METEOROLOGICAL DATA FROM FALLING SPHERE TECHNIQUE COMPARED WITH DATA FROM OTHER SOUNDING METHODS

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SUMMARY

The objective of the Goddard Space Flight Center's Meteorological Sounding Rocket Program is the launch and operation of sounding rocket experiments for making synoptic global measurements of the physical parameters of the atmosphere between 60 and 150 km and to relate the measurements to those obtained from experiments conducted directly above and below this region. In the pursuit of this objective, approximately 50 soundings per year are made of the stratosphere, mesosphere and lower thermosphere utilizing primarily rocket grenade and pitot-tube experiments. It has been recognized that the falling sphere technique offers some potential advantage over these other techniques in terms of economy and operational flexibility provided that the basic accuracy of the sphere technique can be established and maintained. Opportunities to obtain comparative data have been sought, most recently utilizing a sphere which is deployed from a pod mounted to the tail-fin assembly of a Nike Cajun or Nike Apache rocket carrying either a grenade or pitot-tube experiment. The experiments conducted thus far indicate an average density difference of 3 percent above 70 km where the fall rate of the sphere is supersonic and 8 percent below 70 km where the fall rate is subsonic. The difference above 70 km would appear to be largely random (though the sample is smaller) while below 70 km the sphere yields results which are consistently closer to the standard atmosphere than the results of either the grenade or the pitot-tube experiments.

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INTRODUCTION

The potential advantages of the falling sphere experiment over other techniques for mesospheric and lower thermospheric soundings have been recognized for many years. The sensor cost is small when compared with payload instrumentation required to conduct grenade or pitot-tube experiments. The small volume and weight required permit the consideration of a less expensive rocket delivery system. The simplicity of the airborne portion of the system would mean an inherently reliable system. In spite of these potential advantages, the sphere system has not been widely incorporated as a tool in NASA's research program owing largely to the fact that we have not yet developed confidence in the accuracy or the repeatability of the sphere experiment. For the past decade, we have attempted to obtain comparative data either through the nearly simultaneous launch of sphere and other payloads, through the deployment of spheres from grenade payloads, or most recently through the use of a "strap-on" sphere pod which is positioned on the tail-fin assembly of a rocket carrying another experiment. The results of the earlier work have been reported by Jones and Peterson (ref. 1).

The "strap-on" version of the sphere experiment is an inflatable, 26-inch-diameter mylar sphere. It is carried aloft on a Nike Cajun or Nike Apache rocket and, during the ascent portion of the flight, is housed in a cylindrical pod which is about $1\frac{3}{4}$ inches in diameter and about $23\frac{1}{2}$ inches long. The mounting arrangement is shown in figure 1. Each pod (two are required to balance the aerodynamic drag) is capable of housing a sphere, an ejection system, a timer, and a power supply. Thus the entire sphere experiment is self-contained, requiring no connections to the payload. The increased aerodynamic drag and weight of the pods degrade the rocket performance by about 10 to 15 percent. Upon reaching the desired time during the flight, the black powder charge in the ejection system is fired and the sphere is expelled rearward out of the pod. The acceleration of the sphere causes the puncture of a small isopentane capsule that releases the gas required to fully inflate the sphere. The radar systems, which up to this point in the flight have been tracking the rocket, are then switched to track the sphere.

During 1968 inflatable spheres were successfully deployed from three rockets carrying grenade experiments, and from one rocket carrying a pitot-tube experiment. The falling sphere experiments and the pitot-tube experiments were performed by the High Altitude Engineering Laboratory and the Space Physics Laboratory, respectively, of the University of Michigan under contract with GSFC. These combined experiments (one in February, two in July and one in November) were conducted from Wallops Island and utilized either FPS-16 and/or FPQ-6 radar systems in order to track the spheres. In each case the grenade or pitot-tube experiment was conducted on the upleg of the trajectory and the sphere experiment primarily on the downleg of the trajectory. Thus, the time elapsed between the sphere and other measurements is reduced to a few minutes (on the order of 3 minutes at 100 km, lengthening to about 15 minutes at 30 km). Heretofore, the temporal variation in the atmospheric parameters, in all but a few cases, has been an uncertain factor in comparisons of two or more techniques.

