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by Robert M. Henry and James A. Cochrane

Langley Research Center
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WIND LOADS ON VERTICALLY LAUNCHED VEHICLES AT VARIOUS GEOGRAPHIC LOCATIONS AND LAUNCH ALTITUDES

By Robert M. Henry and James A. Cochrane
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SUMMARY

The variation in winds and resulting variation in wind loads on vertically launched vehicles for different worldwide geographical areas are investigated. Methods of determining possible alternate launch sites that offer distinct advantages in wind conditions over presently used sites are discussed; reductions of 50 percent or more in statistically determined peak winds or in statistical values of wind shears at critical altitudes may be realized. Since peak winds and maximum shears are recognized parameters of wind-induced loading, the variations in peak loads that are expected at different launch sites should reflect significant changes in wind environment with geographical regions. For some particular vehicles, variation of a single parameter, such as maximum wind speed, will produce large differences in computed load histories. A simulated liquid-propellant-vehicle system was subjected to various wind inputs. The peaks of the load histories for this particular vehicle appear more strongly related to maximum wind shears than to maximum wind speed.

Simulated vehicle flights from high-altitude launch sites were studied. Only small variations in maximum vehicle loading result from changes in launch altitudes below 10 000 feet (3 kilometers), because the reduction in maximum dynamic pressure was principally offset by an increased rigid-body angle of attack.

INTRODUCTION

Vehicles which rise through the atmosphere on a near vertical trajectory are subjected to wind-induced loads and control disturbances which are significant factors in the design and subsequent reliability of the vehicles. The contribution of wind gusts and wind shears to the loads on some current vehicles may amount to more than half of the total loadings at the maximum load condition. However, although the importance of these wind loads is recognized, the exact manner in which the loads are experienced by any given vehicle is not generally understood. Recent studies (for example, ref. 1) have included examination of load histories for wind measurements from various midlatitude locations.

The locations to be studied were selected on the basis of the most severe wind conditions. The emphasis on the most severe conditions is of obvious importance for military missions, which require "anywhere-anytime" launch capability. For many space applications, the high cost per pound of payload and the limited capability of most vertically launched vehicles make any possible reduction in design requirements advantageous and worthy of consideration along with other factors in the choice of prospective launch sites.

This paper attempts to extend knowledge of geographical variations of wind statistics and corresponding vehicle responses by:

(1) Development of simplified representations of wind parameters which cause significant vehicle response.

(2) Utilization of these simplified wind representations to survey the general patterns and range of wind loading environments over the Northern Hemisphere.

(3) Identification of specific geographic areas of low maximum wind speed and low maximum wind shear for potential use in reducing design loads or increasing vehicle performance.

(4) Construction of statistical wind profiles and comparison of these profiles to similar profiles for existing launch sites.

(5) A study of the bending-moment histories of a simulated vehicle flight through selected statistical wind profiles, and comparison of the load histories to determine the geographical variation of wind loads for this one particular vehicle.

(6) Comparison of the relative effects of variations in peak wind velocity and in peak wind shear on this particular vehicle.

(7) A contrast between load histories of the selected vehicle for various launch altitudes at one location.

Part of the material used in this analysis has been presented in reference 2.

GEOGRAPHICAL VARIATIONS OF WINDS

Basis of Examination

Simple criteria for wind loads are difficult to establish, because a wind condition which produces severe loading on one vehicle may produce relatively light loading on a different type of vehicle. Reference 3 indicates that the magnitude of maximum loads on some vehicles is proportional to the peak wind in the altitude region between 9 to 12 kilometers. The correlation coefficient between such peak winds and loads is shown in reference 3 to be about 0.85 for one vehicle type, whereas the correlation coefficient is only 0.66 for another vehicle type. Thus, the magnitude of peak wind velocity alone is not a sufficient measure of the loads on some vehicles. It is frequently considered that loads may also be strongly dependent on the wind shear, which is defined as the rate of change of wind velocity with altitude. On this basis it appears that both maximum wind and maximum wind shear should be considered in studies of vehicle wind loads.

A first step in the study of large-scale wind-load variations for any vehicle is a representation of hemispheric patterns of maximum wind speeds and wind shears at constant-altitude levels. In this paper the maximum wind speeds are examined at the 300- and 200-millibar pressure levels (altitudes of about 9 and 12 kilometers). These two levels provide horizontal slices of winds in the altitude region where many space vehicle systems encounter maximum dynamic pressure and consequently are most sensitive to wind loading. Coincidentally, this altitude is also in a region of high wind velocities with the result that most present-day space-vehicle systems are likely to experience their greatest wind loads in this region.

The assumption is often made (for example, ref. 4) that winds at a point follow a normal or Gaussian distribution. This assumption permits convenient computation of values which will have a given probability of being exceeded. A common practice in engineering is to refer to the value of the mean plus two standard deviations (2 sigma) as a 95 percent wind and the mean plus three standard deviations (3 sigma) as a 99 percent wind. This usage is followed in the present paper, but it should be recognized that these percentages are rather rough approximations. For a normal distribution, the theoretical probability of being within the limits ±2 sigma of the mean is 95.4 percent and within the limits ±3 sigma of the mean is 99.7 percent.

Although the wind-velocity vector and, consequently, the component of velocity in any given direction are approximately normally distributed, the magnitude of the wind-velocity vector or wind speed may not be approximately normally distributed. Thus, if normal distribution methods are employed, it is necessary to select a particular component direction. For the purpose of this study, the direction of the mean wind at each location was selected. Geographical patterns which result are believed to be representative of extreme wind-speed patterns or extreme zonal component patterns, although exact numerical values would differ.

