MSC/NASTRAN FLUTTER ANALYSES OF T-TAILS INCLUDING HORIZONTAL STABILIZER STATIC LIFT EFFECTS AND T-TAIL TRANSONIC DIP

by

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Summary

An existing method for calculating the effect of static lift of the horizontal stabilizer in yaw and the effect of static deflection of the horizontal stabilizer on T-tail flutter is appended to the MSC/NASTRAN flutter solution.The application of the method to a T-tail of interest shows the expected trends. A strip theory correction scheme is proposed to permit separation and factoring of $C_{L\alpha}$ and $C_{l\beta}$ on the horizontal stabilizer by different factors. A refinement of the T-tail transonic dip calculated with classical methods is obtainable this way.

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List of Symbols

a = aerodynamic center of section relative to midchord; fraction of local semichord, negative forward of the midchord
b = strip semichord
b_r = reference semichord
c = strip chord
$C(k)$ = Theodorsen's function
$C_{L\alpha}$ = horizontal stabilizer lift coefficient per angle of attack
$c_{l\alpha}$ = section lift coefficient per angle of attack
$C_{l\beta}$ = rolling moment on horizontal stabilizer due to interference from vertical fin per sideslip angle
$c_{l\beta}$ = section lift coefficient on horizontal stabilizer due to interference from vertical fin per sideslip angle
DLM = Doublet Lattice Method
$H.S.$ = Horizontal Stabilizer
i = imaginary unity
l = strip lift
$k = \dfrac{\omega b_r}{V}$ = reduced frequency
L_0 = static lift on strip
L_x, L_y, L_z = stabilizer strip aerodynamic forces
M_x, M_y, M_z = stabilizer strip aerodynamic moments
$q = \dfrac{\rho V^2}{2}$ = dynamic pressure
V = true airspeed at flight condition
x, y, z = spatial coordinates
α = angle of attack
β = sideslip angle
ρ = air density
Λ = sweep angle of stabilizer quarter-chord line
ω = modal frequency, rad/sec
$\delta x, \delta y, \delta z$ = translation components of mode of vibration
ϕ = stabilizer strip roll angle

Subscripts
$1, 2$ = inboard and outboard edges of stabilizer strip

1. Introduction

This paper is a summary of the work done at Gulfstream Aerospace Corporation to include the horizontal stabilizer static lift and static deformation effects in the T-tail flutter analysis to show compliance with the recommendations of U.S. Federal Aviation Administration Advisory Circular AC 25.629-1, Paragraph 5(4)(iv) Intersecting Lifting Surfaces: which states in part: "The in-plane forces and motions of one or the other of the intersecting surfaces may have a strong effect on flutter speeds; therefore, the analysis should include the effects of steady flight forces and elastic deformations on the in-plane effects".

Reference 1 presents a strip theory method for including in the flutter calculations the effect of the extra aerodynamic forces which could be important in T-tail flutter stability: the aerodynamic interference between the vertical fin and the horizontal stabilizer which results in a rolling moment on the horizontal stabilizer due to vertical fin yaw, the horizontal stabilizer dihedral resulting from static deformation due to static lift on the horizontal stabilizer and the rolling moment on the horizontal stabilizer in yaw due to static lift on the horizontal stabilizer. The numerical flutter studies presented in Reference 1 for the Boeing YC-14 T-tail model show very good agreement with wind tunnel tests performed on the same model.

In Reference 2 it is pointed out that more modern methods of unsteady aerodynamic analysis such as three-dimensional lifting surface methods remove some of the limitations implicit in the strip theory methods (aspect ratio, taper ratio, sweep and compressibility effects) and they are capable of calculating some of the forces described above, such as the rolling moment on the horizontal stabilizer due to vertical fin yaw. Reference 2 also points out that the yawing moment due to rolling of the horizontal stabilizer should not be neglected.

