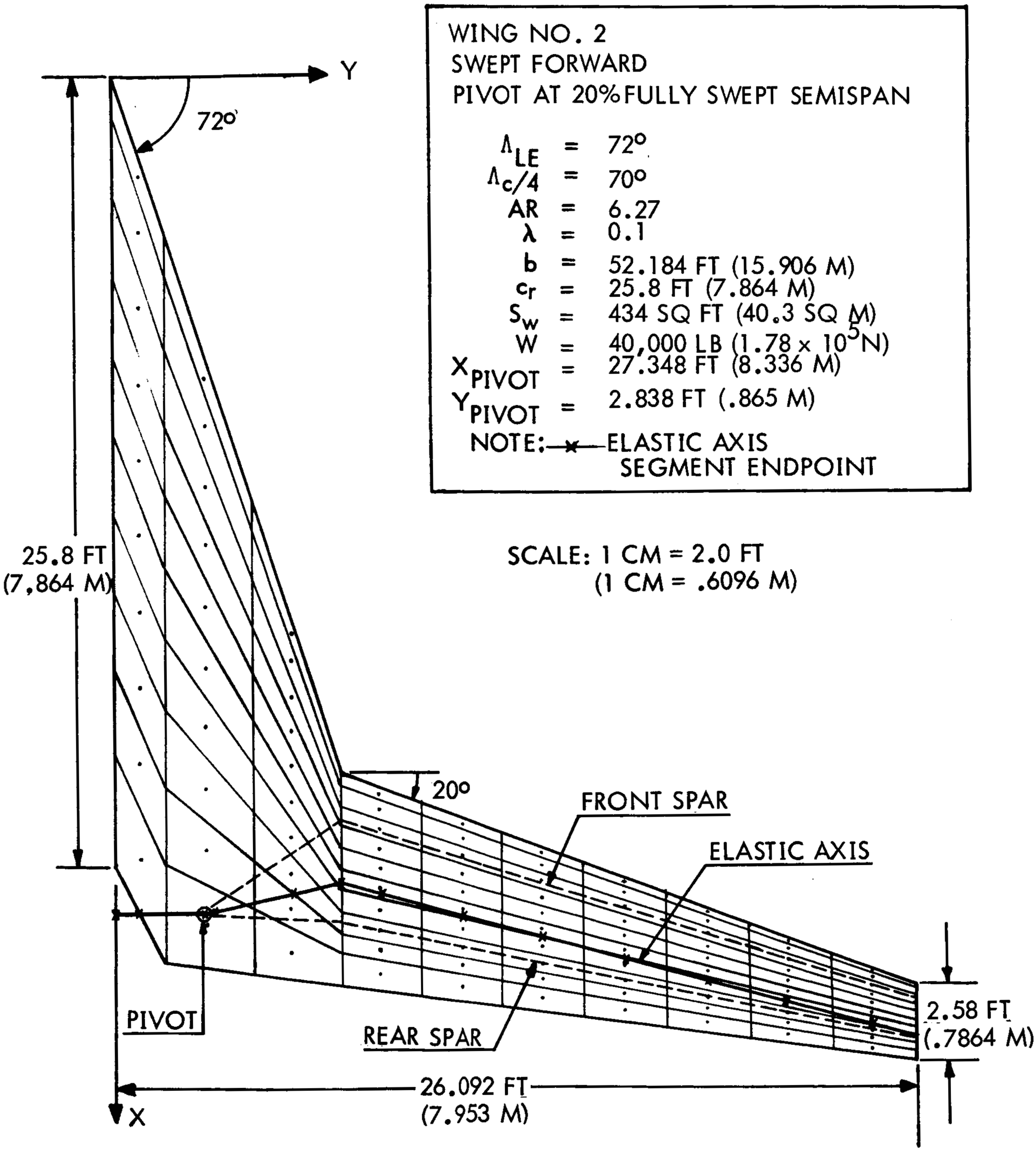


Figure 8 Planform Definition of Wing No. 2

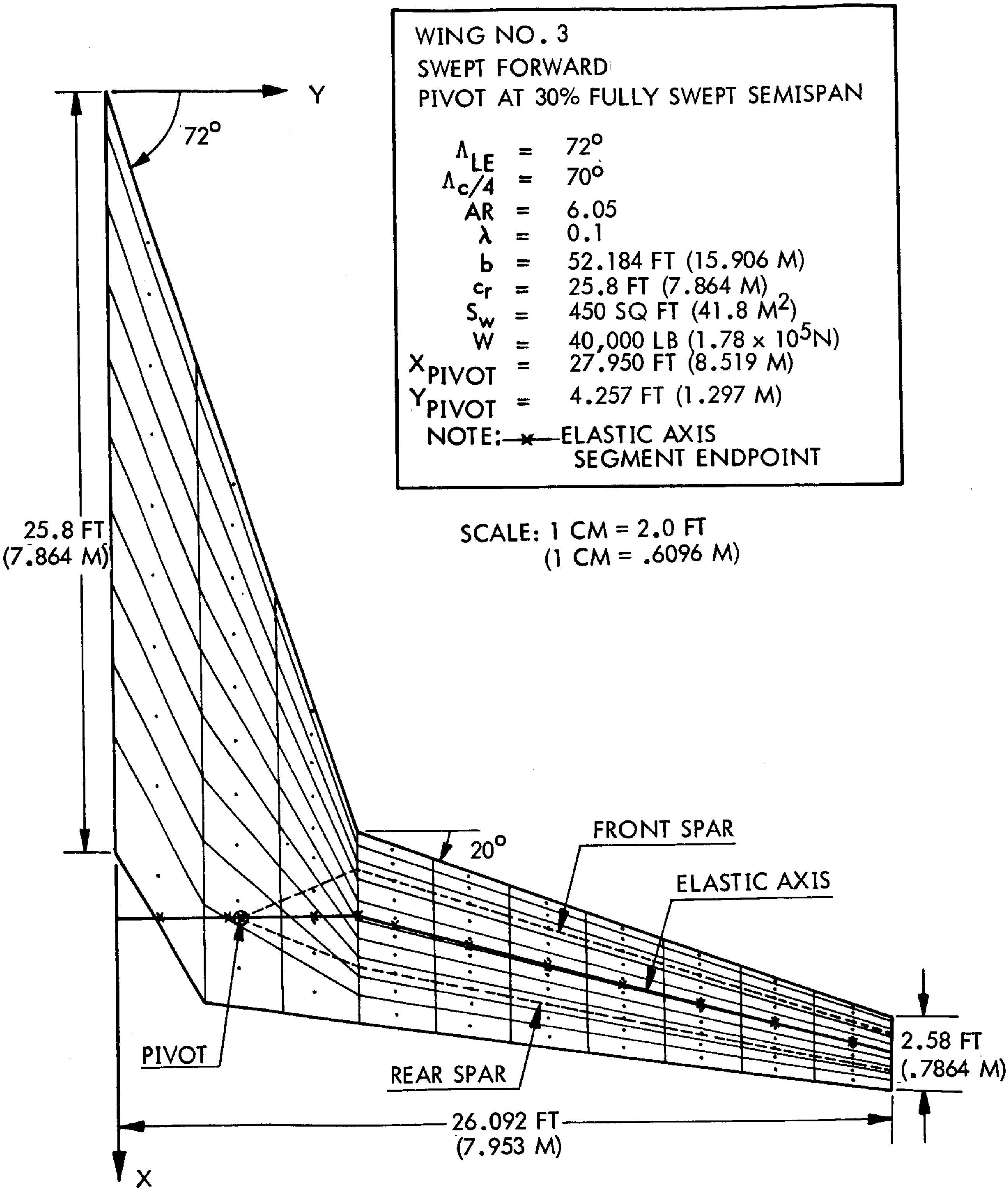


Figure 9 Planform Definition for Wing No. 3

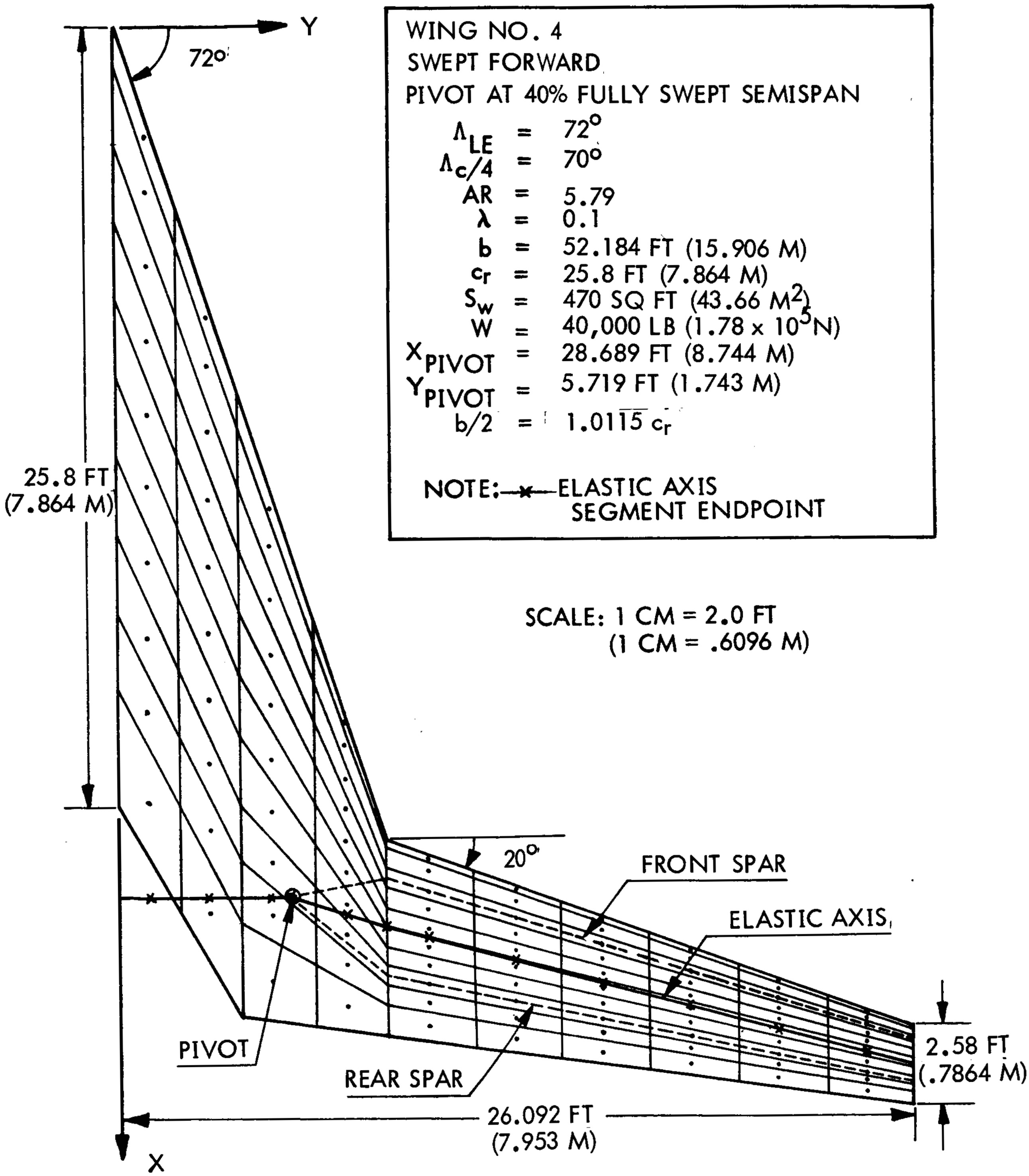


Figure 10 Planform Definition for Wing No. 4

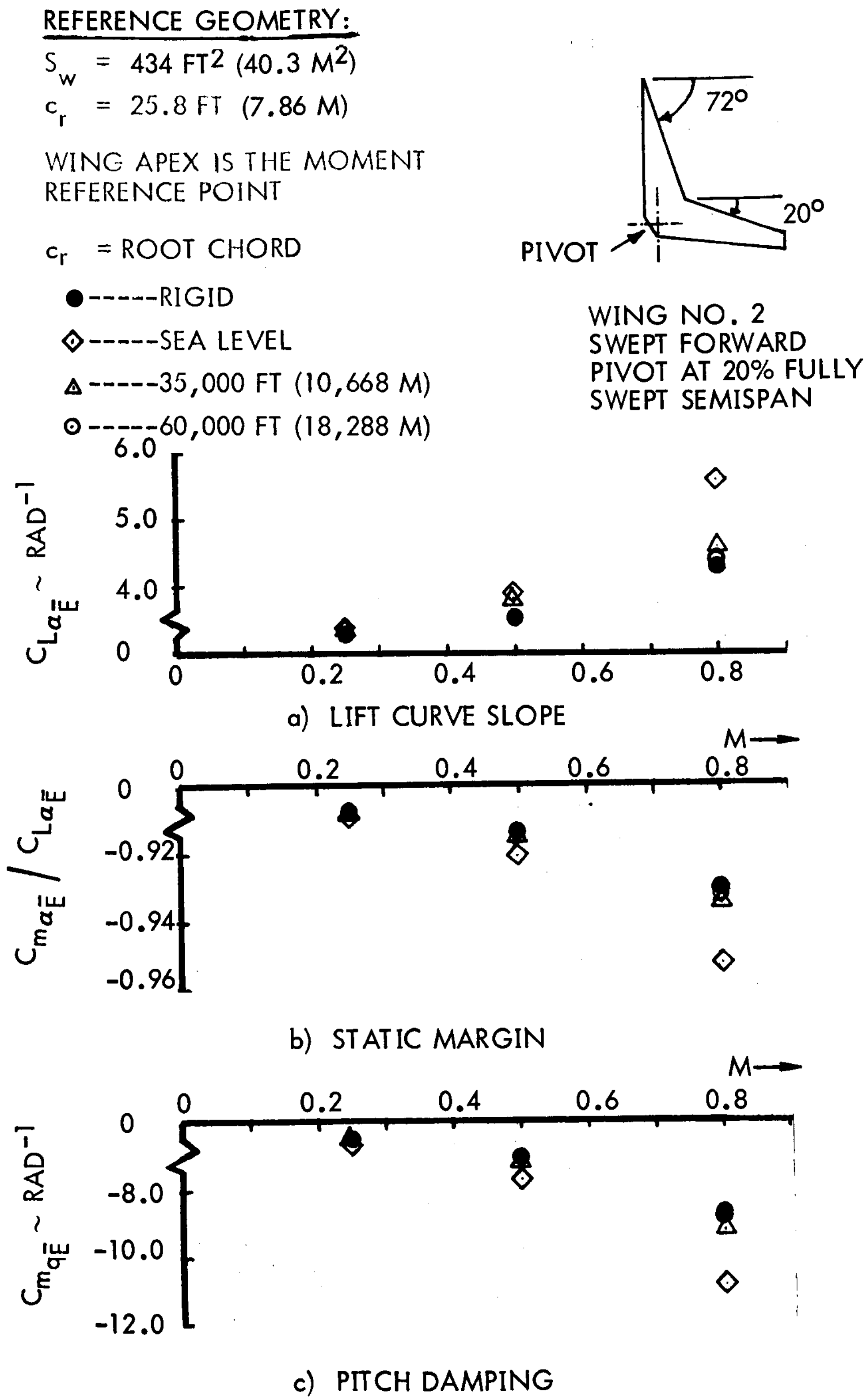


Figure 11. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 2

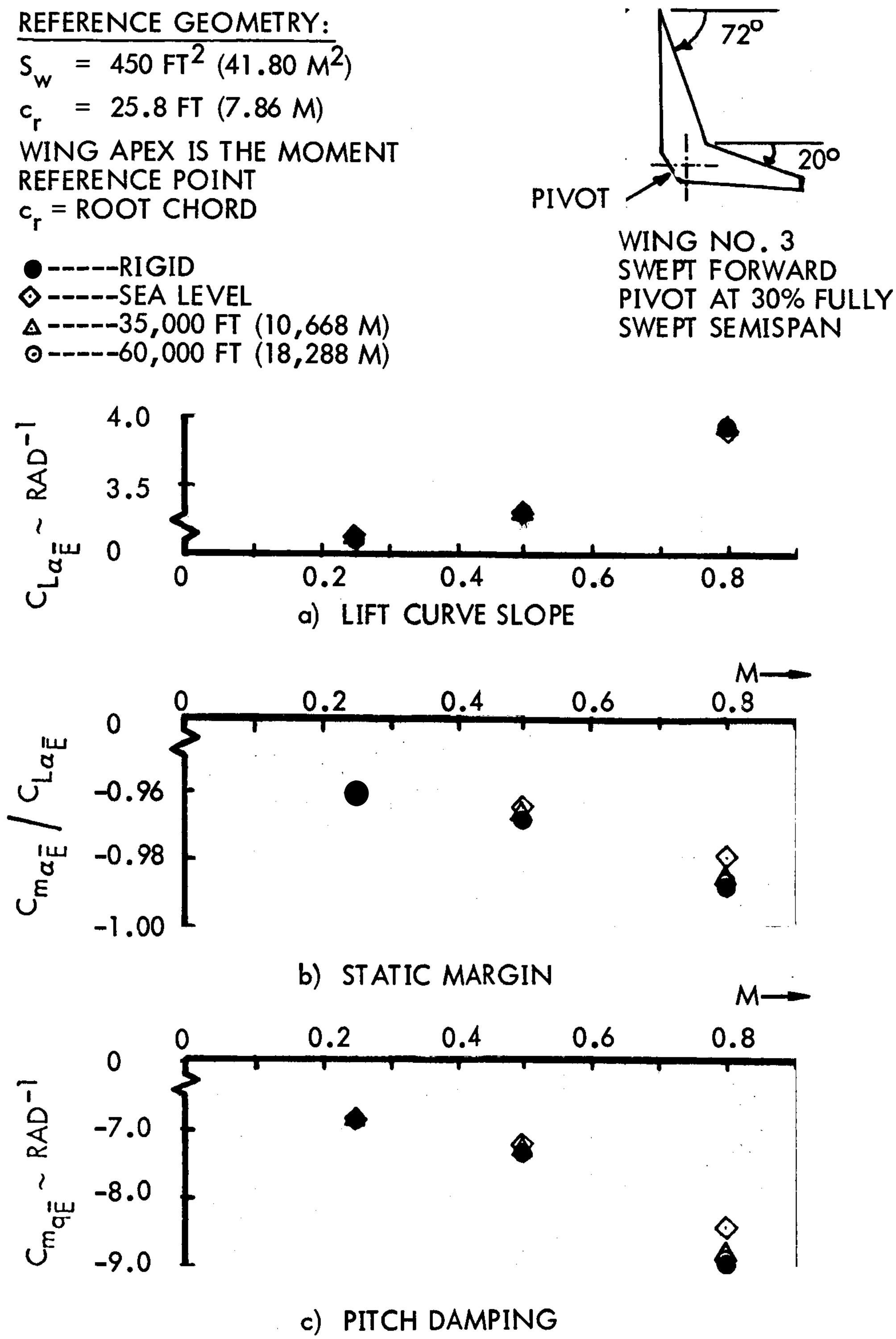


Figure 12. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing No. 3.