Geographical Variations

Maps of the seasonal means and standard deviations of wind velocity at various standard pressure levels over the Northern Hemisphere are published in reference 5 and provide the data used in this analysis. Simple graphical addition of the mean plus two or three standard deviations yields a map of the 95 percent or 99 percent extreme winds over the Northern Hemisphere. Of course, the smoothing inherent in the mapping process will cause the map values to deviate somewhat from the value calculated directly from data for a particular point. In areas of limited data, the smoothed value may perhaps be more representative than the computed point value. This smoothing process is considered beneficial in better delineating the average variations for the large geographical areas encompassed by reference 5.

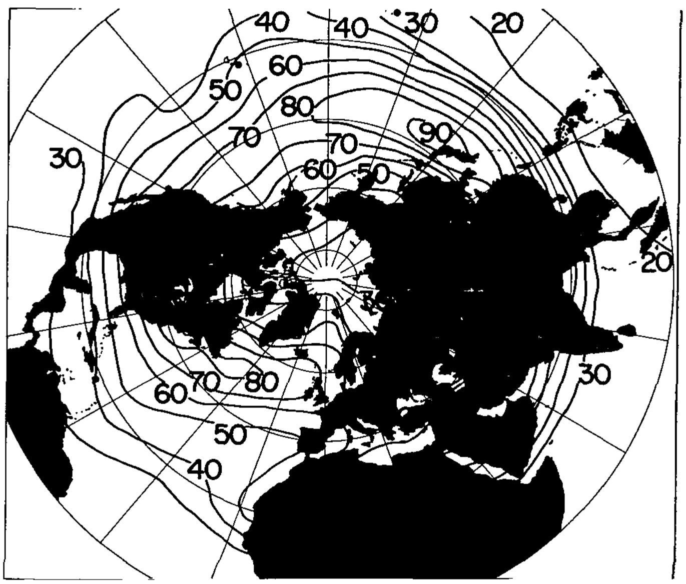

Figure 1.- Isotachs of 99 percent wind velocity components in direction of mean wind, meters per second, during winter season at 300 millibars (approx. 9 km).

Figure 1 shows the pattern of the 99 percent extreme wind over the Northern Hemisphere at 300 millibars (altitude of approximately 9 kilometers) for the winter season (December, January, February). Each isotach represents a contour of constant mean velocity along the line of the 99 percent extreme wind. The black dots on the maps indicate specific geographic sites that are discussed in this paper. In figure 1, it may be noted that the isotach for 60 meters per second passes through the region of Cape Kennedy, Florida; the isotach for 70 meters per second passes near both the White Sands (N. Mex.) Missile Range and the Western Test Range (Santa Maria, Calif.), and the isotach for 80 meters per second runs through the vicinity of Wallops Island, Virginia.

High wind speeds at the 300-millibar level occur over most of the United States. Only the state of Alaska, with winds ranging from 40 to 50 meters per second, has 99 percent extreme winds of a magnitude less than 60 meters per second at this altitude. Moderate reduction may also be found over Hawaii and the tropical islands. On the other hand, the new Kagoshima Space Center in southern Japan lies near the contour for 90 meters per second.

Much lower peak winds are found in the Arctic region, and still lower values are found in the equatorial regions. In addition, a large area of central Asia exhibits peak winds much lower than other midlatitude areas. These lower peak winds suggest that lower vehicle loads would be imposed on vehicles launched from central Asia.

The patterns of the 99 percent winds at the 200-millibar level (altitude of about 12 kilometers) are illustrated in figure 2. The patterns are generally similar to those found at 300 millibars. The maximums over north Africa, Arabia, and Japan are slightly higher, and the maximum over the Unites States is slightly lower than at the 300-millibar level. Reduced peak winds are again found in arctic and tropical regions and in central Asia.

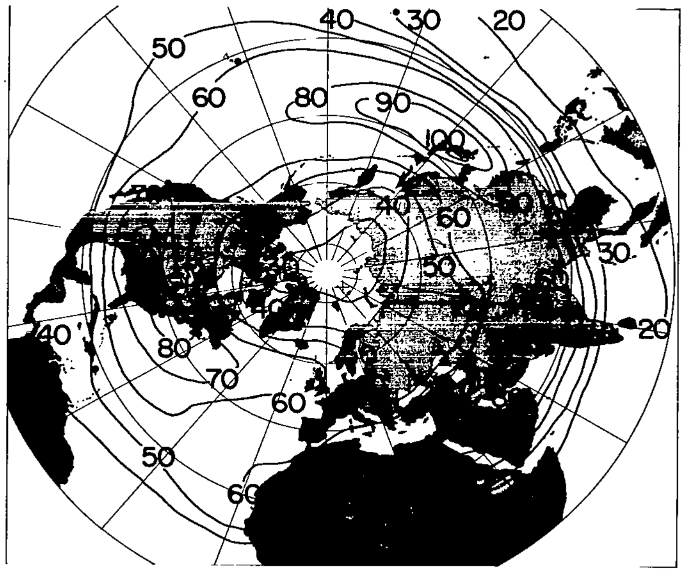

Figure 2.- Isotachs of 99 percent wind velocity components in direction of mean wind, meters per second, during winter season at 200 millibars (approx. 12 km).