RESULTS

The data from the four comparative rocket-borne experiments of 1968 are presented in figures 2, 3, and 4. Figure 2 contains density (in terms of percent of deviation from the 1962 standard atmosphere) versus altitude information. In the first 3 plots of figure 2 the sphere data are compared with data from rocket grenade experiments, while in the 4th plot the sphere data are compared with a pitot-tube experiment. If one takes an average of the absolute value of the difference over the entire height range, one finds that the sphere data agree with those from other techniques within about 6 percent. Further, one finds that the two techniques display different characteristics above and below 70 km. Above 70 km, where both the grenade and pitot-tube error functions are increasing slightly with altitude, the difference between the sphere data and those from other techniques is only about 3 percent. Below 70 km, the average difference between the data from the spheres and the other techniques is about 8 percent. Whereas the 3 percent difference above 70 km appears to be largely random in nature, the 8 percent difference below 70 km appears (within the confidence level that can be obtained with 3 samples) to be biased in a consistent manner. That is, the sphere data consistently show less deviation from the standard atmosphere than do those from the other techniques. Presuming that the data from these experiments are not coincidental, an additional examination of the sphere data handling and reduction appears warranted in an attempt to remove the bias in the subsonic regime, as has apparently been done in the supersonic regime above 70 km.

The density data are used in the falling sphere experiment to derive temperatures. These temperatures are compared with the temperatures measured by the grenade and derived from the pitot-tube experiment in figure 3. Since the sphere temperatures are derived by a differentiation process, the temperature differences do not automatically "track" the density differences. However, the gross features emerge. In the firing conducted on 1 February, the region where the density comparison is very good, naturally, yields the best temperature comparison, an average difference of 4° K. The two firings in July, in which grenade densities are greater than sphere densities, yield sphere temperatures which tend to be higher than the grenade temperatures. The pitot-tube and sphere temperatures are consistent; the pitot-tube densities are lower than the sphere densities, which results in a lower sphere temperature. The average temperature difference between the four experiments conducted is 7° K.

The zonal and meridional components of wind are shown in figure 4 for the three grenade and sphere experiments. The pitot-tube experiment, which was the 4th experiment in the density and temperature comparisons, does not have a wind measuring capability. In general, the wind profile from the falling sphere displays a greater amount of small-scale structure. This is a predictable result, since the grenade experiment averages the winds over a 2 or 3 km layer. The averaging process would be expected to increase the difference between the two techniques to a greater extent with winds than with the other parameters due to the more variable nature of the winds. In spite of this, the average difference between the grenade and sphere winds is about 6 meters per second. Contrary to the density data, the agreement is very good (differences of only 2 to

3 meters per second) at 60 km and below, with the differences increasing to 10 to 15 meters per second between 60 and 70 km.

CONCLUSIONS

The results of the four sphere and grenade or pitot-tube experiments are summarized in figure 5. The salient features of this figure are:

1. Sphere winds which show very good agreement with grenade winds at 60 km and below, and fair agreement at 65 and 70 km.

2. Sphere temperatures which on the average differ 7° K from grenade and pitot-tube experiments. The recognized error in the grenade and pitot-tube experiment accounts for 1.5 to 4° of the total difference.

3. Sphere densities which are closer by about 6 percent to the standard atmosphere than densities derived from either grenade or pitot-tube experiments. The agreement above 70 km is markedly better than below.

It is further offered that the primary obstacle toward the incorporation of the falling sphere experiment in a program of synoptic measurements rests not with the accuracy of the data, but with the requirement for an FPS-16 radar system or one that is better. It is for this reason that GSFC is currently investigating the concept of utilizing the relatively low-cost doppler tracking systems with the relatively low-cost falling sphere payload through the use of a transponder sphere.

REFERENCE

1. Jones, L. M.; and Peterson, J. W.: Falling Sphere Measurements, 30 to 120 km. Meteorol. Monogr., vol. 8, no. 31, Apr. 1968, pp. 176-189.