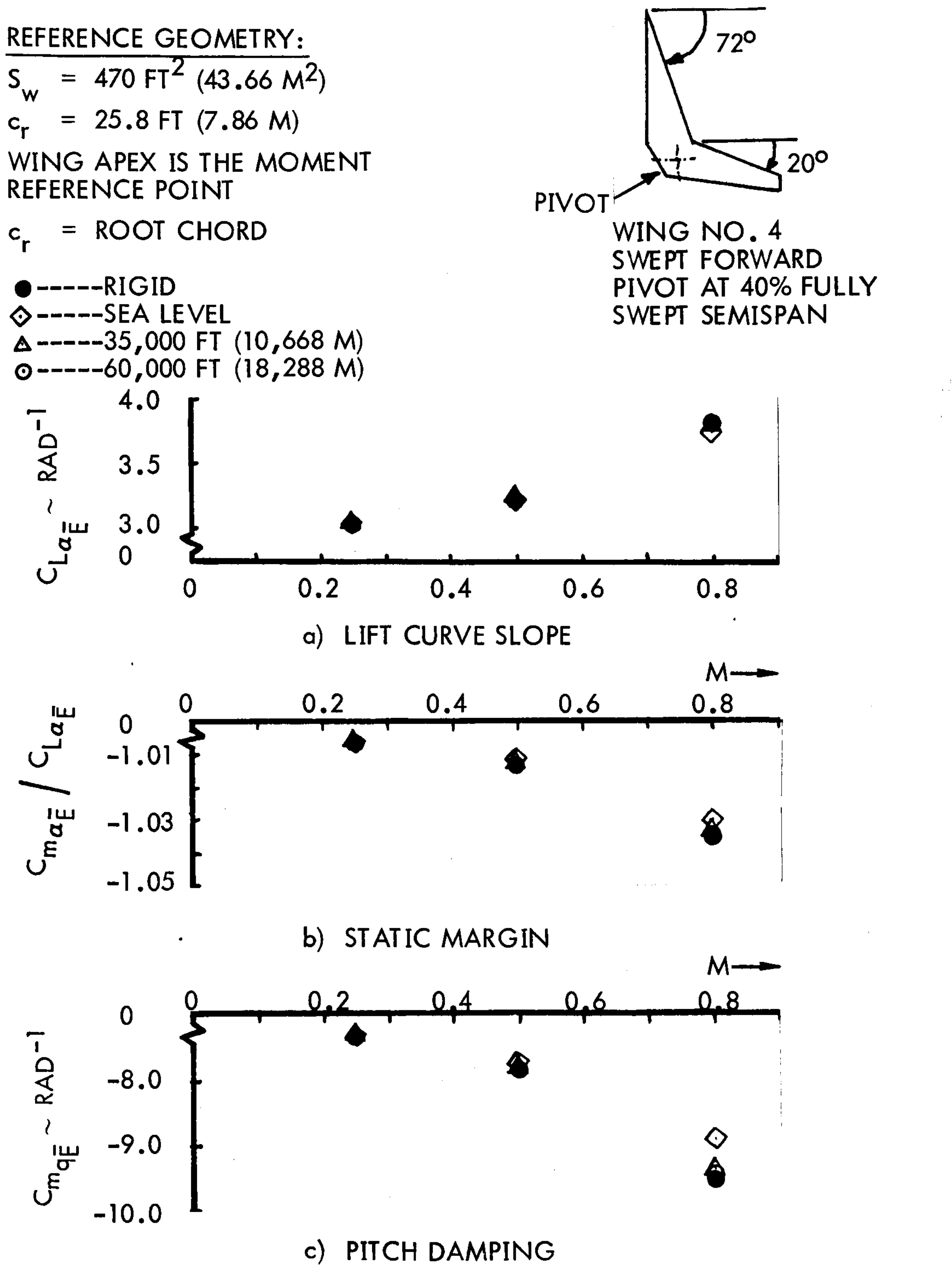


Figure 13. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing No. 4

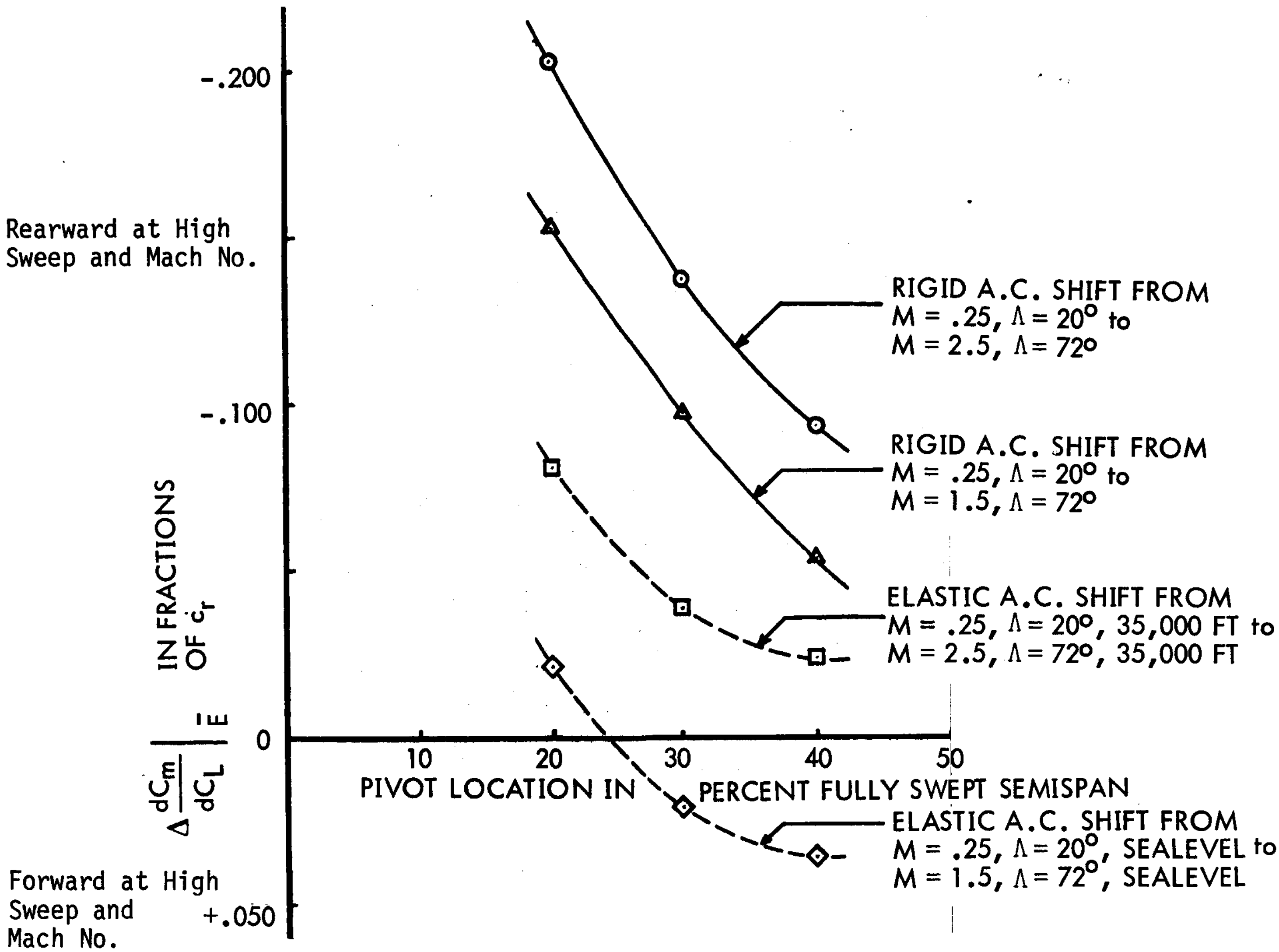


Figure 14. Effect of Pivot Location on Aerodynamic Center Shift

Table 9 Stability Derivatives for the Rigid Wings 2, 3, and 4.

a) Rigid Derivatives Wing 2

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha} / C_{L_\alpha}$
0.25	3.2947	-2.9906	6.9741	-6.5471	-0.90765
0.50	3.5154	-3.2115	7.4604	-7.0394	-0.91356
0.80	4.2567	-3.9617	9.1030	-8.7177	-0.93070

b) Rigid Derivatives Wing 3

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha} / C_{L_\alpha}$
0.25	3.0994	-2.9818	6.8763	-6.8784	-0.96206
0.50	3.2912	-3.1892	7.3217	-7.3658	-0.96902
0.80	3.9200	-3.8777	8.7896	-8.9895	-0.98923

c) Rigid Derivatives Wing 4

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha} / C_{L_\alpha}$
0.25	3.0313	-3.0498	7.0010	-7.3369	-1.0061
0.50	3.2138	-3.2577	7.4431	-7.8465	-1.0137
0.80	3.8056	-3.9407	8.8842	-9.5270	-1.0355

TABLE 10A. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT 20% OF THE SWEPT SEMISPAN (WING 2) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.5 370.80	0.8 949.25
$C_{L_{\alpha_{\bar{E}}}}$	3.3754	3.8861	5.5412
$C_{m_{\alpha_{\bar{E}}}}$	-3.0696	-3.5783	-5.2819
$C_{L_{q_{\bar{E}}}}$	7.1086	8.0732	11.132
$C_{m_{q_{\bar{E}}}}$	-6.6802	-7.6529	-10.839
$C_{L_{q_I}}$	-0.88629	-3.9002	-12.403
$C_{m_{q_I}}$	0.90066	3.9869	12.978
$C_{L_{\dot{w}_I}}$	0.00014664	0.00016133	0.00020040
$C_{m_{\dot{w}_I}}$	-0.00014902	-0.00016492	-0.00020969
$C_{L_{\ddot{\theta}_I}}$	0.0050206	0.0055408	0.0069511
$C_{m_{\ddot{\theta}_I}}$	-0.0050681	-0.0056267	-0.0072245
$\partial C_L / \partial n$	-0.0047219	-0.0051949	-0.0064530
$\partial C_m / \partial n$	0.0047985	0.0053103	0.0067521
$C_{L_{\alpha_E}}$	3.3594	3.8066	5.1959
$C_{m_{\alpha_E}}$	-3.0533	-3.4970	-4.9207
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.90940	-0.92080	-0.95322
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.90888	-0.91868	-0.94703

Reference Geometry: $S_W = 434 ft^2$; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 10B. STABILITY DERIVATIVES FOR THE ELASTIC 72° SWEPT BACK WING WITH PIVOT AT 20% OF THE SWEPT SEMISPAN (WING 2) AT ALTITUDE

ALTITUDES	35,000 ft (10,668 m)	35,000 ft (10,668 m)	35,000 ft (10,668 m)	60,000 ft (18,288 m)
DERIVATIVES	M = 0.25 $\bar{q}$ = 21.803	0.5 87.212	0.8 223.26	0.8 67.155
$C_{L_{\alpha_{\bar{E}}}}$	3.3135	3.5995	4.5530	4.3443
$C_{m_{\alpha_{\bar{E}}}}$	-3.0090	-3.2944	-4.2604	-4.0497
$C_{L_{q_{\bar{E}}}}$	7.0054	7.6006	9.5937	9.2490
$C_{m_{q_{\bar{E}}}}$	-6.5781	-7.1791	-9.2186	-8.8663
$C_{L_{q_I}}$	-0.66891	-2.8968	-9.3287	-9.0996
$C_{m_{q_I}}$	0.67919	2.9489	9.5744	9.3134
$C_{L_{\dot{w}_I}}$	0.00014575	0.00015780	0.00019850	0.00019555
$C_{m_{\dot{w}_I}}$	-0.00014799	-0.00016063	-0.00020373	-0.00020015
$C_{L_{\ddot{\theta}_I}}$	0.0049857	0.0053991	0.0067937	0.0066786
$C_{m_{\ddot{\theta}_I}}$	-0.0050289	-0.0054612	-0.0069335	-0.0067980
$\partial C_L / \partial n$	-0.0046931	-0.0050810	-0.0063917	-0.0062968
$\partial C_m / \partial n$	0.0047652	0.0051724	0.0065600	0.0064448
$C_{L_{\alpha_E}}$	3.3098	3.5823	4.4836	4.3244
$C_{m_{\alpha_E}}$	-3.0052	-3.2769	-4.1892	-4.0294
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.90810	-0.91523	-0.93572	-0.93220
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.90797	-0.91474	-0.93432	-0.93178

Reference Geometry: S_w = 434 ft^2; c_r = 25.8 ft (root chord)
Moment reference center is wing apex

TABLE 11A. STABILITY DERIVATIVES FOR THE ELASTIC SWEPT BACK WING WITH PIVOT AT 30% OF THE SWEPT SEMISPAN (WING 3) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.5 370.80	0.8 949.25
$C_{L_{\alpha_{\bar{E}}}}$	3.1012	3.2945	3.8740
$C_{m_{\alpha_{\bar{E}}}}$	-2.9812	-3.1823	-3.7989
$C_{L_{q_{\bar{E}}}}$	6.8535	7.2124	8.3056
$C_{m_{q_{\bar{E}}}}$	-6.8493	-7.2289	-8.4115
$C_{L_{q_I}}$	-1.4990	-5.9850	-15.454
$C_{m_{q_I}}$	1.6681	6.6799	17.419
$C_{L_{\dot{w}_I}}$	0.00024803	0.00024757	0.00024970
$C_{m_{\dot{w}_I}}$	-0.00027601	-0.00027631	-0.00028146
$C_{L_{\ddot{\theta}_I}}$	0.0081790	0.0081694	0.0082547
$C_{m_{\ddot{\theta}_I}}$	-0.0090800	-0.0090953	-0.0092787
$\partial C_L / \partial n$	-0.0079864	-0.0079717	-0.0080403
$\partial C_m / \partial n$	0.0088875	0.0088973	0.0090629
$C_{L_{\alpha_E}}$	3.0755	3.1882	3.5671
$C_{m_{\alpha_E}}$	-2.9527	-3.0638	-3.4529
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.96131	-0.96596	-0.98060
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.96007	-0.96096	-0.96799

Reference Geometry: $S_w = 450$ ft^2; $c_r = 25.8$ ft (root chord)
Moment reference is wing apex

TABLE 11B. STABILITY DERIVATIVES FOR THE ELASTIC SWEPT BACK WING WITH PIVOT AT 30% OF THE SWEPT SEMISPAN (WING 3) AT ALTITUDE

ALTITUDES	35,000 ft (10,668 m)	35,000 ft (10,668 m)	35,000 ft (10,668 m)	60,000 ft (18,288 m)
DERIVATIVES	M = 0.25 $\bar{q}$ = 21.803	0.5 87.212	0.8 223.26	0.8 67.155
$C_{L_{\alpha_{\bar{E}}}}$	3.0998	3.2910	3.9004	3.9135
$C_{m_{\alpha_{\bar{E}}}}$	-2.9816	-3.1866	-3.8500	-3.8688
$C_{L_{q_{\bar{E}}}}$	6.8708	7.2931	8.6470	8.7446
$C_{m_{q_{\bar{E}}}}$	-6.8714	-7.3305	-8.8228	-8.9372
$C_{L_{q_I}}$	-1.1580	-4.8869	-14.653	-15.235
$C_{m_{q_I}}$	1.2882	5.4462	16.426	17.060
$C_{L_{\dot{w}_I}}$	0.00025231	0.00026620	0.00031179	0.00032741
$C_{m_{\dot{w}_I}}$	-0.00028068	-0.00029667	-0.00034952	-0.00036662
$C_{L_{\ddot{\theta}_I}}$	0.0083185	0.0087763	0.010278	0.010787
$C_{m_{\ddot{\theta}_I}}$	-0.0092325	-0.0097587	-0.011498	-0.012056
$\partial C_L / \partial n$	-0.0081244	-0.0085717	-0.010040	-0.010542
$\partial C_m / \partial n$	0.0090380	0.0095527	0.011254	0.011805
$C_{L_{\alpha_E}}$	3.0936	3.2635	3.8043	3.8825
$C_{m_{\alpha_E}}$	-2.9747	-3.1560	-3.7423	-3.8341
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.96187	-0.96828	-0.98708	-0.98857
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.96157	-0.96705	-0.98369	-0.98753

Reference Geometry: S_w = 450 ft^2; c_r = 25.8 ft (root chord)
Moment reference center is wing apex

TABLE 12A. STABILITY DERIVATIVES FOR THE ELASTIC SWEPT BACK WING WITH PIVOT AT 40% OF THE SWEPT SEMISPAN (WING 4) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.5 370.80	0.8 949.25
$C_{L_{\alpha_{\bar{E}}}}$	3.0343	3.2199	3.7484
$C_{m_{\alpha_{\bar{E}}}}$	-3.0516	-3.2580	-3.8607
$C_{L_{q_{\bar{E}}}}$	6.9801	7.3357	8.3547
$C_{m_{q_{\bar{E}}}}$	-7.3109	-7.7158	-8.9051
$C_{L_{q_I}}$	-1.3953	-5.6433	-14.925
$C_{m_{q_I}}$	1.6030	6.5100	17.446
$C_{L_{\dot{w}_I}}$	0.00023087	0.00023343	0.00024116
$C_{m_{\dot{w}_I}}$	-0.00026523	-0.00026928	-0.00028189
$C_{L_{\ddot{\theta}_I}}$	0.0079542	0.0080460	0.0083212
$C_{m_{\ddot{\theta}_I}}$	-0.0091214	-0.0092641	-0.0097068
$\partial C_L / \partial n$	-0.0074339	-0.0075165	-0.0077652
$\partial C_m / \partial n$	0.0085405	0.0086709	0.0090768
$C_{L_{\alpha_E}}$	3.0099	3.1176	3.4492
$C_{m_{\alpha_E}}$	-3.0235	-3.1401	-3.5110
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-1.0057	-1.0118	-1.0300
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-1.0045	-1.0072	-1.0179

Reference Geometry: $S_w = 470\ ft^2$; $c_r = 25.8$ ft (root chord)
Moment reference center is wing apex

TABLE 12B. STABILITY DERIVATIVES FOR THE ELASTIC SWEPT BACK WING WITH PIVOT AT 40% OF THE SWEPT SEMISPAN (WING 4) AT ALTITUDE

ALTITUDES	35,000 ft (10,668 m)	35,000 ft (10,668 m)	35,000 ft (10,668 m)	60,000 ft (18,288 m)
DERIVATIVES	M = 0.25 $\bar{q}$ = 21.803	0.5 87.212	0.8 223.26	0.8 67.155
$C_{L_{\alpha_{\bar{E}}}}$	3.0320	3.2149	3.7890	3.8004
$C_{m_{\alpha_{\bar{E}}}}$	-3.0502	-3.2574	-3.9186	-3.9339
$C_{L_{q_{\bar{E}}}}$	6.9960	7.4164	8.7447	8.8412
$C_{m_{q_{\bar{E}}}}$	-7.3307	-7.8142	-9.3644	-9.4770
$C_{L_{q_I}}$	-1.0737	-4.5376	-13.625	-14.029
$C_{m_{q_I}}$	1.2330	5.2256	15.827	16.276
$C_{L_{\dot{w}_I}}$	0.00023394	0.00024718	0.00028991	0.00030148
$C_{m_{\dot{w}_I}}$	-0.00026866	-0.00028465	-0.00033677	-0.00034977
$C_{L_{\ddot{\theta}_I}}$	0.0080589	0.0085146	0.0099852	0.010380
$C_{m_{\ddot{\theta}_I}}$	-0.0092384	-0.0097885	-0.011581	-0.012025
$\partial C_L / \partial n$	-0.0075329	-0.0079591	-0.0093352	-0.0097077
$\partial C_m / \partial n$	0.0086509	0.0091658	0.010844	0.011263
$C_{L_{\alpha_E}}$	3.0261	3.1889	3.6983	3.7715
$C_{m_{\alpha_E}}$	-3.0435	-3.2274	-3.8133	-3.9003
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-1.0060	-1.0132	1.0342	-1.0351
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-1.0057	-1.0121	-1.0311	-1.0342

Reference Geometry: S_W = 470 ft^2; c_r = 25.8 ft (root chord)
Moment reference center is wing apex

Table 13 Effect of Pivot Location on Aerodynamic Center Shifts

M	$\left.\frac{dC_m}{dC_L}\right\|_{\bar{E}}$	Λ	Pivot	$\Delta \left.\frac{dC_m}{dC_L}\right\|_{\bar{E}}$ *
0.25	- .907 R - .909 ESL	20°	20%	
0.25	- .962 R - .961 ESL	20°	30%	
0.25	-1.006 R -1.006 ESL	20°	40%	
1.5	-1.060 R - .930 ESL	72°	20%	-.153 R -.021 ESL
2.5	-1.110 R - .990 E35	72°	20%	-.203 R -.081 E35
1.5	-1.060 R - .940 ESL	72°	30%	-.098 R +.021 ESL
2.5	-1.100 R -1.000 E35	72°	30%	-.138 R -.039 E35
1.5	-1.060 R - .970 ESL	72°	40%	-.054 R +.036 ESL
2.5	-1.100 R -1.030 E35	72°	40%	-.094 R -.024 E35

* The shift is computed from M = .25 (rigid (R) or elastic sea level (ESL)) to M = 1.5 (rigid (R) or elastic sea level (ESL)) or to M = 2.5 (rigid (R) or elastic 35,000 ft (E35)).

