Global Reference Atmospheric Model for Aerospace Applications

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Theme

IT has been recommended[1] that range reference atmospheres for the launch site be used for the ascent of the Space Shuttle, that the U.S. Standard Atmosphere 1962 be used for nominal trajectory and aerodynamic heating for the Shuttle Orbiter re-entry, and that the density perturbation model[2] be used to account for re-entry phase variations. Smith et al. also pointed out that as shuttle design studies progressed, improved techniques in the implementation of perturbation models were expected. They established as a goal the development of a so called 4-D model to give pressure, temperature, and density variables and their structure as a function of the three spatial coordinates latitude, longitude, altitude, and the time domain (seasonal and perhaps time of day) over the altitude range from sea level to 185 km. This paper describes an empirical atmospheric model which is a first attempt to meet these goals.

Contents

This empirical model combines the previously developed Jacchia[3] model for above 115 km, the 4-D model[4], for below 25 km, and a newly developed latitude-longitude dependent model, which is an extension of the Groves[5] model for the region between 30 and 90 km. Groves original model consisted only of height and latitude-dependent zonal mean (i.e., averaged over longitude) values, Between 90 km and 115 km, a smooth transition between the modified Groves values and the Jacchia values is accomplished by a fairing technique. Between 25 and 30 km, an interpolation scheme is used between the 4-D results and the modified Groves values.

The Jacchia model is made up of a set of analytical equations which can be evaluated at any desired height, latitude, longitude, and time. For the modified Groves and 4-D sections, the empirical monthly mean values are contained on data tapes, and interpolation is used to fill in between the discrete values on tape. On the 4-D tapes, the resolution is 1 km in height and roughly $5° \times 5°$ in latitude and longitude. For the modified Groves section the resolution is 5 km in height, 10° latitude for zonal means, and 20° latitude by 30° longitude for the modification to the zonal means.

In addition to monthly mean values of pressure, density, temperature, and winds, two types of perturbations are evaluated: quasi-biennial and random. The quasi-biennial perturbations in pressure, density, temperature, and winds, empirically determined to be represented by an 870 day period sinusoidal variation, have amplitudes and phases which vary with height and latitude. An analytical technique based on a Markov chain model is used to ensure proper horizontal and vertical correlations of the random perturbations.

Figure 1 shows a ground plot of a "Mission 3" re-entry and return trajectory. Mission 3 has a 104° orbital inclination with

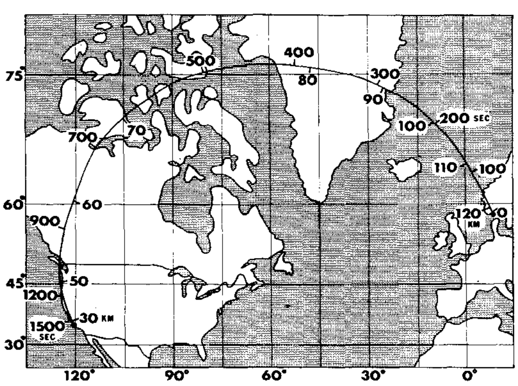

Fig. 1 Ground plot of polar orbit re-entry trajectory.

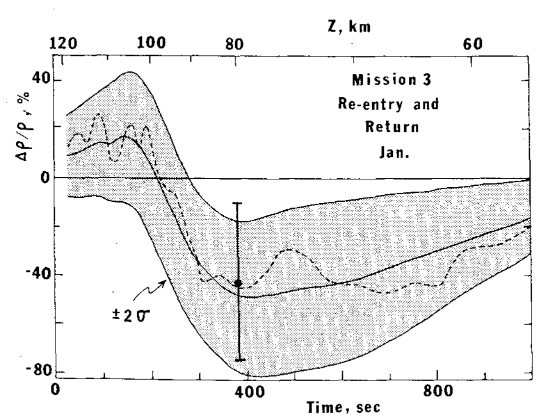

Fig. 2 January density along polar orbit re-entry trajectory.

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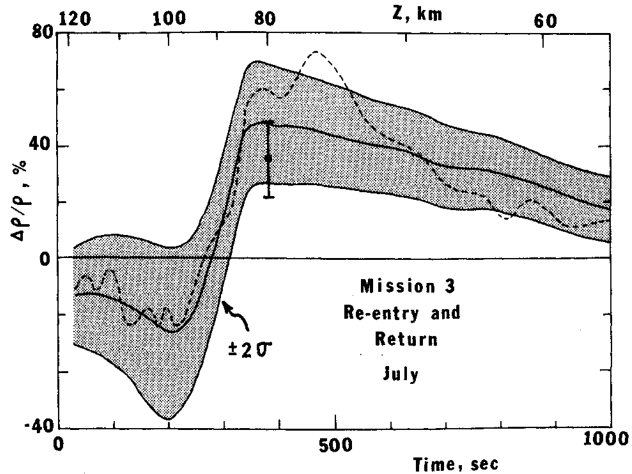

Fig. 3 July density along polar orbit re-entry trajectory.

launch from and return to Vandenburg AFB. The height and time along the trajectory ground plot are also shown in Fig. 1. Figures 2 and 3 show computed density, in percentage deviation from the U.S. Standard Atmosphere, for typical January and July runs to simulate conditions along the return trajectory of Mission 3. The solid lines and shaded areas in Figs. 2 and 3 show the monthly mean and ± 2 standard deviations of the random density perturbations. The dashed lines in Figs. 2 and 3 show typical density profiles of mean plus random components. The data points with error bars at 80 km height show observed mean and ± 2 standard deviations at 80 km above Point Barrow, Alaska,[6] some 5° south and 109° west of the 80 km height point on the trajectory. Notice that the -2σ envelope for the January trajectory in Fig. 3 reaches -80% deviation from the 1962 Standard Atmosphere, while the $+2\sigma$ envelope for the July trajectory reaches a $+70\%$ deviation. Therefore, monthly variations are extremely large for the polar orbit re-entry trajectory. Figures 2 and 3 also show that very large deviations, first positive then negative (or vice versa), could be expected within the $\pm 2\sigma$ limits of variability, even on a single trajectory.

The global reference atmospheric model discussed here, and described more fully elsewhere,[7,8] has been found to be of great value in simulation of mean and perturbation conditions likely to be encountered by vehicles such as the Space Shuttle. It is especially useful for simulation of "data sparse" atmospheric regions such as at high latitudes and at locations which are not well represented by "range reference atmosphere" data.

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