Flutter Speed Degradation of Damaged, Optimized Flight Vehicles

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Abstract

A STUDY of the effects of mass and stiffness changes on the flutter degradation of optimized wings is presented in this paper. The wings were optimized for weight with constraints on strength, displacement, and flutter speed. The mass and stiffness changes are representative of battle damage. The structural box is idealized by finite elements consisting of membranes, shear panels, and bar elements. The aerodynamic force matrix is generated by incompressible strip theory. Five damage models involving two wing boxes are included. The effect of damage on aerodynamic flow is not treated.

Contents

Research is being conducted at the Flight Dynamics Laboratory to develop methods which can effectively predict the effect of damage on structures. Efficient techniques can lead to identification of damage sensitive areas and redesign to improve structural reliability. The following work is an extension of that reported in Ref. 1 to investigate the effects of stiffness and mass changes on flutter degradation, particularly for those wings optimized for weight with flutter speed as one of the constraints.

The flutter problem is expressed in generalized coordinates which are the natural modes of the structure. The complex eigenvalue problem then is expressed as:

$$[\Omega[K]\quad[M]-[Q(k)]]\{\bar{q}\}=\{0\}$$

where $Q(k)$, the matrix of generalized aerodynamic forces, is a function of planform and the natural mode representation. $[K]$ and $[M]$ are respectively the generalized stiffness and mass for the finite element representation of the structure. Ω is the complex eigenvalue and is defined by $\Omega=(1+ig)/w^2$ where g is artificial damping added to the system to yield simple harmonic motion and ω is the cyclic frequency.

The damage is represented as a change in stiffness and/or mass and can be expressed as the matrices $[dK]$ and $[dM]$. Then the eigenvalue problem is solved using an upper Hessenberg method and plotting the resultant eigenvalues to obtain the vanishing artificial damping term characteristic of the flutter condition in the standard k-method.

Two wing boxes were considered. The first was a two spar unswept wing optimized by Rizzi.[2] The second was a three spar swept wing considered in Ref. 3. Damage was assumed to be partial or complete loss of stiffness and mass. The results