4.3. Fixed wing, $\Lambda = 45^{o}$ with and without forward shear at the tip (Wings 5 and 6).

For these wings, longitudinal characteristics were computed for the flight conditions of Table 14.

Table 14 Flight Conditions for Wings 5 and 6

WING NUMBER	WING TYPE	MACH NUMBER	RIGID	ELASTIC		
				Sealevel	35,000 Ft. (10,668 m)	60,000 Ft. (18,288 m)
5	Fixed	.25	x	x	x	
	45^{o} sweep	.80	x	x	x	
	A = 3.0	1.50	x	x	x	x
		2.00	x	x	x	x
6	Fixed	.25	x	x	x	
	45^{o} sweep	.80	x	x	x	
	Tip cranked	1.50	x	x	x	x
	forward to 25^{o}, A = 3.0	2.00	x	x	x	x

Figures 15 and 16 show the planform geometry of wings 5 and 6. Tabulated results for the derivatives are presented in Table 15 for the rigid wings 5 and 6 and Tables 16 and 17 for the elastic wings 5 and 6.

Figures 17 and 18 show the effect of Mach number and dynamic pressure on lift-curve-slope, aerodynamic center location and pitch damping derivative for the zero mass (or constant load-factor) case.

The aeroelastic effects are seen to be very significant. They are all in the expected direction, i.e., reduction of C_{L_α}, C_{L_q}, C_{m_q} and a forward shift in aerodynamic center, all for increasing dynamic pressure. An interesting and useful feature of wing 5 is seen from Figure 17b. The aerodynamic center location at sea level and high Mach numbers is seen to be about the same as that for low Mach numbers. For the rigid wing 5 it is seen that the a.c. shift with Mach number is very large. This planform evidently requires little trimming when accelerating from subsonic to supersonic Mach numbers at sea level. However, at high altitude, Figure 17b shows that this planform will require substantial trimming to compensate for the large a.c. shift between subsonic and supersonic flight. Fom a trim drag point of view, planform 5 is a good low altitude planform. Comparison of Figures 17 and 18 shows that the effect of the forward tip crank is not significant.

Another conclusion that can be drawn from Figures 17 and 18 is that both planforms exhibit very large reductions in lift-curve-slope and in pitch damping with increasing dynamic pressure. The first is beneficial in low level ride qualities although detrimental in maneuvering. The second is detrimental in tailless applications because of the tendency to undamp the short period mode.

The tabulated data of Tables 16 and 17 show again that inertial effects are small for this class of wings. The comments made at the end of Section 4.1 apply to these wings also.

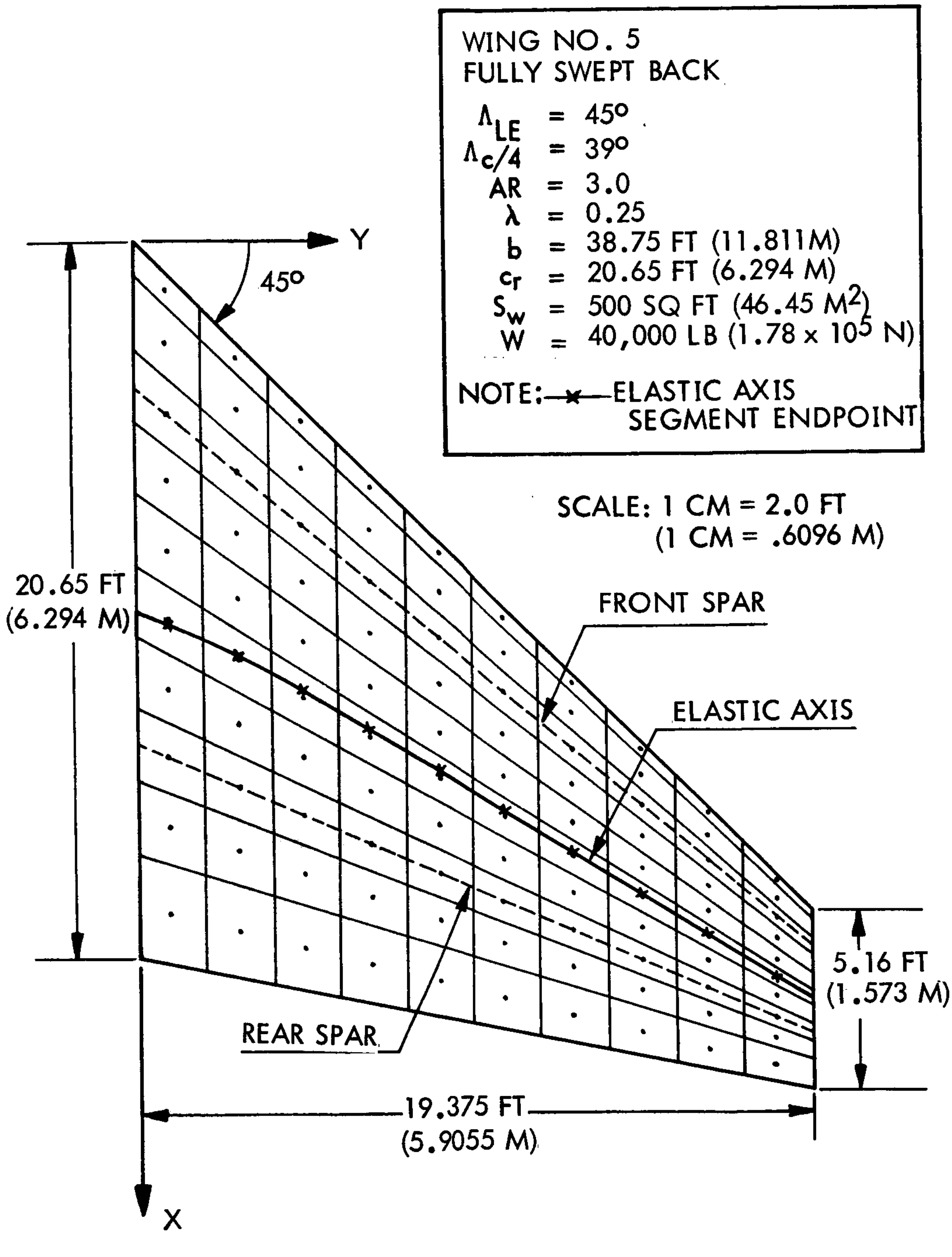


Figure 15 Planform Definition for Wing No. 5

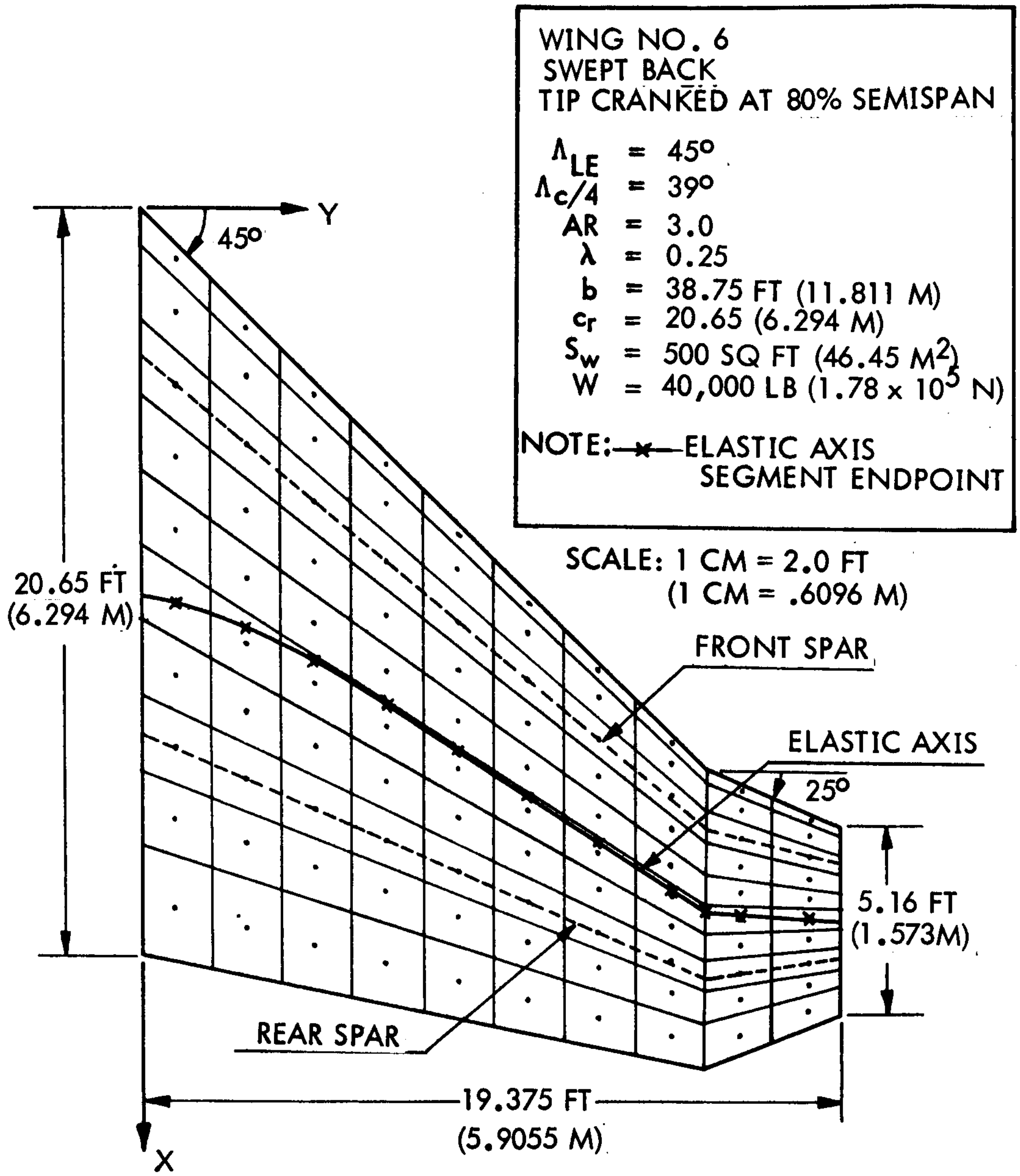


Figure 16 Planform Definition for Wing No. 6

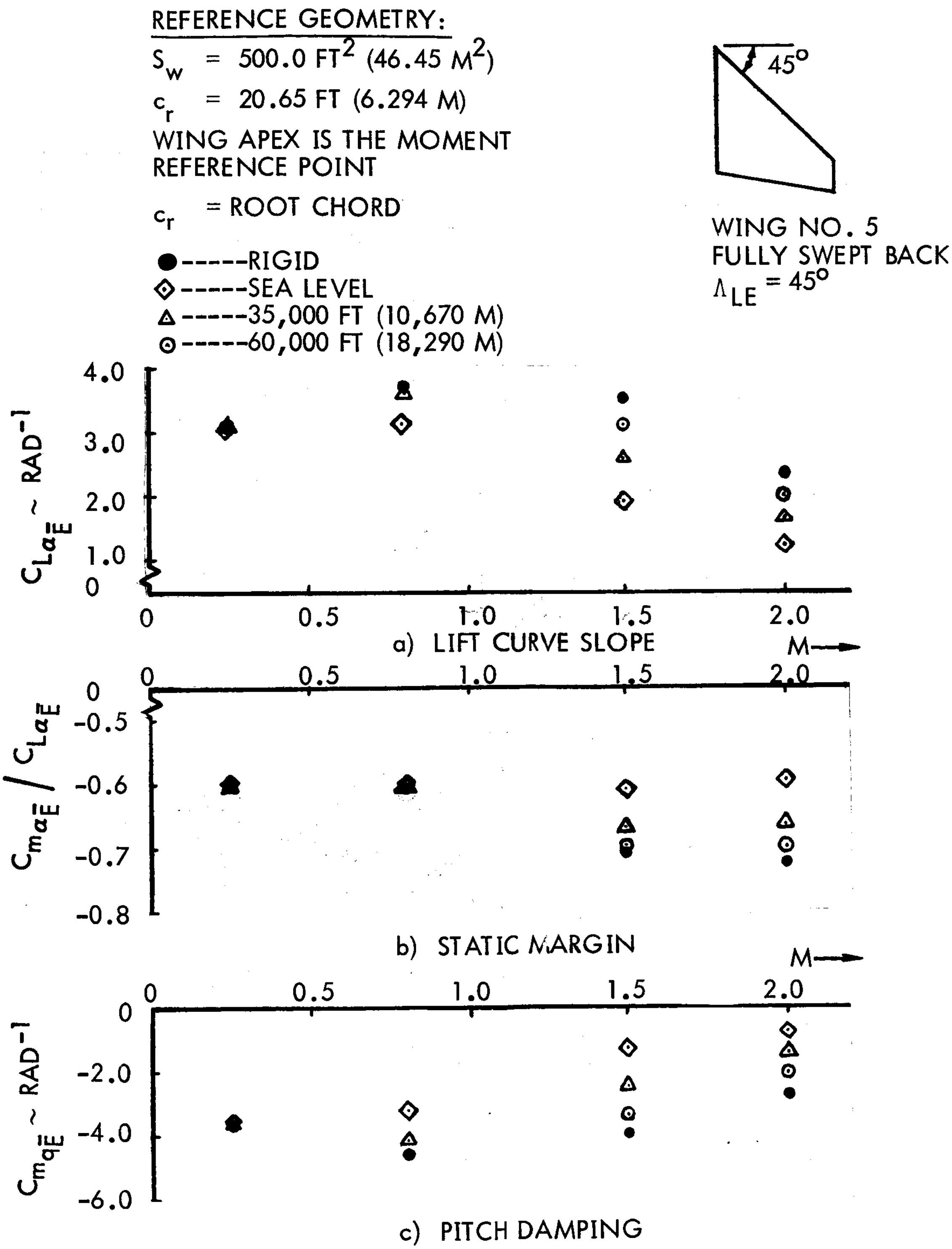


Figure 17 Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing 2.

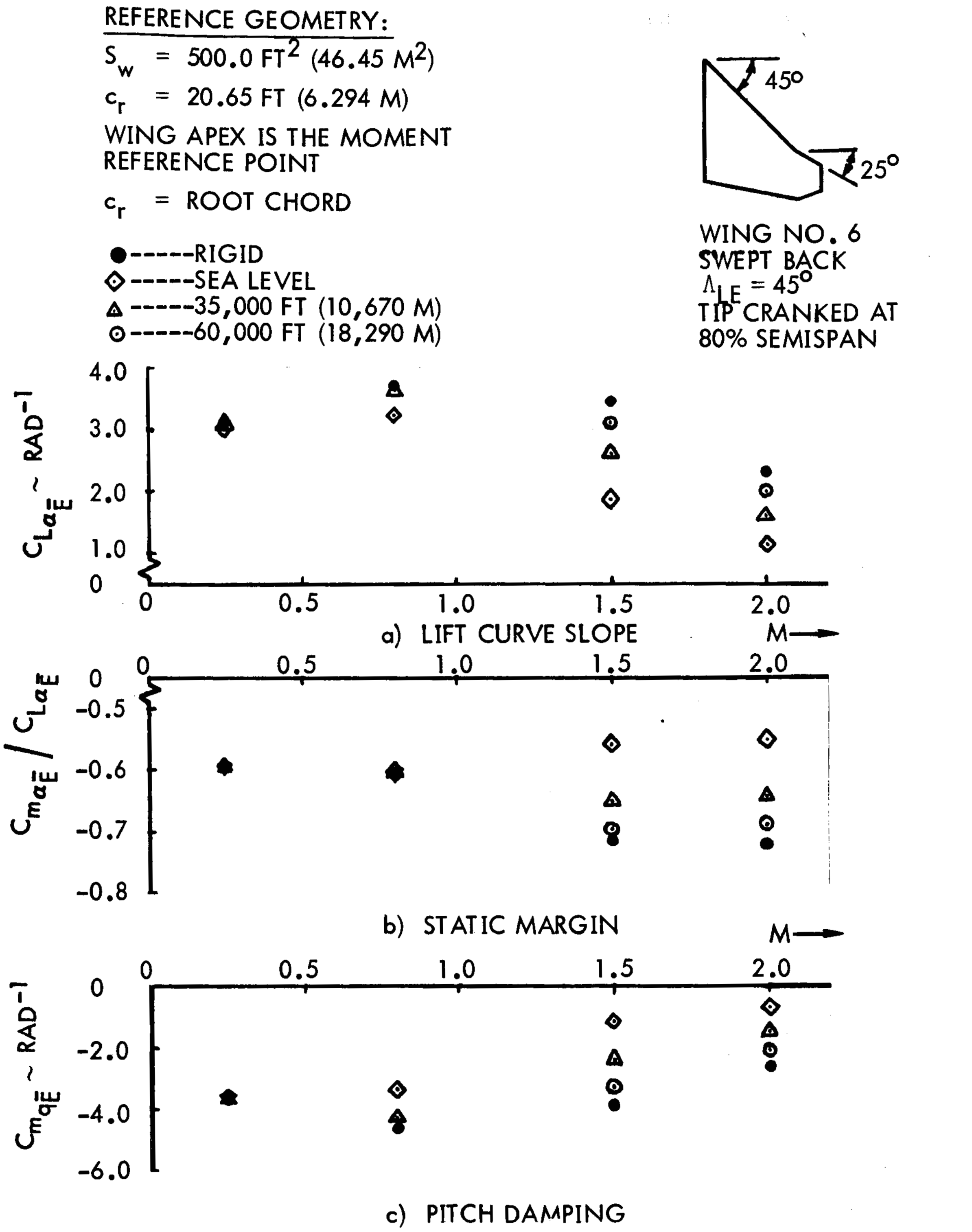


Figure 18. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing No. 6.