The MSC/NASTRAN (Reference 3) flutter solution with DLM aerodynamics (Reference 4) in its present form, while accurately calculating the aerodynamic interference between the vertical fin and horizontal stabilizer and the associated rolling moment, does not readily take into account the additional parameters described above. The DLM and also the MSC/NASTRAN flutter solution is flexible enough, however, to allow for the inclusion of these parameters calculated outside of MSC/NASTRAN.

Following the method of Reference 1, a strip theory program was written to calculate the extra aerodynamic terms. A generalized aerodynamic force matrix is then calculated with the strip theory program using MSC/NASTRAN-generated modeshapes and this additional aerodynamic matrix is added to the one calculated by the DLM program in the MSC/NASTRAN flutter solution. The flutter solution is then carried out with this modified generalized response aerodynamic forces matrix. The static deformation on the horizontal stabilizer is taken into account through a flutter analysis using the deformed shape of the stabilizer under the steady airload.

The method is applied to the T-tail of a complete Gulfstream aircraft model. See Figure 1 for the MSC/NASTRAN DLM aerodynamic representation showing lifting surfaces, interference and slender bodies.

2. Aerodynamic Forces

The additional response strip air forces due to stabilizer static lift are as presented in Reference 1 and are reproduced here for convenience.

1. Strip fore-aft force:

$$L_x = 0$$

2. Strip lateral force due to roll:

$$L_y = -L_0 \phi$$

3. Strip lift due to sideslip:

$$L_z = C(k)\left[-\frac{2i\omega\delta x}{V} L_0 + (L_0 \tan\Lambda + \frac{3}{4} q L_s)(\beta + \frac{i\omega\delta y}{V})\right]$$

where the reduced frequency values k are the ones used in the flutter analysis and

$$L_s = (c_1 l_1 - c_2 l_2)(c_1 + c_2) / 2$$

The compressibility effects are included in the steady lift distribution.

The antisymmetric lift term for the horizontal stabilizer in yaw under symmetric upload

$$L_0 \tan\Lambda + \frac{3}{4} q L_s$$

is calculated based on the work of Queijo (Reference 5). See Figure 2 for a comparison of the antisymmetric section lift distributions as calculated with the method of Queijo and with program VSAERO (Reference 6). In the Queijo estimate of Figure 2, the symmetric VSAERO-calculated section lift is used.

4. Strip rolling moment:

$$M_x = 0$$

5. Strip pitching moment:

$$M_y = -b(0.5 + a) L_z$$

6. Strip yawing moment:

$$M_z = -b(0.5 + a)L_y$$

The yawing moment due to horizontal stabilizer roll rate is not included in the present calculations.

The strip aero forces and the MSC/NASTRAN-calculated modeshapes are used to calculate an additional generalized airforces matrix, ΔQHH, which is added to the generalized airforces matrix calculated by the MSC/NASTRAN DLM:

$$QHH_{analysis} = QHH_{DLM} + \Delta QHH$$

The flutter analysis then proceeds with the total airforces matrix.

3. Numerical Results

The equations contained in Section 2 have been programmed and ΔQHH can readily be calculated for a given upload and flight condition.

Figure 3.a shows the damping vs. airspeed for the airplane with no upload on the horizontal stabilizer. Solution 145 is used. Only the fin bending-torsion flutter mechanism is tracked. In Figure 3.b the damping vs. airspeed for the airplane with upload on the horizontal stabilizer is shown. Note that the vertical fin flutter mechanism, which is the targeted mechanism, shows a significant difference from the same mechanism in Figure 3.a. The other flutter mechanisms are affected much less than the fin mechanism is. This result is expected.

Note that Gulfstream airplanes T-tails have horizontal stabilizers with zero dihedral angles when not loaded. Figure 4 shows the normalized deformed shape of the stabilizer due to a distributed upload as calculated with MSC/NASTRAN Solution 144. The calculation of the mode shapes takes place on the undeformed structure with zero dihedral.

