FTC-TR-6

AD INEXP

IMPORTANT VSTOL AIRCRAFT STABILITY DERIVATIVES IN HOVER AND TRANSITION

AFFTC

J. M. RAMPY
1st Lieutenant, USAF
Project Engineer

TECHNICAL REPORT No. 66-29
OCTOBER 1966

DISTRIBUTION OF THIS DOCUMENT
IS UNLIMITED

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

FTC-TR-66-29

IMPORTANT VSTOL AIRCRAFT STABILITY DERIVATIVES IN HOVER AND TRANSITION

J. M. RAMPY
1st Lieutenant, USAF
Project Engineer

FOREWORD

This report presents a portion of a thesis with the same title prepared while the author was a student at the University of Tennessee Space Institute at Tullahoma, Tennessee. Special thanks are due Dr. R.A. Kroeger, Assistant Professor of Aerospace Engineering for his many suggestions and assistance in conducting the investigation which led to the thesis.

The author also wishes to acknowledge the aid of the personnel of the Air Force Flight Test Center in preparing this paper. The author was assigned to the Flight Research Branch of the Flight Test Center prior to studying at the Space Institute and drew on this experience in conducting this study at the University of Tennessee Space Institute.

This material was presented at the AFSC Junior Officer's Science and Engineering Symposium, 23 August 1966. Publication of this technical report does not constitute Air Force approval of the study's findings or conclusions. It is published only for the exchange and stimulation of ideas in the area of VSTOL aircraft stability.

ABSTRACT

During recent years, increased interest has been shown in Vertical and Short Take-off and Landing (VSTOL) aircraft. Although several aircraft have been designed and flown, progress in VSTOL aircraft development has been slow. This is due in part to lack of specific mission requirements and handling qualities criteria as well as suitable power plant and airframe combinations. The optimization of engine-airframe combinations and the specification of handling qualities require accurate aerodynamic data. Conflicting results have been obtained from ground-based facilities. Because of limited flight experience, data obtained by ground testing have not been compared with flight test results. In order to design better ground test facilities and to specify handling qualities criteria, the aerodynamic parameters that effect VSTOL aircraft behavior must be identified. The purpose of this study was to identify these parameters for the critical flight regime of hover through transition. Both analog and digital computers were used in the study. The purpose of the analog simulation was to qualitatively analyze the behavior of VSTOL aircraft to control inputs and identify the most important derivatives. Two typical VSTOL aircraft were investigated. The method used to determine the important derivatives was that of varying the stability derivatives about some basic value. The amount of simulator response identified the most important derivatives. Once the important derivatives were identified, the digital computer was used to affix a magnitude to the relative importance of each derivative. To establish the relative importance, a sensitivity factor was

derived. The information necessary to calculate this factor was obtained from a mathematical analysis of the equations of motion. The important derivatives were identified for both longitudinal and lateral-directional motion.

table of contents

list of figures

list of tables

list of symbols and coefficients

I_{xx}	Moment of inertia about X axis
I_{yy}	Moment of inertia about Y axis
I_{zz}	Moment of inertia about Z axis
I_{xz}	Product of inertia
K	Wind tunnel value of stability derivative
K_ε	Value of stability derivative with induced error
L	Rolling moment about X axis
L_p	$\frac{1}{I_{xx}} \frac{\partial L}{\partial p}$
L_r	$\frac{1}{I_{xx}} \frac{\partial L}{\partial r}$
L_v	$\frac{1}{I_{xx}} \frac{\partial L}{\partial v}$
M	Pitching moment about Y axis
m	Mass of aircraft
M_q	$\frac{1}{I_{yy}} \frac{\partial M}{\partial q}$
M_u	$\frac{1}{I_{yy}} \frac{\partial M}{\partial u}$
M_w	$\frac{1}{I_{yy}} \frac{\partial M}{\partial w}$
$M_{\dot{w}}$	$\frac{1}{I_{yy}} \frac{\partial M}{\partial \dot{w}}$
N	Yawing moment about Z axis

N_p	$\frac{1}{I_{zz}} \frac{\partial N}{\partial p}$
N_r	$\frac{1}{I_{zz}} \frac{\partial N}{\partial r}$
N_v	$\frac{1}{I_{zz}} \frac{\partial N}{\partial v}$
p	Perturbation angular rate about X axis
q	Perturbation angular rate about Y axis
r	Perturbation angular rate about Z axis
S	Sensitivity factor
s	Laplace transform variable
T	Time to double or halve amplitude
T_r	Rolling mode time constant
T_s	Spiral mode time constant
T_{sp_1}	Short period mode time constant
T_{sp_2}	Short period mode time constant
U	Velocity along X axis
u	Perturbation velocity along X axis
V	Velocity along Y axis
v	Perturbation velocity along Y axis
W	Velocity along Z axis
w	Perturbation velocity along Z axis
$\dot{w}$	Perturbation acceleration along Z axis
X_q	$\frac{1}{m} \frac{\partial X}{\partial q}$
X_u	$\frac{1}{m} \frac{\partial X}{\partial u}$
X_w	$\frac{1}{m} \frac{\partial X}{\partial w}$
Y_p	$\frac{1}{mU} \frac{\partial Y}{\partial p}$
Y_r	$\frac{1}{mU} \frac{\partial Y}{\partial r}$
Y_v	$\frac{1}{mU} \frac{\partial Y}{\partial v}$
Z_q	$\frac{1}{m} \frac{\partial Z}{\partial q}$

Z_u	$\frac{1}{m}\frac{\partial Z}{\partial u}$
Z_w	$\frac{1}{m}\frac{\partial Z}{\partial w}$
δ_a	Aileron deflection
δ_r	Rudder deflection
ε	Incremental error
ζ	Damping ratio of linear second order system
ζ_D	Damping ratio of Dutch roll mode
ζ_p	Damping ratio of phugoid mode
ζ_{sp}	Damping ratio of short period mode
θ	Pitch angle
ρ	Mass density of air
ϕ	Roll angle
ω_d	Damped natural frequency
ω_{d_D}	Damped natural frequency of Dutch roll mode
ω_{d_p}	Damped natural frequency of phugoid mode
$\omega_{d_{sp}}$	Damped natural frequency of short period mode
ω_n	Undamped natural frequency
ω_{n_D}	Dutch roll mode undamped natural frequency
$\omega_{n_{sp}}$	Short period mode undamped natural frequency
ω_{n_p}	Phugoid mode undamped natural frequency

INTRODUCTION

Stability derivatives are directly related to the natural frequency and damping ratio of an aircraft's dynamic response and thus are important parameters to the flight test, control system design, and handling qualities engineer. The purpose of this study was to identify the important stability derivatives of two typical VSTOL aircraft for the critical flight regime of hover through transition. These aircraft were the XC-142 and X-22A.

In order to simplify this task, only the open loop stick-fixed dynamics were investigated. This entails investigating the transient response of the aircraft to disturbances from trimmed flight. Both analog and digital computer programs were used in the analysis and the important longitudinal and lateral-directional derivatives were identified. An attempt was also made to establish the relative importance of each derivative.

ANALYSIS

The study was conducted in two phases. The first phase utilized analog simulations to qualitatively identify the important derivatives and the second phase made use of a digital program to provide quantitative information on the relative importance of each derivative in determining vehicle dynamics.

The linearized equations of motion given in reference (1) were used for the analog simulations. Wind tunnel values were used for the stability derivatives. The aircraft was disturbed in the longitudinal mode of motion by an elevator pulse and in lateral-directional motion by rudder and aileron pulses. The stability derivatives were varied independently about their wind tunnel values by ±100 percent and the amount of change in simulator response was indicative of their importance. Several trimmed flight speeds were investigated for the hover and transition regime.

The linearized equations of motion conveniently form two sets of three simultaneous, constant coefficient, and non-homogeneous differential equations. One set describes longitudinal motion and the other set describes the lateral-directional motion. These differential equations are reduced to algebraic equations by using Laplace transform theory. The algebraic equations are solved by obtaining the roots of the characteristic equations formed by expanding the determinant of the coefficients. The coefficients of the characteristic equations are the stability derivatives. The roots are the principal modes of motion of the aircraft and are direct functions of the stability derivatives.

The solution of the longitudinal characteristic equation had two forms for the XC-142. These forms were:

$$(s^2 + 2\zeta_{sp}\omega_{n_{sp}} + \omega_{d_{sp}}^2)$$

$$(s^2 + 2\zeta_p\omega_{n_p} + \omega_{n_p}^2) = 0 \qquad (1)$$

and

$$\left(s + \frac{1}{T_{sp_1}}\right)\left(s + \frac{1}{T_{sp_2}}\right)$$

$$\left(s^2 + 2\zeta_p \omega_{n_p} + \omega_{n_p}^2\right) = 0 \qquad (2)$$

The solution of the lateral-directional characteristic equation was of the form

$$\left(s + \frac{1}{T_r}\right)\left(s + \frac{1}{T_s}\right)$$

$$\left(s^2 + \zeta\omega_{n_D} + \omega_{n_D}^2\right) = 0 \qquad (3)$$

The terms are defined as follows:

ζ = damping ratio

ω_n = undamped natural frequency

ω_d = damped natural frequency

T_i = time constant of ith mode

The subscripts sp and p correspond to the well known short period and phugoid modes respectively, D to the Dutch roll mode, r to roll mode, and s to the spiral mode.

Solving for the complex roots of the equations gives

$$s = -\zeta\omega_n \pm i\omega_n\sqrt{1 - \zeta^2}$$

or

$$s = -\zeta\omega_n \pm i\omega_d$$

Thus, the real part of the complex root corresponds to the damping ratio multiplied by the natural frequency and the imaginary part to the damped natural frequency. Four roots are possible for each solution of the characteristic equation and they are normally presented on a root-locus similar to figure 1.