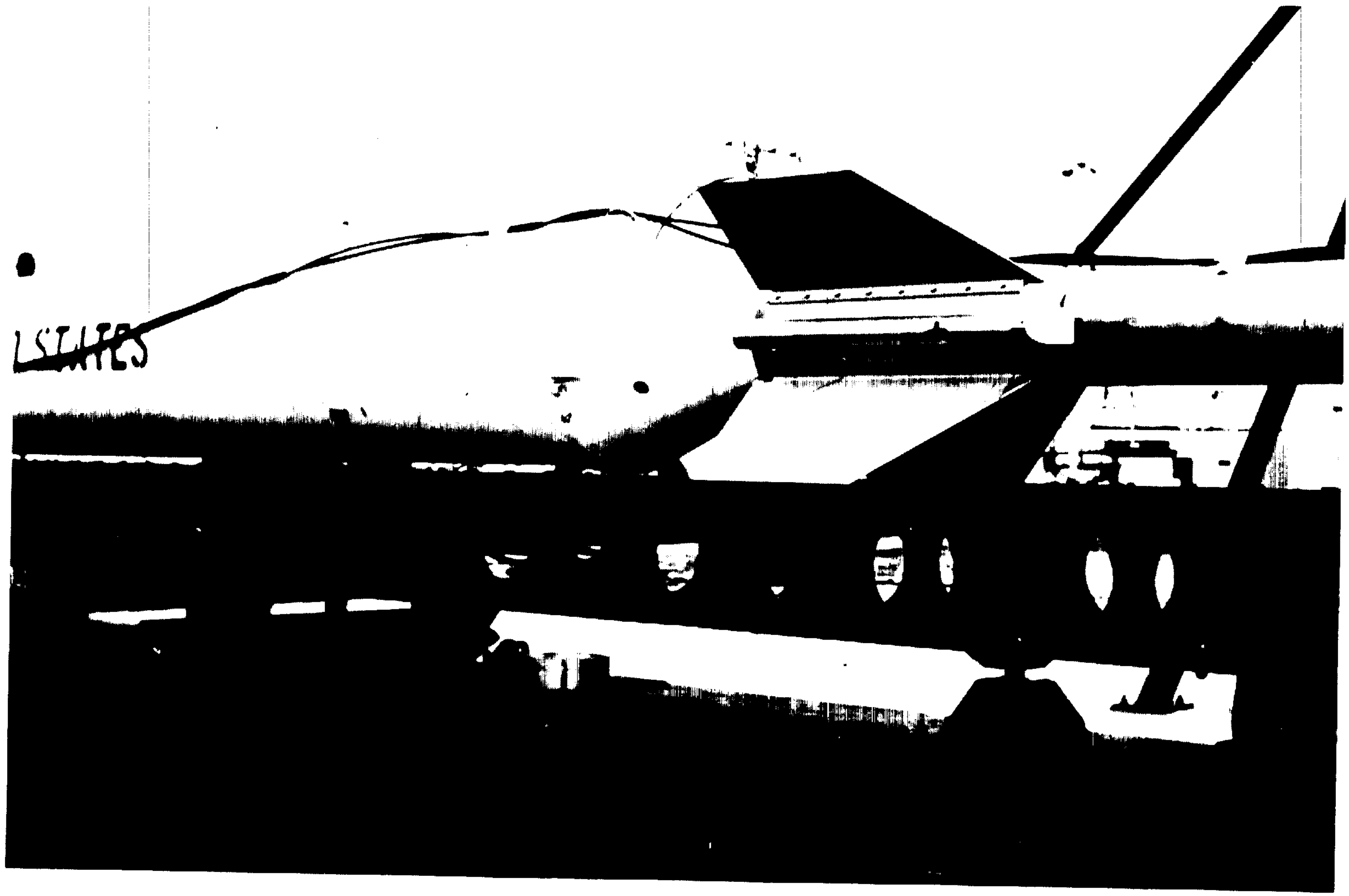

Figure 1.- Tail-fin assembly of an Apache rocket showing one of the pods containing an ejectable sphere.