The aerodynamic surface of the horizontal stabilizer is represented in three ways as seen in Figure 4: first as a planar surface with zero dihedral angle, then as a planar surface with dihedral angle defined by a straight line from root to tip of the deformed surface ("rigid" dihedral) and finally, the aerodynamic surface takes the exact shape of the "elastic" dihedral.

Figure 5 shows a comparison of calculated normalized T-tail flutter speeds vs. normalized horizontal stabilizer lift coefficient for the three cases: zero dihedral for the horizontal stabilizer aerodynamic surface, then "rigid" dihedral and lastly "elastic" dihedral. The structural model remains undeformed. The major contributors to the flutter speed decrease are the extra aerodynamic forces of Section 2. Calculations with "rigid" and "elastic" dihedral on the horizontal stabilizer show that the "elastic" dihedral causes more of a flutter speed decrease than the "rigid" dihedral approximation but only marginally.

For a more complete analysis, the mode shapes should be calculated starting with the correct deformed shape of the horizontal stabilizer under upload and the additional aerodynamic matrix should be calculated from these mode shapes. The changes in the vertical fin flutter speed are expected to be small, however.

4. Separation and Factoring of $C_{L\alpha}$ and $C_{l\beta}$ on the Horizontal Stabilizer

Understanding the importance of the antisymmetric lift on the horizontal stabilizer on T-tail flutter, a look at the components of this lift is in order. First, there is the unsteady lift due to horizontal stabilizer torsion. This lift is factored usually by the ratio between the steady-state experimental $C_{L\alpha}$ values and theoretical steady-state $C_{L\alpha}$ values. Another contributor to the horizontal stabilizer antisymmetric lift comes from the aerodynamic interference from the vertical fin in yaw, $C_{l\beta}$. The steady symmetric upload effects and their inclusion in the MSC/NASTRAN flutter solution are discussed in the main body of this paper and they are different in nature from the forces under consideration here.

The DLM program calculates $C_{L\alpha}$ and $C_{l\beta}$ based on the elastic mode shapes of the horizontal stabilizer and vertical fin and as it is implemented in MSC/NASTRAN, does not and cannot separate the two. Typically, both $C_{L\alpha}$ and $C_{l\beta}$ on the horizontal stabilizer are factored by the $C_{L\alpha}$ factor in the factoring schemes currently in use in the industry. Experimental evidence indicates that the two quantities vary differently with Mach Number and should therefore be factored by different factors.

Based on the work presented in the main body of this paper, a simple strip theory method is proposed here: the idea is to add/subtract $C_{l\beta}$ for each elastic mode multiplied by the difference between the correction factors for $C_{L\alpha}$ and $C_{l\beta}$..

The correction scheme is as follows:

$C_{l\beta}$ on the horizontal stabilizer is calculated for a few elastic modes of the vertical fin at zero frequency. Only fin modes of the order of magnitude of the fin bending and torsion modes need be considered.

For each mode, the $\Delta C_{l\beta}$ with which strip theory generalized air forces are calculated is:

$$\Delta C_{l\beta} = C_{l\beta} \text{ DLM*(Factor } C_{l\beta} \text{-Factor } C_{L\alpha})$$

where

$$\text{Factor } C_{l\beta} = C_{l\beta} \text{ Experimental/} C_{l\beta} \text{ NASTRAN DLM}$$

at zero frequency

and

$$\text{Factor } C_{L\alpha} = C_{L\alpha} \text{ Experimental}/C_{L\alpha} \text{ NASTRAN DLM}$$

at zero frequency.

The addition/subtraction of the $\Delta C_{l\beta}$ distribution to the NASTRAN DLM-calculated one takes place at the generalized force level. The calculated flutter speed will converge with the addition of sufficient modes above the vertical fin torsional mode.

5. Conclusions

An existing method for calculating the effect of static lift on the horizontal stabilizer in yaw and the effect of static deformation of the horizontal stabilizer on T-tail flutter has been appended to the MSC/NASTRAN flutter solution. Numerical results show the expected trends. A simple correction scheme is introduced to permit separation and factoring of $C_{l\alpha}$ and $C_{l\beta}$ on the horizontal stabilizer by different factors.