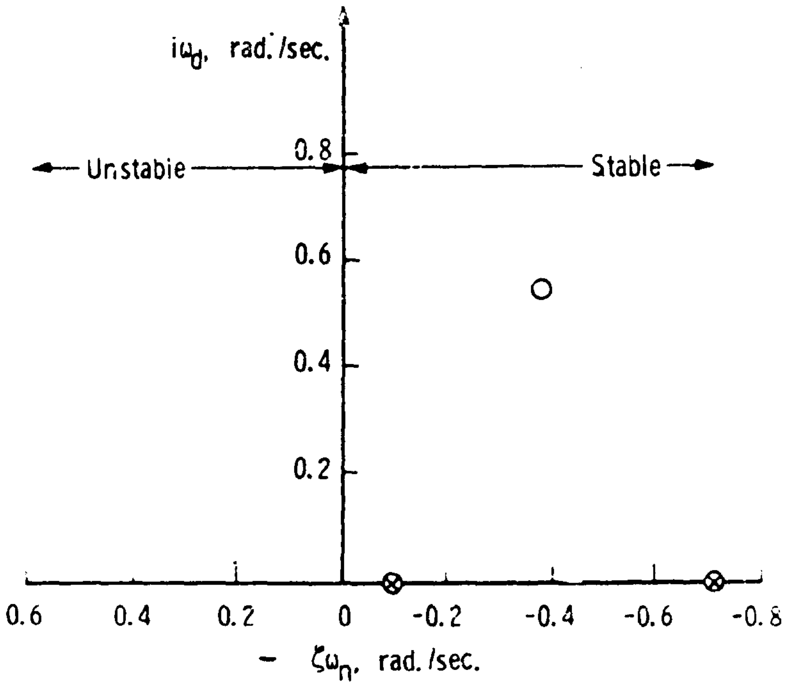

Figure 1. A typical root-locus diagram.

Characteristic Equation:

$$\left(s + \frac{1}{T_r}\right)\left(s + \frac{1}{T_s}\right)\left(s^2 + 2\zeta_D\omega_{n_D} + \omega_{n_D}^2\right) = 0$$

As the derivative values are varied, the roots migrate or move about in the complex plane. This movement denotes changes in damping ratio and frequency. Thus, the importance of each derivative could be defined in terms of the amount of root migration. In order to attach a numerical value to this migration, a sensitivity factor was defined. The following terms are used in the definition of the sensitivity factor:

K = wind tunnel value of derivative

ϵ = induced error in a derivative

K_ϵ = value of derivative with induced error so

$$K_\varepsilon = K(1 + \varepsilon)$$

Consider point A on figure 2 to be the location of one complex root with wind tunnel values used or the derivatives. In this calculation, ε is equal to zero. Now increase one derivative to 1.1 times its wind tunnel value by setting ε equal to 0.1 while holding all the other derivatives at their tunnel values. The root has now migrated to point C. Since the root is complex, the real part has increased by $\Delta(\zeta\omega_n)$ and the imaginary part by $\Delta(i\omega_d)$. Considering the total movement from point A to point C to be represented by a vector, the magnitude would be

$$\overline{AC}^2 = [\Delta(\zeta\omega_n)]^2 + [\Delta(i\omega_d)]^2$$

In order to represent the increase in magnitude of this number, the sensitivity factor was defined as

$$S = \frac{|(\Delta\zeta\omega_n)^2| + |(\Delta i\omega_d)^2|}{|(\Delta\varepsilon)^2| + |(\Delta\zeta\omega_n)^2| + |(\Delta i\omega_d)^2|}$$

If ε is varied in increments of 0.1, the sensitivity factor is 100 times the value of $\overline{AC}^2$. Since it is possible for all roots to change in magnitude with a change in one stability derivative, each root change has a sensitivity factor associated with every derivative change.

Problem: Calculate a sensitivity factor for the s_3 root due to the derivative C_{n_β}.

Assume the roots of the lateral-directional characteristic equation have the following values based on the wind tunnel values of the stability derivatives.

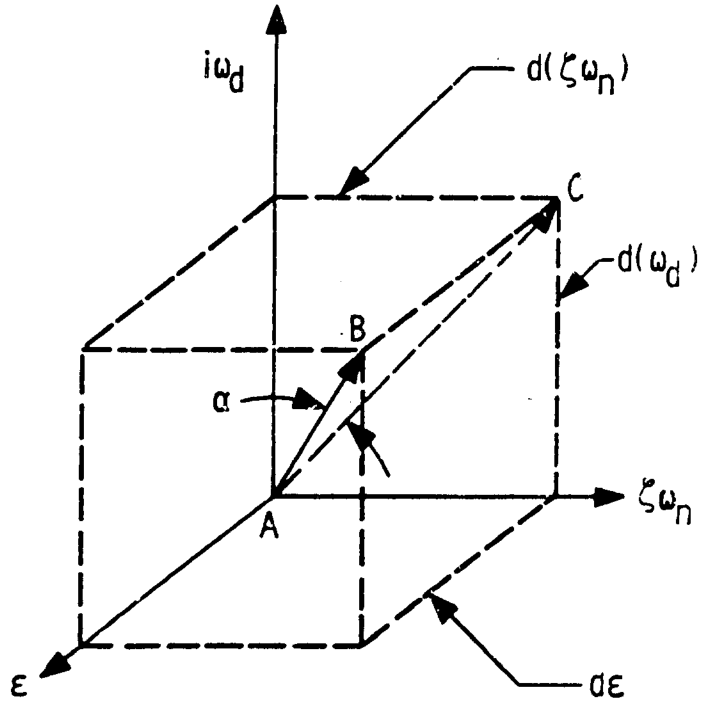

Figure 2 The geometry of the sensitivity factor.

$$s_1 = -0.7 = \frac{1}{T_r}$$

$$s_2 = -0.1 = \frac{1}{T_s}$$

$$s_3, s_4 = -0.4 \pm i0.6$$

$$= -\zeta_D\omega_{n_D} \pm i\omega_{n_D}$$

This corresponds to point A on figure 2. Assume C_{n_β} to have a wind tunnel value of -0.002 per degree. Holding all derivatives at their wind tunnel values C_{n_β} is allowed to increase as follows:

$$K_\varepsilon = K(1 + \varepsilon)$$

or

$$C_{n_\beta} = -0.002(1 + 0.1) = -0.0022$$

The roots are now

$s_1 = -0.8$

$s_2 = -0.2$

and

$s_3, s_4 = -0.5 \pm i0.8$

This root location for s_3 corresponds to point B on figure 2. Now compute a sensitivity factor for the root, s_3.

$$|(\Delta i\omega_d)^2| = |(0.8 - 0.6)^2| = 0.04$$

$$|(\Delta\zeta\omega_n)^2| = |[-0.5 - (-0.4)]^2| = 0.01$$

$$|(\Delta\varepsilon)^2| = |(0.1 - 0)^2| = 0.01$$

The value of the s_3 sensitivity factor due to C_{n_β} becomes

$$S = \frac{0.01 + 0.04}{0.01 + 0.01 + 0.04} = 0.833$$

RESULTS

Sensitivity factors for all derivatives were calculated for each of the four roots of the characteristic equation using a digital computer program. Thus, the importance of each stability derivative in determining root location or value was established. The derivatives were varied ±100 percent about their wind tunnel values by allowing ε to vary from -1.0 to 1.0.

LONGITUDINAL

The data obtained from the analog simulation showed M_u, M_q, Z_w, and X_u to be the most important derivatives for both XC-142 and X-22 in hover. Both aircraft exhibited an unstable oscillatory mode in hover and low-speed flight.

The solution of the longitudinal characteristic equation was of the form given by equation 2. This solution gave two real roots and a complex pair. The roots are designated as follows:

s_1 = the largest real root in absolute magnitude

s_2 = the smallest real root in absolute magnitude

s_3 and s_4 = the complex roots

Only s_3 of the complex pair will be shown on root-locus diagrams.

Figure 3 shows the XC-142 periodic or oscillatory mode to be unstable in hover. The damping of this mode is seen to depend on M_q and X_u and the natural frequency is determined by M_u. The intersection of the M_u, X_u and M_q vectors is the root location for wind tunnel values of the stability derivatives and the vector lengths are indicative of each derivative's importance. This is verified by the sensitivity factors for M_u, X_u, and M_q given for s_3 given in table I for a velocity of 1 foot per second. Figure 4 shows the dependence of the real roots, s_1 and s_2, on the various derivatives. This graph shows the value of the s_1 root located on the lower half of the figure to be dependent on M_u, M_q, and X_u. The root, s_2, is shown on the top half of figure 4 and depends in value only on Z_w. It should be noted that these roots have only real parts, and so for clarity each root is shown with a

