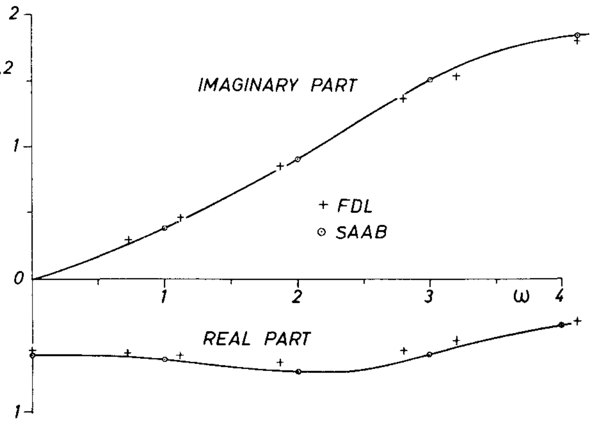

Fig. 2 Aerodynamic coefficient corresponding to the body bending mode, Mach number $M = 0.7$.

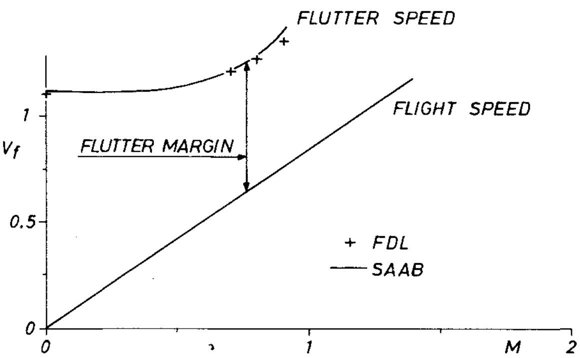

Fig. 3 Normalized flutter speed for sea-level density and flight speed for sea-level temperature.

linear equations can therefore be stored on file for later use in combination with arbitrary modes.

The aerodynamic coefficients obtained in this application are referred to the freestream dynamic pressure $\rho U^2/2$, a reference length L equal to 1.41 times the semispan s, and a reference area $S = 0.84\ L^2$. One of the coefficients is plotted in Fig. 2 vs the reduced frequency $\omega = \omega' L/U$; ω' is the circular frequency. The figure shows that the results of the FDL calculation and the SAAB calculation are in good agreement.

The flutter speed was determined in the FDL calculation by the *p-k* method and in the SAAB calculation by the *p* method. Decay rates calculated by these methods may be more reliable[10] than that obtained by the *V-g* method, but all three methods yield the same result for the flutter speed. The SAAB calculation was carried through by using a new Fortran program system called AEREL which includes the subprograms HCOEFF, PCP, and STAB. HCOEFF determines analytic deflection modes and mass matrices, PCP generates aerodynamic matrices by the Polar Coordinate Method, and STAB solves the eigenvalue problem by various methods. In case of the *p* method or the *p-k* method, the eigenvalue problem is solved by iteration. In each iteration step, a new eigenvalue is calculated by employing an aerodynamic matrix corresponding to the eigenvalue obtained in the preceding step and a program for solution of eigenvalues of a general complex matrix.[11] Approximate polynomials in $i\omega$ with real coefficients are used in STAB in each step for generation of the aerodynamic matrix. Each subprogram can read input data from a file generated by another subprogram.

Results from the two calculations for the flutter speed are plotted vs Mach number M for standard-day sea-level density in Fig. 3. The + signs represent the FDL results and the upper curve the SAAB results for the normalized flutter speed $v_f = U_f/\omega_1' L$. The agreement is seen to be very satisfactory. The results for the flutter frequency also agree very well. They decrease monotonically from 1.36 ω_1' at $M = 0$ to 1.30 ω_1' at $M = 0.9$. It is essentially the first two elastic modes that form the flutter mode.

The straight line in Fig. 3 represents the normalized flight speed $v = U/\omega_1' L$ for standard-day sea-level temperature. Comparing the upper curve to this, we see that the flutter speed is much greater than the flight speed or that a large flutter margin exists. The minimum value of this is about 77% of the flight speed in the Mach number range considered.

In conclusion it may be said that it is satisfying that the two calculations have produced agreeing results. The methods and programs employed in both of them therefore seem reliable. It is also satisfying that the calculations predict a large flutter margin. This corroborates previous results.[4] It must be added, however, that the calculations apply only to one flight condition, namely zero angle of incidence. For an increasing angle of incidence, the aerodynamic coefficients probably increase due to the developing leading edge vortices. This may reduce the flutter speed, but the remaining margin probably is large and sufficient.