Table 15 Stability Derivatives for the Rigid Wings 5 and 6

Rigid Data Wing 5
Straight 45° Sweep

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha}/C_{L_\alpha}$
0.25	3.0801	-1.8613	+5.5315	-3.7016	-0.60429
0.80	3.6773	-2.2596	+6.7325	-4.6104	-0.61447
1.50	3.4679	-2.4746	+4.9785	-4.0095	-0.71357
2.0	2.3397	-1.6979	+3.3480	-2.7247	-0.72569

Rigid Data Wing 6
Straight 45° Sweep, Cranked Tip

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha}/C_{L_\alpha}$
0.25	3.1007	-1.8539	5.5370	-3.6596	-0.59790
0.80	3.7163	-2.2561	6.7622	-4.5684	-0.60708
1.50	3.4535	-2.4489	4.9324	-3.9408	-0.70910
2.0	2.3195	-1.6664	3.3004	-2.6567	-0.71843

TABLE 16A. STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK WING (WING 5) AT SEA LEVEL

DERIVATIVES	M = 0.25 $\bar{q}$ = 92.701	0.8 949.25	1.5 3337.2	2.0 5932.8
$C_{L_{\alpha_{\bar{E}}}}$	3.0371	3.1076	1.9164	1.1912
$C_{m_{\alpha_{\bar{E}}}}$	-1.8337	-1.8865	-1.1694	-0.70957
$C_{L_{q_{\bar{E}}}}$	5.3787	4.7895	1.7470	1.0609
$C_{m_{q_{\bar{E}}}}$	-3.5985	-3.2642	-1.2707	-0.76753
$C_{L_{q_I}}$	-3.8760	-32.413	-31.279	-32.415
$C_{m_{q_I}}$	2.7659	24.130	26.300	26.983
$C_{L_{\dot{w}_I}}$	0.00051330	0.00041919	0.00011506	0.000067073
$C_{m_{\dot{w}_I}}$	-0.00036629	-0.00031207	-0.000096748	-0.000055833
$C_{L_{\ddot{\theta}_I}}$	0.010805	0.0086964	0.0023036	0.0013370
$C_{m_{\ddot{\theta}_I}}$	-0.0077512	-0.0065242	-0.0019591	-0.0011264
$\partial C_L / \partial n$	-0.016528	-0.013498	-0.0037051	-0.0021598
$\partial C_m / \partial n$	0.011795	0.010049	0.0031153	0.0017978
$C_{L_{\alpha_E}}$	2.9800	2.6785	1.6598	1.0267
$C_{m_{\alpha_E}}$	-1.7929	-1.5670	-0.95367	-0.57265
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.60376	-0.60705	-0.61021	-0.59570
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_E}}$	-0.60164	-0.58504	-0.57456	-0.55777

Reference Geometry: S_W = 500 ft^2; = c_r = 20.65 ft (root chord) Moment reference center is wing apex

TABLE 16B. STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK WING (WING 5) AT 35,000 FT. (10,668 m)

DERIVATIVES	$M = 0.25$ $\bar{q} = 21.803$	0.8 223.26	1.5 784.91	2.0 1395.4
$C_{L_{\alpha_{\bar{E}}}}$	3.0699	3.5317	2.6256	1.6367
$C_{m_{\alpha_{\bar{E}}}}$	-1.8548	-2.1655	-1.7641	-1.0875
$C_{L_{q_{\bar{E}}}}$	5.4950	6.1764	3.1782	1.9628
$C_{m_{q_{\bar{E}}}}$	-3.6770	-4.2288	-2.4819	-1.5251
$C_{L_{q_I}}$	-3.0209	-34.198	-55.971	-59.367
$C_{m_{q_I}}$	2.1522	24.929	47.458	50.656
$C_{L_{\dot{w}_I}}$	0.00052684	0.00058241	0.00027114	0.00016177
$C_{m_{\dot{w}_I}}$	-0.00037533	-0.00042456	-0.00022990	-0.00013803
$C_{L_{\ddot{\theta}_I}}$	0.011100	0.012232	0.0056003	0.0033330
$C_{m_{\ddot{\theta}_I}}$	-0.0079482	-0.0089665	-0.0047814	-0.0028660
$\partial C_L / \partial n$	-0.016964	-0.018754	-0.0087308	-0.0052090
$\partial C_m / \partial n$	0.012086	0.013671	0.0074028	0.0044447
$C_{L_{\alpha_E}}$	3.0558	3.3560	2.4184	1.5003
$C_{m_{\alpha_E}}$	-1.8447	-2.0374	-1.5884	-0.97118
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.60419	-0.61317	-0.67187	-0.66446
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.60367	-0.60711	-0.65678	-0.64730

Reference Geometry: $S_W = 500\ ft^2$; $c_r = 20.65$ ft (root Chord)

Moment reference center is wing apex

TABLE 16C. STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK WING (WING (WING 5) AT 60,000 FT (18,288m)

DERIVATIVES	$M = 1.5$ $\bar{q} = 236.09$	2.0 419.72
$C_{L_{\alpha_{\bar{E}}}}$	3.1139	2.0083
$C_{m_{\alpha_{\bar{E}}}}$	-2.1759	-1.4094
$C_{L_{q_{\bar{E}}}}$	4.2142	2.6970
$C_{m_{q_{\bar{E}}}}$	-3.3614	-2.1588
$C_{L_{q_I}}$	-78.536	-89.963
$C_{m_{q_I}}$	66.603	77.394
$C_{L_{\dot{w}_I}}$	0.00038425	0.00024759
$C_{m_{\dot{w}_I}}$	-0.00032586	-0.00021300
$C_{L_{\ddot{\theta}_I}}$	0.0080156	0.0051645
$C_{m_{\ddot{\theta}_I}}$	-0.0068335	-0.0044680
$\partial C_L / \partial n$	-0.012373	-0.0079723
$\partial C_m / \partial n$	0.010493	0.0068585
$C_{L_{\alpha_E}}$	3.0042	1.9277
$C_{m_{\alpha_E}}$	-2.0828	-1.3400
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.69876	-0.70175
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.69331	-0.69512

Reference Geometry: $S_w = 500\ ft^2$; $c_r = 20.65$ ft (root chord)
Moment reference center is wing apex

TABLE 17A. STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK AND CRANKED WING (WING 6) AT SEA LEVEL

DERIVATIVES	M = 0.25 $\bar{q}$ = 92.701	0.8 949.25	1.5 3337.2	2.0 5932.8
$C_{L_{\alpha_{\bar{E}}}}$	3.0677	3.2246	1.8629	1.1556
$C_{m_{\alpha_{\bar{E}}}}$	-1.8347	-1.9648	-1.1197	-0.67926
$C_{L_{q_{\bar{E}}}}$	5.4049	4.9219	1.6861	1.0269
$C_{m_{q_{\bar{E}}}}$	-3.5746	-3.3470	-1.2154	-0.73703
$C_{L_{q_I}}$	-3.9127	-35.640	-32.972	-33.971
$C_{m_{q_I}}$	2.7231	26.026	27.418	28.024
$C_{L_{\dot{w}_I}}$	0.00051816	0.00046092	0.00012129	0.000070293
$C_{m_{\dot{w}_I}}$	-0.00036062	-0.00033658	-0.00010086	-0.000057988
$C_{L_{\ddot{\theta}_I}}$	0.010560	0.0092922	0.0023686	0.0013671
$C_{m_{\ddot{\theta}_I}}$	-0.0073834	-0.0068289	-0.0019899	-0.0011401
$\partial C_L / \partial n$	-0.016685	-0.014842	-0.0039056	-0.0022634
$\partial C_m / \partial n$	0.011612	0.010838	0.0032477	0.0018672
$C_{L_{\alpha_E}}$	3.0095	2.7417	1.6019	0.98947
$C_{m_{\alpha_E}}$	-1.7942	-1.6122	-0.90264	-0.54222
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.59807	-0.60931	-0.60104	-0.58780
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.59617	-0.58801	-0.56348	-0.54799

Reference Geometry: S_w = 500 ft^2; c_r = 20.65 ft (root chord)
Moment reference center is wing apex

TABLE 17b STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK AND CRANKED WING (WING 6) AT 35,000FT (10,668 m)

DERIVATIVES	M = 0.25 q = 21.803	0.8 223.26	1.5 784.91	2.0 1395.4
$C_{L_{\bar{\alpha}_E}}$	3.0930	3.6111	2.5888	1.6201
$C_{m_{\bar{\alpha}_E}}$	-1.8494	-2.1969	-1.7271	-1.0714
$C_{L_{\bar{q}_E}}$	5.5057	6.2788	3.1401	1.9434
$C_{m_{\bar{q}_E}}$	-3.6395	-4.2529	-2.4402	-1.5042
$C_{L_{q_I}}$	-3.0282	-35.352	-57.875	-62.014
$C_{m_{q_I}}$	2.1032	25.123	48.283	52.041
$C_{L_{\dot{w}_I}}$	0.00052811	0.00060208	0.00028037	0.00016898
$C_{m_{\dot{w}_I}}$	-0.00036680	-0.00042786	-0.00023390	-0.00014181
$C_{L_{\ddot{\theta}_I}}$	0.010769	0.012250	0.0056261	0.0033846
$C_{m_{\ddot{\theta}_I}}$	-0.0075138	-0.0087471	-0.0047212	-0.0028590
$\partial C_L / \partial n$	-0.017005	-0.019387	-0.0090279	-0.0054413
$\partial C_m / \partial n$	0.011811	0.013777	0.0075316	0.0045663
$C_{L_{\alpha_E}}$	3.0787	3.4257	2.3781	1.4796
$C_{m_{\alpha_E}}$	-1.8395	-2.0651	-1.5513	-0.95350
$C_{m_{\bar{\alpha}_E}} / C_{L_{\bar{\alpha}_E}}$	-0.59793	-0.60837	-0.66712	-0.66131
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.59749	-0.60284	-0.65232	-0.64443

Reference Geometry: $S_W = 500\ ft^2$; $c_r = 20.65$ ft (root chord)

Moment reference center is wing apex

TABLE 17c STABILITY DERIVATIVES FOR THE ELASTIC 45° SWEPT BACK AND CRANKED WING (WING 6) AT 60,000 FT (18,288 m)

DERIVATIVES	M = 1.5 $\bar{q}$ = 236.09	2.0 419.72
$C_{L_{\alpha_{\bar{E}}}}$	3.0930	2.0006
$C_{m_{\alpha_{\bar{E}}}}$	-2.1482	-1.3949
$C_{L_{q_{\bar{E}}}}$	4.1817	2.6826
$C_{m_{q_{\bar{E}}}}$	-3.3132	-2.1312
$C_{L_{q_I}}$	-79.629	-91.497
$C_{m_{q_I}}$	66.412	77.166
$C_{L_{\dot{w}_I}}$	0.00038959	0.00025181
$C_{m_{\dot{w}_I}}$	-0.00032493	-0.00021237
$C_{L_{\ddot{\theta}_I}}$	0.0078788	0.0050935
$C_{m_{\ddot{\theta}_I}}$	-0.0066004	-0.0043163
$\partial C_L / \partial n$	-0.012545	-0.0081083
$\partial C_m / \partial n$	0.010463	0.0068382
$C_{L_{\alpha_E}}$	2.9826	1.9190
$C_{m_{\alpha_E}}$	-2.0560	-1.3260
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.69452	-0.69722
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.68936	-0.69101

Reference Geometry: S_w = 500 ft^2; c_r = 20.65 ft (root chord)
Moment reference center is wing apex

4.4. Fixed wing, $\Lambda = 60^{\circ}$ with and without forward shear at the tip (Wings 7 and 8).

For these wings longitudinal characteristics were computed for the flight conditions of Table 18.

Table 18 Flight Conditions for Wings 7 and 8

WING NUMBER	WING TYPE	MACH NUMBER	RIGID	ELASTIC			
				Sealevel	15,000 ft (4,572 m)	35,000 ft (10,668 m)	60,000 ft (18,288 m)
7	Fixed	.25	x	x		x	
	60° sweep,	.80	x	x		x	
	A = 2.0	1.50	x	x	x	x	x
		2.00	x		x	x	x
8	Fixed	.25	x	x		x	
	60° sweep,	.80	x	x		x	
	Tip cranked	1.50	x	x		x	x
	forward to	2.00	x			x	x
	24°, A = 2.0						

Figures 19 and 20 show the planform geometry of wings 7 and 8. Tabulated results for the derivatives are presented in Table 18 for the rigid wings 7 and 8 and Tables 20 and 21 for the elastic wings 7 and 8. Figures 21 and 22 show the effect of Mach number and dynamic pressure on lift-curve-slope, aerodynamic center and pitch damping derivative for the zero mass (or constant load-factor) case.

Aeroelastic effects on wings 7 and 8 are very significant and in the expected direction, i. e., decreasing lift-curve-slope, decreased pitch damping and forward shift in aerodynamic center. Figure 21b demonstrates that there is very little a.c. shift between subsonic flight at low altitudes and supersonic flight at intermediate altitudes. From a trim drag point of view, this planform would be good for intermediate altitude applications.

Comparing the data of Figure 21 with those of Figure 22 it is shown that the effect of forward tip crank is very small. Both planforms are seen to experience large reductions in lift-curve-slope and pitch damping with increasing dynamic pressure.

The tabulated data of Tables 20 and 21 suggest again that inertial effects, although detectable, are small. The comments made at the end of Section 4.1 apply to these wings also.

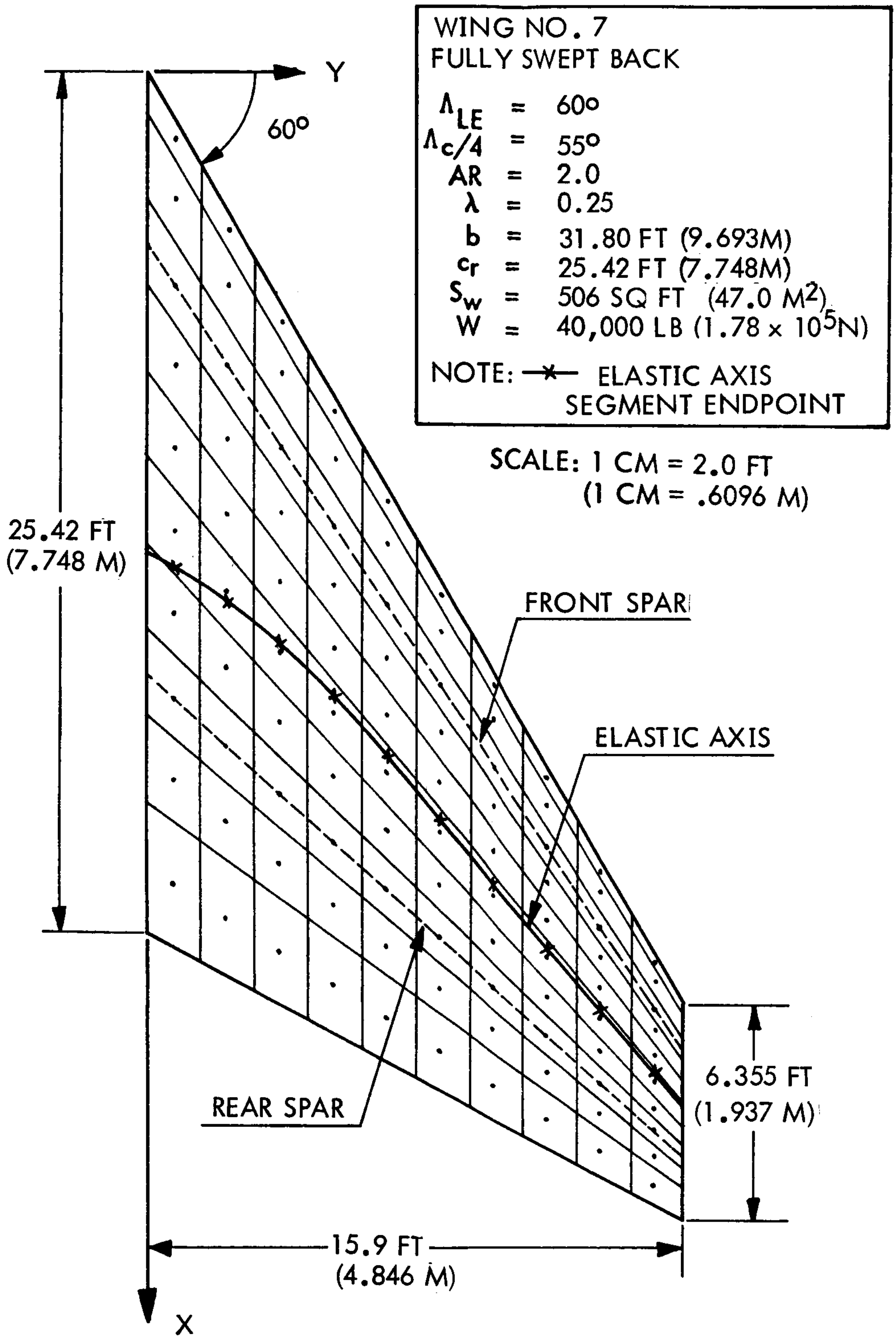


Figure 19 Planform Definition for Wing No. 7

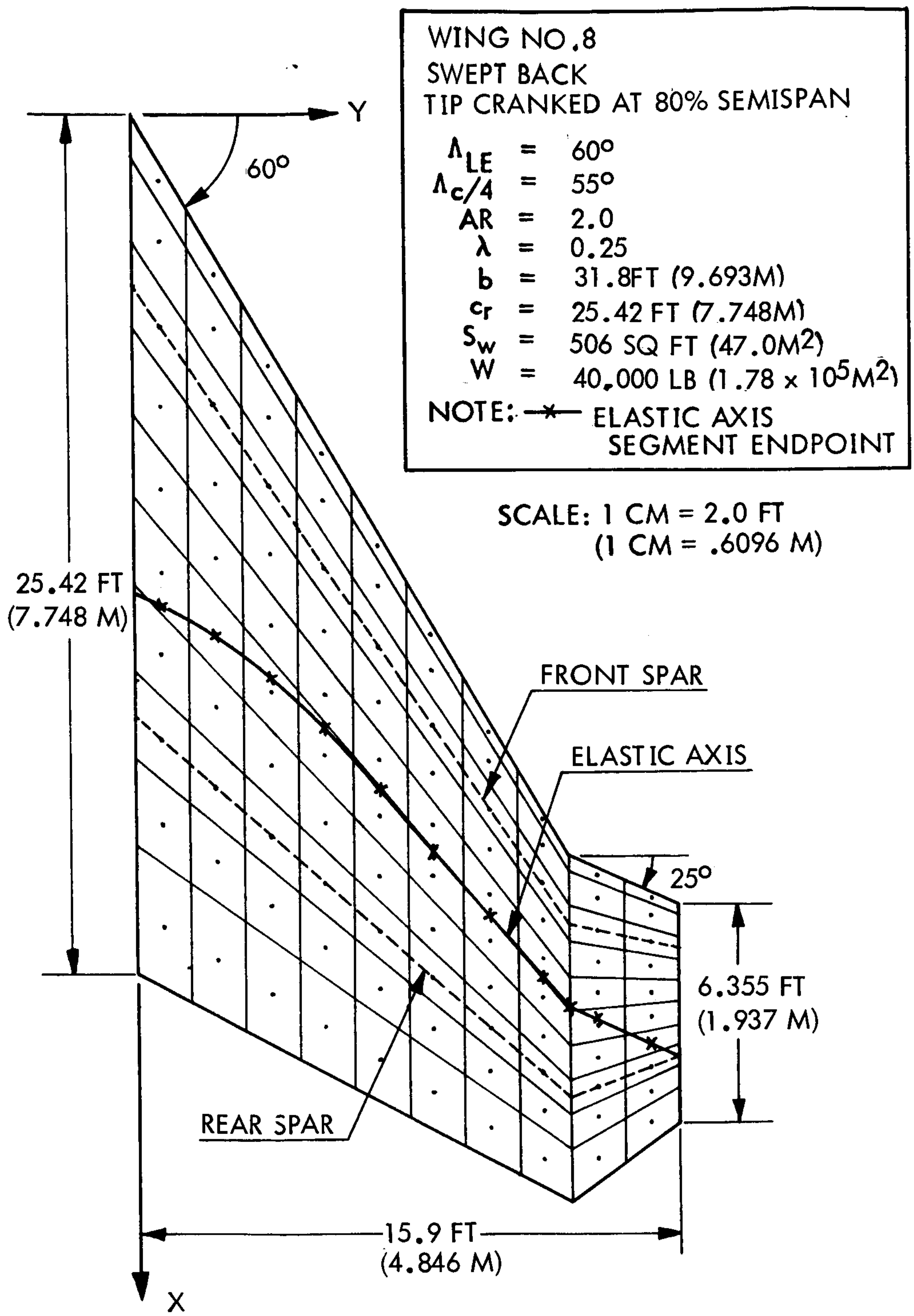


Figure 20 Planform Definition for Wing No. 8

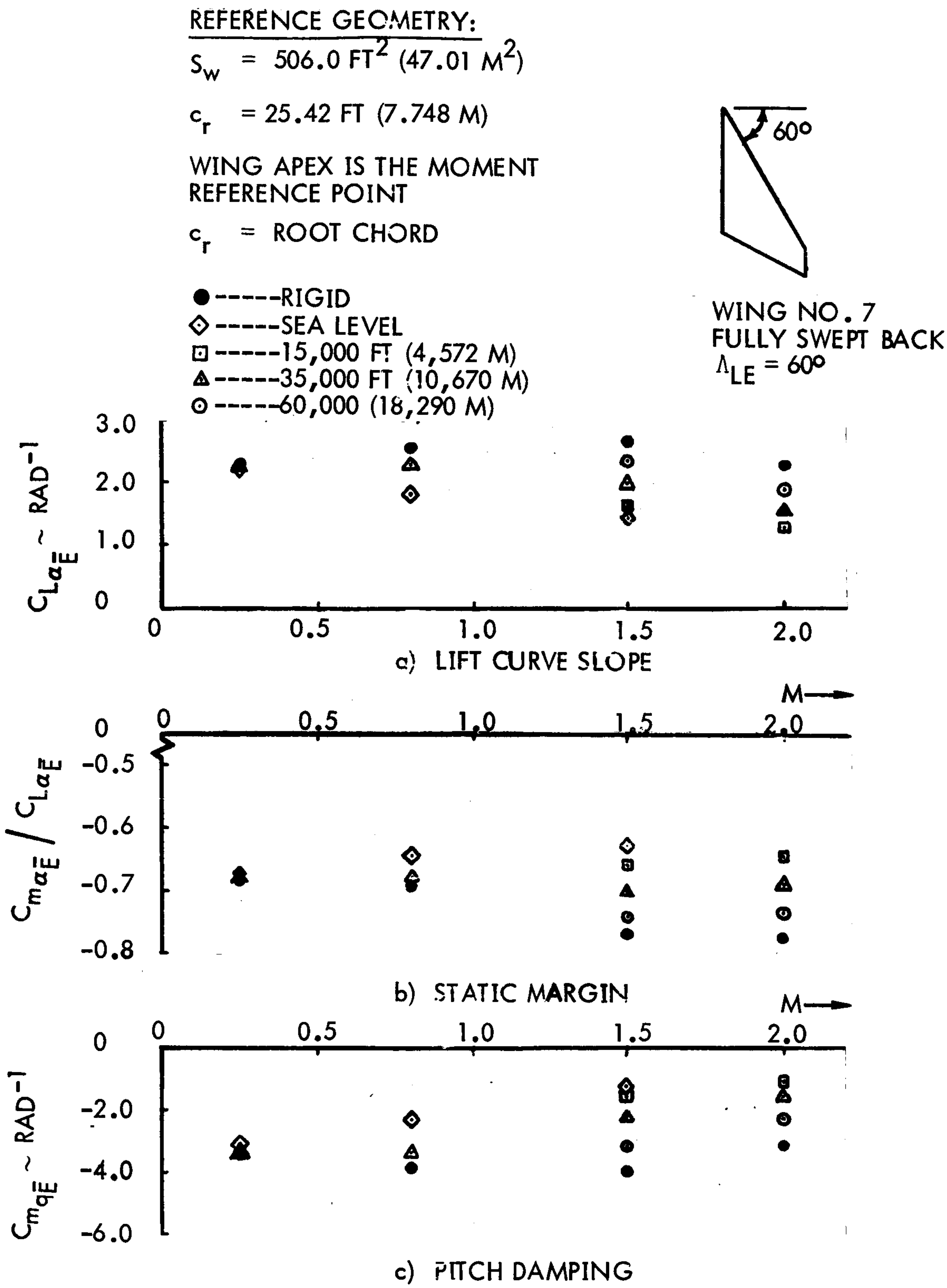


Figure 21. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing No. 7.