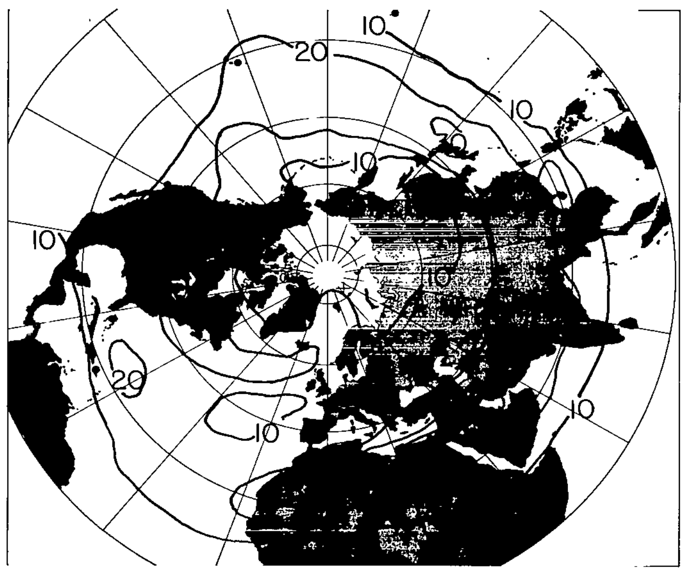

Figure 3.- Isopleths of wind difference, meters per second, representing 99 percent winds at altitude differences between 9.2 kilometers minus 5.6 kilometers.

As indicated previously, the variations of wind shear with geographical regions may be of significance to vehicle loading, and an area of low peak wind could still have regions of high shears. The maximum wind shear values are usually determined from an altitude interval abutting and below the altitude of the peak wind, that is, in the range of about 6 to 9 kilometers. Since the wind data needed to compute accurate maximum wind-shear values over the entire Northern Hemisphere are not available, geographical wind-shear patterns in the region of about 6 to 9 kilometers will be indicated by differences between the 99 percent extreme wind at the 500-millibar and 300-millibar levels. Points of constant wind speed difference are connected to form isopleths as is shown in figure 3.

These isopleths of wind difference follow closely the isotach patterns of figures 1 and 2. The highest wind differences – 30 meters per second or higher – occur over Japan and northern Africa. A region of wind differences of 20 meters per second or above occurs in the mid-latitude regions over all of the continental land masses of the Northern Hemisphere. The extreme equatorial and polar regions have wind differences of 10 meters per second or less. Belts of wind differences from 10 to 20 meters per second exist over the most southern and northern areas of North America and extend to cover large portions of northern Asia.

STATISTICAL WIND PROFILES

Assumptions for Constructing Profiles

As a supplement to the foregoing information on wind speed and shear for given geographical regions, more detailed examination of specific sites was made by utilizing complete statistical wind profiles. A digital-computer program was written to facilitate calculations in which the technique for constructing statistical profiles in reference 6 was used. These profiles are constructed to represent, for some reference or "key level," the most severe wind and wind shear conditions expected in some given large percentage of cases such as the 95 or 99 percent wind. The key level (altitude of peak wind) may correspond to a critical region in the trajectory of a particular vehicle such as the transonic region of maximum dynamic pressure, or profiles may be constructed for several key levels in the region of high winds.

The choice of specific sites for this study was restricted to areas where the presently available samples of wind data (rawinsonde) were large enough to permit statistical treatment. Since this study is concerned only with the general patterns of the most extreme wind conditions, the seasonal statistics with the highest key-level winds are selected to compute profiles. Thus, this criterion means that only the worst possible conditions at each site were contrasted. For example, a March profile which was derived from the most severe key-level winds during the year above one site is compared with the profile at a different site computed from the most severe key-level wind, even though the key-level wind at the second site may have occurred in a different month.

The single large peak associated with the key level of these profiles is characteristic of synthetic profiles. The altitude of the peak wind has been shifted in some cases so that all peaks coincide and fall at the same altitude level. The profiles of this study have been confined to the zonal (west-to-east) plane in order to be consistent in generating extreme loading conditions. (The strongest winds usually prevail from a westerly direction and maximum simulated vehicle loading results from flying a pitch plane profile.)

Profiles for Existing United States Launch Sites

Figure 4 shows the zonal statistical profiles for the 99 percent wind and a key level of 10 kilometers necessary for "anywhere-anytime" design at four U.S. launch sites. Cape Kennedy, Florida, is the only site for which sufficient wind data have been collected directly at the site (ref. 7) to enable profile construction. Wallops Island, Virginia, data (ref. 8) and White Sands, New Mexico, data were approximated from data[1] from locations

[1]These data were obtained from the U.S. Weather Bureau-Sandia Corporation Cooperative Project in Climatology, Sandia Corp.,Dept.5120.

in close proximity to each site. Santa Maria, California, data (ref. 7) are used for the Western Test Range. The widely separated locations of these sites reveal the degree of geographic variation in winds that might be expected to occur within the United States. The magnitude of the peaks and an approximate shear value for the 2-kilometer interval below the peak wind are presented in table I. (The reader is cautioned against using this shear value as a precise number, since the value may differ from values obtained by empirical methods as in ref. 9.) From table I, it can be seen that Wallops Island winds are expected to be more severe than the winds above Cape Kennedy. White Sands winds are more moderate, whereas the expected peaks at the Western Test Range are between 40 and 50 percent of those at Cape Kennedy.

