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

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*Research Associate, Department of Aeronautical Engineering.

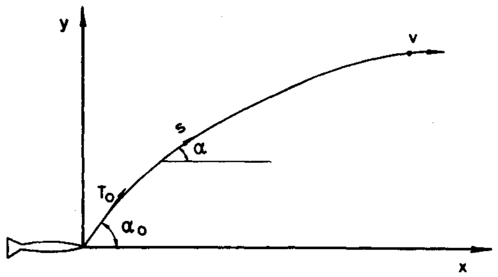

Fig. 1 Geometry of towing system.

write three static equilibrium equations for the body, and solve them to obtain its angle of attack, the tension T_0 and angle α_0 at this end of the cable.

Considering now the equilibrium of an element ds of the cable, the following differential equations result:

$$\frac{dL}{ds}+\frac{d}{ds}(T\sin\alpha)-\frac{W}{l}=0 \tag{1}$$

$$\frac{dD}{ds}-\frac{d}{ds}(T\cos\alpha)=0 \tag{2}$$

where W is the weight of the cable and l its length. The aerodynamic forces per unit length may be written

$$\frac{dL}{ds}=\frac{1}{2}\rho V^2 dC_L \qquad \frac{dD}{ds}=\frac{1}{2}\rho V^2 dC_D$$

where d is the diameter of the cable. Defining the nondimensional quantities

$$\sigma=\frac{s}{l} \qquad t=\frac{T}{\frac{1}{2}\rho V^2 dl} \qquad w=\frac{W}{\frac{1}{2}\rho V^2 dl} \tag{3}$$

the differential equations become

$$C_L+\frac{d}{d\sigma}(t\sin\alpha)-w=0 \tag{4}$$

$$C_D-\frac{d}{d\sigma}(t\cos\alpha)=0 \tag{5}$$

The lift and drag coefficients depend, of course, on flight conditions. In this work the relations which were given by Hoerner[4] for subcritical Reynolds number were assumed:

$$C_L=1.1\sin^2\alpha\cos\alpha \qquad C_D=0.02+1.1\sin^3\alpha \tag{6}$$

It is convenient to change the variable from α to

$$a=\sin\alpha \tag{7}$$

Putting Eqs. (6) and (7) into Eqs. (4) and (5), one obtains after some manipulations,

$$t'=wa+0.02\sqrt{1-a^2} \tag{8}$$

$$(0.02+1.1a)a\sqrt{1-a^2}+ta'-w(1-a^2)=0 \tag{9}$$

with the initial conditions

$$t_0=\frac{T_0}{\frac{1}{2}\rho V^2 dl} \qquad a_0=\sin\alpha_0 \tag{10}$$

Obviously, a straight line for which $a=a_c$ satisfies Eqs. (8) and (9) where

$$\frac{0.02a_c+1.1a_c^2}{\sqrt{1-a_c^2}}=w \tag{11}$$

However, this will conform to the initial conditions (10) only in the special case of $a_0=a_c$. Alternatively, the value of a_c determined by Eq. (11) may be interpreted as the slope of a free cable ($T_0=0$) or the slope of a long cable, far enough from the towed vehicle.

The pair of first-order equations, (8) and (9), may be reduced to a single equation of the second order:

$$[w(1-a^2)-(0.02a+1.1a^2)\sqrt{1-a^2}]a'' + [3wa+\frac{0.02+1.1a}{\sqrt{1-a^2}}(2-3a^2)]a'^2=0 \tag{12}$$

For $a_0=a_c$ the solution of this equation was shown to be a straight line. A perturbation solution therefore might be constructed

$$a=a_c+(a_0-a_c)\times a_1(\sigma) \tag{13}$$

for $a_0-a_c \ll a_c$.

Substituting this into Eq. (12) and taking only terms of the lowest order, which are of order $(a_0-a_c)^2$, one obtains the following nonlinear equation for a_1

$$-[0.02+1.1a_c(2-a_c^2)]a_1a_1''+(0.04+2.2a_c)a_1'^2=0 \tag{14a}$$

with the initial conditions

$$a_1(0)=1 \tag{14b}$$

$$a_1'(0)=a'(0)/(a_0-a_c) \tag{14c}$$

$a'(0)$ can be calculated directly from Eq. (9).

Equation (14) may be written in a somewhat different form

$$a_1''/a_1'=n(a_1'/a_1)$$

where

$$n=\frac{0.04+2.2a_c}{0.02+1.1a_c(2-a_c^2)} \tag{15}$$

As may be verified easily, the solution of this equation is

$$a_1=(A_1+A_2\sigma)^{-k} \tag{16a}$$

$$k=1/(n-1) \tag{16b}$$

The constants of integration A_1, A_2 are determined by the initial conditions (14b) and (14c), yielding

$$A_1=1 \qquad A_2=-\frac{a'(0)}{k(a_0-a_c)} \tag{17}$$

Thus, the change of angle of attack of the cable along its length is known. In order to obtain the shape explicitly, in Cartesian coordinates, notice that $a=\sin\alpha=dy/ds$ and, therefore,

$$\frac{y}{l}=\int_0^\sigma a\,d\sigma=a_c\sigma+\frac{a_0-a_c}{(k-1)A_2}\left[1-\frac{1}{(1+A_2\sigma)^{k-1}}\right] \tag{18}$$