6. References

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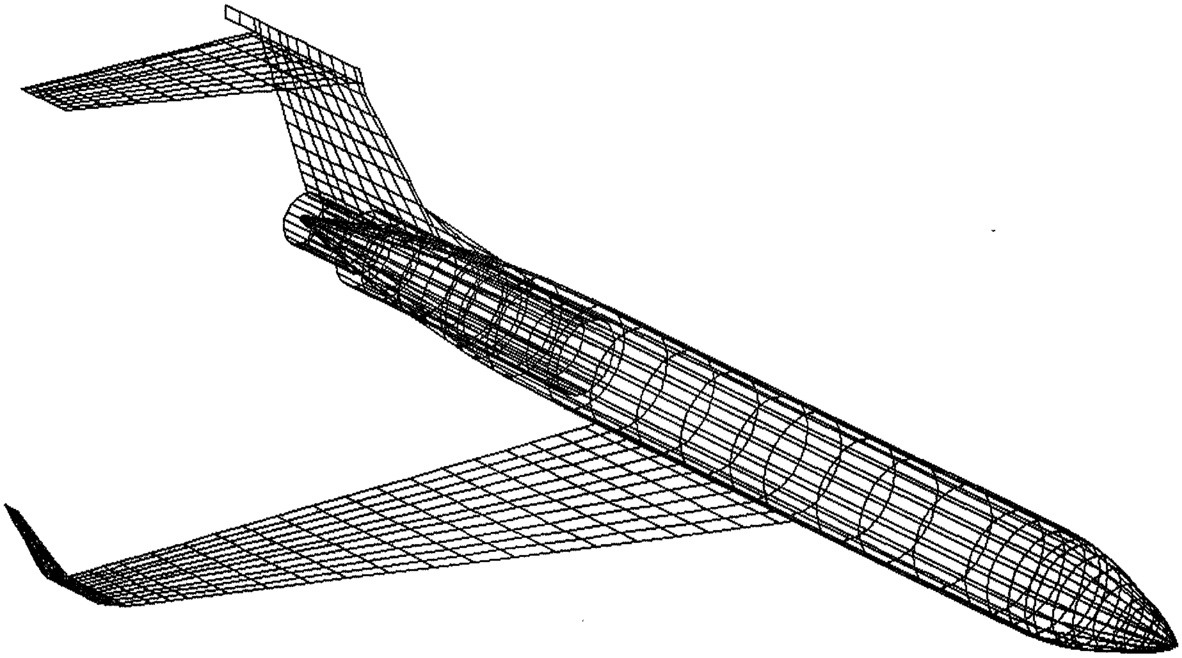

Figure 1.
Doublet Lattice Aerodynamic Representation of Complete Gulfstream Aircraft