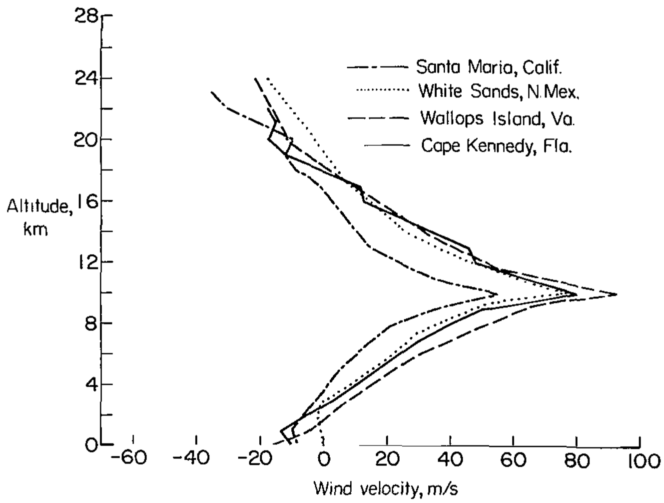

Figure 4.- Statistical-model profiles of west-to-east component of 99 percent winds for a key level of 10 kilometers at four launch sites.

For nonmilitary launch vehicles, many designers use profiles for the 95 percent wind (preferring to accept a 5 percent probability of schedule postponement in exchange for increased performance and payload capability as discussed in ref. 6). In figure 5, the profiles for the 95 percent wind are presented for the same key level and the same

TABLE I.- WIND VELOCITY AND WIND SHEAR VALUES FOR THE ZONAL WIND COMPONENT AT SEVERAL U.S. LAUNCH SITES

Geographical site	Probability, percent	Maximum wind velocity, m/s, for key level of:		Wind shear, sec^{-1}, in interval from:	
		10 km	12 km	8 to 10 km	10 to 12 km
Cape Kennedy,	95	65.3	72.1	0.015	0.016
Fla.	99	81.0	88.0	.022	.023
Wallops	95	75.8	73.6	0.014	0.014
Island, Va.	99	93.2	90.2	.019	.018
White Sands,	95	60.4	61.4	0.015	0.013
N. Mex.	99	76.8	77.3	.018	.019
Santa Maria,	95	42.7	42.8	0.012	0.010
Calif.	99	55.4	54.8	.018	.016

four sites of figure 4. It is seen that the general relationships and shapes of the profiles have been preserved. Only the magnitudes of the peaks appear reduced. Figures 6 and 7 show that a 2-kilometer change in key level to about 12 kilometers had little effect on the relative positions of the profiles for the 99 and 95 percent winds. Notice that the sharpness of the shear spike varies with a change in key level. Some of the information on peak wind and approximate shears from these figures is summarized in table I.

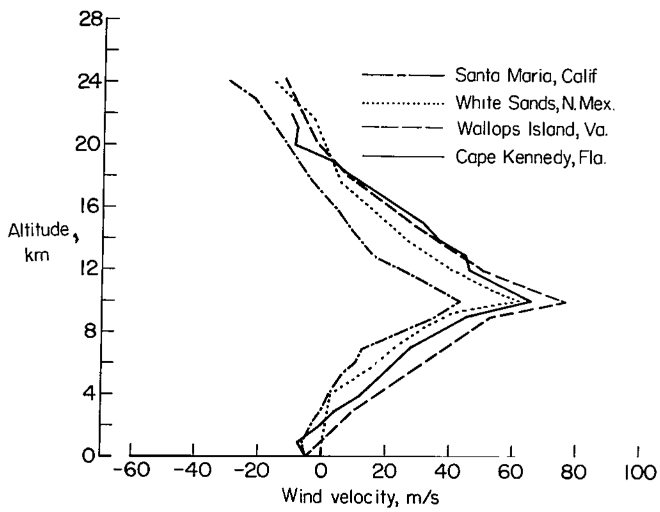

Figure 5.- Statistical-model profiles of west-to-east component of 95 percent winds for a key level of 10 kilometers at four launch sites.

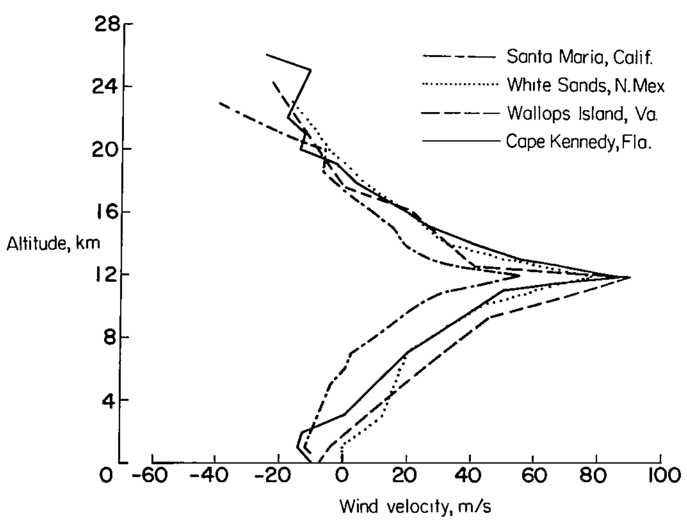

Figure 6.- Statistical-model profiles of west-to-east component of 99 percent winds for a key level of 12 kilometers at four launch sites.

Profiles for Selected Sites in the Northern Hemisphere

Inasmuch as figures 1, 2, and 3 indicate that the wind speeds and wind shears are of considerably lower magnitudes over equatorial and arctic regions than in midlatitude regions of the Northern Hemisphere, statistical wind profiles were constructed for given northern and southern locations for comparison with the profiles of figures 4 to 7. Albrook Air Force Base, Panama Canal Zone, and Kwajalein, Marshall Islands, were chosen for equatorial sites and Point Barrow, Alaska, was chosen as an arctic site.

