The overall transfer function is

$$\frac{X_L}{I}=\frac{KsvWn^2}{S^2+2SWnS+W^2}\;\frac{Kq\beta A/V}{MS^3+(\beta M/RvV+B)S^2(K+\beta B/RvV+\beta A^2/V)S+K\beta/RvV} \tag{1}$$

Simplifying Assumptions

1) B is very small compared to the terms it adds to (generally true).

2) The servovalve is reasonably well damped at the frequencies of interest so that it can be represented as a single time constant, Tsv.

Under these conditions the transfer function is

$$\frac{X_L}{I}=\frac{Ksv}{TsvS+1}\times\frac{Kq\beta A/V}{(MS^3+(\beta M/RvV)S^2+(K+\beta A^2/V)S+K\beta/RvV} \tag{2}$$

Further Simplification

Assumption—the servovalve time constant is small enough that it has no significant effect in the frequency range of interest and can be neglected. Combining Ksv and Kq into a single gain term, Kq', the transfer function becomes

$$\frac{X_L}{I}=\frac{Kq'\beta A/V}{MS^3+(\beta M/RvV)S^2+(K+\beta A^2/V)S+K\beta/RvV} \tag{3}$$

Having an electronic actuator model, its output can be compared to the output of an actuator under test when both are subjected to like commands. Limits are set, within a comparator, to established tolerance levels and a logical pass/fail signal results. Through a variety of test configurations and the resultant data an assessment of the actuator's performance is achieved and determination of the nature of indicated problems is possible.

Conclusions

Since a variation of this concept has already been successfully utilized by the contractor, there should not be any major problems with the PSTS project. Except for a few variations, the PSTS will be a repackaging of existing electronic equipment. Once the PSTS is operational, the Air Force should be able to save large sums of money.

AIAA 82-4086

Wing/Control Surface Flutter Analysis Using Experimentally Corrected Aerodynamics

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Introduction

EXPERIENCE has shown that in most cases where aircraft have encountered flutter problems, control surfaces were involved. For this reason it is important that the wing/control surface/tab be accurately modeled when doing flutter analysis on an aircraft. Problems associated with aerodynamic modeling of control surfaces were discussed by Wassweman et al.[1] as early as 1944 when they suggested reducing the tab aerodynamic coefficients by 30% to account for the poor airflow found over control surface tabs. Therefore it is standard practice when using strip theory aerodynamics to include the variations of control surface aerodynamic coefficients as parameters in the flutter analysis. Considering the improvements that have been made in the area of theoretical unsteady aerodynamics over the last 15 years, should the variations in control surface aerodynamics remain a parameter in the flutter analysis, and if so, how should it be done? Experimental pressure data have been obtained by Hertrich[2,3] for both steady and oscillatory motion for several wing/flap configurations. In using this data to compare experimental and theoretical lifting pressure distribution on an airfoil with oscillating flap in two-dimensional flow, Albano and Rodden[4] indicated that the theory would overpredict the pressure. A similar comparison was made by Tijdeman and Zwaan[5] which also indicated that the pressure over the control was overestimated by theory, but they indicated that the differences are of the same order as for the pressure distributions over wings without control surfaces. Therefore corrections for one mode could be used on another mode under similar conditions: Mach number, frequency, etc. Forsching et al.[6] obtained experimental oscillatory pressure distribution data on a wind-tunnel model similar to one used by Hertrich. A detailed comparison of this data with theoretical pressure distribution was made by LaBarge.[7] He indicated that at the trailing edge the theoretical results tend to overpredict the pressure values, thus modifications to the theoretical pressure values will be necessary when using the predicted values to make hinge moment estimates. The above experimental and theoretical comparisons were reviewed by Ashley and Rodden[8] with similar comments being made on the significant differences that appear between the experimental and theoretical pressure distribution at the trailing edge of the control surface. Rowe et al.[9] indicated that considerable variation in results may be obtained when using the doublet-lattice program to model wing/control surfaces depending upon the method used in defining the control point distribution, but results would approach asymptotic values provided that either a sufficiently large number of control points were used or by using a smaller number of carefully spaced control points. They also indicated that theoretical and experimental data were in good agreement except for a small area around the wing/control surface hingeline. In a paper by Rowe et al.[10] it was found that the theoretical unsteady hinge moment could vary by as much as 20% from experimental results on a wing-aileron-tab configuration.

In each of the above comparisons, the indications are that theoretical unsteady aerodynamics overpredicts the pressure distribution on the wing/control surface interface and the control surface itself. What has not been discussed in these studies is the effect this will have on the predicted flutter speed. If these effects tend to make the flutter analysis unconservative or change the flutter mechanism, then these effects must be included in the flutter analysis in some manner.