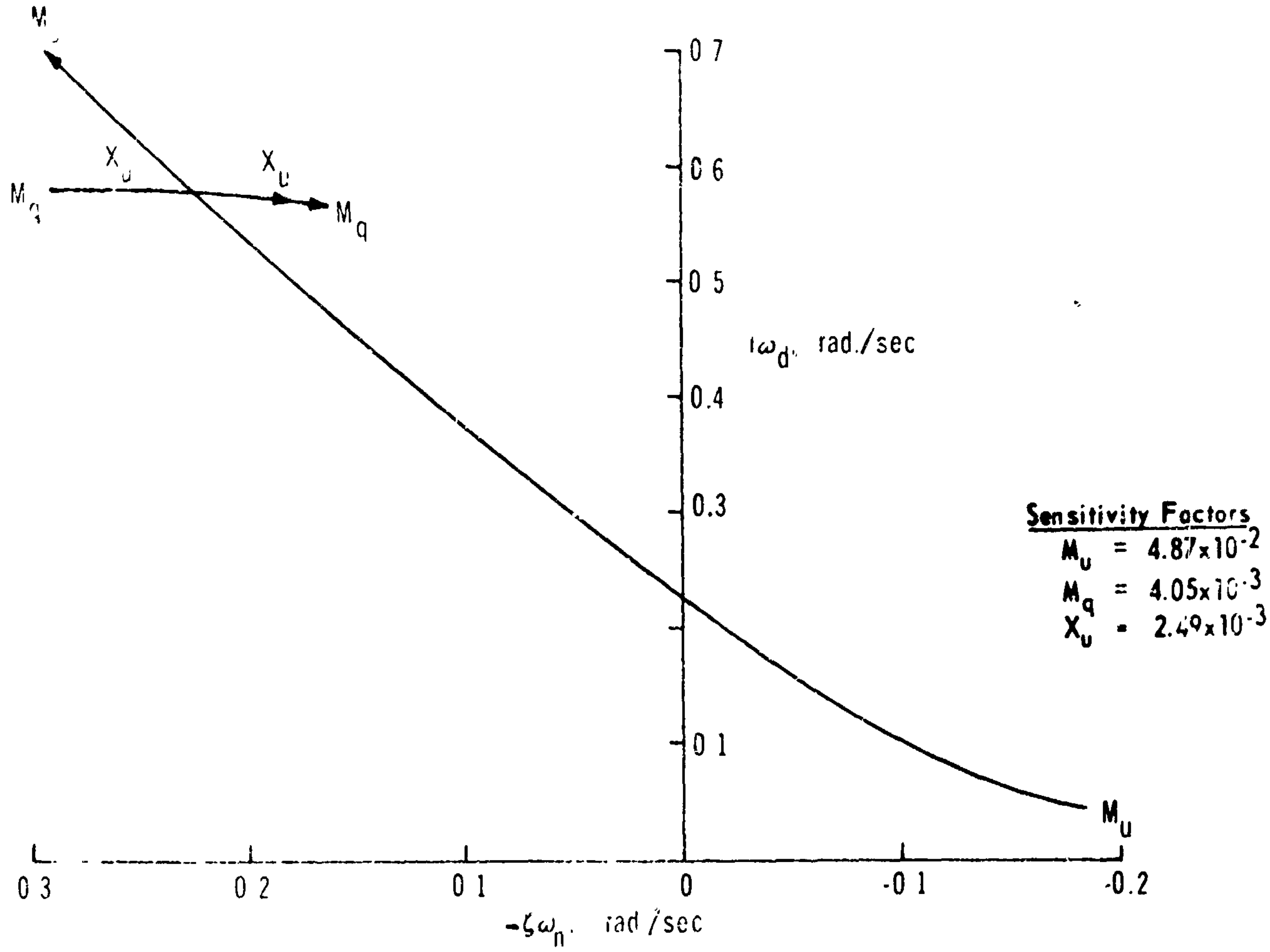

Figure 3 Migration of the longitudinal s_3 with error for the XC-142 at a velocity of 1 ft/sec

new zero vertical location. All roots use the same horizontal scale. Table I shows the sensitivity values for M_u, M_q, and X_u to be much larger than other derivatives for s_1 at 1 foot per second. It also shows the sensitivity factor of Z_w to be several orders of magnitude larger than those for other derivatives for the root, s_2. Table I is a tabulation of all the derivative's sensitivity factors for each root. Thus, the relative importance of each derivative to all four roots may be found for the speeds shown by comparing the values of the factors from the horizontal line opposite each root and speed in question.

Example: Find the relative importance of each derivative in determining the value of s_3 at 1 foot per second.

Their order of importance from table I is:

$M_u = 4.87 \times 10^{-2}$

$M_q = 4.05 \times 10^{-3}$

$X_u = 2.49 \times 10^{-3}$

$X_q = 4.86 \times 10^{-6}$

$M_w = 9.31 \times 10^{-7}$

$Z_q = 1.64 \times 10^{-7}$

$Z_w = 5.21 \times 10^{-8}$

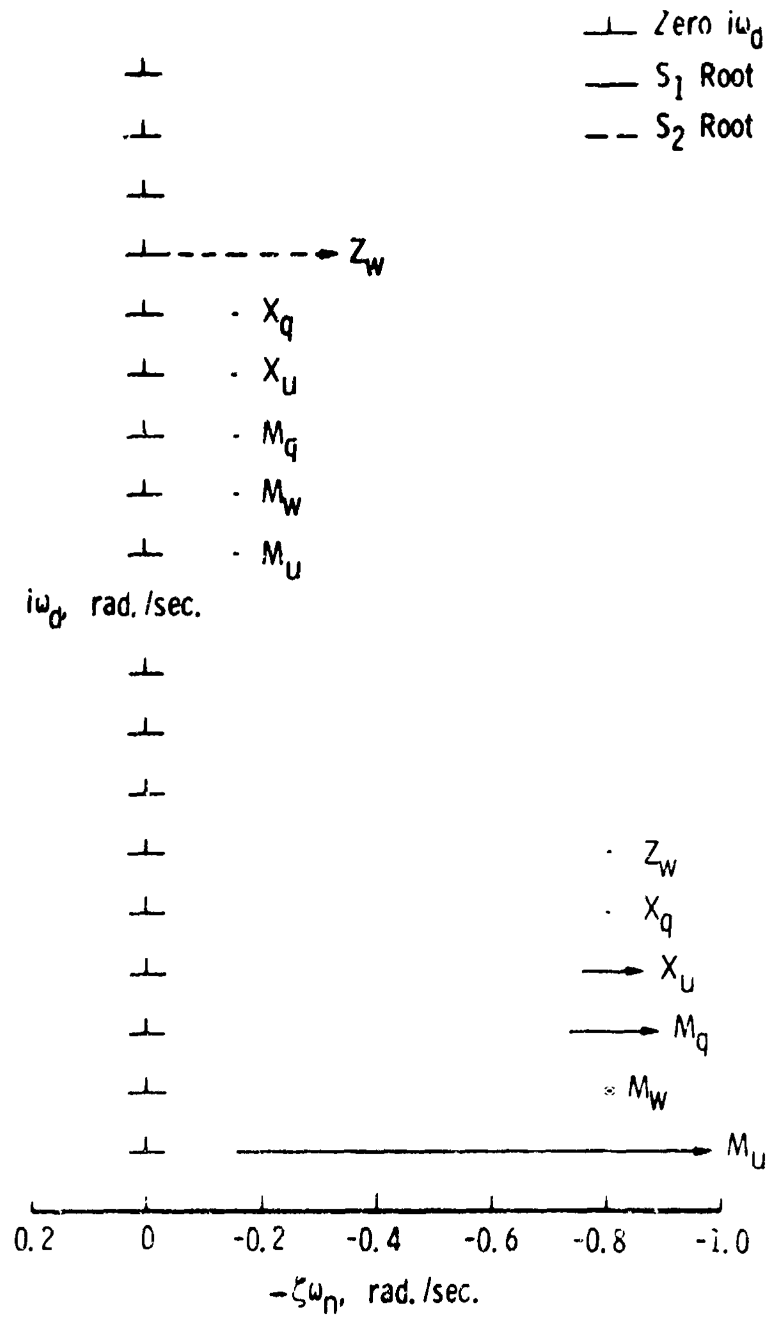

Figure 4 Migration of longitudinal s_1 and s_2 with error for the XC-142 at a velocity of 1 ft./sec.

Table II gives the same information for the X-22A. This table shows M_u, M_q, X_u, X_w, and Z_w to be the only important derivatives in hover and this is verified by figures 5 and 6.

Figure 7 shows the oscillatory root of the XC-142 to be stable at a speed of 67 feet per second. Figure 8 shows s_2 to be stable and s_1 unstable at this speed. As these figures indicate, more derivatives become important as the plane accelerates through transition. Again, table I should be consulted to obtain their relative importance.

TABLE I

XC-142 LONGITUDINAL DERIVATIVE SENSITIVITY

Roots	Velocity ft./sec.	Derivative Sensitivity M_u	M_q	M_w	$M_{\dot{w}}$	X_u	X_q	X_w	Z_u	Z_q	Z_w
	1.0	4.88×10^{-2}	5.77×10^{-3}	1.59×10^{-6}	-	2.83×10^{-3}	7.86×10^{-6}	-	-	2.81×10^{-7}	$1.07 \times 10^{[illegible]}$
S_1	33.8	1.15×10^{-3}	7.68×10^{-4}	4.17×10^{-2}	-	7.19×10^{-3}	3.15×10^{-4}	2.09×10^{-8}	1.01×10^{-2}	1.88×10^{-5}	5.52×10^{-3}
	67.6	2.18×10^{-3}	7.86×10^{-4}	5.34×10^{-3}	2.04×10^{-2}	3.61×10^{-3}	4.23×10^{-6}	3.69×10^{-5}	8.92×10^{-3}	1.75×10^{-6}	3.75×10^{-2}
	1.0	1.94×10^{-10}	0.00	1.87×10^{-10}	-	3.04×10^{-8}	1.25×10^{-15}	-	-	3.31×10^{-11}	2.65×10^{-2}
S_2	33.8	1.93×10^{-3}	1.13×10^{-3}	5.67×10^{-2}	-	1.10×10^{-3}	4.26×10^{-5}	2.66×10^{-9}	1.45×10^{-2}	2.47×10^{-5}	6.89×10^{-3}
	67.6	4.29×10^{-3}	6.32×10^{-4}	2.75×10^{-3}	1.15×10^{-3}	2.21×10^{-3}	1.06×10^{-6}	5.91×10^{-6}	7.89×10^{-5}	6.42×10^{-9}	8.16×10^{-3}
	1.0	4.37×10^{-2}	4.05×10^{-3}	9.31×10^{-7}	-	2.49×10^{-3}	4.86×10^{-6}	-	-	1.64×10^{-7}	5.21×10^{-5}
S_3, S_4	33.8	1.56×10^{-3}	2.53×10^{-4}	6.56×10^{-3}	-	1.42×10^{-2}	1.52×10^{-4}	4.63×10^{-9}	2.97×10^{-2}	1.37×10^{-5}	1.88×10^{-3}
	67.6	3.66×10^{-3}	2.99×10^{-4}	5.76×10^{-4}	6.44×10^{-4}	2.02×10^{-2}	5.57×10^{-6}	1.36×10^{-5}	1.02×10^{-2}	4.54×10^{-7}	2.81×10^{-3}