The profiles for the 95 and 99 percent winds at Albrook Air Force Base (data from ref. 7) are given in figure 8 for a key level of 10 kilometers. The corresponding Cape Kennedy profiles have been added for comparison. It may be noted from this figure that in contrast to the moderate-to-severe profiles at existing launch sites, the Albrook profiles have much smaller shear spikes. The 99 percent wind at Albrook is about 40 percent of the 99 percent wind at Cape Kennedy. Figure 9 shows a similar reduction in shear spikes when the key level is 12 kilometers. Peak winds and approximate shears from figures 8 and 9 are presented in table II.

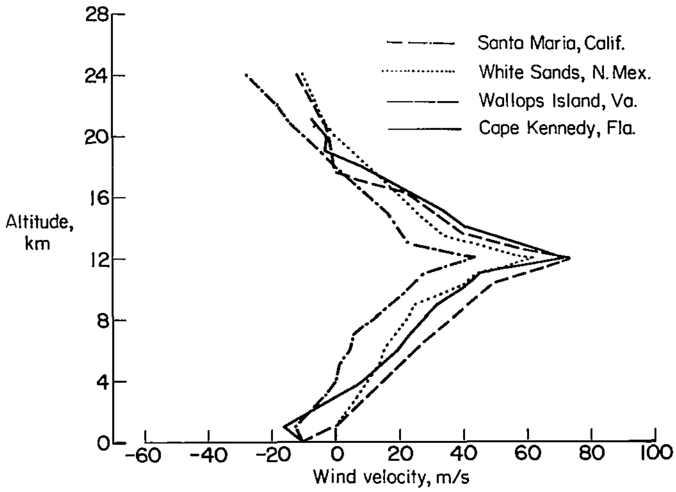

Figure 7.- Statistical-model profiles of west-to-east component of 95 percent winds for a key level of 12 kilometers at four launch sites.

The profiles for the 95 and 99 percent winds at Kwajalein are given in figure 10. The wind data used in constructing the profiles were taken from electronic computer tabulations (1958) furnished by the Climactic Center, Air Weather Service. The interest in the 99 percent profile at this location is stimulated by the fact that military launch and testing facilities exist at Kwajalein. A most noticeable difference is that the 99 percent peak at Kwajalein is considerably less than the same statistical wind over Cape Kennedy and much of the continental United States. Table II summarizes the relevant peaks and shears for this profile.

In figure 11, 95 and 99 percent profiles at Point Barrow, also from the Air Weather Service tabulations, are plotted along with reference Cape Kennedy profiles. The 99 percent peak and the 95 percent peak at Point Barrow are about 47 and 43 percent, respectively, of the corresponding Cape Kennedy peaks. By again allowing the key levels

TABLE II.- WIND VELOCITY AND WIND SHEAR VALUES FOR THE ZONAL WIND COMPONENT AT VARIOUS LOCATIONS IN THE NORTHERN HEMISPHERE

Geographical site	Probability, percent	Maximum wind velocity, m/s, for key level of:		Wind shear, sec^{-1}, in interval from:	
		10 km	12 km	8 to 10 km	10 to 12 km
Albrook,	95	24.8	31.1	0.012	0.014
Panama Canal Zone	99	33.1	41.0	.017	.020
Kwajalein,	95	24.0	29.0	0.010	0.007
Marshall Is.	99	32.0	38.0	.014	.010
Point Barrow,	95	28.3	26.8	0.007	0.008
Alaska	99	37.7	35.0	.010	.011

to be shifted to 12 kilometers as shown in figure 12, the same small shear spike appears at Point Barrow. The peaks and shears from these profiles are also included in table II.

Although the wind profiles in this section have been used to suggest areas of possible low wind loading, figures 1, 2, and 3 could similarly be used to indicate areas of severe wind loading. This latter use is important to military vehicle systems for "anywhere-anytime" evaluation. Several wind studies (ref. 1) have successfully established severe design loads for such military vehicles, but the fact remains that many of the vehicle prototypes are evaluated and reliability confirmed in areas of possible low wind loading. This means, for example, that a Pacific test area (such as Kwajalein) may not be adequate for testing some vehicle types.

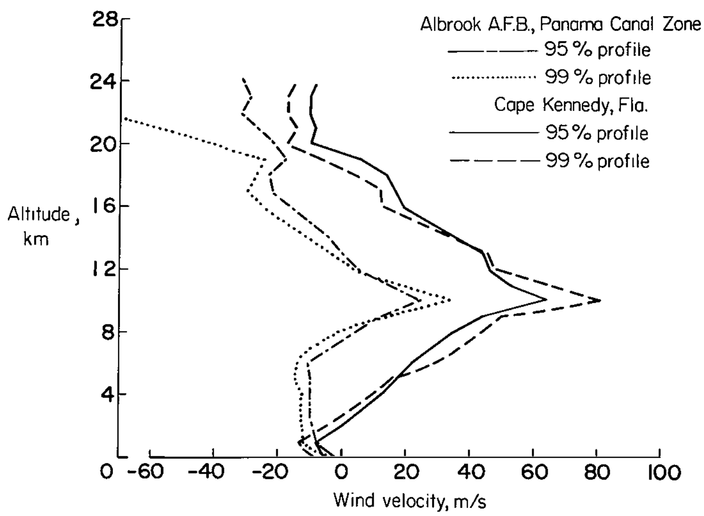

Figure 8.- Statistical-model profiles of west-to-east component of 95 percent and 99 percent winds for a key level of 10 kilometers at Albrook Air Force Base and Cape Kennedy.