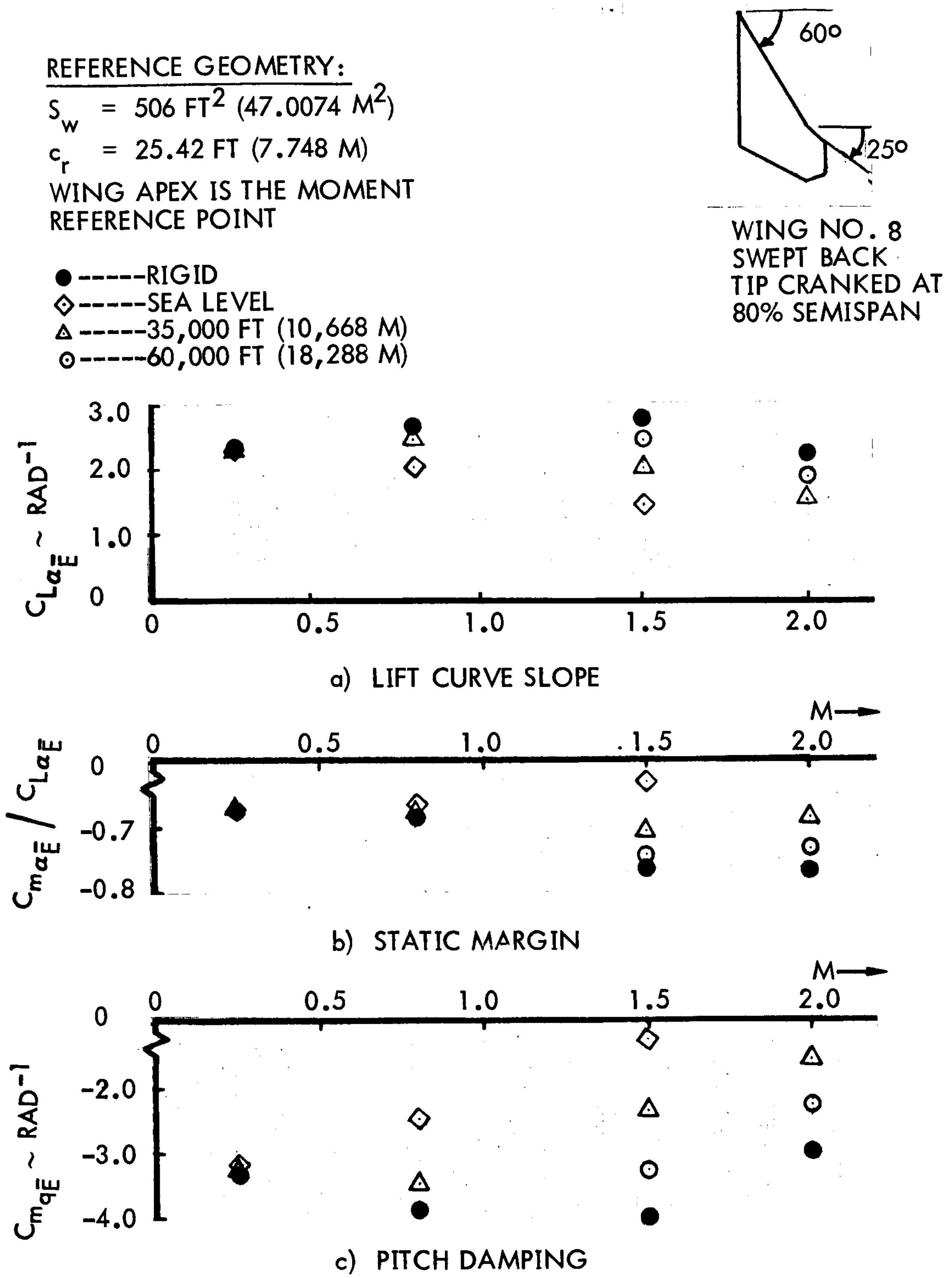


Figure 22. Variation of Zero Mass Lift Curve Slope, Aerodynamic Center and Pitch Damping with Mach Number and Dynamic Pressure for Wing No. 8.

Table 19. Stability Derivatives for the Rigid Wings 7 and 8

Rigid Data Wing 7
Straight 60° Sweep

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha}/C_{L_\alpha}$
0.25	2.2974	-1.5709	+4.4552	-3.3620	-0.68376
0.80	2.5767	-1.7926	+5.0793	-3.9108	-0.69569
1.50	2.7185	-2.0925	+4.6448	-4.0325	-0.76972
2.0	2.2742	-1.7621	+3.5110	-3.0681	-0.77482

Rigid Data Wing 8
Straight 60° Sweep, Cranked Tip

M	C_{L_α}	C_{m_α}	C_{L_q}	C_{m_q}	$C_{m_\alpha}/C_{L_\alpha}$
0.25	2.3356	-1.5742	4.4972	-3.3350	-0.67400
0.80	2.6372	-1.8062	5.1603	-3.8996	-0.68489
1.50	2.7569	-2.1046	4.6449	-3.9800	-0.76339
2.0	2.2763	-1.7432	3.4676	-2.9948	-0.76884

TABLE 20a STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK WING (WING 7) AT SEA LEVEL

DERIVATIVES	M = 0.25 $\bar{q}$ = 21.803	0.8 223.26	1.5 784.91	2.0 1395.4
$C_{L_{\alpha_{\bar{E}}}}$	2.2756	2.3259	1.9855	1.5546
$C_{m_{\alpha_{\bar{E}}}}$	-1.5532	-1.5864	-1.3956	-1.0704
$C_{L_{q_{\bar{E}}}}$	4.3958	4.3787	2.8440	1.9539
$C_{m_{q_{\bar{E}}}}$	-3.3137	-3.3302	-2.2978	-1.5568
$C_{L_{q_I}}$	-3.2526	-31.751	-50.336	-56.211
$C_{m_{q_I}}$	2.6987	26.947	48.258	53.934
$C_{L_{\dot{w}_I}}$	0.00069827	0.00066566	0.00030017	0.00018855
$C_{m_{\dot{w}_I}}$	-0.00057936	-0.00056495	-0.00028778	-0.00018092
$C_{L_{\ddot{\theta}_I}}$	0.019413	0.018391	0.0080914	0.0050506
$C_{m_{\ddot{\theta}_I}}$	-0.016200	-0.015715	-0.0078267	-0.0048939
$\partial C_L/\partial n$	-0.022484	-0.021434	-0.0096656	-0.0060714
$\partial C_m/\partial n$	0.018655	0.018191	0.0092655	0.0058255
$C_{L_{\alpha_E}}$	2.2616	2.1933	1.8119	1.4043
$C_{m_{\alpha_E}}$	-1.5416	-1.4739	-1.2291	-0.92621
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.68254	-0.68207	-0.70287	-0.68855
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.68164	-0.67200	-0.67836	-0.65955

Reference Geometry: S_w = 506 ft^2; c_r = 25.42 (root chord)
Moment reference center is wing apex

TABLE 20b STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK WING (WING 7)

ALTITUDES	15, 000 ft (4,512 m)	15,000 ft (10,668 m)	60,000 ft (18,288 m)	60,000 ft (18,288 m)
DERIVATIVES	$M = 1.5$ $\bar{q} = 1882.4$	2.0 3346.5	1.5 236.09	2.0 419.72
$C_{L_{\alpha_E}}$	1.6673	1.3059	2.3672	1.9041
$C_{m_{\alpha_{\bar{E}}}}$	-1.0997	-0.83813	-1.7652	-1.4040
$C_{L_{q_{\bar{E}}}}$	2.1437	1.4644	3.7810	2.6917
$C_{m_{q_{\bar{E}}}}$	-1.6334	-1.0940	-3.1983	-2.2695
$C_{L_{q_I}}$	-34.819	-37.436	-79.202	-95.620
$C_{m_{q_I}}$	33.092	35.471	76.296	92.538
$C_{L_{\dot{w}_I}}$	0.00017580	0.00010632	0.00047701	0.00032394
$C_{m_{\dot{w}_I}}$	-0.00016709	-0.00010074	-0.00045951	-0.00031350
$C_{L_{\ddot{\theta}_I}}$	0.0046360	0.0027818	0.013069	0.0088549
$C_{m_{\bar{\theta}_I}}$	-0.0044585	-0.0026685	-0.012671	-0.0086299
$\partial C_L / \partial n$	-0.0056609	-0.0034236	-0.015360	-0.010431
$\partial C_m / \partial n$	0.0053802	0.0032439	0.014796	0.010095
$C_{L_{\alpha_E}}$	1.4695	1.1408	2.2721	1.8043
$C_{m_{\alpha_E}}$	-0.91171	-0.68170	-1.6650	-1.3074
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.65956	-0.64179	-0.74288	-0.73736
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.62041	-0.59755	-0.73278	-0.72462

Reference Geometry: $S_w = 506\ ft^2$; $c_r = 25.42$ ft (root chord)
Moment reference center is wing apex

TABLE 20c STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK WING (WING 7) AT 35,000 FT (10,668 m)

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.8 949.25	1.5 3337.2
$C_{L_{\alpha_{\bar{E}}}}$	2.2091	1.8701	1.4850
$C_{m_{\alpha_{\bar{E}}}}$	-1.4994	-1.2116	-0.93266
$C_{L_{q_{\bar{E}}}}$	4.2154	3.1527	1.7697
$C_{m_{q_{\bar{E}}}}$	-3.1667	-2.3106	-1.2863
$C_{L_{q_I}}$	-4.0445	-25.123	-25.607
$C_{m_{q_I}}$	3.3593	21.570	24.109
$C_{L_{\dot{w}_I}}$	0.00065935	0.00039996	0.00011596
$C_{m_{\dot{w}_I}}$	-0.00054763	-0.00034339	-0.00010917
$C_{L_{\ddot{\theta}_I}}$	0.018298	0.010822	0.0030070
$C_{m_{\ddot{\theta}_I}}$	-0.015291	-0.0093916	-0.0028693
$\partial C_L/\partial n$	-0.021231	-0.012879	-0.0037338
$\partial C_m/\partial n$	0.017634	0.011057	0.0035154
$C_{L_{\alpha_E}}$	2.1556	1.6199	1.2831
$C_{m_{\alpha_E}}$	-1.4549	-0.99684	-0.74253
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.67874	-0.64789	-0.62804
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.67494	-0.61536	-0.57871

Reference Geometry: $S_w = 506\ ft^2$; $c_r = 25.42$ ft (root chord)
Moment reference center is wing apex

TABLE 21a STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK AND CRANKED WING (WING 8) AT SEA LEVEL

DERIVATIVES	$M = 0.25$ $\bar{q} = 92.701$	0.8 949.25	1.5 3337.2
$C_{L_{\alpha_{\bar{E}}}}$	2.2741	2.0216	1.4623
$C_{m_{\alpha_{\bar{E}}}}$	-1.5283	-1.3407	-0.92180
$C_{L_{q_{\bar{E}}}}$	4.3141	3.3726	1.7245
$C_{m_{q_{\bar{E}}}}$	-3.1946	-2.4996	-1.2470
$C_{L_{q_I}}$	-3.8585	-27.705	-26.231
$C_{m_{q_I}}$	3.0951	23.241	24.524
$C_{L_{\dot{w}_I}}$	0.00062902	0.00044106	0.00011879
$C_{m_{\dot{w}_I}}$	-0.00050456	-0.00037000	-0.00011105
$C_{L_{\ddot{\theta}_I}}$	0.016859	0.011643	0.0030206
$C_{m_{\ddot{\theta}_I}}$	-0.013584	-0.0098385	-0.0028562
$\partial C_L / \partial n$	-0.020254	-0.014202	-0.0038249
$\partial C_m / \partial n$	0.016247	0.011914	0.0035760
$C_{L_{\alpha_E}}$	2.2214	1.7275	1.2593
$C_{m_{\alpha_E}}$	-1.4860	-1.0939	-0.73199
$C_{m_{\alpha_{\bar{E}}}} / C_{L_{\alpha_{\bar{E}}}}$	-0.67204	-0.66317	-0.63037
$C_{m_{\alpha_E}} / C_{L_{\alpha_E}}$	-0.66896	-0.63325	-0.58127

Reference Geometry: $S_w = 506\ ft^2$; $c_r = 25.42$ ft (root chord)
Moment reference center is wing apex

TABLE 21b STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK AND CRANKED WING (WING 8) AT 35,000 FT (10,668 m)

DERIVATIVES	M = 0.25 $\bar{q}$ = 21.803	0.8 223.26	1.5 784.91	2.0 1395.4
$C_{L_{\alpha_{\bar{E}}}}$	2.3208	2.4592	2.0319	1.5380
$C_{m_{\alpha_{\bar{E}}}}$	-1.5632	-1.6724	-1.4376	-1.0543
$C_{L_{q_{\bar{E}}}}$	4.4529	4.6019	2.8765	1.9267
$C_{m_{q_{\bar{E}}}}$	-3.3010	-3.4647	-2.3246	-1.5305
$C_{L_{q_I}}$	-3.0449	-31.732	-51.767	-57.289
$C_{m_{q_I}}$	2.4379	26.057	48.574	53.895
$C_{L_{\dot{w}_I}}$	0.00065369	0.00066631	0.00030870	0.00019217
$C_{m_{\dot{w}_I}}$	-0.00052337	-0.00054629	-0.00028967	-0.00018079
$C_{L_{\ddot{\theta}_I}}$	0.017537	0.017813	0.0081078	0.0050250
$C_{m_{\ddot{\theta}_I}}$	-0.014102	-0.014676	-0.0076569	-0.0047625
$\partial C_L/\partial n$	-0.021049	-0.021455	-0.0099403	-0.0061879
$\partial C_m/\partial n$	0.016853	0.017591	0.0093273	0.0058213
$C_{L_{\alpha_E}}$	2.3074	2.3189	1.8496	1.3867
$C_{m_{\alpha_E}}$	-1.5525	-1.5574	-1.2666	-0.91206
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.67357	-0.68005	-0.70752	-0.68554
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.67283	-0.67160	-0.68478	-0.65770

Reference Geometry: S_w = 506 ft^2 ; c_r = 25.42 ft (root chord)
Moment reference center is wing apex

TABLE 21c STABILITY DERIVATIVES FOR THE ELASTIC 60° SWEPT BACK AND CRANKED WING (WING 8) AT 60,000 FT (18,288 m)

DERIVATIVES	M = 1.5 $\bar{q}$ = 236.09	2.0 419.72
$C_{L_{\alpha_{\bar{E}}}}$	2.4382	1.9041
$C_{m_{\alpha_{\bar{E}}}}$	-1.8104	-1.3995
$C_{L_{q_{\bar{E}}}}$	3.8426	2.6897
$C_{m_{q_{\bar{E}}}}$	-3.2292	-2.2554
$C_{L_{q_I}}$	-77.910	-93.690
$C_{m_{q_I}}$	73.067	88.465
$C_{L_{\dot{w}_I}}$	0.00046923	0.00031740
$C_{m_{\dot{w}_I}}$	-0.00044007	-0.00029970
$C_{L_{\ddot{\theta}_I}}$	0.012456	0.0084172
$C_{m_{\ddot{\theta}_I}}$	-0.011736	-0.0079885
$\partial C_L / \partial n$	-0.015109	-0.010220
$\partial C_m / \partial n$	0.014170	0.0096504
$C_{L_{\alpha_E}}$	2.3331	1.8063
$C_{m_{\alpha_E}}$	-1.7118	-1.3071
$C_{m_{\alpha_{\bar{E}}}}/C_{L_{\alpha_{\bar{E}}}}$	-0.74251	-0.73498
$C_{m_{\alpha_E}}/C_{L_{\alpha_E}}$	-0.73370	-0.72364

Reference Geometry: S_w = 506 ft^2 ; c_r = 25.42 ft (root chord)
Moment reference center is wing apex

5. THE EFFECT OF STIFFNESS MAGNITUDE AND ELASTIC AXIS LOCATION ON LONGITUDINAL STABILITY CHARACTERISTICS

The purpose of this chapter is to discuss results of a structural parameter sensitivity analysis. In Chapter 4, the effects of static aeroelasticity on longitudinal stability characteristics were described for a family of wings. In this chapter, it is shown that the longitudinal stability characteristic of an entire elastic airplane are sensitive to changes in stiffness magnitude and elastic axis location. The configuration selected for this study is shown in Figure 23. Although the configuration is arbitrary, it is typical for a fighter configuration. Wing planform as well as stiffness and mass characteristics were selected to be similar to those of Wing 5 of Chapter 4. The horizontal tail and fuselage characteristics selected are typical for a fighter airplane having a gross weight of 52,191 lbs. (232,250N). Substantiation and explanation of the geometry and stiffness data is found in References 6 and 9. The mass data determination is explained in Reference 8.

Figure 24 shows that the effect of stiffness magnitude on the aerodynamic center location (reflected by C_{M_α}) is important. The results of Figure 24 were obtained by halving the EI and GJ values about the elastic axis. Since the structural designer must satisfy strength requirements, he would not arbitrarily reduce the stiffness as done herein; however, this reduction is instructive in order to understand grossly the aeroelastic sensitivity of the airplane. The results of Figure 24 indicate that a trade-off in stiffness magnitudes of the structure (against weight, trim drag and maneuverability considerations) should be considered in future designs. It is suggested that these effects may be important trade considerations in the design of control-configured vehicles.