TABLE II

X-22A LONGITUDINAL DERIVATIVE SENSITIVITY

Roots	Velocity ft./sec.	Derivative Sensitivity M_u	M_q	M_w	$M_{\dot{w}}$	X_u	X_q	X_w	Z_u	Z_q	Z_w
	1.0	8.78×10^{-2}	1.68×10^{-3}	-	-	6.96×10^{-3}	-	1.58×10^{-2}	-	-	5.21×10^{-4}
S_1	33.8	8.43×10^{-3}	8.18×10^{-3}	3.44×10^{-3}	-	6.38×10^{-3}	-	2.19×10^{-2}	4.64×10^{-5}	-	1.13×10^{-4}
	67.6	6.12×10^{-2}	1.59×10^{-2}	4.73×10^{-2}	-	2.96×10^{-3}	-	2.44×10^{-2}	4.35×10^{-4}	-	3.06×10^{-3}
	1.0	6.35×10^{-10}	1.56×10^{-8}	-	-	1.83×10^{-9}	-	1.48×10^{-3}	-	-	1.03×10^{-2}
S_2	33.8	8.61×10^{-6}	7.98×10^{-9}	7.96×10^{-6}	-	2.01×10^{-6}	-	1.99×10^{-4}	1.59×10^{-5}	-	1.08×10^{-3}
	67.6	5.17×10^{-4}	4.27×10^{-7}	5.57×10^{-4}	-	1.28×10^{-4}	-	1.01×10^{-3}	9.74×10^{-4}	-	9.37×10^{-3}
	1.0	8.91×10^{-2}	1.81×10^{-2}	-	-	5.29×10^{-3}	-	1.20×10^{-2}	-	-	3.67×10^{-4}
S_3, S_4	33.8	1.05×10^{-1}	5.99×10^{-3}	3.90×10^{-3}	-	7.37×10^{-3}	-	2.26×10^{-2}	3.27×10^{-5}	-	7.12×10^{-5}
	67.6	1.36×10^{-1}	8.66×10^{-3}	4.60×10^{-2}	-	9.47×10^{-3}	-	3.19×10^{-2}	3.98×10^{-4}	-	1.15×10^{-3}

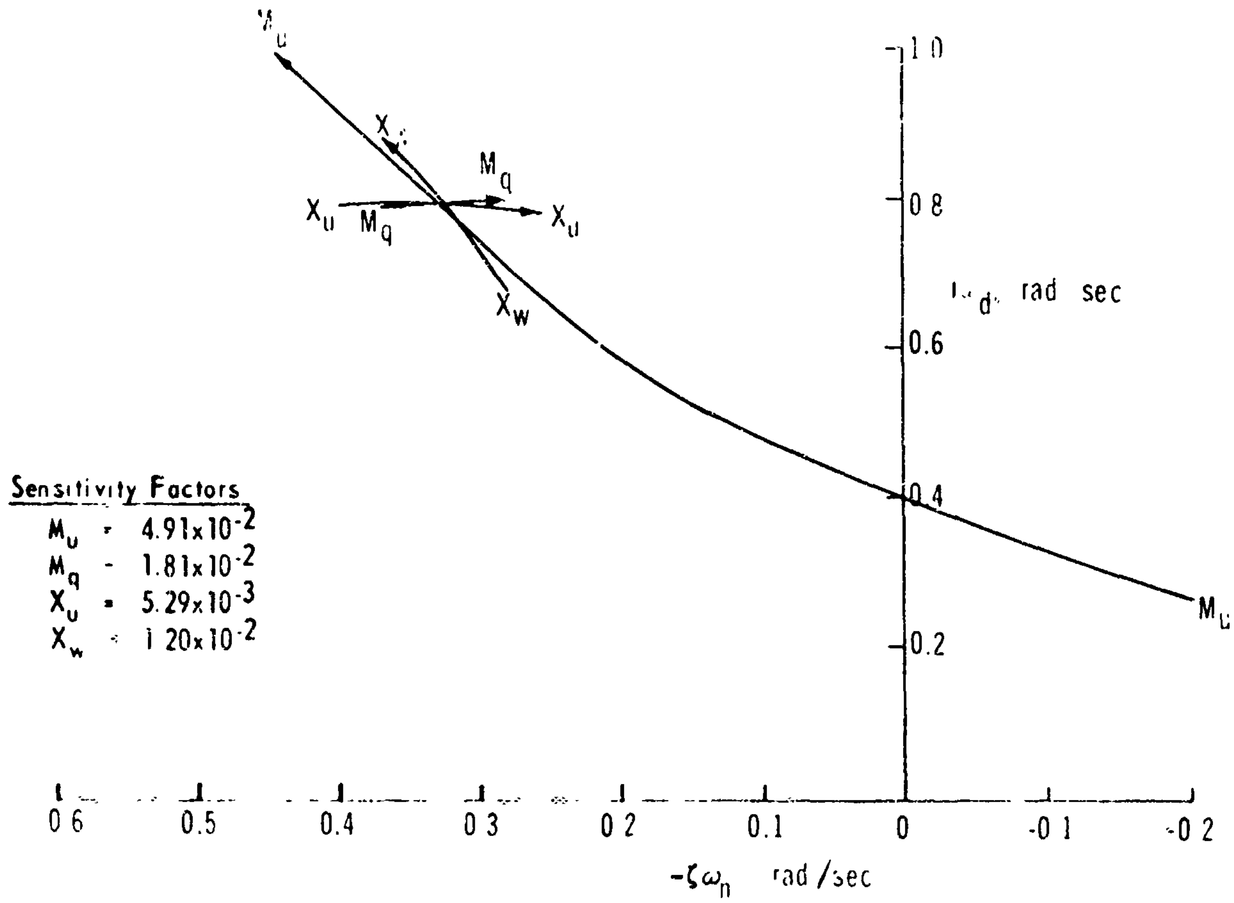

Figure 5 Migration of the longitudinal s_3 with error for the X-22A at a velocity of 1 ft sec

Figure 9 shows the change in aircraft behavior as the XC-142 progresses through transition. It shows the root locations at several different speeds using wind tunnel values for the stability derivatives. The root, s_3, is seen to become stable between 0 and 33 feet per second. The root, s_2, is initially stable, then goes unstable. The root s_1 remains stable throughout the speed range and finally combines with s_2 to form a stable short period oscillatory mode at the higher speeds. This figure shows the aircraft to be unstable at hover and low speeds and then becomes stable with characteristics similar to a conventional aircraft at higher speeds.

LATERAL-DIRECTIONAL

The analog simulations of the XC-142 and X-22A showed the Dutch roll mode to be unstable up to about 100 feet per second. The important derivatives for hover were L_v, L_p, and N_r.

Figure 10 shows the Dutch roll mode to be dependent on L_v and L_p only. The damping changes at essentially constant frequency for variations in L_p. Figure 11 shows the spiral and roll modes sensitive to L_v, L_p, and N_r. Both modes are stable in hover as well as the other speeds through transition. Tables III and IV give the derivative sensitivity factors for the three modes of lateral-directional motion of both the XC-142 and X-22A. As before, the relative importance of each derivative to a particular mode of motion is shown for several speeds.