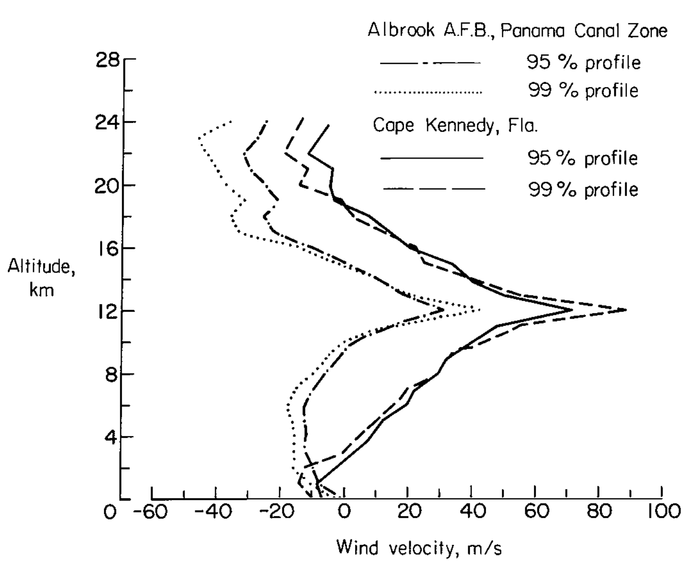

Figure 9.- Statistical-model profiles of west-to-east component of 95 percent and 99 percent winds for a key level of 12 kilometers at Albrook Air Force Base and Cape Kennedy.

WIND LOADS

Wind Load Histories for Selected Sites in Northern Hemisphere

The significance of the geographical differences in winds discussed in the previous section can best be judged by comparing the responses of simulated vehicle flights through 10-kilometer and 12-kilometer statistical profiles. For this comparison, the rigid-body, pitch-plane bending-moment responses of a large liquid-propellant vehicle have been calculated by a digital computational method developed at the Langley Research Center (ref. 10). The vehicle motion is referenced to a body-fixed Cartesian coordinate system. Aerodynamic forces are computed by using either slender-body momentum coefficients or quasi-steady coefficients. Control forces are produced by thrust vectoring or a movable fin. The control system equation included the following types of feedback: (1) attitude, (2) attitude rate, (3) angle of attack, and (4) acceleration.

The resulting bending moments in newton-meters as a function of altitude in kilometers are plotted in figure 13 for each of the four sites previously selected for study, namely: Cape Kennedy, Albrook, Point Barrow, and Kwajalein. The histories of figure 13 were calculated from 10-kilometer key level, 95 percent profiles. For each site the largest negative values of bending moment occur near the altitude of peak wind and quickly change to positive values as wind shear reverses. Maximum peak bending moments resulted for the Cape Kennedy profile. The Albrook load history has the same broad outline as the load history at Cape Kennedy but less severe maximums. The effect of the low wind speed at Albrook was partially neutralized by the more severe wind shear. The values of bending moment at Kwajalein and Point Barrow indicate the reduced loading resulting from reduction in both wind speed and wind shear. An analysis of the load histories from 95 percent wind profiles at a key level of 12 kilometers (not shown) showed similar results.

Table III summarizes (for the 95-percent wind) maximum winds, maximum positive shears, and maximum negative bending-moment response in terms of the ratio of these quantities at Albrook, Point Barrow, and Kwajalein to the values at Cape Kennedy. As noted earlier, these statistical shear values are only approximate. Nevertheless, the ratios of approximate shears (derived from the

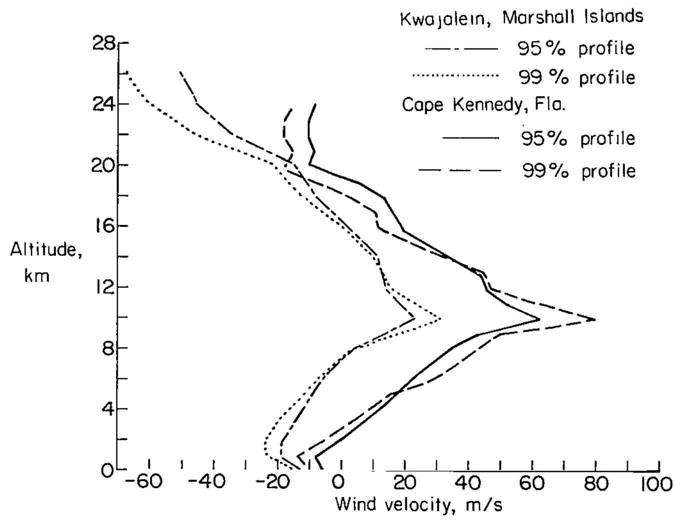

Figure 10.- Statistical-model profiles of west-to-east component of 95 percent and 99 percent winds for a key level of 10 kilometers at Kwajalein and Cape Kennedy.

