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Design Criteria for Wind-Induced Flight Loads on Large Boosted Vehicles

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Introduction

IN rising through the atmosphere above the launch pad, a boosted vehicle may well experience sizable loads induced by rapidly changing wind conditions. To insure a high probability that the vehicle will traverse these winds without damage, adequate strength must be incorporated through the adoption of a realistic design philosophy and the development of design methods consistent with this philosophy. This paper is based upon a design philosophy that accepts a small percentage loss for any given vehicle when that vehicle is fired from a most critical geographical location during the worst season of the year. The loss rate considered herein is 1%.

In order to calculate the design load associated with a 1% loss rate, load statistics are derived directly by calculating the vehicle response from each individual sounding of a sample of wind soundings. This method, referred to as a "statistical load survey," is presented by Hobbs and his associates in Ref. 1.

Wing Sounding Samples

To determine design loads by means of a statistical load survey, an adequate sample is needed. Adequacy of the sample implies consistency with design philosophy, the greatest possible freedom from error and bias, and a sufficient size to provide both meaningful statistical information and a satisfactory representation of the climatology of any given launch site. To be consistent with the design philosophy specified previously, the sample should consist of measurements from the most severe geographical location during the season of the most severe winds (winter). The need for an error-free sample of winds is obvious, but its attainment is quite another matter. It generally is agreed that the accuracy and precision of present wind-measuring systems need considerable improvement.[2] For the present, one must be content using the best available data while urging the rapid development of improved measuring systems. Of the systems now available, only the AN/GMD-1 rawinsonde has been operational long enough to measure wind samples of the size needed for meaningful load statistics. Wind samples used in the present study are based on AN/GMD-1 measurements.

To represent the climatology of a given geographical location satisfactorily, a sample should include the variation in weather conditions from year to year. A 5- or 10-year period of data probably is representative of the general conditions at a given location, although there is no guarantee that more extreme conditions will not occur in the future.

In Ref. 1, the sample sizes associated with specific load accuracies and confidence levels are presented for a given vehicle-site combination. Typically, a sample size of 200 soundings usually provides a reasonable compromise, between the amount of calculation needed on the one hand, and the accuracy and confidence level for the determination of loads corresponding to a 1% loss rate on the other.

Using the foregoing criteria and sorting and reducing individual soundings by methods described in Ref. 3, wind samples of 200 soundings were made up for each of 11 geographical locations. Seven of these are distributed more or less evenly throughout the United States; they are Long Beach, Calif.; Denver, Colo.; Seattle, Wash.; Fort Worth, Tex.; International Falls, Minn.; Montgomery, Ala.; and Caribou, Me. Four foreign sites were considered also; they are Kadena, Okinawa; Tripoli, Libya; Bitburg, Germany; and Keflavik, Iceland. The Okinawa and Libya sites were chosen especially because of the occurrence of high winds in these areas. Keflavik was chosen so that the effects of winds in a cyclonic area could be studied.

Calculating Loads

Trajectories and loads were calculated by means of a five-degree-of-freedom rigid-body system of equations. For each vehicle considered, the most critical wind direction was chosen; for example, for a vehicle most sensitive to side winds, trajectories were flown normal to the mean wind direction. At representative stations on each vehicle, bending moments were calculated first in the pitch plane and yaw plane separately and then combined vectorially to obtain the resultant bending moment.

For any particular station on the vehicle, the design load for a given launch site is obtained by using the wind sample from that site, as follows. First, bending moment is calculated as a function of altitude for each of the 200 wind soundings in the sample. The peak bending moment from each sounding then is used to obtain a statistical distribution that defines the cumulative probability of exceeding a given bending moment.

Typical of the results of such a procedure are the data plotted in Fig. 1 which represent peak loads experienced

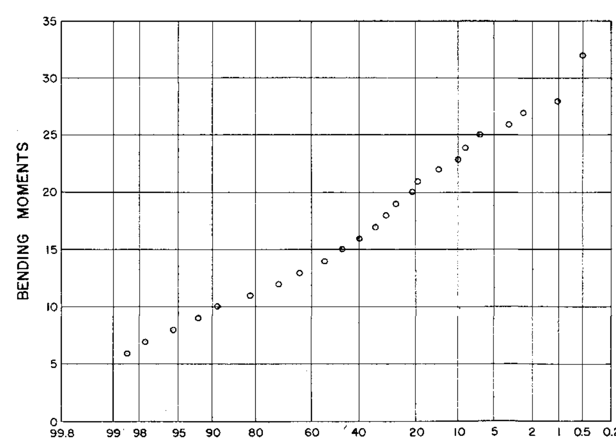

Fig. 1 Typical distribution of peak resultant bending moments

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Table 1 1% peak resultant bending moments at various sites as a ratio of the 1% peak resultant bending moments calculated for Montgomery, Ala.—vehicles A, B, and C