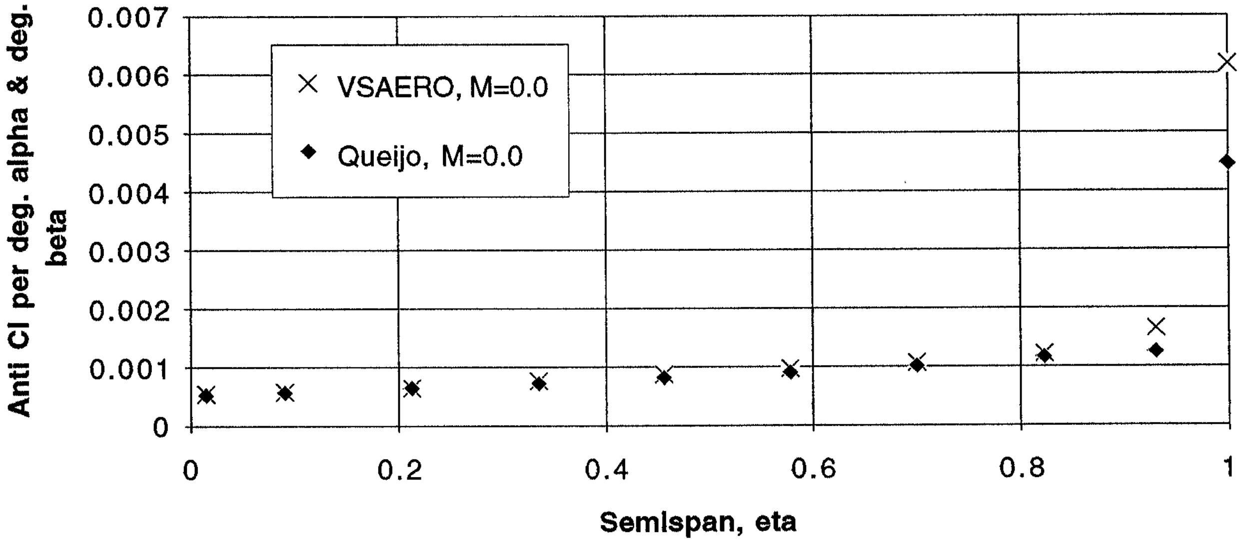

Figure2.
VSAERO-Calculated Antisymmetric Section Lift for the Isolated H.S.; Comparison with Queijo with VSAERO-Calculated Symmetric Section Lift

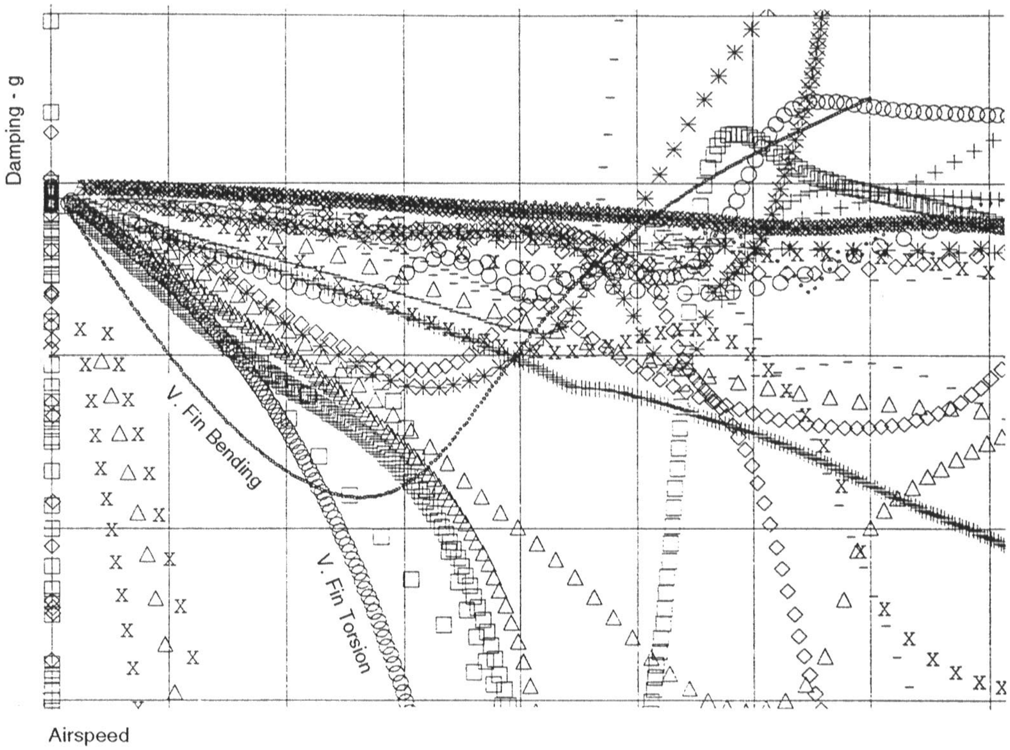

Figure 3a.
Vertical Fin Flutter Mechanism with No Upload on Horizontal Stabilizer. No Dihedral.