An opportunity for additional design trades is shown in Figure 25. Here, the effect of small shifts in the wing elastic axis location on the longitudinal stability characteristics are shown to be quite important. The results of Figure 24 were obtained by shifting the elastic axis locations in the manner illustrated in Figure 26. The designer can exercise control over the elastic axis location by selecting the spar locations within a planform but he must keep in mind the requirements for flaps or control surfaces which define those areas not available for primary structure. The data of Figure 25 suggest that the effect of static elasticity should also play a role in the selection of torque box location within a planform. Figure 27 illustrates the very large effect that varying the stiffness magnitude and elastic axis location has on the longitudinal stability characteristics. This figure was obtained by halving the EI and GJ values about the elastic axis and simultaneously shifting the location of the elastic axis as shown in Figure 26. By comparing Figure 27 and Figure 25 it can be seen that by varying both of the previously mentioned parameters, in some cases there will be a smaller overall effect on the longitudinal stability characteristics than by merely shifting the elastic axis.

Tabulated data for all derivatives computed in this chapter are shown in Table 22. The data indicate considerable effect of elastic axis shift on the inertial derivatives, in particular the load factor derivatives $\partial C_L / \partial n$ and $\partial C_m / \partial n$.

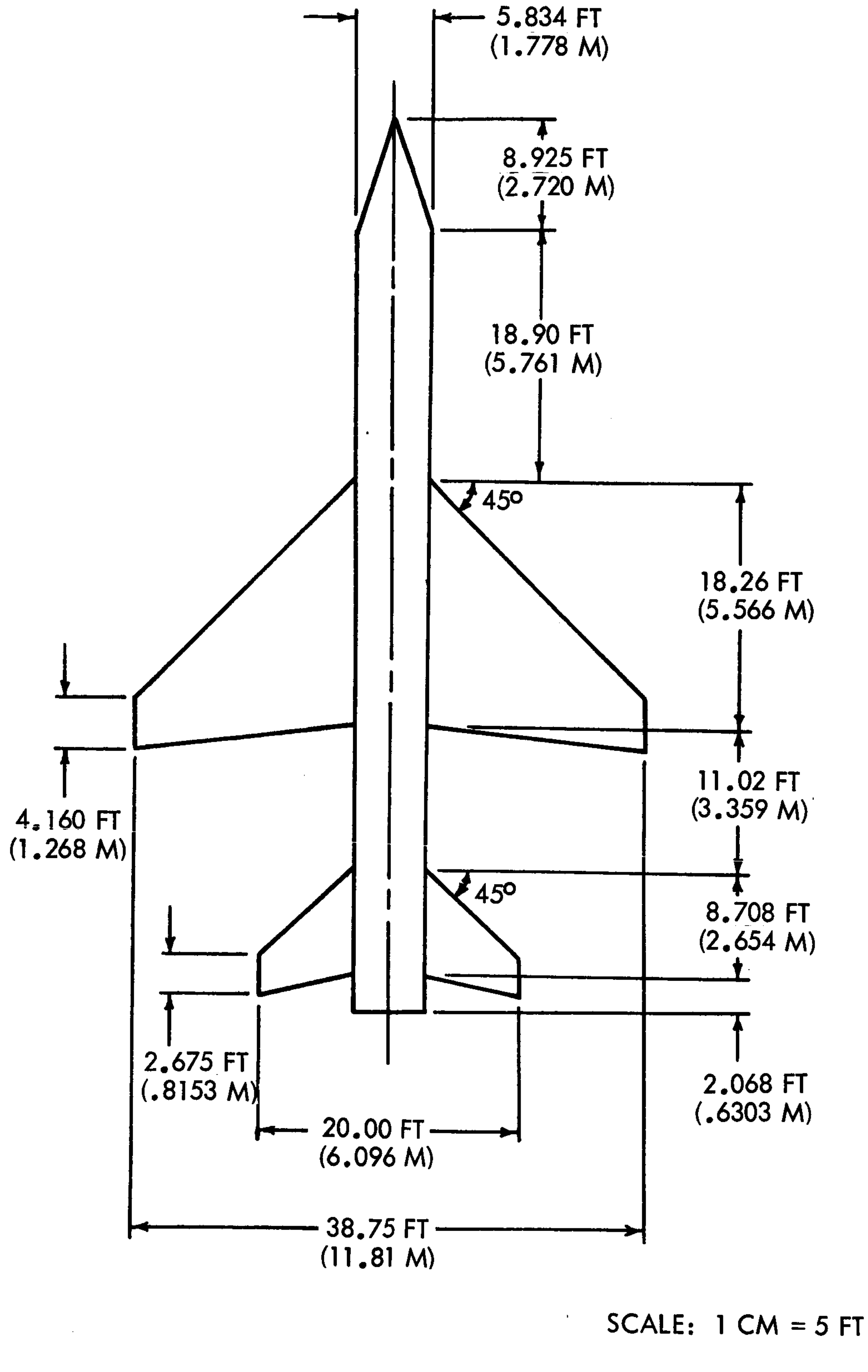


Figure 23. Example Wing-Fuselage-Tail Configuration.

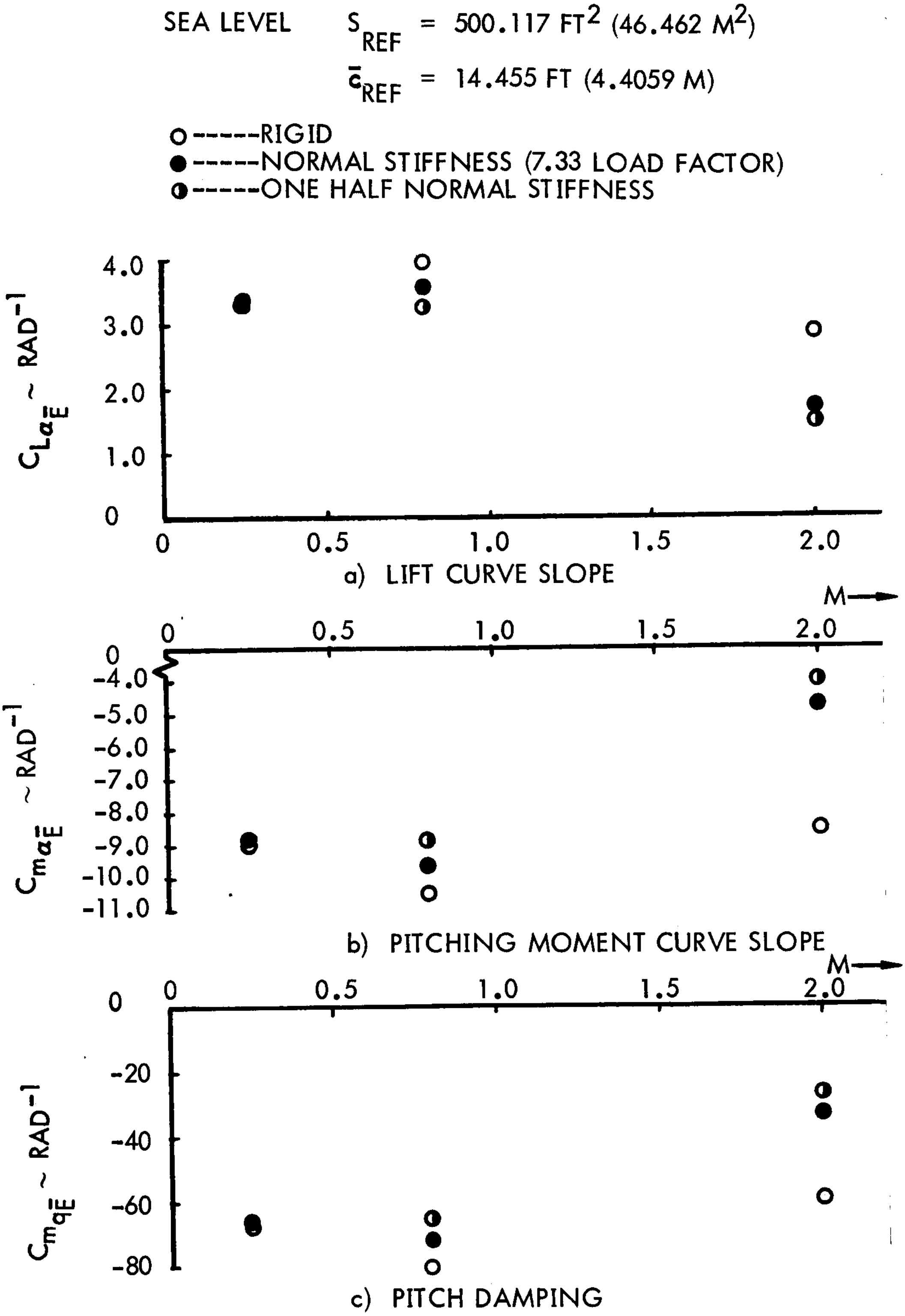


Figure 24. Effect of Stiffness Magnitude on the Longitudinal Stability Characteristics of the Fighter Configuration of Figure 23.

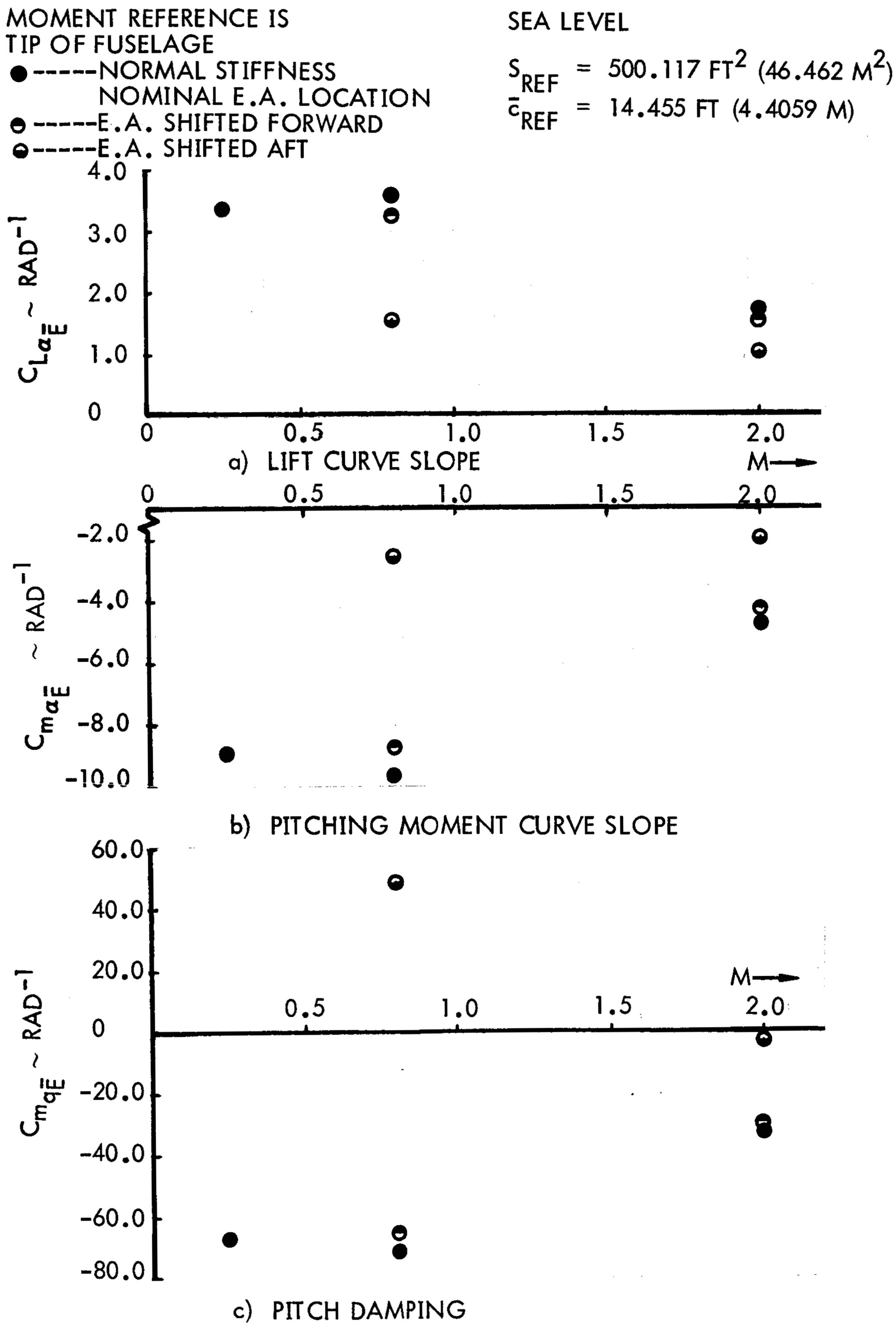


Figure 25. Effect of Wing Elastic Axis Location on the Longitudinal Stability Characteristics of the Fighter Configuration of Figure 23.

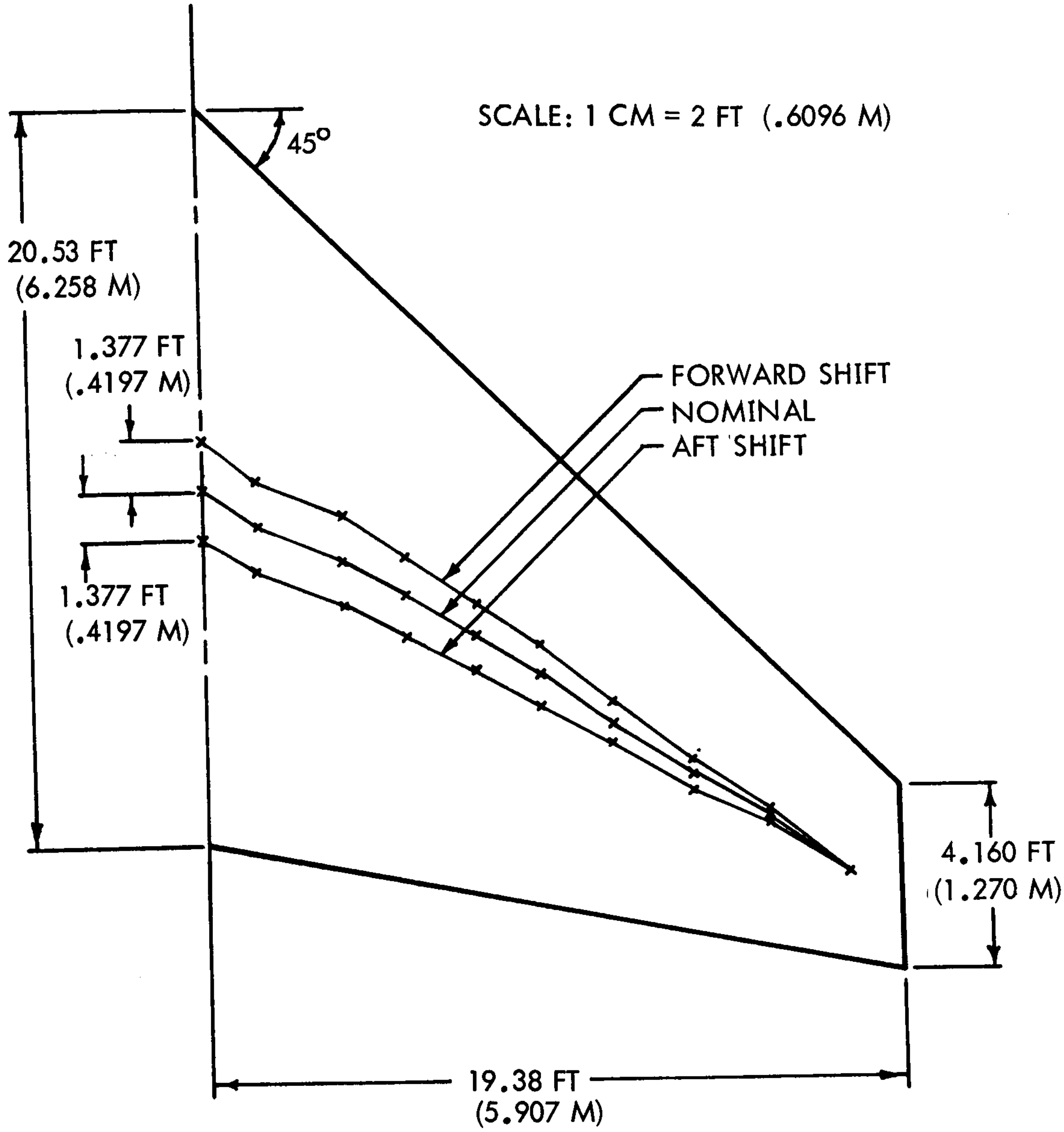


Figure 26. Illustration of Wing Elastic Axis Shifts Used in Computing the Results of Figure 25.

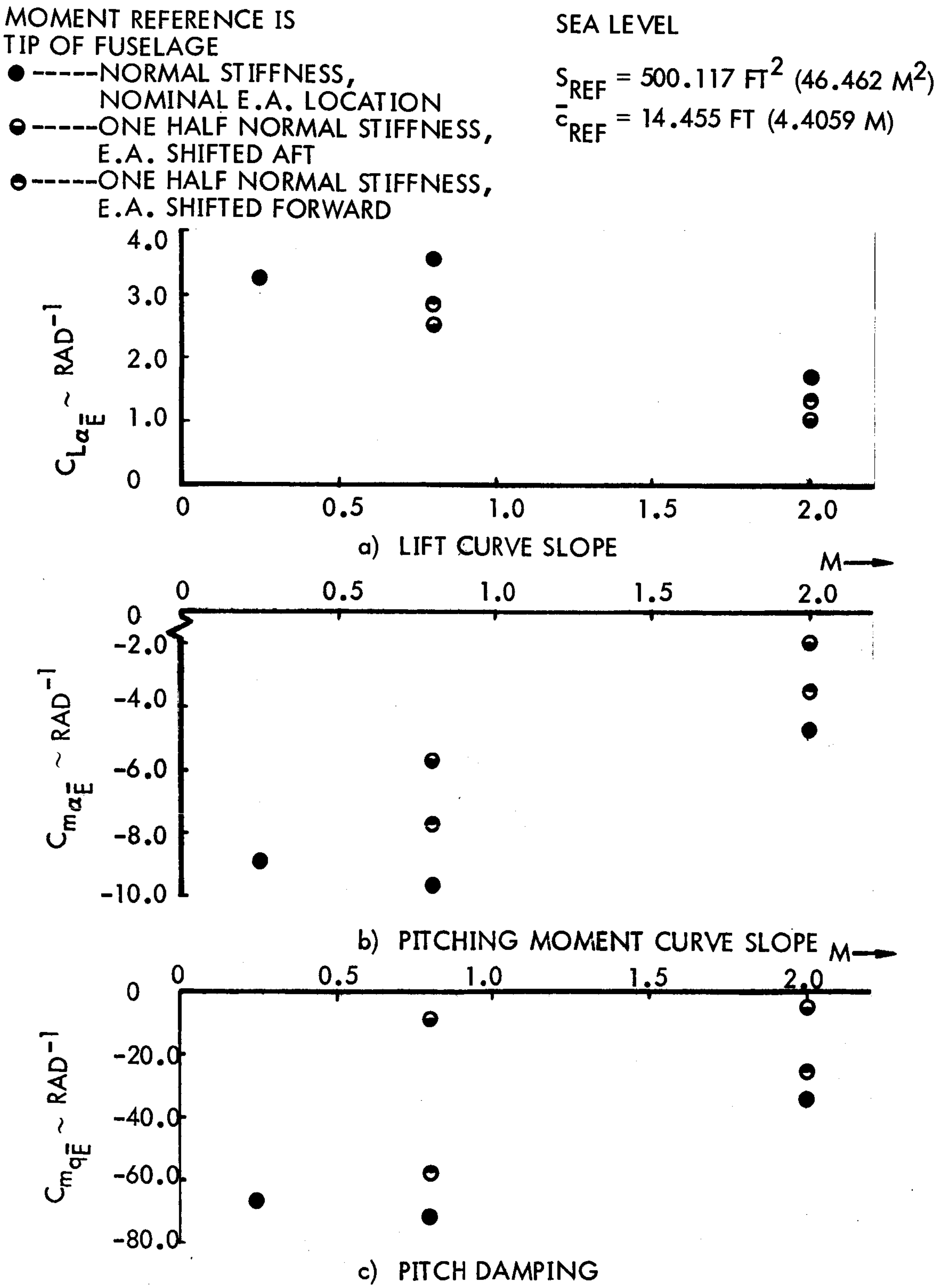


Figure 27. Effect of Varying Stiffness Magnitude and Elastic Axis Location on the Longitudinal Stability Characteristics of the Fighter Configuration of Figure 23.

