WIND AND GUST DESIGN CRITERIA FOR THE MARTIAN ATMOSPHERE

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Presented at the Third National Conference
on Aerospace Meteorology

New Orleans, Louisiana
May 6-9, 1968

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INTRODUCTION

The effects of winds and gusts have been of concern since the earliest days of aviation. With the advent of space travel, winds and gusts in the atmospheres of planets other than Earth also become of interest. Winds and gusts are major inputs to the design of vehicles operating in the atmosphere of Earth and similar inputs are needed for spacecraft which enter the atmospheres of Mars, Venus, or other planets. The purpose of this paper is to explore the problems associated with the specification of wind and gust values for early design work for the atmosphere of Mars.

SYMBOLS

g	acceleration of gravity, m/sec
H_ρ	density scale height, km
Ri	Richardson number, nondimensional
Ri_{local}	local Richardson number, nondimensional
T	absolute temperature, ^oK
Z	altitude, km
Γ	adiabatic lapse rate, $^oK/km$
ρ	density, kg/m^3

Subscripts:

E	Earth
M	Mars

DESIGN CONSIDERATIONS

For the Earth's atmosphere, wind and gust design inputs are needed primarily for the ascent, or exiting, phase of flight, with entry winds of secondary interest from a design viewpoint. For early Mars flights, interest centers on the entry phase, partly because early missions will probably not attempt return flight, but also because of differences in the mission requirements, and in the types of vehicles under consideration.

For the Earth's atmosphere structural loads and control disturbances form the principal design requirements. For Mars, desired entry experiments add significant additional requirements to those imposed by structures and control systems. These requirements are particularly critical with regard to television or other imaging techniques, where accurate pointing control is required for interpretation and where rotation rates may cause smearing of the image. Antenna pointing and rotation are also important to radar instrumentation used for either guidance or scientific instrumentation, and angle-of-attack disturbances may affect many measurements.

In addition, the type of vehicle used for the Martian entry may be quite different from the exiting vehicles for which most Earth atmosphere criteria have been formulated. Two principal types of entry systems have been considered - either a retropropulsion system of the type used in Surveyor Moon landings, or a parachute or other aerodynamic decelerator. Any design criteria to be used in early design work should be applicable to either type of system. For the retrosystem, the magnitude of an applied gust is of great importance but the rate of gust buildup may be less important. For the aerodynamic decelerator, the rate of change is most important and the magnitude may be less important. For general use, gust criteria must specify both of these parameters along with some measure of the gust length which may be important to either system.

MARTIAN DATA

Wind data for Mars is notable principally for its absence. The only "direct" source of data is the observation of cloud movement through Earth based telescopes. Many years of cloud observations were cataloged by Gifford,[1] and form the basis for most wind estimates. It should be noted that, at best, these represent rather large-scale average winds, and that independent estimates for the same periods by

Gifford and by deVaucouleurs[2] differ by as much as a factor of four, indicating the difficulty involved in tracing these cloud movements.

Another source of large-scale wind estimates is the use of physical or mathematical models of the Martian atmospheric circulation. One of the most complete models is that of Mintz and Leovy[3]. A less elaborate model by Bates[4] yields estimates of mean circulation with greater vertical detail which is needed for vehicle response studies.

All of these sources combine to give a reasonably consistent picture of the large-scale wind pattern which permits the establishment of design criteria either on an overall basis as in reference 4 or by individual seasons, as in reference 3. In contrast, there are simply no data at all for application to the small-scale or "gust" component of the winds.

APPLICABILITY OF EARTH ANALOGY

In the absence of Martian data, the only recourse appears to be the use of Earth analogies. The question arises as to whether such values would represent conservative design values. In this connection, it is of interest to examine the relative values of wind shear corresponding to the same value of Richardson number in the two atmospheres. The wind shear is an important value for vehicles of the types under consideration, and maximum shears are thought to be controlled by the occurrence of a critical value of Richardson's number. Richardson's number is defined (ref. 5) by

$$\mathrm{Ri} = -\frac{\frac{g}{T}\left(\Gamma + \frac{\partial T}{\partial z}\right)}{\left(\frac{\partial V}{\partial z}\right)^2} \tag{1}$$

and for equal Richardson number in the two atmospheres we must have

$$\left(\frac{\partial V}{\partial z}\right)_M = \left(\frac{\partial V}{\partial z}\right)_E \sqrt{\frac{g_M}{g_E}\,\frac{T_E}{T_M}\,\frac{\Gamma_M + \left(\frac{\partial T}{\partial z}\right)_M}{\Gamma_E + \left(\frac{\partial T}{\partial z}\right)_E}} \tag{2}$$

or, substituting reasonable numerical values:

$$\left(\frac{\partial V}{\partial z}\right)_M = \left(\frac{\partial V}{\partial z}\right)_E \sqrt{\frac{3.75}{9.81} \times \frac{220}{85} \times \frac{4.8 + \left(\frac{\partial T}{\partial z}\right)_M}{10 + \left(\frac{\partial T}{\partial z}\right)_E}} \tag{3}$$

On Earth the largest values of shear are usually encountered just above the tropopause where $\partial T/\partial z$ is commonly near zero. For isothermal lapse rates in both atmospheres, equation (3) becomes

$$\left(\frac{\partial V}{\partial z}\right)_M \approx 0.7\left(\frac{\partial V}{\partial z}\right)_E \tag{4}$$

and in general the highest shears expected for Mars would be slightly lower than those expected for Earth with the same lapse rate. The highest values of $\partial T/\partial z$ (the strongest inversions) in the Earth's upper atmosphere accompany ozone or atomic oxygen layers, and only very small amounts of these constituents are expected in the atmosphere of Mars.