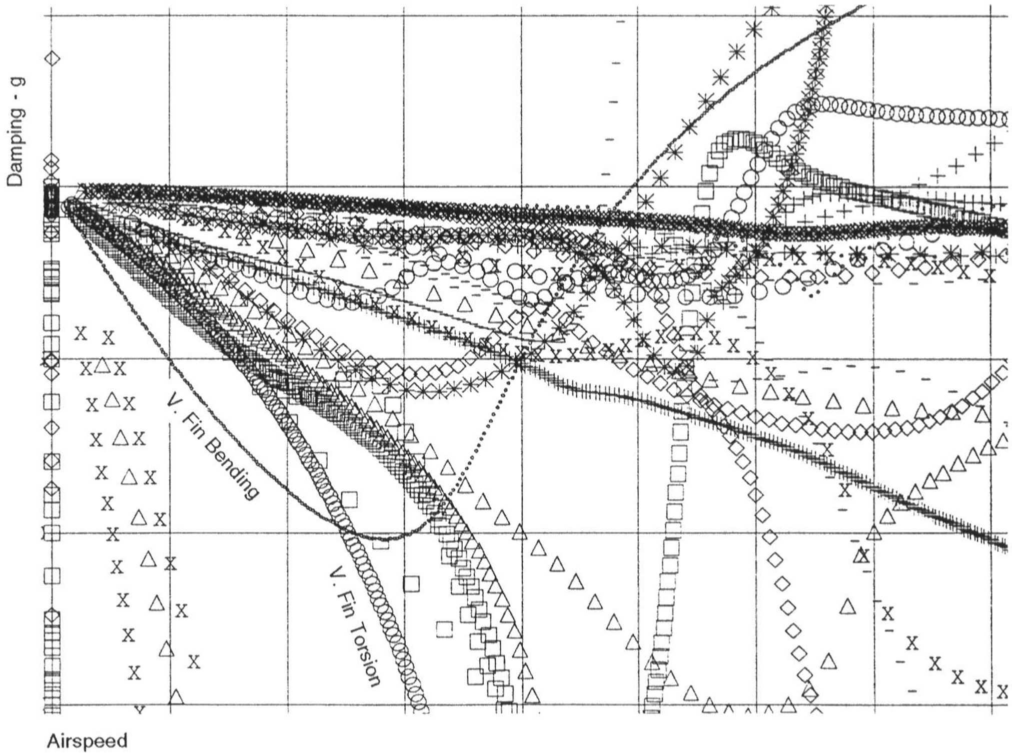

Figure 3b.
Vertical Fin Flutter Mechanism with Upload on Horizontal Stabilizer. No Dihedral.