TABLE 22a LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH NORMAL STIFFNESS AND NOMINAL ELASTIC AXIS LOCATION

Note: All data at Sealevel

DERIVATIVE	M = 0.25	M = 0.80	M = 2.00
C_{L_α}	3.3704	3.9241	2.8865
C_{m_α}	- 8.9596	-10.468	- 8.5357
C_{L_q}	23.294	27.232	18.490
C_{m_q}	-67.530	-79.296	-59.398
$C_{L_{\alpha_E}}$	3.3465	3.5740	1.7132
$C_{m_{\alpha_E}}$	- 8.9033	- 9.6537	- 4.7553
$C_{L_{q_E}}$	23.075	24.088	10.534
$C_{m_{q_E}}$	-66.989	-71.534	-33.432
$C_{L_{q_I}}$	- 3.1565	-31.650	-48.721
$C_{m_{q_I}}$	8.8821	91.414	174.07
$C_{L_{\dot{w}_I}}$	.00029262	.00028653	.000070571
$C_{m_{\dot{w}_I}}$	- .00082338	- .00082756	- .00025213
$C_{L_{\ddot{\theta}_I}}$	.013921	.013652	.0035612
$C_{m_{\ddot{\theta}_I}}$	- .039318	- .039639	- .012441
$\partial C_L/\partial n$	- .0094222	- .0092262	- .0022724
$\partial C_m/\partial n$	.026513	.026647	- .0081186
$C_{L_{\alpha_E}}$	3.3273	3.3791	1.5735
$C_{m_{\alpha_E}}$	- 8.8494	- 9.0908	- 4.2561

TABLE 22b LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH ONE HALF NORMAL STIFFNESS AND NOMINAL ELASTIC AXIS LOCATION

Note: All data at Sealevel

DERIVATIVE	M = 0.80	M = 2.00
$C_{L_{\alpha_{\bar{E}}}}$	3.2525	1.4992
$C_{m_{\alpha_{\bar{E}}}}$	- 8.8725	- 3.9922
$C_{L_{q_{\bar{E}}}}$	21.505	8.8398
$C_{m_{q_{\bar{E}}}}$	-64.930	-27.353
$C_{L_{q_I}}$	-51.083	-60.026
$C_{m_{q_I}}$	152.30	228.75
$C_{L_{\dot{w}_I}}$	.00046245	.000086946
$C_{m_{\dot{w}_I}}$	- .0013788	- .00033134
$C_{L_{\ddot{\theta}_I}}$	.022144	.0045984
$C_{m_{\ddot{\theta}_I}}$	- .066352	0 .016671
$\partial C_L / \partial n$	- .014891	- .0027996
$\partial C_m / \partial n$	.044397	.010669
$C_{L_{\alpha_E}}$	2.9755	1.3513
$C_{m_{\alpha_E}}$	- 8.466	- 3.4289

TABLE 22c LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH NORMAL STIFFNESS AND ELASTIC AXIS OF WING SHIFTED FORWARD AS SHOWN IN FIGURE 26

Note: All data at Sealevel

DERIVATIVE	M = 0.80	M = 2.00
$C_{L_{\alpha_{\bar{E}}}}$	3.2313	1.5434
$C_{m_{\alpha_{\bar{E}}}}$	- 8.7454	- 4.2370
$C_{L_{q_{\bar{E}}}}$	21.925	9.6271
$C_{m_{q_{\bar{E}}}}$	-65.751	-30.587
$C_{L_{q_I}}$	-38.453	-56.112
$C_{m_{q_I}}$	110.58	196.80
$C_{L_{\dot{w}_I}}$	.00034811	.000081276
$C_{m_{\dot{w}_I}}$	- .0010010	- .00028505
$C_{L_{\ddot{\theta}_I}}$	..016303	.0039904
$C_{m_{\ddot{\theta}_I}}$	- .047252	- 0.13859
$\partial C_L / \partial n$	- .011209	- .0026171
$\partial C_m / \partial n$	.032233	.0091787
$C_{L_{\alpha_E}}$	3.0197	1.4002
$C_{m_{\alpha_E}}$	- 8.1368	- 3.7348

TABLE 22d LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH NORMAL STIFFNESS AND ELASTIC AXIS OF WING SHIFTED AFT AS SHOWN IN FIGURE 26

Note: All data at Sealevel

DERIVATIVE	M= 0.80	M = 2.00
$C_{L_{\alpha_{\bar{E}}}}$	1.5745	1.0384
$C_{m_{\alpha_{\bar{E}}}}$	- 2.5489	- 1.9176
$C_{L_{q_{\bar{E}}}}$	-10.541	2.9635
$C_{m_{q_{\bar{E}}}}$	48.217	- 2.8680
$C_{L_{q_I}}$	-87.433	-32.177
$C_{m_{q_I}}$	284.88	117.74
$C_{L_{\dot{w}_I}}$	.00079152	.000046607
$C_{m_{\dot{w}_I}}$	- .0025790	- .00017054
$C_{L_{\ddot{\theta}_I}}$	.045583	.0027347
$C_{m_{\ddot{\theta}_I}}$	- .14939	- .0095095
$\partial C_L / \partial n$	- .025487	- .0015008
$\partial C_m / \partial n$	.083043	.0054913
$C_{L_{\alpha_E}}$	1.3581	.98089
$C_{m_{\alpha_E}}$	- 1.8438	- 1.7071

TABLE 22e LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH ONE HALF NORMAL STIFFNESS AND ELASTIC AXIS OF WING SHIFTED FORWARD

Note: All data at Sealevel

DERIVATIVE	M = 0.80	M = 2.00
$C_{L_{\alpha_{\bar{E}}}}$	2.8169	1.3282
$C_{m_{\alpha_{\bar{E}}}}$	- 7.6909	- 3.4818
$C_{L_{q_{\bar{E}}}}$	18.872	7.9927
$C_{m_{q_{\bar{E}}}}$	-57.699	-24.739
$C_{L_{q_I}}$	-56.921	-69.786
$C_{m_{q_I}}$	170.00	258.07
$C_{L_{\dot{w}_I}}$	.00051530	.00010108
$C_{m_{\dot{w}_I}}$	- .0015390	- .00037380
$C_{L_{\ddot{\theta}_I}}$	.024289	.0051270
$C_{m_{\ddot{\theta}_I}}$	- .073132	- .018405
$\partial C_L / \partial n$	- .016593	- .0032548
$\partial C_m / \partial n$	.049556	.012036
$C_{L_{\alpha_E}}$	2.5522	1.1784
$C_{m_{\alpha_E}}$	- 6.9002	- 2.9276

TABLE 22f LONGITUDINAL STABILITY DERIVATIVES FOR THE FIGHTER CONFIGURATION OF FIGURE 23 WITH ONE HALF NORMAL STIFFNESS AND ELASTIC AXIS OF WING SHIFTED AFT AS SHOWN IN FIGURE 26

Note: All data at Sea level

DERIVATIVE	M = 0.80	M = 2.00
$C_{L_{\alpha_{\bar{E}}}}$	2.5208	1.0556
$C_{m_{\alpha_{\bar{E}}}}$	- 5.7939	- 1.9656
$C_{L_{q_{\bar{E}}}}$	6.4686	3.4240
$C_{m_{q_{\bar{E}}}}$	- 9.0511	- 4.5715
$C_{L_{q_I}}$	-67.232	-26.174
$C_{m_{q_I}}$	212.20	109.33
$C_{L_{\dot{w}_I}}$	.00060864	.000037911
$C_{m_{\dot{w}_I}}$	- .0019210	- .00015836
$C_{L_{\ddot{\theta}_I}}$	.032627	.0025639
$C_{m_{\ddot{\theta}_I}}$	- .10365	- .0090736
$\partial C_L / \partial n$	- .019598	- .0012207
$\partial C_m / \partial n$	.061858	.0050992
$C_{L_{\alpha_E}}$	2.2457	1.0075
$C_{m_{\alpha_E}}$	- 4.9254	- 1.7649

6. AEROELASTIC EFFECTS ON INDUCED DRAG

The configurations chosen for this investigation are shown in Figs. 15 and 23. For both configurations, the flight conditions used in the computation are $M_\infty = 0.8$ and 1.5 at sea level, so that the aeroelastic effects are expected to be large due to the high dynamic pressure. For detailed computing methodology, See Reference 12.

The results for the wing alone case are shown in Table 23. The spanwise induced drag distribution and the span loading are given in Figures 28 and 29. In both cases, the trend of variation is typical. Due to the aeroelastic unloading, both C_{L_α} and C_{D_i} are reduced by the structural flexibility. On the other hand, the induced drag parameters C_{D_i} / C_L^2, are increased because the span loading becomes less elliptical at $M_\infty = 0.8$. Note that in computing the elastic C_{D_i}/C_L^2 distribution, C_{L_α} with mass effect has been used, instead of the rigid C_{L_α}.

Table 23 Comparison of Rigid and Elastic Aerodynamic Properties for a 45° - Sweep Wing at Sea Level

	$M_\infty = 0.8$			$M_\infty = 1.5$		
	C_{L_α} rad^{-1}	C_{D_i}	C_{D_i}/C_L^2	C_{L_α} rad^{-1}	C_{D_i}	C_{D_i}/C_L^2
Rigid	3.653	1.439	0.1078	3.4357	3.4357	0.29106
Elastic	2.8911	1.1701	0.13999	1.7735	1.2549	0.39896

For the wing-body-tail combination, the results are compared in Table 24. Figs. 30 and 31 show the spanwise induced drag distribution and the span loading on the wing and the tail surfaces. From Table 24, it is seen that the results follow the same trend as in the wing alone case.

Table 24 Comparison of Rigid and Elastic Aerodynamic Properties for a Wing-Body-Tail Combination at Sea Level

	$M_\infty = 0.8$			$M_\infty = 1.5$		
	C_{L_α} rad^{-1}	C_{D_i}	C_{D_i}/C_L^2	C_{L_α} rad^{-1}	C_{D_i}	C_{D_i}/C_L^2
Rigid	3.7998	1.5922	0.11027	3.8946	3.8946	0.25677
Elastic	3.2906	1.3923	0.12859	2.3306	1.8991	0.34963

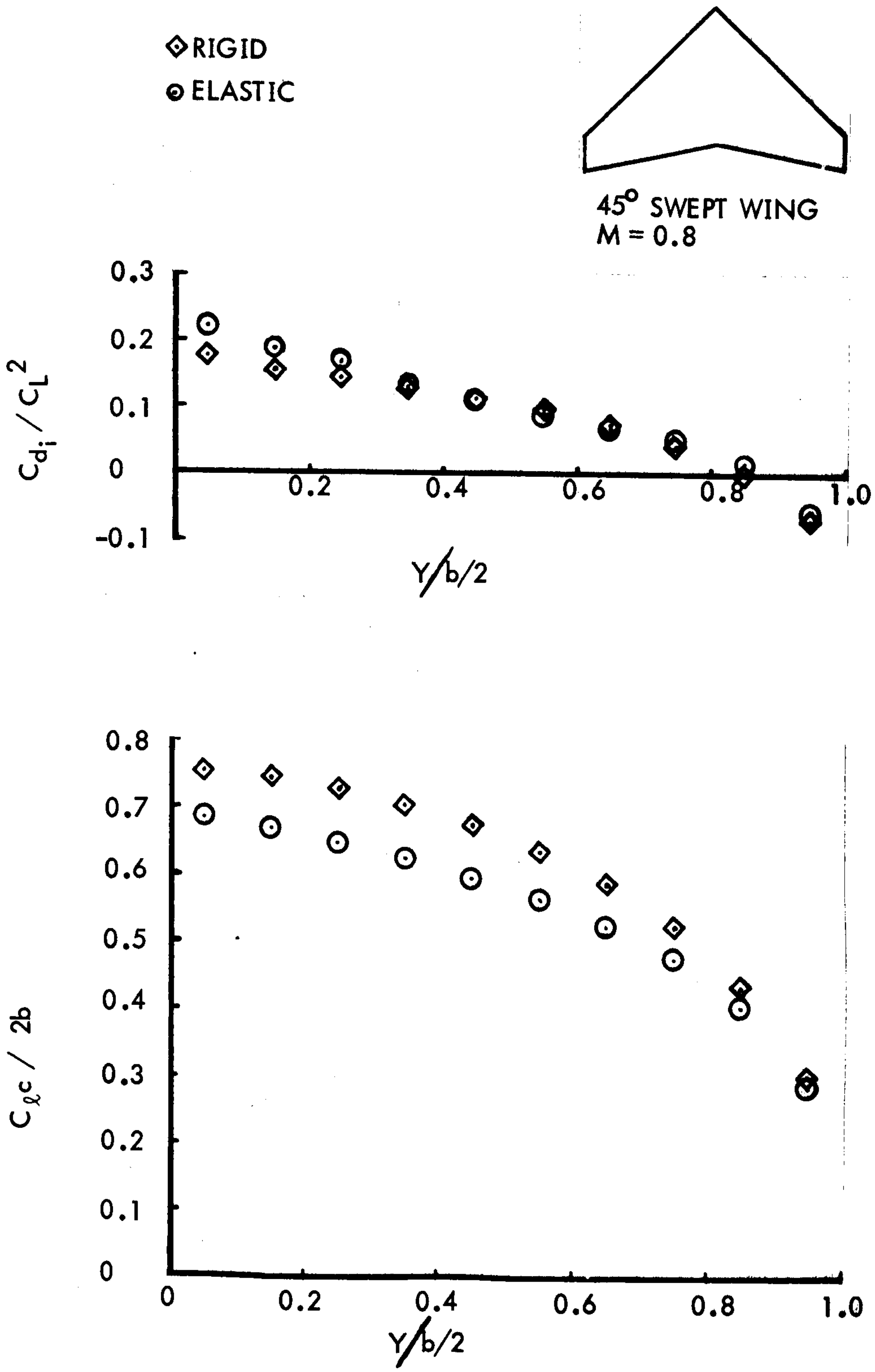


Figure 28. Rigid and Elastic Induced Drag Distribution and Span Loading for Wing 5 at $M_\infty = 0.8$.

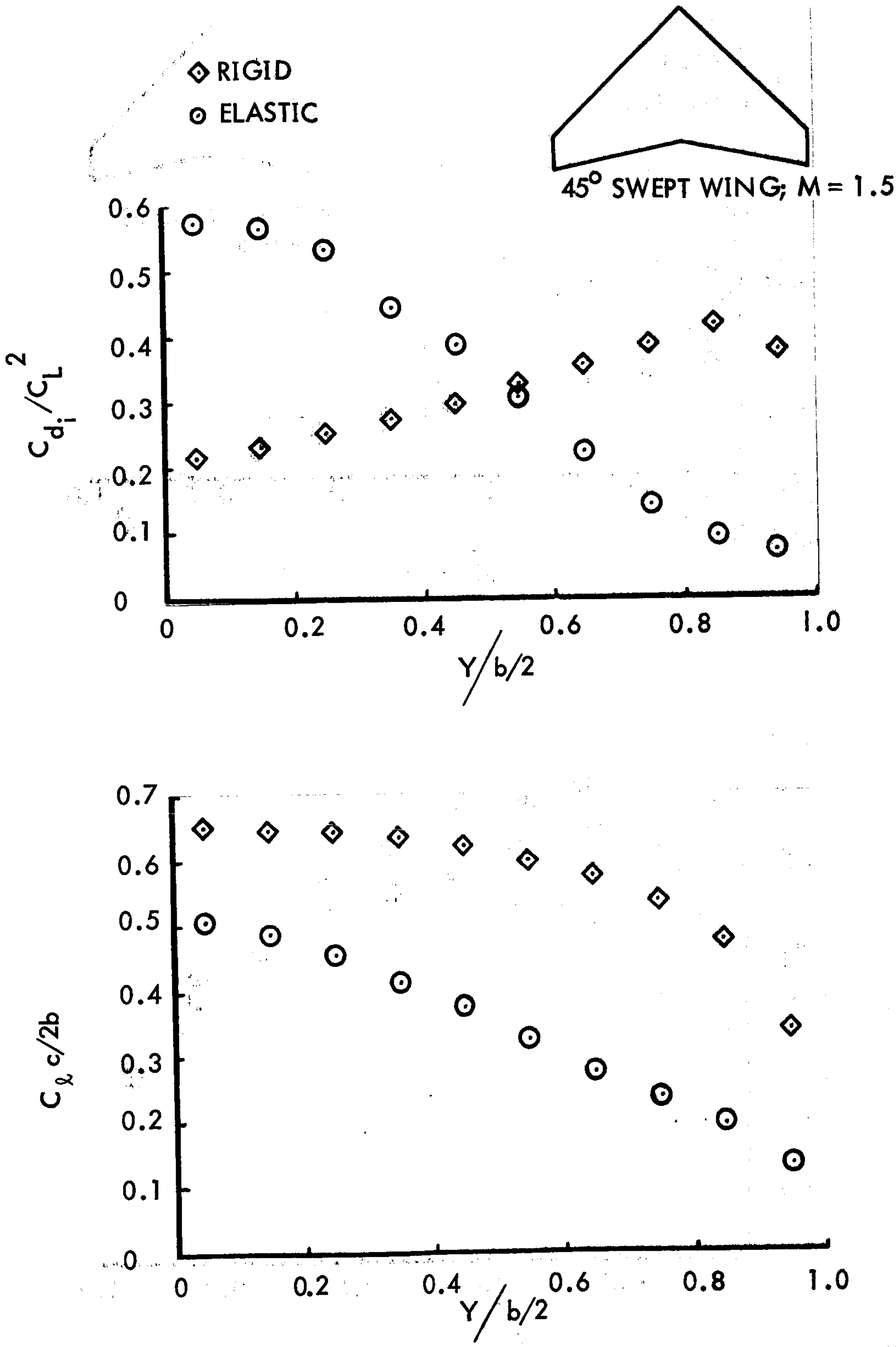


Figure 29. Rigid and Elastic Induced Drag Distribution and Span Loading for Wing 5 at $M_\infty = 1.5$.