Flutter Study

To determine if the above effects are critical to the flutter analysis, an analytical flutter model of the experimental model used by Forsching[6] et al. was developed.

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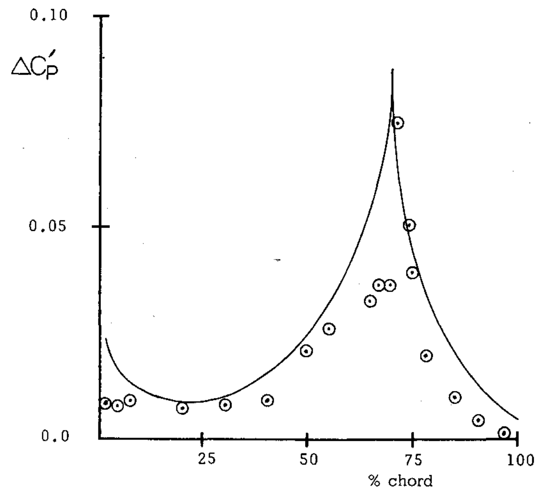

Fig. 1 Real part of coefficient of pressure amplitude, $\Delta C_p'$, vs chord position for a flap amplitude of 0.66 deg at a reduced frequency of 0.372.

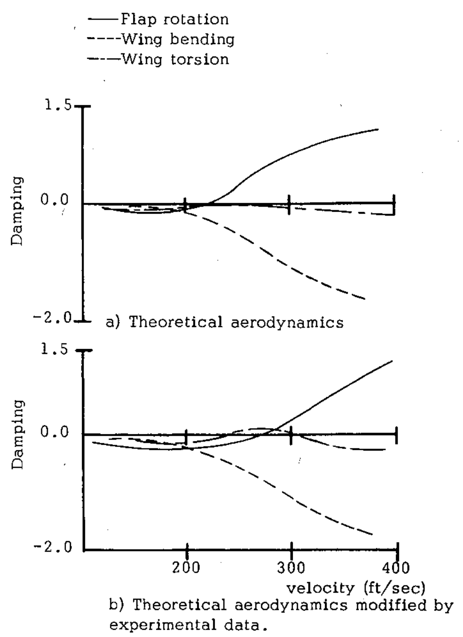

Fig. 2 Damping vs velocity.

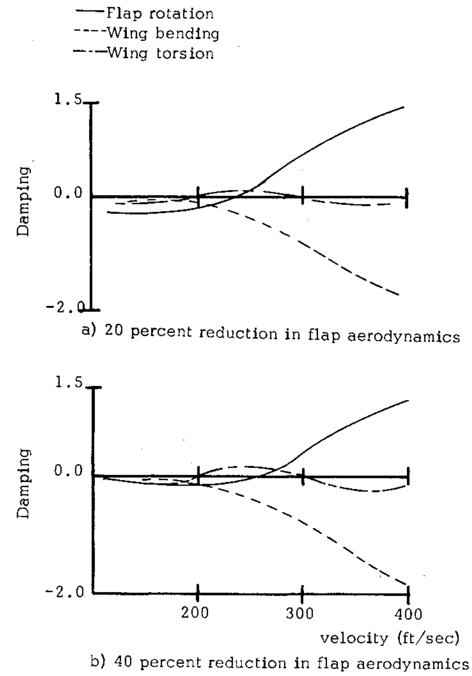

Fig. 3 Damping vs velocity.

The doublet-lattice aerodynamic model used for the flutter analysis contained 414 boxes. A flutter analysis of this model was done by developing an analytical flutter model in which the critical mode was similar to one of the mode shapes presented in their paper. To correct the wing/control surface aerodynamics a matrix method recommended by Rodden was applied to the analytic aerodynamic data and in this manner it was possible to use the experimental pressure with the analytical flutter model. For complete details of the method used see Ref. 11. In addition to this analysis a second set of analysis was done using a percentage reduction in the flap aerodynamics, 20 and 40%. The in-phase pressure distribution for wing station along the wing/control surface chord is given in Fig. 1. As Fig. 1 indicates, the maximum difference between theoretical and experimental data occurs at the leading and trailing edge of both the wing and flap. These results are similar to results shown by Tijdeman,[5] LaBarge,[7] and Rowe.[9,10]

The results of the flutter analysis without any modification to the aerodynamics is given in Fig. 2a. Next the analytical unsteady pressure distribution was modified to match the experimental pressure distribution and the flutter analysis was repeated. The damping vs velocity plot for the second flutter analysis is shown in Fig. 2b. Comparison of the two flutter analyses indicated that with corrected aerodynamics the wing torsion mode shows a region of instability while the flap flutter instability occurs at a higher velocity. The uncorrected model yielded conservative results as far as the flutter velocity was concerned, but failed to indicate the wing torsion instability. Figure 3 shows the results of reducing only the flap aerodynamics by the set percentages, 20 and 40%. As shown in Fig. 3a, reducing the flap aerodynamics by 20% yielded results with the correct trends while remaining conservative.