Another criterion for the stability of a shear layer is the so-called local Richardson number. The local Richardson number is defined by

$$\mathrm{Ri}_{\mathrm{local}} = \frac{-\frac{g}{\rho}\frac{\partial \rho}{\partial z}}{\left(\frac{\partial V}{\partial z}\right)^2} \tag{5}$$

The expression $-\frac{1}{\rho}\frac{\partial\rho}{\partial z}$ is the reciprocal of the density scale height H_ρ so

$$Ri_{local} = \frac{g}{H_\rho\left(\frac{\partial V}{\partial z}\right)^2} \tag{6}$$

Assuming that the critical value of local Richardson number is the same for the atmospheres of both planets, we can solve for the shear in the Martian atmosphere:

$$\left(\frac{\partial V}{\partial z}\right)_M = \left(\frac{\partial V}{\partial z}\right)_E\sqrt{\frac{g_M}{g_E}\frac{H_{\rho M}}{H_{\rho E}}} \tag{7}$$

using typical values for Earth and Mars

$$\left(\frac{\partial V}{\partial z}\right)_M = \left(\frac{\partial V}{\partial z}\right)_E\sqrt{\frac{3.75}{9.81}\frac{6 \text{ to } 10}{5.5 \text{ to } 25}} \tag{8}$$

for altitudes below 75 km. Taking the worst combination, the critical shears are related by

$$\left(\frac{\partial V}{\partial z}\right)_M \approx 0.8\left(\frac{\partial V}{\partial z}\right)_E \tag{9}$$

From the considerations above, it appears that critical values of wind shear in the Martian atmosphere are slightly lower than for the Earth's atmosphere, and therefore wind-shear criteria based on Earth atmosphere values will be appropriate for the Martian atmosphere.

EARTH DATA

Even though it appears that Earth data may be suitable for use in formulating criteria for Mars, it is not appropriate to simply apply Earth criteria to Mars entry vehicles for several reasons. As indicated earlier, the vehicles concerned are quite different and the mission requirements also differ from the Earth case. Further, because they were designed for ascending vehicles, many Earth criteria are concerned primarily with the wind speed relative to the planet surface, which may be of relatively small importance to the entering vehicle. Finally, many of the recent treatments for the Earth's atmosphere employ a degree of sophistication which can hardly be justified in the case of the Mars atmosphere.

Because of the nature of the missions and of the candidate systems, the most important parameter to be specified is the wind shear or gust gradient. The shape, length, and magnitude of the gust must also be specified, but for the present case are subordinate to the gradient or shear.

While extreme values of wind shear encountered in the Earth's atmosphere vary with the distance across which they are measured (the thickness of the shear layer), it does not appear reasonable to include such variation in Mars criteria, and a simple triangular or trapezoidal shape gust is recommended, with a constant magnitude of shear for both the increasing and decreasing portion of the gust.

Extreme values of shear are difficult to determine for small layer thicknesses because small errors in position or velocity produce large errors in shear. Data from a wide variety of sources (ref. 6) indicate extreme shears of 0.09 meter per second per meter for 100-foot layers with smaller values for thicker layers. Examination of approximately 200 smoke-trail measurements made by the Langley Research Center (refs. 7 to 10) indicate that even for smaller thicknesses the maximum shear values are about 0.1 meter per second per meter except for a few cases which are supported by only a single data point at each end of the layer. Even if these higher values are real, they have a very low probability of occurrence, and, in addition, represent very thin layers which would have a limited effect on entering systems.

The values above refer to wind changes along the vertical in stable shear layers, which are felt as gusts by the entering system. It is also of interest to consider wind-shear values occurring in unstable or turbulent situations. Wind-shear measurements are not usually made in turbulence research, and, in fact, values in clear-air turbulence are generally too low to measure accurately. Figure 1 (taken from ref. 11) shows an extreme case of shear during a thunderstorm flight. The value of the shear here is about 0.2 meter per second per meter, over a distance of about 600 feet. While this shear value is about twice the value found for stable shear layers, such high values have been found only in thunderstorm turbulence. Figure 2, also taken from reference 11, indicates that the intensity of clear-air turbulence is only about one-fourth of the intensity of thunderstorm turbulence, suggesting maximum shear values of around 0.05 meter per second per meter.

Examination of the smoke-trail data mentioned earlier indicates that the largest individual shear layers or "gusts" have a magnitude of about 20 meters per second, and this value is recommended as a criterion for the Mars atmosphere. This value is equal to the highest value used for Earth atmosphere criteria. Coincidentally, it is approximately equal to the current airplane gust criterion although the values are not strictly comparable.