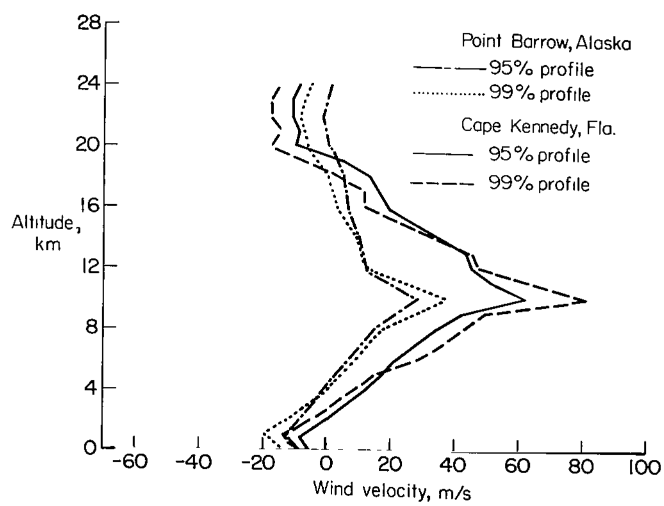

Figure 11.- Statistical-model profiles of west-to-east component of 95 percent and 99 percent winds for a key level of 10 kilometers at Point Barrow and Cape Kennedy.

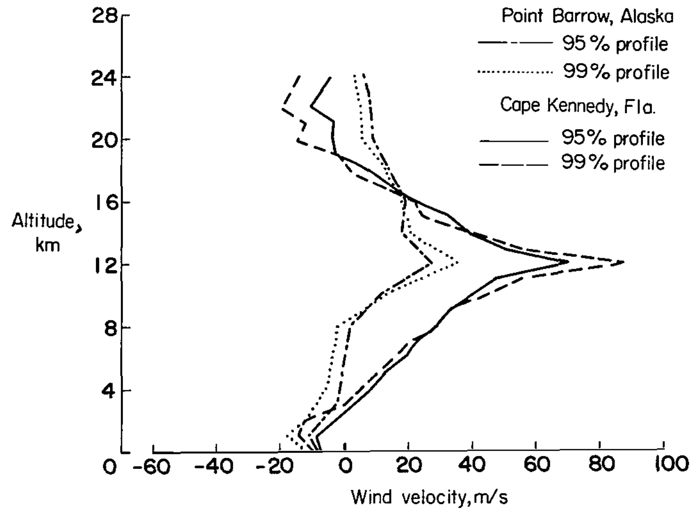

Figure 12.- Statistical-model profiles of west-to-east component of 95 percent and 99 percent winds for a key level of 12 kilometers at Point Barrow and Cape Kennedy.

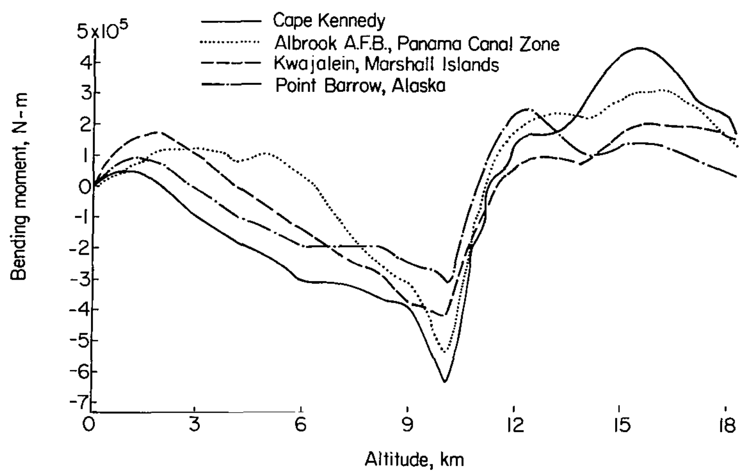

Figure 13.- Bending-moment load as a function of altitude computed from profiles of 95 percent winds for a key level of 10 kilometers for four geographical areas.

2-kilometer region immediately below the altitude where the peak wind occurs) appear to be far more accurate predictors of the load ratios at each site than the ratios of wind magnitudes. The best estimates, however, would take into account both wind speed and wind shear ratios.

For the vehicle chosen for this study, such load studies indicate that a Point Barrow launch site would reduce the expected bending moment for a 95 percent wind by about 50 percent below Cape Kennedy's.

It should be stressed that table III and the preceding discussion are applicable only for a specific vehicle configuration. A similar study would have to be made for each vehicle configuration to determine whether or not wind speeds or wind shears accurately predict the wind loads on the vehicle.

Effects of Launch Altitudes on Vehicle Loads

Some geographical areas such as the region near Quito, Ecuador, provide the possibility of launching a vehicle from heights far above sea level. Figure 14 shows the dynamic pressure histories from simulated vehicle flights through typical equatorial profiles beginning at sea level and the altitudes of 1.5 kilometers (5,000 ft), 3 kilometers (10,000 ft), and 4.5 kilometers (15,000 ft). The same profile for 95 percent wind at a key level of 10 kilometers at Albrook Air Force Base (shown in fig. 8) is used to approximate all four cases. The initial value for the wind speed for each altitude is obtained by instantaneously increasing the wind speed to the values at

TABLE III.- RELATIONSHIPS BETWEEN THE ZONAL WIND COMPONENT AND VEHICLE LOADINGS FOR VARIOUS LOCATIONS IN THE NORTHERN HEMISPHERE

Geographical site	Key level, km	Ratio of maximum positive velocity to that at Cape Kennedy from 95 percent wind	Ratio of shear in 2-km region below peak wind to that at Cape Kennedy from 95 percent wind	Ratio of maximum negative bending moment to that at Cape Kennedy from 95 percent wind
Albrook,	10	0.38	0.82	0.85
Panama Canal Zone	12	0.43	0.86	0.86
Kwajalein,	10	0.37	0.64	0.65
Marshall Is.	12	0.41	0.58	0.59
Point Barrow,	10	0.43	0.44	0.50
Alaska	12	0.37	0.48	0.52
Cape Kennedy,	10	1.00	1.00	1.00
Fla.	12	1.00	1.00	1.00