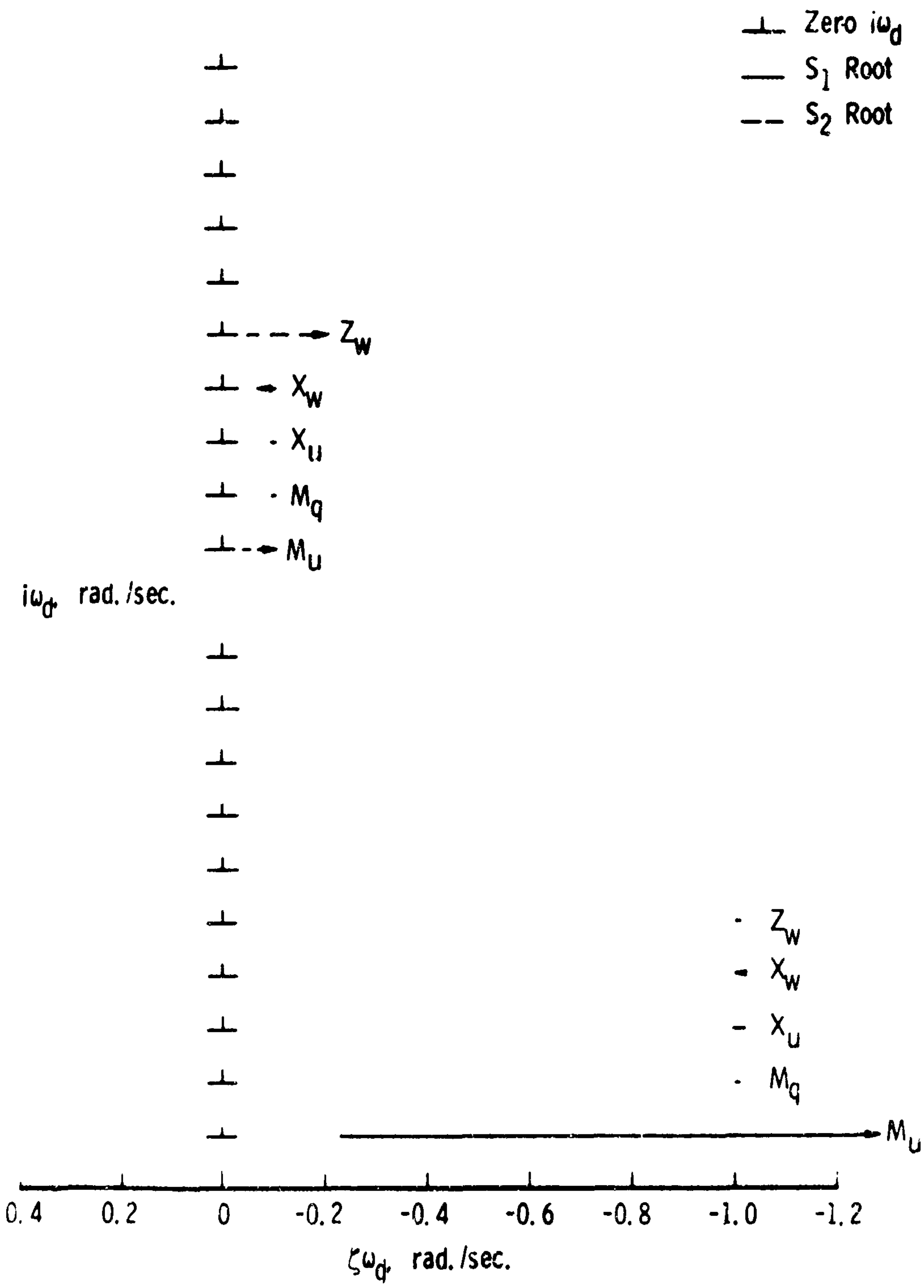

Figure 6. Migration of the longitudinal s_1 and s_2 with error for the X-22A at a velocity of 1 ft./sec.

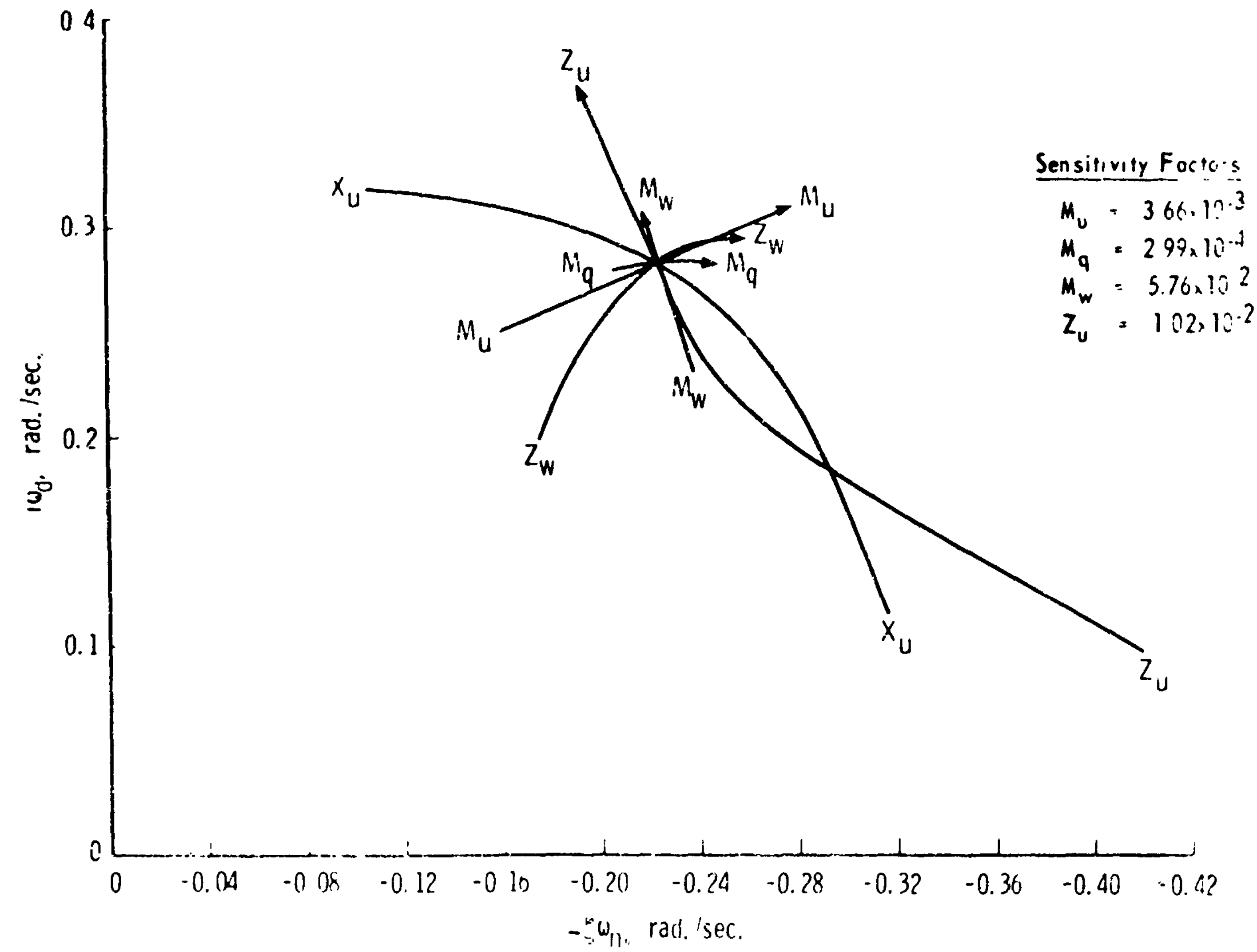

Figure 7. Migration of the longitudinal s_3 with error for the XC-142 at a velocity of 67.6 ft/sec.

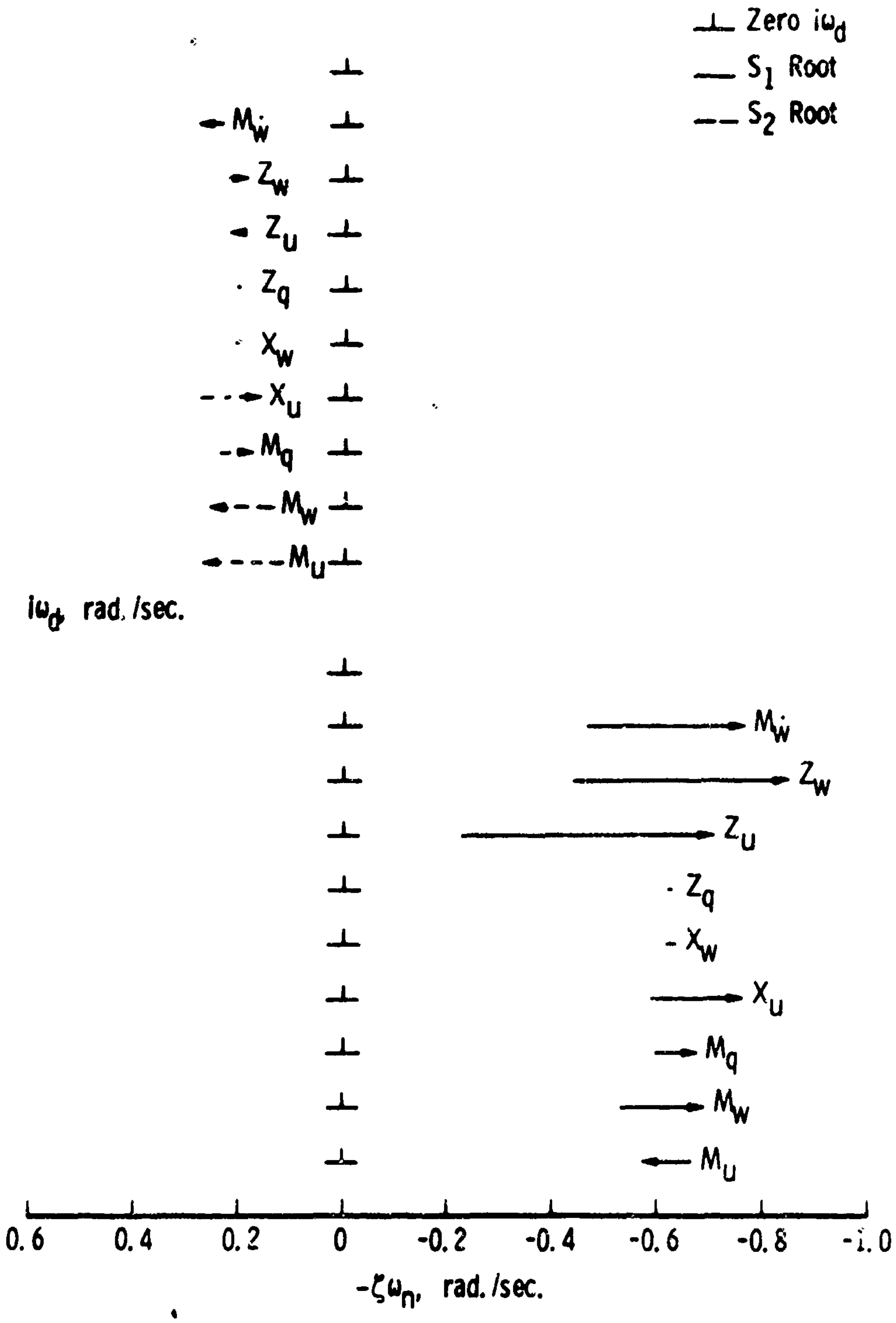

Figure 8 Migration of the longitudinal s_1 and s_2 with error for the XC-142 at a velocity of 67.6 ft./sec.

