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%.

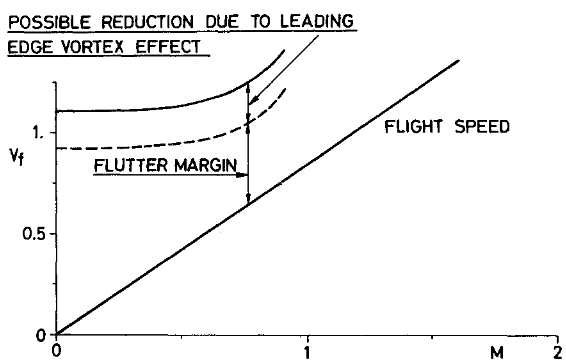

Fig. 1 Flutter speed reduction due to leading-edge vortex effect.

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.

References

[1] Brown, D. A., "Flutter Model Tests of Advanced Wing Configurations at Initial Angles of Attack," North American Aviation, Columbus Division, ASD-TDR-62-498, 1963.

[2] Pines, S., "An Elementary Explanation of the Flutter Mechanism," *Proceedings of the National Specialists Meeting on Dynamics and Aeroelasticity*, AIAA, Fort Worth, Texas, Nov. 1958, pp. 52-58.

[3] Landahl, M. T., "Graphical Technique for Analyzing Marginally Stable Dynamic Systems," *Journal of Aircraft*, Vol. 1, May 1964, pp. 293-299.

[4] Ferman, M. A., "Conceptual Flutter Analysis Techniques," McDonnell Company, Rept. F322, Feb. 1967.

[5] Stark, V. J. E., "Test of Pines Approximate Method in a Flutter Calculation for the Viggen Aircraft," *Journal of Aircraft*, Vol. 14, July 1977, pp. 702-703.

[6] Stark, V. J. E., "Application to the Viggen Aircraft Configuration of the Polar Coordinate Method for Unsteady Subsonic Flow," *The 9th Congress of the International Council of the Aeronautical Sciences*, ICAS Paper No. 74-03, Aug. 1974.

[7] Stark, V. J. E. and Cooley, D. E., "Comparative Flutter Calculations for the Viggen Aircraft," *Journal of Aircraft*, Vol. 14, Sept. 1977, pp. 920-921.

Electrochemical Battery Trends for Aircraft and Missile Applications

Wayne S. Bishop*
Air Force Aero Propulsion Laboratory,
Wright-Patterson Air Force Base, Ohio

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,

Presented as Paper 77-481 at the AIAA Conference on the Future of Aerospace Power Systems, St. Louis, Mo., March 1-3, 1977; submitted March 22, 1977; revision received May 18, 1977.

Index categories: Subsystem Design; Batteries; Spacecraft Electric Power.

*Task Manager, Battery Development, Aerospace Power Division.

higher starting loads and more stringent low-temperature operating requirements resulted in the use of vented nickel-cadmium batteries aboard the majority of aircraft over the past 15 to 20 years. At the same time, starting load requirements and poor low-temperature battery cranking performance initiated a trend away from electrical starting of engines in many aircraft. Other problems with nickel-cadmium batteries have been high maintenance costs, short life, and thermal runaway.

A number of new concepts are being introduced either to eliminate or to reduce the effects of these problems. Replacement of the cellulose-based gas barrier in vented nickel-cadmium cells with controlled-porosity polymer-base materials, which are resistant to oxidation and strong alkali, has been shown to be effective in preventing thermal runaway. The new barriers retain integrity even after extended periods of exposure to oxygen in the presence of hot alkaline electrolytes. Under the same environment, the cellulose-type barriers are degraded rapidly, allowing leakage of oxygen generated at the positive electrode during charging and overcharging and recombination at the negative electrode with the resulting thermal runaway. Other new innovations include the use of an onboard battery monitoring system and charger. The charger will control the charge to the batteries and rates of charge for the operating conditions. The onboard monitor units can determine overheated batteries or short circuited cells and warn of this condition. More sophisticated units are being developed which will warn of conditions indicative of impending catastrophic battery failure. The disadvantage of onboard chargers and monitors are cost, along with added weight and size. Another development is the sealed, low-maintenance nickel-cadium battery, which incorporates both monitoring and charging units. These units are not prone to thermal runaway because of the charger and monitor functions and eliminate the need for periodic removal from the aircraft and reconditioning in the battery shop. There does not appear to be any near-term solution to the problem of poor low-temperature cranking performance other than increasing battery size and weight or redesigning the battery for increased power density and reduced energy content.