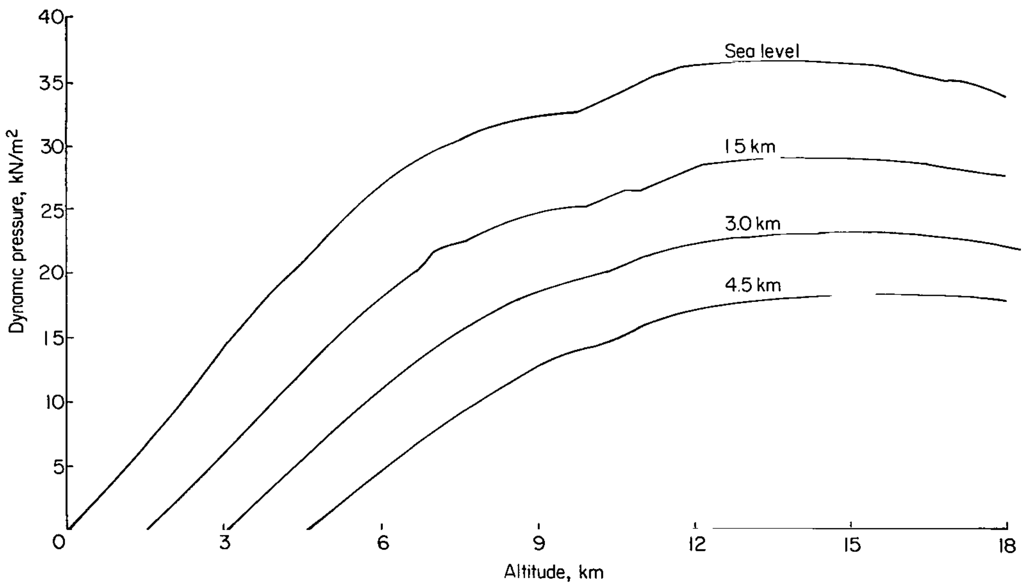

Figure 14.- Dynamic pressure as a function of altitude computed from profiles of 95 percent winds for a key level of 10 kilometers for four different launch altitudes.

1.5 kilometers, 3 kilometers, and 4.5 kilometers to obtain three different cases for launch altitude studies. Lower portions of the profiles were truncated. The same prescribed pitch command was used for each high-altitude launch; however, additional launches with a vertical flight path produced similar results.

Several of the important vehicle loading parameters such as the atmospheric density and the velocity of the vehicle are very different during the early stages of flight for the four launch altitudes of figure 14. These effects are reflected in the shifts of the dynamic-pressure curves with altitude of launch. However, all four curves are of the same general shape. (The slow increase of dynamic pressure on the rising vehicle in each case reflects a steady increase of vehicle velocity and a steady decrease in atmospheric density during the early stages of the vehicle flight.)

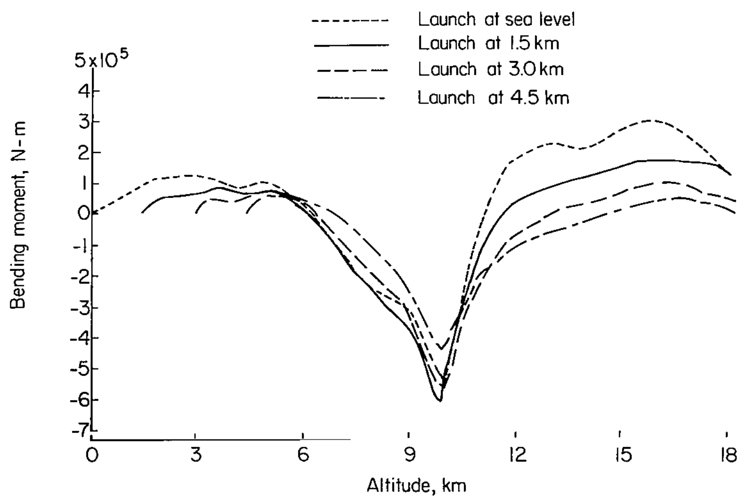

Figure 15.- Bending-moment load as a function of altitude computed from profiles of 95 percent winds for a key level of 10 kilometers for four different launch altitudes.

The bending-moment responses as a function of altitude are plotted for these four launch altitudes in figure 15. The magnitude of the maximum bending moment is only slightly reduced for launch at altitudes of 1.5 kilometers and 3 kilometers. This result is primarily due to an increase in the rigid-body angle of attack, which offsets the effect of reduced maximum dynamic pressure. For launch near 4.5 kilometers, the reduced maximum dynamic pressure is the dominating factor, and the maximum bending moment is notably less than that resulting from a sea level launch. The peaks in bending moment for each curve in figure 15 occur near 10 kilometers and reflect the wind shear spike at this altitude.

CONCLUDING REMARKS

The results of the present study show that there may be very significant variations of the wind loading on a particular vehicle with geographical location. The variation in bending moment with launch altitude was much less significant. The importance of the location factor suggests that the wind environment of possible launching sites should be, if possible, studied before the choice of launching site is made rather than first choosing a launch or test area and then examining the wind in detail. This study also indicates that consideration of potential launch sites for space vehicles should not be limited to the 48 adjacent states of the United States. The design procedures for launch vehicles should involve careful consideration of the needs for a particular mission as related to the wind environment of potential launch sites.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 28, 1965.

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NASA-Langley, 1966 L-4265

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