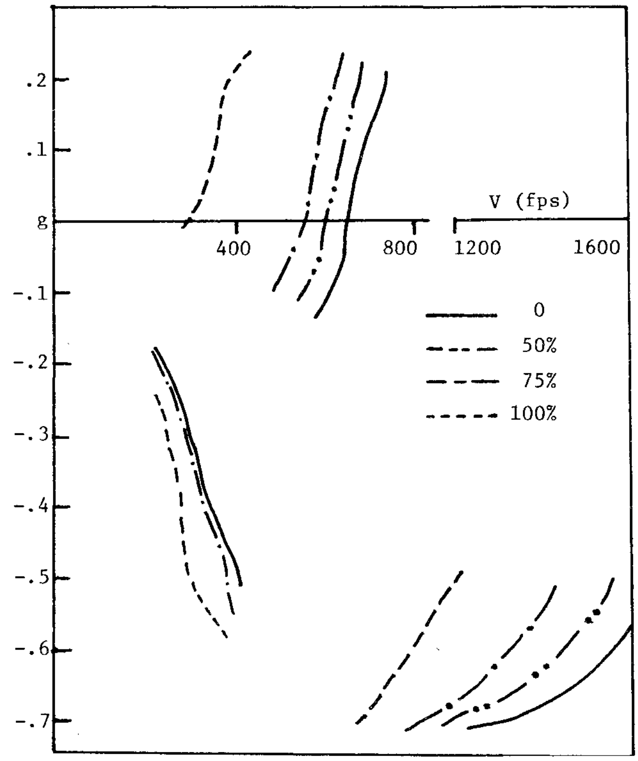

Fig. 1 ***V-g* diagram, structure I, case 1.**

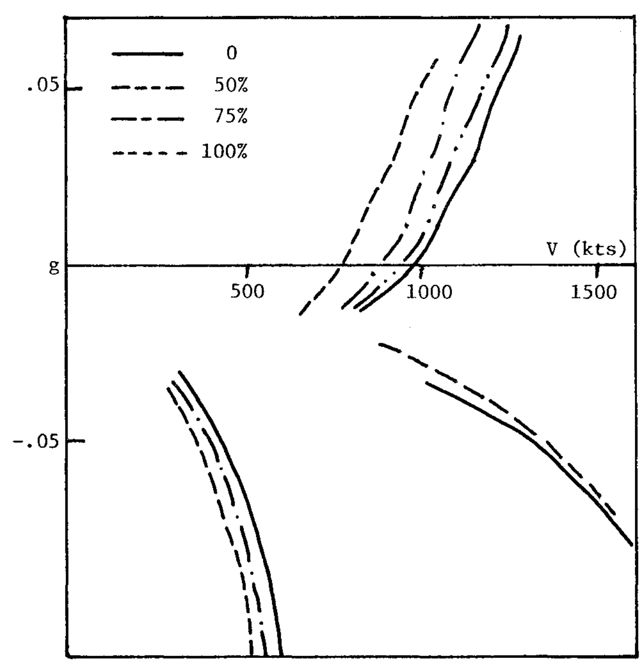

Fig. 2 ***V-g* diagram, structure II, case 3.**

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Table 1 Results—structure I

Case	% damage	V_f, fps	ω_f, Hz	k_f
0	0	688	7.07	0.134
1	50	640	6.82	0.139
1	75	573	6.84	0.150
1	100	323	4.94	0.200
1*	50	586	6.50	0.149
1*	75	498	5.99	0.157
1*	100	258	4.50	0.222
2	50	711	7.05	0.130

Table 2 Description of cases

Structure	Case	Description of damage
I. Two-spar rectangular wing	1	Upper and lower skins outer box
	1*	Same as case 1 but with original modes retained
	2	Rear spar outboard
II. Three-spar intermediate complexity wing	1	Elements 14, 34, outer box
	2	Elements 13, 33, outer box
	3	Cases 1 and 2 combined
	4	Elements 7, 27, upper and lower skins aft midspar
	5	Elements 6, 26, upper and lower skins ahead of midspar
	6	Case 4, case 5, combined with element 47, inboard middle spar
	7	Element 52, rear spar inboard

for structure I are listed in Table 1 with the damage cases described in Table 2. Table 3 lists the results for structure II. Typical *V-g* plots are shown in Fig. 1 for structure I, case 1 and in Fig. 2 for structure II, case 3.

The use of fixed modes are investigated for structure I, case 1 and in comparison with recomputing the modes the error in flutter speed was over 20%. For the three spar wing the largest change in flutter speed was only 20%.

Conclusions reached from the study were that to determine the effect of damage on flutter speed, a systematic efficient means of reanalysis is essential. With the loss of certain elements the flutter speed actually increased, thereby pointing out the interrelationship of behavior when a structure is optimized with respect to multiple constraints. The error in using fixed modes for generalized coordinates was seen to be negligible when the flutter speed changes little but became significant when the damage became critical. Where fixed modes may be satisfactory for small structural changes, such as in an optimization step, updated modes may be necessary when determining the effects of damage.

Table 3 Results—structure II

Case	% damage	V_f, knots	ω_f, Hz	k_f
0	0	963	48.70	0.560
1	50	940	47.76	0.563
1	75	916	46.73	0.565
1	100	856	43.86	0.567
2	50	940	47.90	0.565
2	75	918	47.27	0.570
2	100	872	45.87	0.582
3	50	918	46.97	0.566
3	75	874	45.19	0.572
3	100	768	40.18	0.579
4	50	953	47.92	0.557
4	100	938	46.28	0.547
5	50	956	48.17	0.559
5	75	952	47.56	0.555
5	100	946	46.34	0.549
6	50	949	47.12	0.550
6	75	943	45.44	0.534
6	88	943	44.00	0.516
6	100	952	41.75	0.484
7	50	956	48.71	0.564
7	75	945	48.69	0.570
7	99	910	48.22	0.589
7	100	778	47.86	0.683

References

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[3] Wilkinson, K., Markowitz, J., et al., "An Automated Procedure for Flutter and Strength Analysis and Optimization of Aerospace Vehicles," Air Force Flight Dynamics Lab., AFFDL-TR-75-137, Dec. 1975.