In at least two instances, silver-zinc batteries have been used aboard aircraft; however, even though they are a small, lightweight, high-power-density battery, they have very short lifetimes (under 2 years) and have resulted in high maintenance and life cycle costs. Two new battery systems recently have become available: sealed lead-acid batteries and nickel-zinc batteries. The sealed lead-acid batteries promise a very low life-cycle-cost option for applications which do require high power density or extreme low-temperature performance. The nickel-zinc battery is a compromise between the lead-acid, silver-zinc, and nickel-cadmium batteries. A nickel-zinc battery offers low volume and weight, good power density, fair low-temperature performance, reasonable life, and an affordable cost. Nickel-zinc and sealed lead-acid batteries seem particularly well suited to the remotely piloted vehicle application.

The special purpose or dedicated batteries generally have been of both the small vented and sealed nickel-cadmium type, with an integral charging unit. These units have performed well; however, they have not been particularly low cost or low maintenance items. Two new concepts may be applied. The concepts are the new sealed lead-acid rechargeable batteries, which are compatible with a constant potential charging bus without the use of a charger and the new lithium nonrechargeable batteries. The new lithium batteries can provide over 10 times the energy of a lead-acid or nickel-cadmium battery in the same size and weight package. This latter concept is interesting in that it represents a departure from the rechargeable battery and introduces the idea of throwaway batteries for dedicated "avionics-type" standby batteries.

Missile Batteries

In the past, reserve-type, automatically activated silver-zinc batteries have been the mainstay of the batteries used for onboard missile power; however, recently there has been limited use of thermal batteries. Use of thermal batteries in these applications represents a sacrifice of performance to obtain reduced cost. The thermal battery offers an additional advantage of having a very long shelf life. It would appear that this trend will continue, with silver-zinc batteries being used where performance is of uppermost interest. There are new developments which may impact the applications. First, significant reductions (30%) in silver-zinc battery weight and volume may be possible for certain applications where battery characteristics can be optimized. A new primary battery type, the nickel-zinc, currently is being investigated as an alternate to the silver-zinc battery. Noble metal is not used and initial performance has been encouraging. The new lithium organic and inorganic electrolyte-type batteries have been developed to date only as moderate-to-low-rate primary systems. It may be possible to make very large (twofold or greater) reductions in battery weight and volume through the exploitation of this new technology. Thermal battery technology is advancing also. Long life (up to 1 hour) thermal batteries have been demonstrated by Sandia Laboratories and development efforts are underway to use this technology to make the conventional calcium/calcium-chromate battery a competitor, on a performance basis, for many silver-zinc applications. Spinoff from the rechargeable high-temperature batteries such as the sodium/sulfur and lithium-aluminum/iron-sulfide may result in dramatic improvements in thermal battery performance along with development of new thermal battery couples such as the aluminum/molybdenum-pentachloride and aluminum/copper-chloride types.

Conclusions

There are several new developments and technology advances which are likely to have a major impact on battery performance for aircraft and missile applications. The schedule for utilization of advanced battery technology depends upon user willingness to accept new product risks in return for performance gains, as well as availability of resources for development.

Approximate Solution for the Shape of Flexible Towing Cables

Yahli Narkis*
Technion – Israel Institute of Technology, Haifa, Israel

Introduction

THE shape of a flexible towing cable is of much practical interest. Glauert,[1] who was one of the first to treat this problem, considered the case of a heavy towed vehicle and neglected tangential drag forces. The case of a very light cable was investigated by Landweber and Protter.[2] More recently, Genin and Cannon[3] solved the complete problem numerically, showing the relative importance of different factors. The aim of this Note is to present an approximate analytical solution, which takes into account both the tangential drag and the weight of the cable.

Analysis

The towing system is illustrated in Fig. 1. Knowing the aerodynamic characteristics of the towed vehicle, one can

Received April 26, 1977.
Index categories: Aerodynamics; Military Missions.
*Research Associate, Department of Aeronautical Engineering.