The remaining values to be specified are the gust length and the point of application in the trajectory. In the absence of any appropriate data for the Martian atmosphere, it is recommended that these be chosen so as to produce the maximum effect for the system under consideration.

GUST CRITERIA

Final design criteria for any system must be selected in light of the characteristics of the particular system, the specific mission requirements, and the degree of risk which is acceptable. Much preliminary design work, however, must be done using generalized design criteria. Such general criteria are also useful for comparing different types of systems, and can serve as a basis for specialized criteria. The criteria in the following paragraphs are intended for general use and for preliminary design work.

These gust criteria are intended to be superimposed on a profile of large-scale or mean winds.

Gust Shape

The gust shall consist of a linear increase with altitude from the mean wind to the maximum value, followed by a constant velocity portion, followed by a linear decrease to the mean wind value as shown in figure 3.

Gust Gradient

The rate of increase and decrease with altitude (shear) shall be 0.1 meter per second per meter.

Gust Magnitude

The magnitude of the increase in velocity in the gust shall be 20 meters per second.

Gust Length

The length or altitude extent shall be chosen to produce a maximum disturbance to the system being designed. For shorter gust lengths which do not allow the stated gust magnitude to be reached at the stated gust gradient, a triangular gust having the stated gust gradient and a reduced gust magnitude shall be used as shown in figure 4.

Point of Application

The gust shall be applied at the point or points in the trajectory where the effects are most critical. Consecutive or repeated gusts will not be considered.

CONCLUDING REMARKS

Although some data exist for use in formulating mean wind criteria there are no data available for direct application to "gust" criteria.

Richardson number considerations indicate that Martian gust criteria can be appropriately based on Earth atmosphere data.

For the types of vehicle and missions expected for early Mars flights, the wind shear or gust gradient is an important parameter and requires specification in the gust criteria.

A simple gust criteria using a trapezoidal or triangular shape with a specified gradient is proposed for preliminary design work. Final design work may require modification to satisfy particular mission requirements.

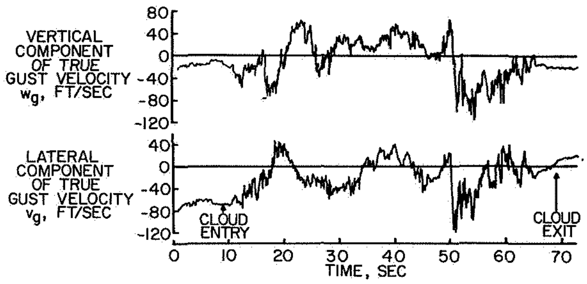

Figure 1.- Time histories of vertical and lateral components of true gust velocity for a thunderstorm traverse.

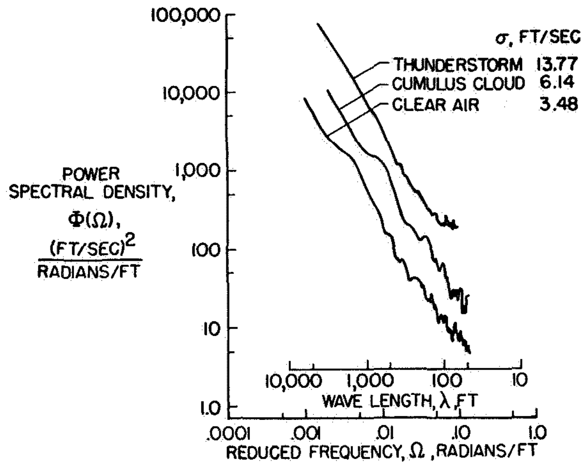

Figure 2.- Typical power spectra for three weather conditions.

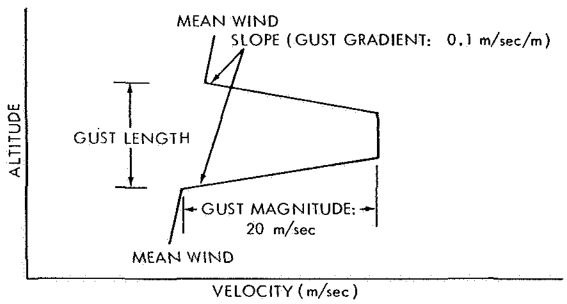

Figure 3.- Basic gust shape for Martian atmosphere.

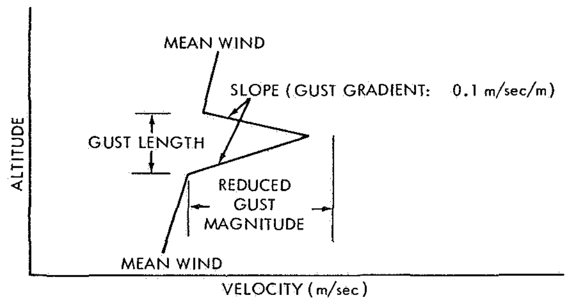

Figure 4.- Modified gust shape for Martian atmosphere for use with short gust length.

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