In order to evaluate the horizontal coordinate $x(\sigma)$, one has to integrate $\cos\alpha$, which cannot be done analytically. Instead, constructing a perturbation solution for $b = \cos\alpha$ and

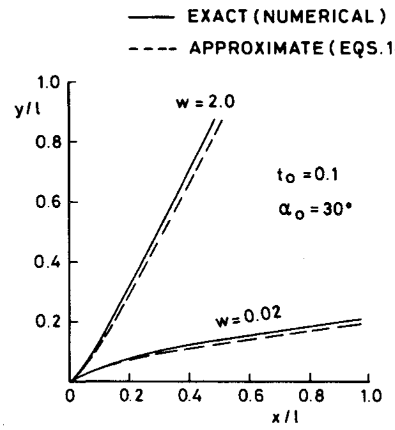

Fig. 2 Shape of towing cables.

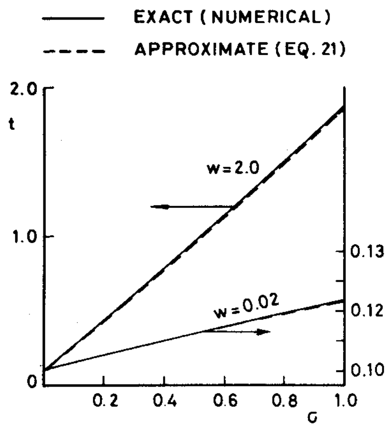

Fig. 3 Variation of tension along the cable.

following the same procedure that was taken for a, one obtains a similar solution

$$b_l = (B_l + B_2\sigma)^{-k} \tag{19a}$$

$$B_l = l \tag{19b}$$

$$B_2 = -\frac{b'(0)}{k(b_0 - b_c)} = -A_2 \frac{a_0}{b_0} \frac{a_0 - a_c}{b_0 - b_c} \tag{19c}$$

from which

$$\frac{x}{l} = b_c\sigma + \frac{b_0 - b_c}{(k-l)B_2}\left[l - \frac{l}{(l+B_2\sigma)^{k-l}}\right] \tag{20}$$

Finally, the tension variation along the cable may be calculated by integrating Eq. (8)

$$t = t_0 + w\,y/l + .0.02x/l \tag{21}$$

In practice, the exact shape of the cable is of less importance than the vertical separation and horizontal distance between the towing aircraft and the towed vehicle, and the maximal tension in the cable. All of these are obtained directly by putting $\sigma = 1$ in Eqs. (18), (20), and (21).

As was stated previously, the perturbation solution is of order $(a_0 - a_c)^2$, and might be expected to give good results even for $(a_0 - a_c)$ values that are not so small relative to a_c. To illustrate this, the approximate solution is compared to the exact (numerical) solution in Figs. 2 and 3. Calculations were carried out for typical values for towed targets, of $t_0 = 0.1$, $\alpha_0 = 30$ deg and two extreme cable weights of $w = 0.02$ and 2.0. It is seen that the approximate solution gives satisfactory results for both cable shape and tension even in these extreme conditions.

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Natural vs Man-Made Stratospheric Particulate Loading

Alden McLellan*

Impact Environmental Research, Madison, Wis.

Introduction

THERE is abundant evidence that the earth's climate has been subject to a wide variety of fluctuations whose periods have ranged from decades to millenia.[1-6] At present, there is concern that the activities of man are influencing or even causing a global climatic change.[7-9] The main force driving the climate of the earth-atmosphere system is solar radiation. The incoming solar energy absorbed by this system is in approximate balance with the outgoing infrared radiant energy. However, variation in the radiative properties of the earth's surface and the composition of the atmosphere are very important factors, because they govern the nature and magnitude of changes in the heat balance.

Particulate Matter

Suspended particles are observed throughout the entire earth's atmosphere. These particles have an effect on the global energy budget by their modification of the atmospheric radiation balance through the scattering and absorption of light.[10] The sizes of the particles that are suspended in the atmosphere range from about 10^{-7} cm ($10^{-3}\mu$) to 10^{-2} cm ($10^{2}\mu$). In general, these particles cause Mie scattering, in which most of the solar radiation is scattered in the forward direction. For particles whose sizes are much less than the wavelength of light, the Mie scattering equation can be approximated by the Rayleigh scattering equation. In both situations, a component of this radiation is scattered into space, a component of it absorbed, and a component reaches the surface of the earth, where it is absorbed. Thus, these atmospheric particles can change the total sunlight that is scattered by the earth back into space. In this way, the global albedo is modified. However, these particles also radiate energy in the infrared spectrum, modifying the field of terrestrial radiation in a manner that depends on the optical properties of the particles and the temperature structure of the atmosphere.[11]

As seen in the preceding, there exists a mechanism whereby atmospheric particulate matter can produce important changes in the global heat budget. There can be natural

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*Director, Impact Environmental Research. Member AIAA.