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Leading-Edge Vortex Effect on the Flutter Speed

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BECAUSE of the vortices that develop at a swept leading edge for increasing angle of incidence α, the slope of the local lift coefficient curve increases at outboard wing stations. The flutter speed, therefore, decreases. This has been shown

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by Brown,[1] by means of a model with highly swept leading edge.

Brown used a rigid spring-suspended model instead of a scaled dynamic model. The reason for this probably was that a scaled dynamic model of an actual wing cannot carry the appearing steady loading. The flutter speed reduction due to the vortex effect therefore must be predicted theoretically. The required lift distributions on an oscillating wing for nonzero angles of incidence can be determined either experimentally or theoretically by now-emerging methods, but this is expensive. Therefore, it is interesting to note that the approximate method of Pines[2] seems to offer a possibility to limit the measurement or calculation to the case of steady flow. This possibility is considered here.

Pines[2] and Landahl[3] emphasized that flutter is often due to a loss of resultant stiffness, and Ferman[4] showed by many examples that Pines' approximation, which is based on this observation, yields an accurate prediction of the flutter speed for primary surfaces. This approximation does not presuppose that the flutter frequency is small. As the flutter mechanism probably is the same in the presence and in the absence of leading edge vortices, we assume that Pines' approximate method is applicable for $\alpha > 0$ if it is applicable for $\alpha = 0$.

The applicability for $\alpha = 0$ which was demonstrated in Ref. 5 is quoted in support of the following hypothesis. This states that it is the stiffness terms in the equations of motion which are the important terms in the Viggen case, and that the following prediction procedure therefore should be significant.

The aerodynamic matrix employed for the prediction was obtained by running a program based on the Polar Coordinate Method[6,7] in a special way. By using suitable input data, a correction factor was formed and applied to the calculated pressure jump prior to the evaluation of the integrals for the aerodynamic coefficients. The factor, which is defined as the ratio between the local lift curve slopes for nonzero and zero angle of incidence, was determined on the basis of measured pressures on a rigid model in steady flow. For an angle of incidence of about 3 deg, the factor is close to unity on the inboard half of the semispan, and increases rapidly on the outboard half toward a value slightly greater than 2 at the wingtip.

It should be mentioned that this factor is thought to represent the worst case, and that it is very approximate, since the data available were not sufficient for an accurate determination. But it is not unreal. A complex factor with unit modulus for simulating phase shifts also was applied, but the effect of this was very small.

The flutter speed was found to exhibit a significant decrease when the correction factor was applied. This decrease is illustrated in Fig. 1. The solid and the dashed curves represent the normalized flutter speed v_f for zero- and 3-deg angle of incidence and sea level density as functions of Mach number M. For this increase of the angle of incidence, the prediction yields a flutter speed reduction of about 17%.

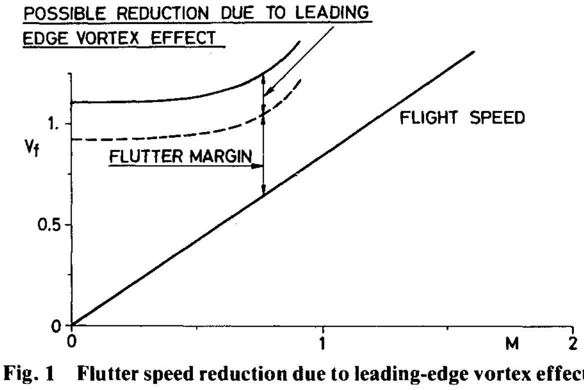

Fig. 1 Flutter speed reduction due to leading-edge vortex effect.

The straight line in the figure represents the flight speed for sea-level temperature. The minimum flutter margin in the subsonic range appears at a high-subsonic Mach number, and is seen to be about 50% of the flight speed. In conclusion, it may be said that a satisfactory flutter margin remains in spite of the possible reduction due to the leading edge vortices.

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Electrochemical Battery Trends for Aircraft and Missile Applications

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Introduction

THIS paper is divided into two sections. The first deals with aircraft-type batteries, primarily the rechargeable types. The second section discusses missile-type batteries and, in particular, the reserve nonrechargeable automatically activated type batteries.

Aircraft Batteries

Batteries used aboard aircraft generally fall into two categories: main dc electrical system batteries, and special-purpose batteries dedicated to specific systems or electronic equipment. The main dc electrical system batteries are used for such items as emergency dc power, engine/auxiliary power unit starting, and ground canopy and ladder activation. The special purpose batteries usually provide emergency backup or no-break power to items such as computers, navigation equipment, and flight control systems. This latter type of battery generally floats on the bus or charger and does nothing except provide, in some cases, stability to the electrical system until an abnormal operating condition occurs. Reliable power is expected until the abnormal condition is corrected.

For the main dc electrical system, conventional lead-acid batteries were used in virtually all early aircraft; however,

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