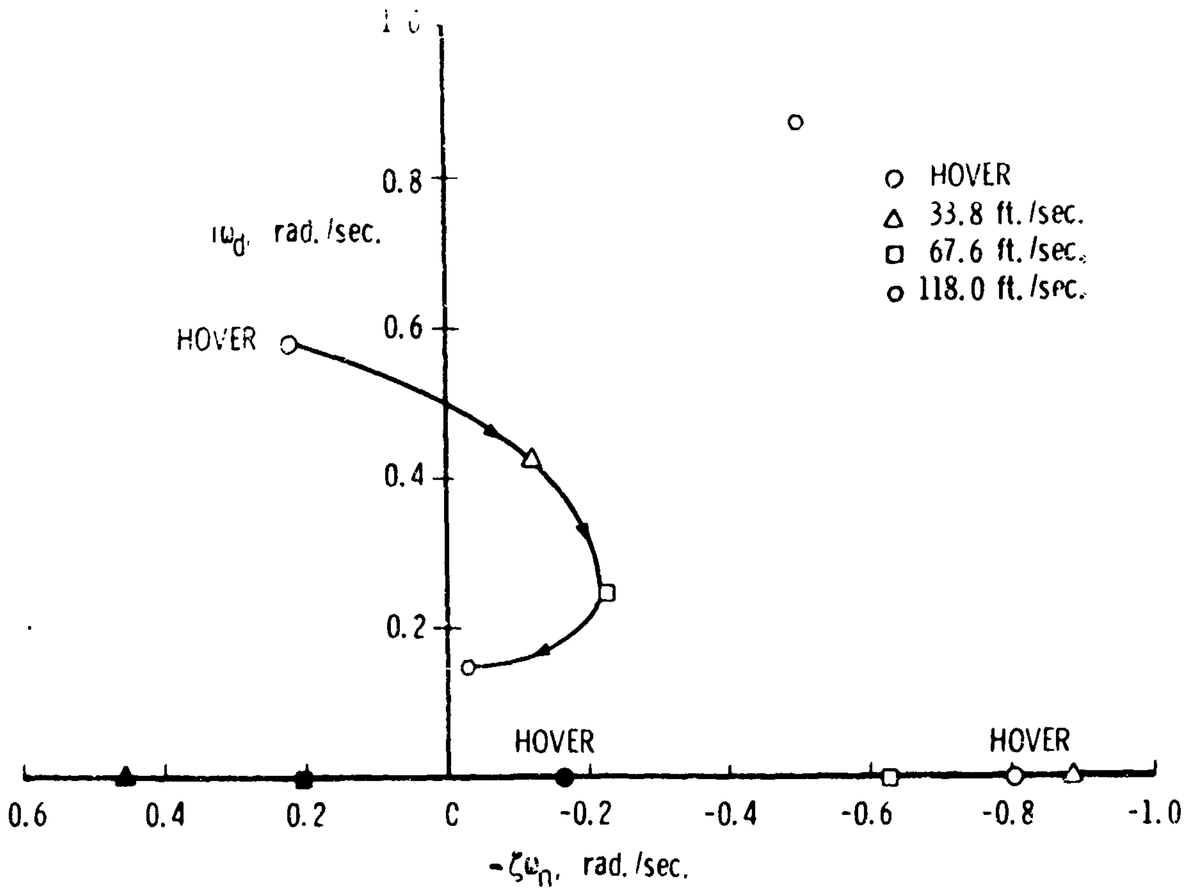

Figure 9 Migration of the XC-142 longitudinal characteristic roots with velocity.

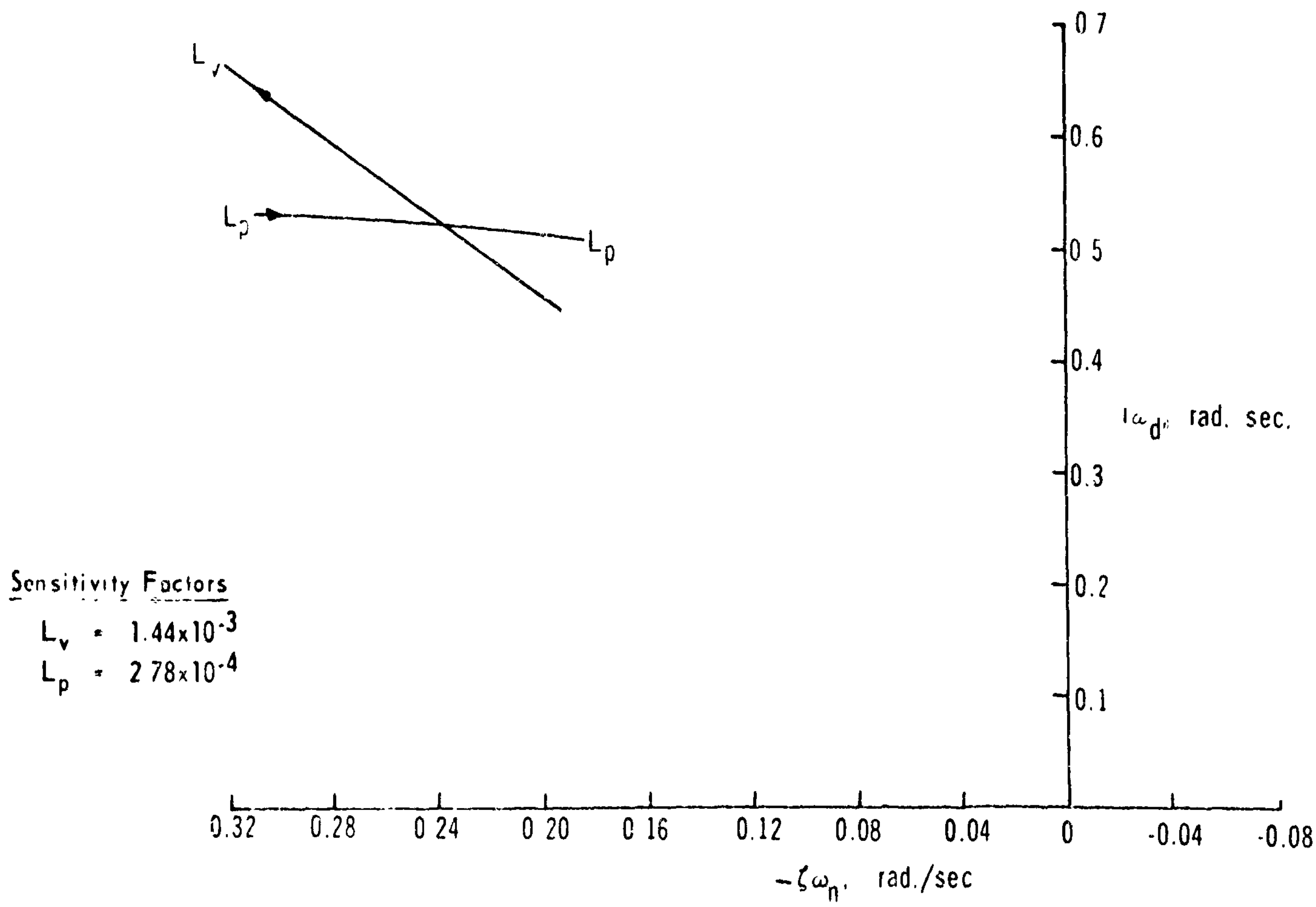

Figure 10 Migration of the lateral s_3 with error for the XC-142 at a velocity of 1 ft./sec