	Vehicles		
Site	A	B	C
Long Beach	0.950	0.766	1.014
Denver	0.952	1.159	0.791
Seattle	0.875	0.935	0.957
Fort Worth	0.956	0.970	0.923
International Falls	0.905	1.033	0.818
Caribou	1.213	1.413	1.074
Kadena	1.132	1.182	1.080
Tripoli	0.994	1.145	0.976
Bitburg	0.838	0.946	0.962
Kehavik	1.122	1.167	1.060

by a certain vehicle flying a sample of 200 Montgomery, Ala. wind soundings. This distribution of peak loads deviates substantially from a normal distribution, in which all points would plot in a straight-line path. As a matter of fact, for some vehicle-site combinations, the 1% load obtained from a normal distribution with the same mean and same standard deviation would be as much as 20% lower than that obtained from the likes of Fig. 1.

For the vehicles and GMD-1 wind samples considered here, the calculation of 1% loads for each sample of 200 soundings varied between 2.5 and 5.5 hr of IBM 7090 time, depending upon the time increment needed to insure a stable numerical solution. The load calculation procedure is applicable to wind soundings of any degree of coarseness; the finer the wind sounding, however, the more is the machine time required to compute the loads.

Discussion of Results

Table 1 presents the 1% peak bending moments for vehicles A, B, and C as a ratio of the 1% peak bending moments calculated at the Montgomery, Ala. site. The most severe loads on vehicles A and B are obtained for the Caribou wind sample, whereas for vehicle C, the Kadena site is most critical.

The differences between the 1% loads for Caribou and Montgomery for vehicles A and B, 21% and 41% greater, respectively, at Caribou, are particularly surprising. Climatological data in Ref. 4 indicate that, at the altitude of maximum winds, the Montgomery winds are more severe than the Caribou winds. However, the results in Table 1 are partially explanable upon close study of the wind samples. Of all the samples considered, the Caribou sample is the only one for which the altitude of the highest 1% wind differs from the altitude of the highest mean wind. This 1% wind for Caribou is higher than that of any other site even though the mean winds at Caribou are lower than some others. The Caribou sample also shows more very high shears than any of the other sites and more variation in wind direction with altitude.

The Keflavik wind sample possesses many of the same characteristics as the Caribou sample and, therefore, also provides higher loads than those from Montgomery. It was expected that the Kadena and Tripoli winds might provide more severe loads than the winds from Montgomery because of the higher winds reported at these locations. This expectation is verified in all cases for Kadena and for vehicle B at Tripoli.

Some interesting variations in loading are noticeable among all the United States sites other than Caribou. At the Long Beach site, the 1% loads for vehicles A and C are very close to those for the Montgomery site, whereas on vehicle B they are 24% lower than the Montgomery loads. It also is worth noting that Denver proved to be the second most severe United States site for vehicle B while being the least severe for vehicle C. The least severe United States sites for vehicles A, B, and C are Seattle, Long Beach, and Denver, respectively.

Although Caribou winds provided the most severe loads of any of the United States sites considered, the severity of loading for other sites varies widely among the different vehicles studied. This behavior suggests that wind characteristics alone do not determine the load response of a vehicle and that vehicle parameters—such as aerodynamic characteristics, thrust-to-weight ratios, and control system characteristics—also may be quite important. It suggests, furthermore, that Caribou may not be the most critical United States site for new vehicles.

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Effects of Surface Curvature on Laminar Boundary-Layer Flow

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SOME authors have investigated the effects of surface longitudinal curvature K on laminar boundary-layer flow for the case where the potential flow velocity U_1 is constant and $K \propto x^{-1/2}$, x being the distance along the surface. Tani[1] developed a small perturbation theory neglecting terms of $0(A^2)$, where $A = K(\nu x/U_1)^{1/2}$, and showed that the skin friction coefficient C_f increases with decrease of A. Murphy[2] independently analyzed the same problem by similarity consideration and obtained similar results. Recently, Yen[3,5] and Toba[4,5] re-examined the problem and found inverse effects. The purpose of this note is to clarify the reason for this discrepancy and to obtain the correct effects of surface curvature on laminar boundary-layer flow.

First it will be shown that Murphy's Eq. (32) and Yen's Eq. (A-3) are essentially the same. Yen's Eq. (A-3) can be integrated to give

$$f''' + (f + 2C)f'' = Be^{-2C\chi} \tag{1}$$

provided $\beta = 0$, where B is an integration constant and primes denote differentiation with respect to χ. Note that their numerical work is concerned with this value of β. Now it can be shown that B must be zero in order that f'' should tend to zero as $\exp(-\chi^2/2)$ when $\chi \to \infty$. With the transformation $\phi = f + 2C$, Eq. (1) reduces to

$$\phi''' + \phi\phi'' = 0 \tag{2}$$

The boundary conditions are $\phi(0) = 2C$, $\phi'(0) = 0$, $\phi'(\infty) =$

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