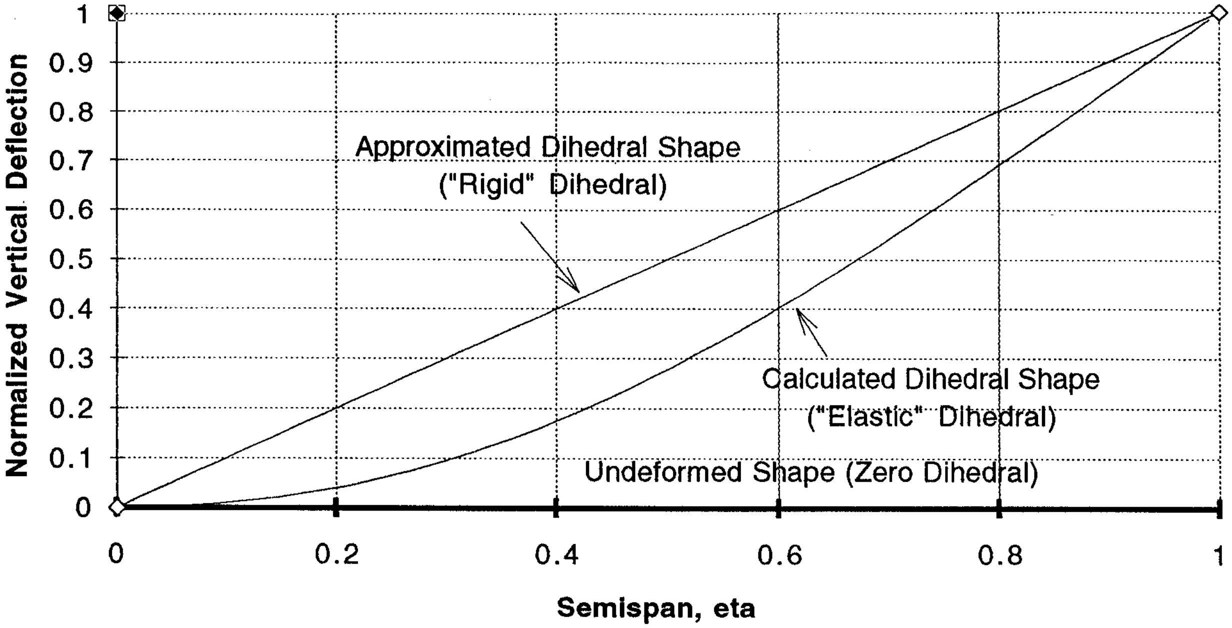

Figure 4.
Normalized Horizontal Stabilizer Deflection Due to Upload

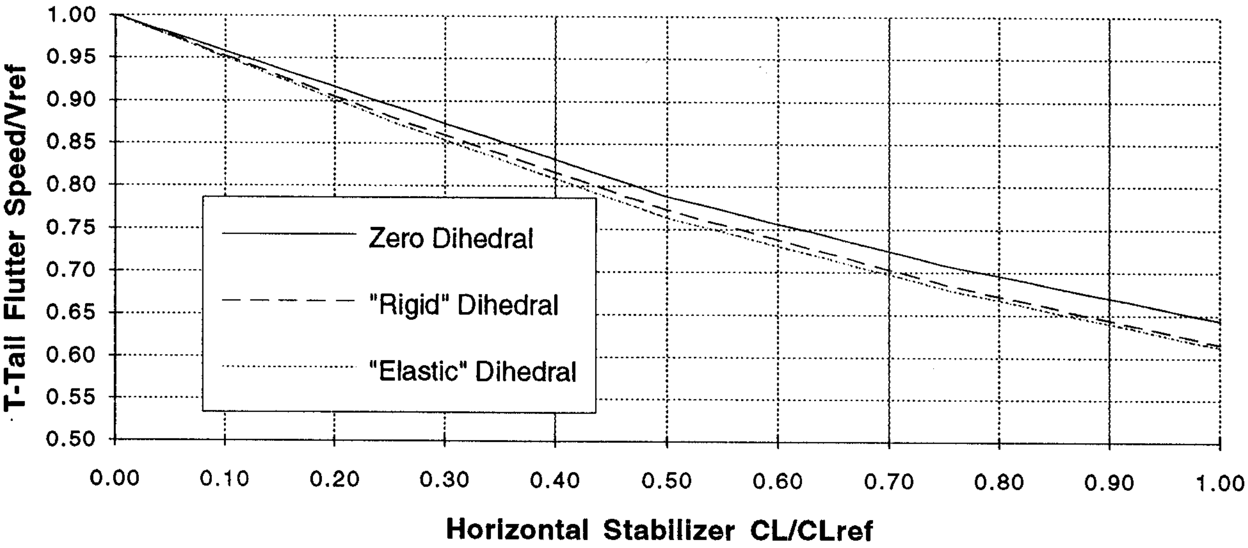

Figure 5.
Normalized Vertical Fin Flutter Speed vs.
Horizontal Stabilizer Static Lift Reference Coefficient.
Flutter Speeds Are Not Matched.