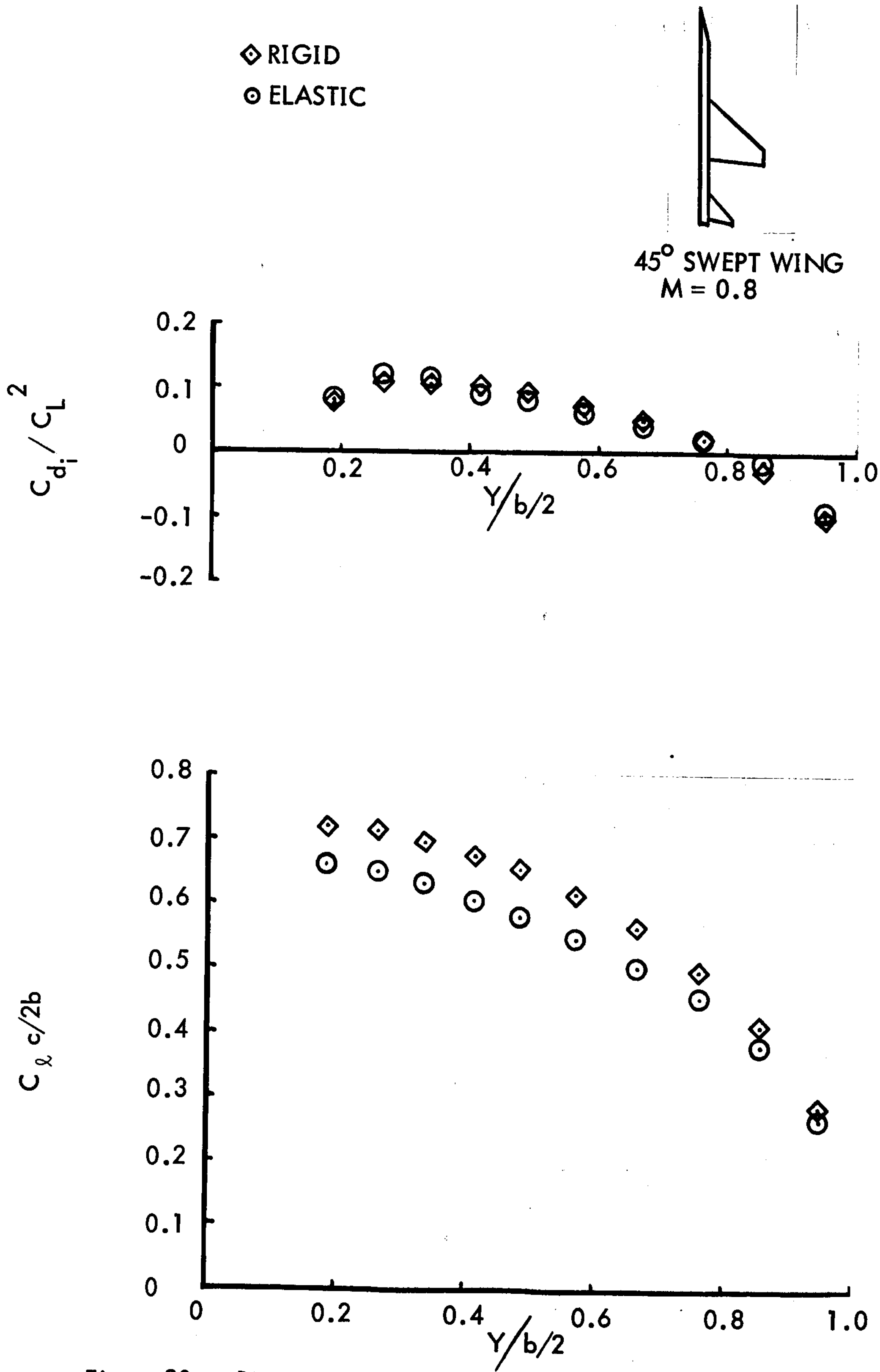


Figure 30a. Rigid and Elastic Induced Drag Distribution and Span Loading for the Fighter Configuration of Figure 23 at $M_\infty = 0.8$. Wing Surface.

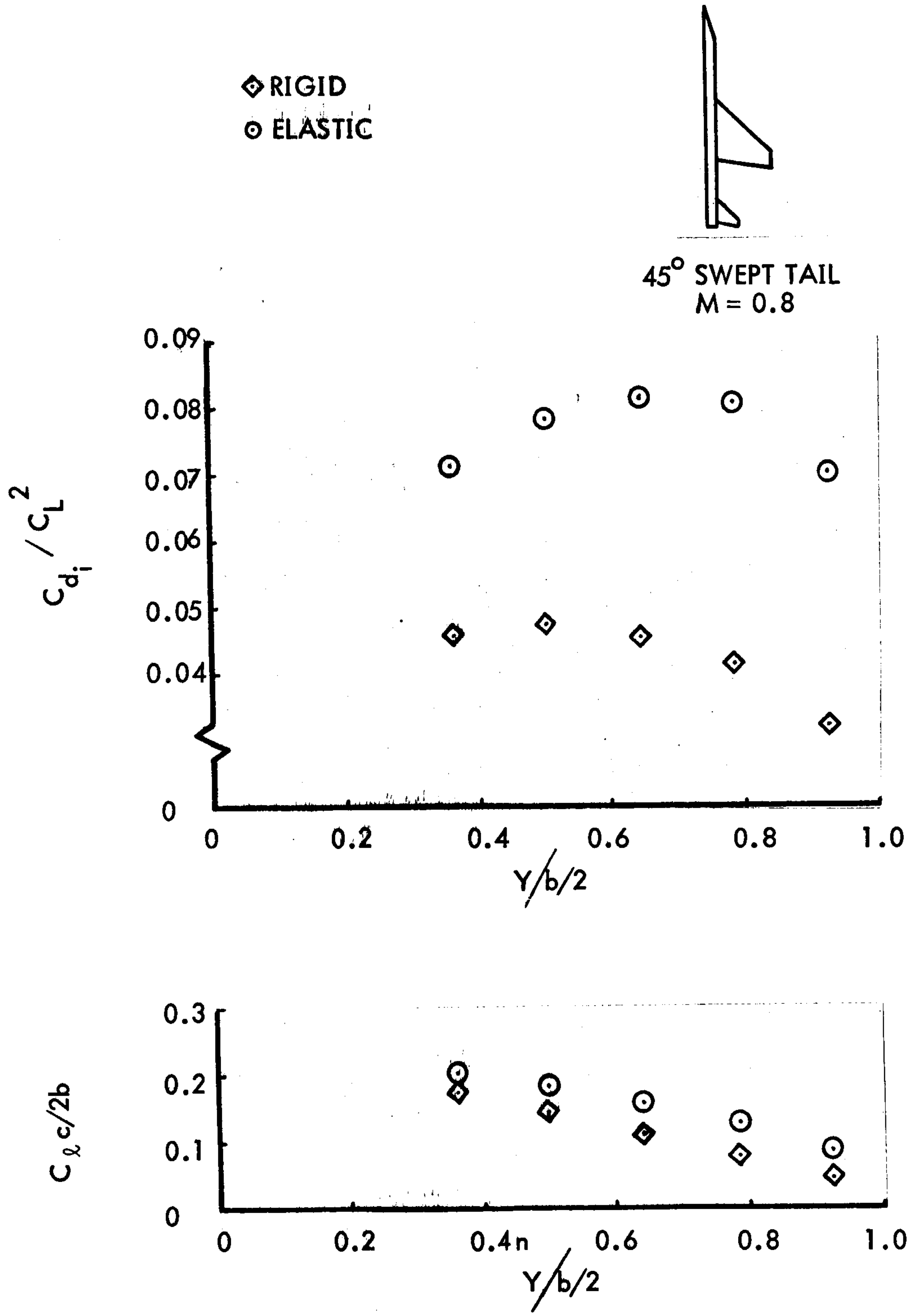


Figure 30b. Rigid and Elastic Induced Drag Distribution and Span Loading for the Fighter Configuration of Figure 23 at $M_\infty = 0.8$. Tail Surface.

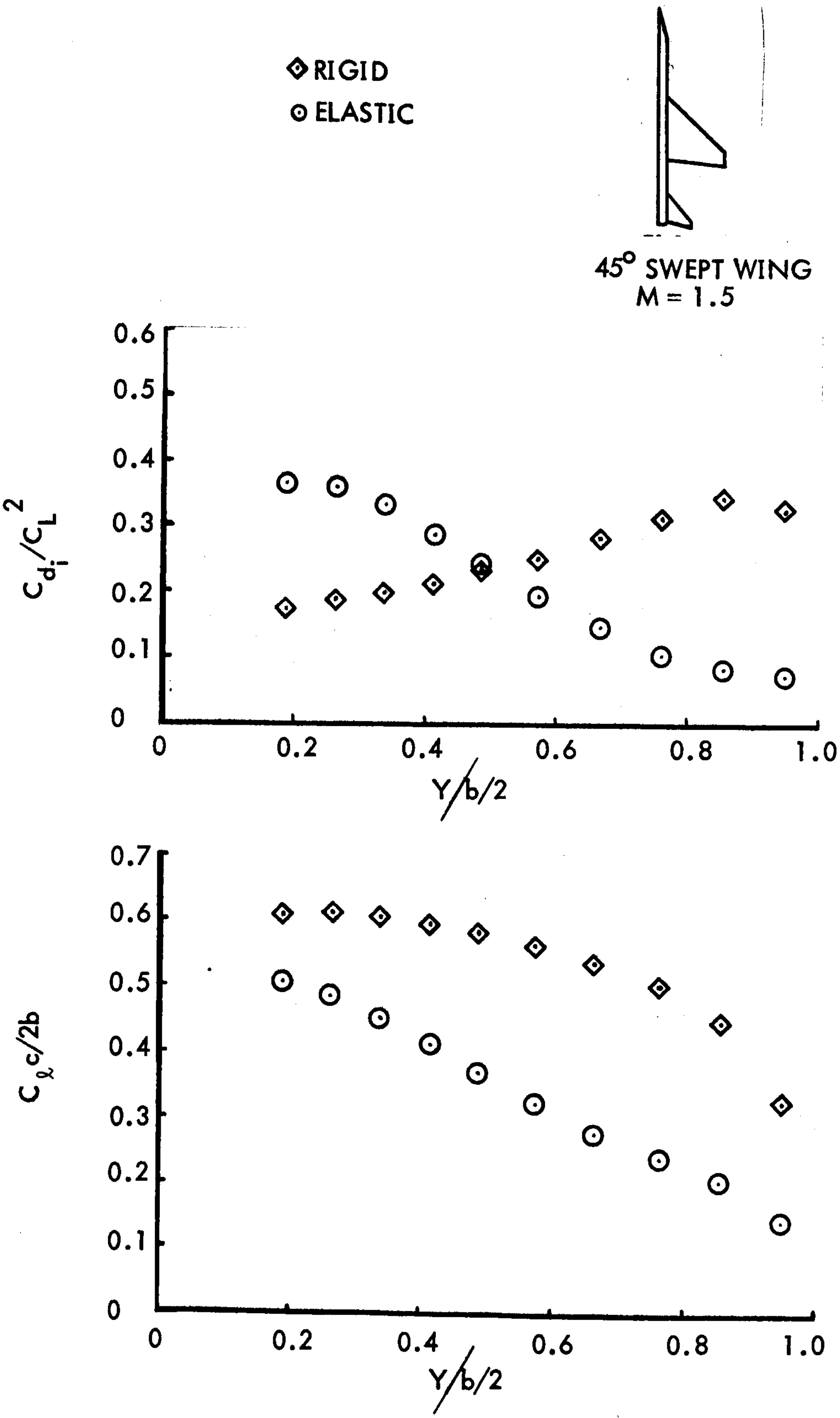


Figure 31a. Rigid and Elastic Induced Drag Distribution and Span Loading for the Fighter Configuration of Figure 23 at $M_\infty = 1.5$. Wing Surface.

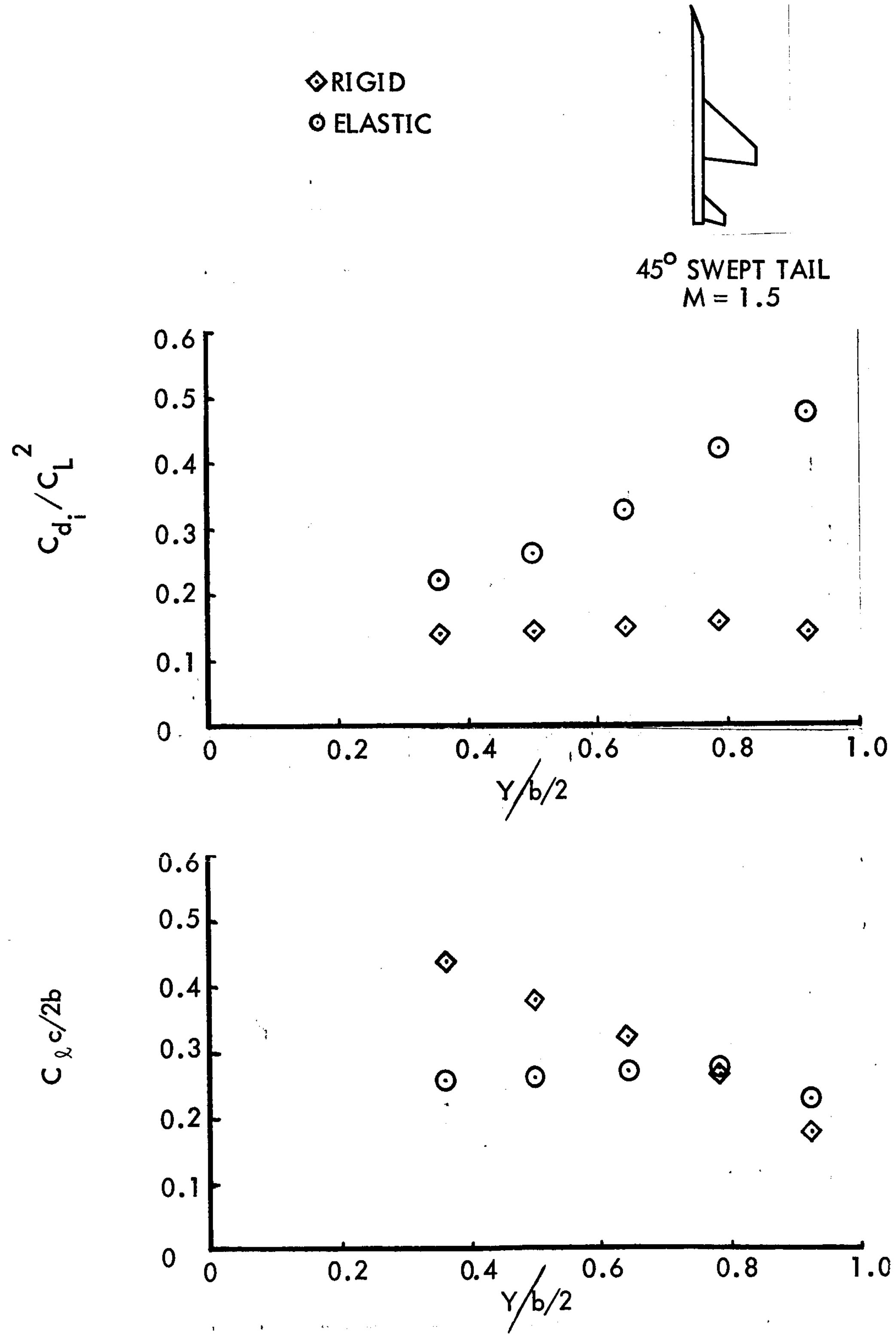


Figure 31b. Rigid and Elastic Induced Drag Distribution and Span Loading for the Fighter Configuration of Figure 23 at $M_\infty = 1.5$. Tail Surface.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been derived from this study:

1. Inertially induced steady state aeroelastic effects on longitudinal stability characteristics are small.
2. Basic (i.e. zero-mass) steady state aeroelastic effects on longitudinal stability characteristics are large for a range of planforms.
3. For variable sweep wings, it appears that tailoring of pivot location and elastic characteristics is a must to achieve relative balance objectives between extreme flight conditions. An appropriate pivot location for a given airplane design can be determined from trade-off information such as that shown in Figure 14. For the wings studied here, assuming the objective is to minimize the a.c. shift between $M = .25$, $\Lambda = 20^o$, sea level, and $M = 1.5$, $\Lambda = 72^o$, 35,000 ft, the 40% pivot location seems best.
4. It is possible to tailor fixed sweep planforms in such a way that trim requirements between selected extreme flight conditions are minimized.
5. By selecting the right combination of stiffness magnitude and spar locations, the designer can exercise a considerable amount of control over longitudinal stability characteristics.

The fact is emphasized, that these conclusions apply only to the planforms studied here. It is conjectured however, that these conclusions are typical for fighter type aircraft in the 40,000 lbs. (178,000N) and 7.33 load-factor range.

The following recommendations are made for future research:

1. For parametric design studies, use of 'chase-around-charts' have been found to be useful. It is recommended that such charts be made for specific classes of planforms, for specific ranges of flight conditions and for specific ranges of load factor.
2. It is recommended that studies similar to those made here, be initiated with regard to the lateral-directional characteristics of airplanes.
3. It is recommended that studies similar to those made here, be initiated for 'low load-factor' airplanes such as V/STOL, high subsonic and supersonic transports.

8. REFERENCES

1. Anon.; An Analysis of Methods for Predicting the Stability Characteristics of an Elastic Airplane; Summary Report; NASA CR-73277; Prepared by The Boeing Company as D6-20659-1, November, 1968 under Contract NASA 2-3662, NASA, Ames.

2. Anon.; An Analysis of Methods for Predicting the Stability Characteristics of an Elastic Airplane; Appendix A, Equations of Motion and Stability Criteria; NASA CR-73274; Prepared by The Boeing Company as D6-20659-2, November, 1968 under Contract NASA 2-3662, NASA, Ames.

3. Anon.; An Analysis of Methods for Predicting the Stability Characteristics of an Elastic Airplane; Appendix B, Methods for Determining Stability Derivatives; NASA CR-73275; Prepared by The Boeing Company as D6-20659-3, November, 1968 under Contract NASA 2-3662, NASA, Ames.

4. Anon.; An Analysis of Methods for Predicting the Stability Characteristics of an Elastic Airplane; Appendix C, Methods for Predicting Stability and Response Characteristics; NASA CR-73276; Prepared by The Boeing Company as D6-20659-4, November, 1968 under Contract NASA 2-3662, NASA, Ames.

5. Roskam, J., Lan, C., and Mehrotra, S.; "A Computer Program for Calculating α - and q- Stability Derivatives and Induced Drag for Thin Elastic Aeroplanes at Subsonic and Supersonic Speeds," NASA CR- 112229 ; Prepared for NASA by the Flight Research Laboratory of the University of Kansas under NASA Grant NGR 17-002-071, October, 1972. Appendix A of the Summary Report, NASA CR-2117 .

6. Roskam, J., Smith, H., and Gibson, G.; "Method for Computing the Structural Influence Coefficient Matrix of Nonplanar Wing-Body-Tail Configurations," NASA CR-112230 ; Prepared for NASA by the Flight Research Laboratory of the University of Kansas under NASA Grant NGR 17-002-071, October, 1972. Appendix B of the Summary Report, NASA CR-2117 .

7. Roskam, J., Lan, C., and Mehrotra, S.; "Method for Computing the Aerodynamic Influence Coefficient Matrix of Nonplanar Wing-Body-Tail Configurations," NASA CR- 112231 ; Prepared for NASA by the Flight Research Laboratory of the University of Kansas under NASA Grant NGR 17-002-071, October, 1972. Appendix C of the Summary Report, NASA CR-2117 .

8. Roskam, J., Hamler, F.R., and Reynolds, D.; "Procedures Used to Determine the Mass Distribution for Idealized Low Aspect Ratio Two Spar Fighter Wings," NASA CR-112232 ; Prepared for NASA by the Flight Research Laboratory of the University of Kansas under NASA Grant NGR 17-002-071, October, 1972. Appendix D of the Summary Report, NASA CR-2117 .

9. Roskam, J., Lan, C., Smith, H., and Gibson, G.; "Procedures Used to Determine the Structural Representation for Idealized Low Aspect Ratio Two Spar Fighter Wings," NASA CR-112233 ; Prepared for NASA by the Flight Research Laboratory of the University of Kansas under NASA Grant NGR 17-002-071, October, 1972. Appendix E of the Summary Report, NASA CR-2117 .

10. Woodward, F.A.; Analysis and Design of Wing-Body Combinations at Subsonic and Supersonic Speeds; Journal of Aircraft, Vol. 5, No. 6, Nov.-Dec., 1968.

11. Roskam, J.; Flight Dynamics of Rigid and Elastic Airplanes; Published by the author, 519 Boulder Street, Lawrence, Kansas, 66044, 1972.

12. Lan, C., Mehrotra, S., and Roskam, J., "Leading-Edge Force Features of the Aerodynamic Finite Element Method" CRINC-FRL Report No. 72-007, April 1972, Flight Research Laboratory, University of Kansas.

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