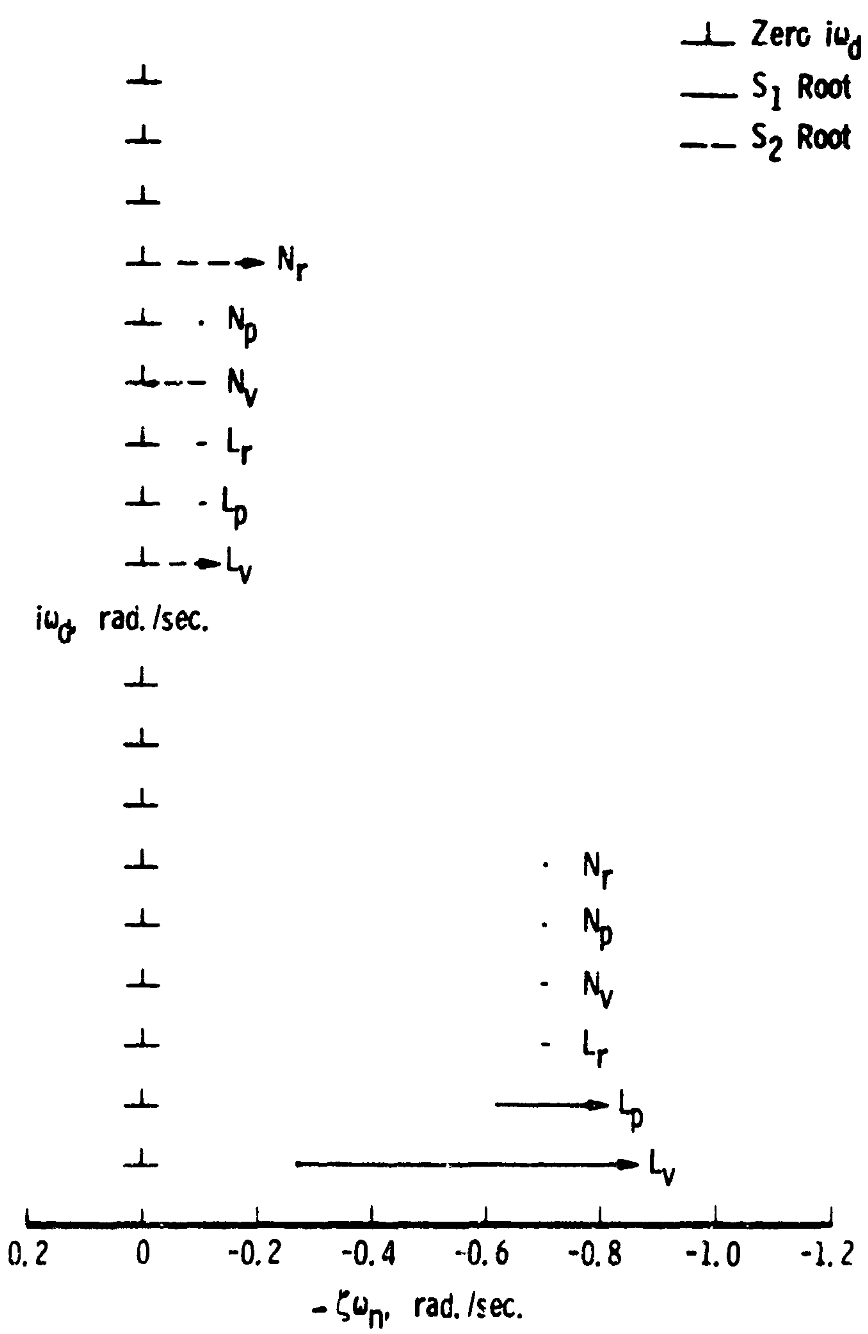

Figure 11 Migration of the lateral s_1 and s_2 with error for the XC-142 at a velocity of 1 ft./sec.

TABLE III

XC–142 LATERAL AND DIRECTIONAL DERIVATIVE SENSITIVITY

Roots	Velocity ft./sec.	Derivative Sensitivity								
		L_v	L_p	L_r	N_v	N_p	N_r	Y_v	Y_p	Y_r
S_1	1.0	1.44×10^{-3}	2.78×10^{-4}	5.78×10^{-8}	4.48×10^{-8}	1.36×10^{-8}	3.29×10^{-9}	—	—	—
	33.8	1.04×10^{-3}	2.76×10^{-4}	9.50×10^{-6}	1.36×10^{-5}	2.58×10^{-6}	9.36×10^{-6}	2.09×10^{-6}	6.83×10^{-10}	2.40×10^{-11}
	67.6	1.53×10^{-3}	8.21×10^{-4}	5.02×10^{-4}	4.46×10^{-6}	4.13×10^{-6}	2.28×10^{-5}	1.77×10^{-5}	3.51×10^{-10}	1.97×10^{-10}
	118.0	1.90×10^{-5}	3.87×10^{-3}	3.58×10^{-4}	6.78×10^{-6}	2.15×10^{-6}	2.95×10^{-4}	5.82×10^{-7}	3.60×10^{-10}	1.89×10^{-12}
S_2	1.0	2.69×10^{-7}	2.02×10^{-10}	2.31×10^{-7}	2.20×10^{-7}	3.00×10^{-10}	3.70×10^{-4}	—	—	—
	33.8	2.77×10^{-5}	7.84×10^{-6}	2.46×10^{-5}	1.98×10^{-5}	4.24×10^{-6}	1.48×10^{-3}	1.81×10^{-1}	6.95×10^{-13}	2.22×10^{-12}
	67.6	4.19×10^{-4}	6.55×10^{-5}	4.53×10^{-4}	1.25×10^{-4}	2.47×10^{-5}	3.63×10^{-3}	5.46×10^{-6}	2.09×10^{-11}	1.55×10^{-10}
	118.0	1.89×10^{-3}	3.39×10^{-5}	1.72×10^{-3}	2.68×10^{-3}	4.82×10^{-8}	7.40×10^{-3}	1.15×10^{-6}	4.97×10^{-14}	1.72×10^{-12}
S_3, S_4	1.0	$11.52^3 \times 10^{-3}$	9.00×10^{-5}	1.59×10^{-8}	2.04×10^{-8}	2.93×10^{-9}	3.66×10^{-10}	—	—	—
	33.8	1.01×10^{-3}	1.60×10^{-4}	1.36×10^{-6}	2.54×10^{-5}	2.62×10^{-6}	2.56×10^{-6}	2.62×10^{-6}	4.91×10^{-10}	4.26×10^{-12}
	67.6	3.31×10^{-1}	3.21×10^{-4}	3.19×10^{-6}	2.17×10^{-5}	2.91×10^{-5}	4.40×10^{-6}	1.04×10^{-5}	2.78×10^{-10}	1.07×10^{-13}
	118.0	6.10×10^{-4}	4.08×10^{-4}	4.78×10^{-4}	2.81×10^{-3}	2.62×10^{-3}	2.73×10^{-3}	5.38×10^{-5}	1.01×10^{-10}	7.02×10^{-11}

TABLE IV

X–22A LATERAL AND DIRECTIONAL DERIVATIVE SENSITIVITY

Roots	Velocity ft./sec.	Derivative Sensitivity								
		L_v	L_p	L_r	N_v	N_p	N_r	Y_v	Y_p	Y_r
S_1	1.0	3.94×10^{-3}	3.96×10^{-4}	-	-	-	5.00×10^{-15}	2.01×10^{-4}	-	-
	33.8	2.82×10^{-3}	2.30×10^{-3}	1.96×10^{-6}	2.53×10^{-5}	1.68×10^{-4}	4.33×10^{-6}	7.65×10^{-5}		
	67.6	4.76×10^{-3}	7.77×10^{-3}	2.31×10^{-7}	6.27×10^{-8}	7.70×10^{-4}	1.76×10^{-5}	1.21×10^{-4}	-	-
	101.5	4.36×10^{-3}	1.87×10^{-2}	1.04×10^{-7}	4.19×10^{-5}	5.33×10^{-4}	6.61×10^{-6}	7.13×10^{-5}	-	-
S_2	1.0	5.00×10^{-17}	8.40×10^{-17}	-	-	-	8.50×10^{-3}	2.00×10^{-16}	-	-
	33.8	9.30×10^{-5}	3.64×10^{-6}	1.40×10^{-6}	7.16×10^{-6}	2.92×10^{-5}	3.43×10^{-4}	1.10×10^{-8}	-	-
	67.6	5.99×10^{-8}	5.61×10^{-8}	4.82×10^{-10}	2.19×10^{-8}	9.70×10^{-5}	6.36×10^{-4}	7.76×10^{-8}	-	-
	101.5	2.19×10^{-5}	2.16×10^{-5}	1.12×10^{-7}	1.79×10^{-5}	5.37×10^{-5}	6.74×10^{-4}	1.29×10^{-7}	-	-
S_3, S_4	1.0	4.03×10^{-3}	2.87×10^{-4}	-	-	-	1.74×10^{-16}	1.81×10^{-4}	-	-
	33.8	3.49×10^{-3}	1.03×10^{-3}	3.67×10^{-7}	8.50×10^{-5}	2.02×10^{-4}	2.25×10^{-6}	1.10×10^{-4}	-	-
	67.6	5.58×10^{-3}	2.20×10^{-3}	1.20×10^{-7}	2.60×10^{-7}	7.36×10^{-4}	3.29×10^{-5}	2.57×10^{-4}	-	-
	101.5	4.93×10^{-3}	2.48×10^{-3}	1.50×10^{-7}	3.43×10^{-4}	4.89×10^{-4}	7.01×10^{-5}	2.88×10^{-4}	-	-

Figure 12 shows the root locations at several speeds for the XC-142 using wind tunnel values for the stable derivatives. In hover, the Dutch roll mode is unstable with a time to diverge to double amplitude of about 3 seconds. The Dutch roll mode becomes stable around 100 feet per second and has the same characteristics as a conventional aircraft.

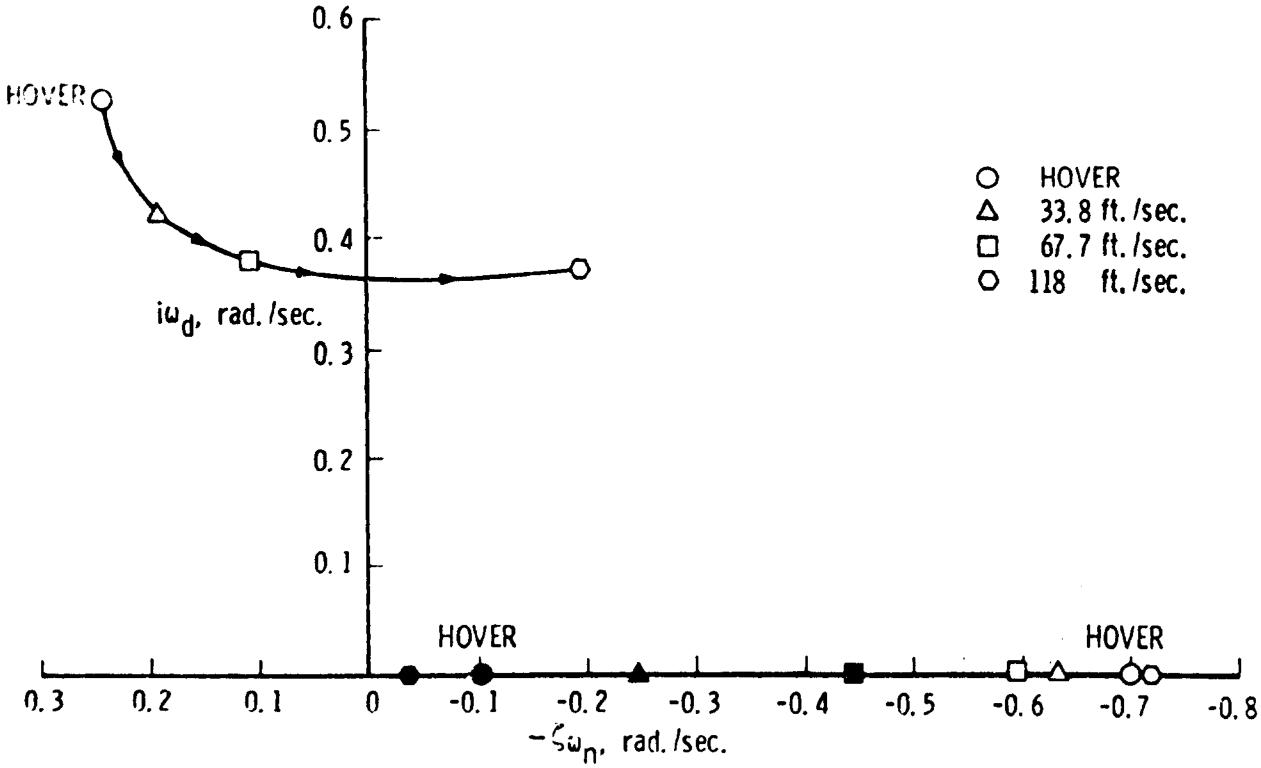

Figure 12. Migration of the XC-142 lateral characteristic roots with velocity.