Conclusions

Results from this study indicate that 1) for this flutter model a conservative flutter velocity was predicted when using theoretical aerodynamics but one possible instability was not indicated; and 2) a percentage reduction in the theoretical flap aerodynamics yielded both the correct instabilities and a conservative flutter speed prediction.

There is still a need to investigate the other mode shapes given in Refs. 3 and 6 and their effect on the wing/control surface flutter results. Since this study only looked at the wing/control surface problem, there is a continuing need to investigate the wing/control surface/tab flutter problem.

Acknowledgments

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Navy A-7 Fuel Conservation Program

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Background

THE 1973 embargo by OPEC (Organization of Petroleum Exporting Countries) and the resulting increase in the cost of petroleum-based fuels prompted the United States government and citizenry to undertake comprehensive fuel conservation measures. The U.S. Navy is doing its share through the Navy Energy Office (OPNAV-413).[1] The Navy Aircraft Fuel Conservation (NAFC) Program is a subelement of the energy program. The specific goal for aircraft is a 5% *reduction in fuel consumption per flight hour* by 1985, based on recorded fuel use for 1975.

Six aircraft types annually use nearly 75% of the total Naval aviation fuel. In the order of highest to lowest usage, the aircraft are the F-4, P-3, A-6, A-7, A-4, and F-14. The following discussion provides an example of the NAFC program. The research, development, test, and evaluation (RDT&E) approach to achieve the fuel conservation goal for the Navy's fleet of A-7 aircraft is highlighted.

A-7 Fuel Saving Technology Applications Study

The A-7 fuel conservation project started (as did the other projects within the NAFC program) with a technology applications study. The three-phase study was conducted by the Vought Corporation. Representative technologies and concepts for increasing the aircraft's fuel efficiency included composite applications for weight reduction, drag reduction through clean-up and fairing additions, engine modifications to reduce thrust specific fuel consumption, and even added collection systems to eliminate small fuel losses. A total of 59 concepts were defined. Evaluation criteria included the practicality and ease of retrofit, implementation period and cost, fuel savings potential, and impacts on reliability, maintainability, and survivability.

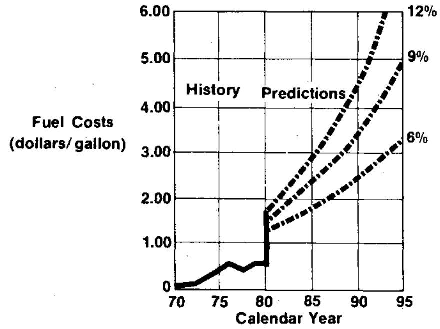

Fig. 1 JP-5 fuel cost increases through 1995 (based on 1981 dollars).

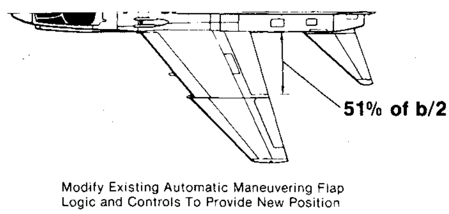

Fig. 2 Trailing-edge cruise flap.

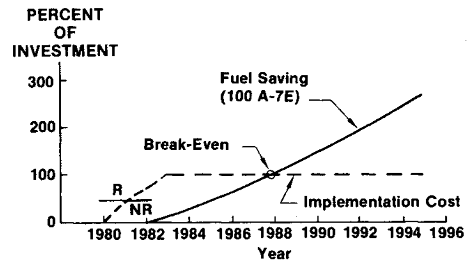

Fig. 3 Payback potential for cruise flap.

Elements of the concept evaluations are illustrated below. Fuel costs are shown in Fig. 1. The history is included along with the future increase projections, which range from 6 to 12% annually (based on 1981 dollars). The drooped flap concept, Fig. 2, would improve performance during cruise flight by lowering the large, semispan trailing-edge flaps about 5 deg. On the A-7, the modification is primarily a control system change which permits the intermediate stop. Figure 3 indicates the relative implementation cost, fuel savings, and payback for this modification.[2] Nine concepts survived the evaluations with positive payback potential. Navy evaluations resulted in the selection of eight for validation and development. Without exception, the concepts exhibit a savings potential of 1-3% and a cost break-even period of 3-6 years. This cost payback compares favorably with the remaining 15 years of planned A-7E service with the Navy. The status of each is given below.

Validation and Development Status

The drooped trailing-edge flap concept, shown in Fig. 2, has been tested. The wind-tunnel tests have shown a trim drag reduction of approximately 8-10 counts ($\Delta C_D = 0.0008$-0.0010). This translates into a 3% improvement in cruise

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