CONCLUSIONS

An analysis of the longitudinal and lateral-directional characteristics of two typical VSTOL aircraft revealed the following:

1. Unstable periodic modes exist in hover for both longitudinal and lateral-directional motion. This unstable longitudinal mode is due primarily to M_u which can normally be neglected for conventional aircraft investigations.

2. The aircraft become stable as forward flight speeds are approached.

3. The solution of the longitudinal characteristic equation yields two real roots and a complex pair at hover and low speeds. Conventional aircraft usually have a complex pair, i.e., the short period and phugoid mode.

4. The longitudinal dynamic response in hover depends heavily on the derivatives M_u, M_q, X_u, X_w, and Z_w.

5. The lateral-directional dynamic response in hover is determined by the values of L_v, L_p, Y_v, and N_r.

6. As normal forward flight speeds are approached, the dynamic response depends on more of the derivatives. The relative importance of these derivatives to particular modes has been established and tabulated in tables I - IV.

REFERENCES

1. Northrop Aircraft, Inc., "Dynamics of the Airframe," Navy Bureau of Aeronautics Report AE-61-4-II, September, 1952.

-0.8

DISTRIBUTION LIST

1. Defense Documentation Center
   Cameron Station
   Alexandria, Va. 22314

2. Dept. of Defense
   DDR&E (OT&E)
   Wash, D.C. 20330

3. AFSC (SCL)
   Andrews AFB, Wash D.C. 20331

4. AFSC (SCS)
   Andrews AFB, Wash D.C. 20331

5. AFSC (SCSA)
   Andrews AFB, Wash D.C. 20331

6. AFSC (SCSAB)
   Andrews AFB, Wash D.C. 20331

7. AFSC (SCSR)
   Andrews AFB, Wash D.C. 20331

8. AFSC (SCSS)
   Andrews AFB, Wash D.C. 20331

9. AFSC (SCSST)
   Andrews AFB, Wash D.C. 20331

10. AFSC (SCT)
    Andrews AFB, Wash D.C. 20331

11. Scientific and Technical Information Facility
    Attn: NASA Representative (S-AK/DL)
    P.O. Box 5700
    Bethesda, Maryland 20014

12. APGC (PGBPS-12)
    Eglin AFB, Fla. 32542

13. Lt Col Reese S. Martin
    or
    Carl D. Simmons
    USAF/GMOD Joint Flight Test Group
    Munich Sub-District
    APO New York 09407

14. Federal Aviation Agency
    ATTN: Security Control Point, AC-47.2
    FOR DELIVERY TO: Dr. Richard Snyder
    AM-119
    P.O. Box 1802
    Oklahoma City, Oklahoma 73101

15. Chief Project Engineer
    Flight Test Division
    Naval Air Test Center
    Patuxent River, Md.

16. Director, USAF Project RAND
    Via: Air Force Liaison Office
    The RAND Corporation
    1700 Main Street
    Santa Monica, Calif. 90406
    Attn: Library

17. AFSC Scientific and Technical Liaison Office
    c/o The Boeing Company
    Seattle 24, Washington

18. Bureau of Naval Weapons
    Attn: Code R-53
    Wash 25, D.C. 20360

19. Federal Aviation Agency
    Library Services Division
    Information Retrieval Branch Hq-630
    Wash 25, D.C. 20553

20. Federal Aviation Agency
    Medical Library, Hq-640
    Wash 25, D.C.

21. Hq USAF (AFRDQPM)
    Wash 25, D.C.

22. Hq USAF (AFRDQRD)
    Wash D.C.

23. USAF (AFRDDE/Col H.E. Collins)
    Wash 25, D.C.

24. AFFDL (FDCC)
Wright-Patterson AFB, Ohio
45433

25. AFFDL (FDCC Attn: Mr. Flynn)
Wright-Patterson AFB, Ohio
45433

26. ASD (ASZTF)
Wright-Patterson AFB, Ohio
45433

27. FDV
Wright-Patterson AFB, Ohio
45433

28. Foreign Technology Division
Bldg 828, Area A
Wright-Patterson AFB, Ohio
45433

29. RTD (SENY)
Wright-Patterson AFB, Ohio
45433

30. SEA
Wright-Patterson AFB, Ohio
45433

31. SEF
Wright-Patterson AFB, Ohio
45433

32. SEFDS
Wright-Patterson AFB, Ohio
45433

33. SEFS
Wright-Patterson AFB, Ohio
45433

34. SEG (SEFDP)
Wright-Patterson AFB, Ohio
45433

35. SEJ
Wright-Patterson AFB, Ohio
45433

36. SEM
Wright-Patterson AFB, Ohio
45433

37. SENS
Wright-Patterson AFB, Ohio
45433

38. SENX
Wright-Patterson AFB, Ohio
45433

39. SESE
Wright-Patterson AFB, Ohio
45433

40. SESS
Wright-Patterson AFB, Ohio
45433

41. Systems Engineering Group (RTD)
ATTN: SEPIR
Wright-Patterson AFB, Ohio
45433

42. California State Polytechnic College
Attn: Prof. C.J. Price
Aeronautical Eng. Dept.
San Luis Obispo, Calif. 93401

43. Library
PARKS AIR COLLEGE
East St. Louis, Illinois
62201

44. Mech. Eng. Dept.
Univ. of S. California
University Park
Los Angeles, Calif. 90007

45. Miss. State University
Aerophysics Dept.
P.O. Box 248
State, College, Mississippi

46. Prof. Louis C. Miller
Calif. State Polytechnic College
San Luis Obispo, Calif.

47. SEG Eng. Rep (SEMHP)
U.S. Army AE and SW Board
Fort Bragg, N.C. 28307

48. Tech Info Service Library
750 Third Avenue
New York, New York 10017

49. U.S. Army Aviation Test Activity
ATTN: STEAV-PO
Edwards AFB, Calif.

50. Lockheed Aircraft Corp.
Sci-Tech Info Dept.
Dept. 72-34, Z-26
Attn: C.K. Bauer, Manager
Lockheed-Georgia, Co.
Marietta, Ga.

51. Lockheed-Georgia Company
Central Library
Dept. 77-14, Bldg 170,
Plant B-1
Burbank, Calif. 91503

52. Ling Tempco Vaught
(George Booth)
P.O. Box 5907
Dallas, Texas 75222

53. Sperry Pheonix
Attn: Mr. R. Tribken
P.O. Box 2529
Pheonix, Arizona

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Flight Test Center Edwards AFB, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

Important VSTOL Aircraft Stability Derivative in Hover and Transition

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final

5. AUTHOR(S) (Last name, first name, initial)

Rampy, Johnny M.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1966	17	1

8a. CONTRACT OR GRANT NO. N/A	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. N/A	FTC-TR-66-29
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	None

10. AVAILABILITY/LIMITATION NOTICES

Qualified requestors may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	Directorate for Systems Test (FTT) Edwards AFB, California

13. ABSTRACT Progress in VSTOL aircraft development has been slow, due in part to a lack of specific mission requirements and handling qualities criteria as well as suitable power plant and airframe combinations. Optimization of these combinations and specifications requires accurate aerodynamic data. Conflicting results have been obtained from ground-based facilities. Because of limited flight experience, data obtained by ground testing have not been compared with flight test results. To design better ground test facilities and to specify handling qualities criteria, the aerodynamic parameters involved must be identified. The purpose of this study was to identify these parameters for the critical flight regime of hover through transition. Both analog and digital computers were used in the study. The purpose of the analog simulation was to qualitatively analyze the behavior of VSTOL aircraft to control inputs and identify the most important derivatives. Two typical VSTOL aircraft were investigated. The method used to determine the important derivatives was that of varying the stability derivatives about some basic value. The amount of simulator response identified the most important derivatives. Next, the digital computer was used to affix a magnitude to the relative importance of each derivative. To establish the relative importance, a sensitivity factor was derived. The information necessary to calculate this factor was obtained from a mathematical analysis of the equations of motion. The important derivatives were identified for both longitudinal and lateral-directional motion.

DD FORM 1 JAN 64 1473

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
VSTOL Aircraft Analog Simulation of VSTOL Aircraft in Hover and Transition Stability Derivatives of VSTOL Aircraft Hover Derivatives of VSTOL Aircraft Longitudinal Motion of VSTOL Aircraft Lateral-Directional Motion of VSTOL Aircraft						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.