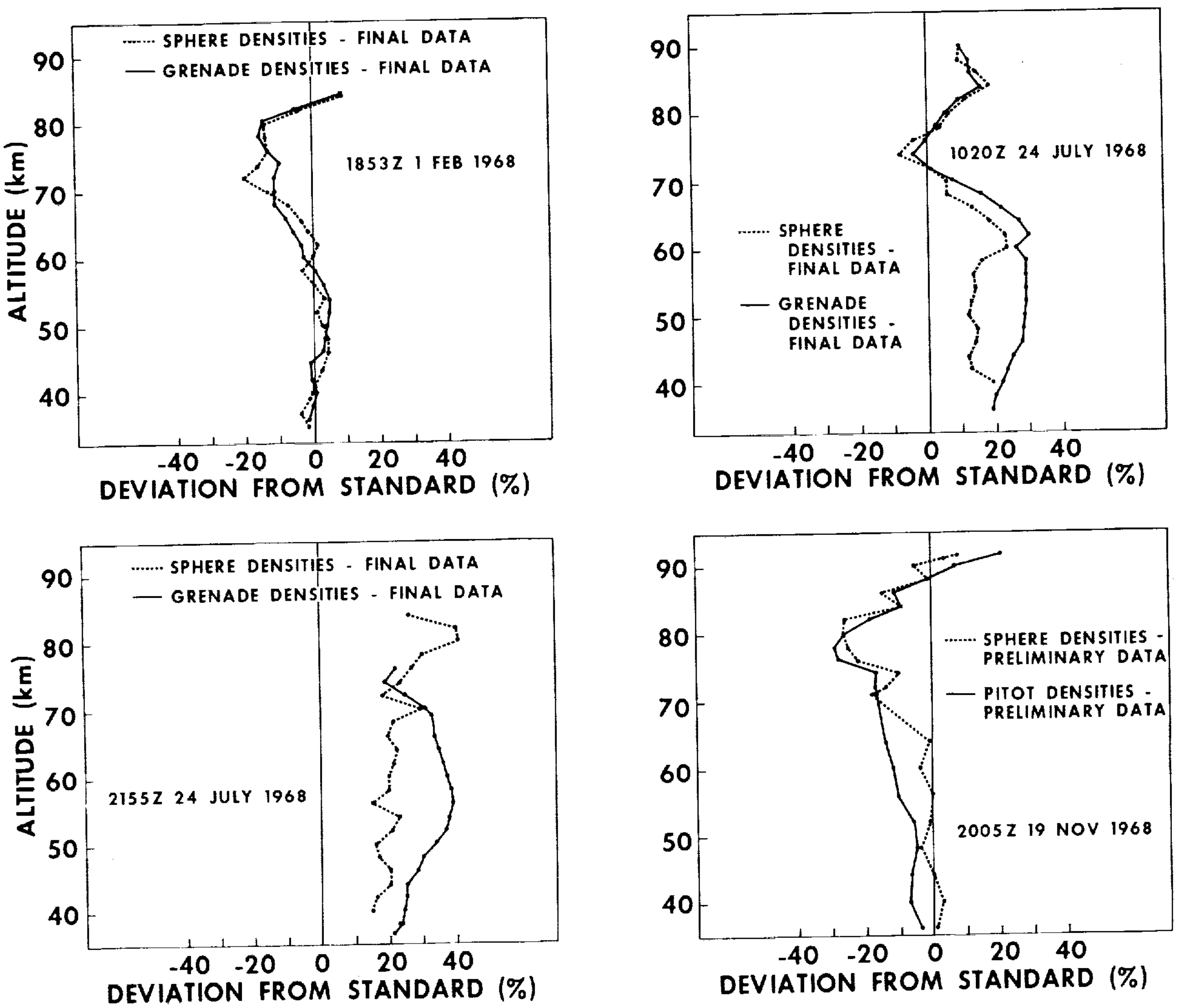

Figure 2.- Density data, in terms of percent of deviation from 1962 U.S. Standard Atmosphere, as derived from sphere and grenade or pitot-tube experiments versus altitude.

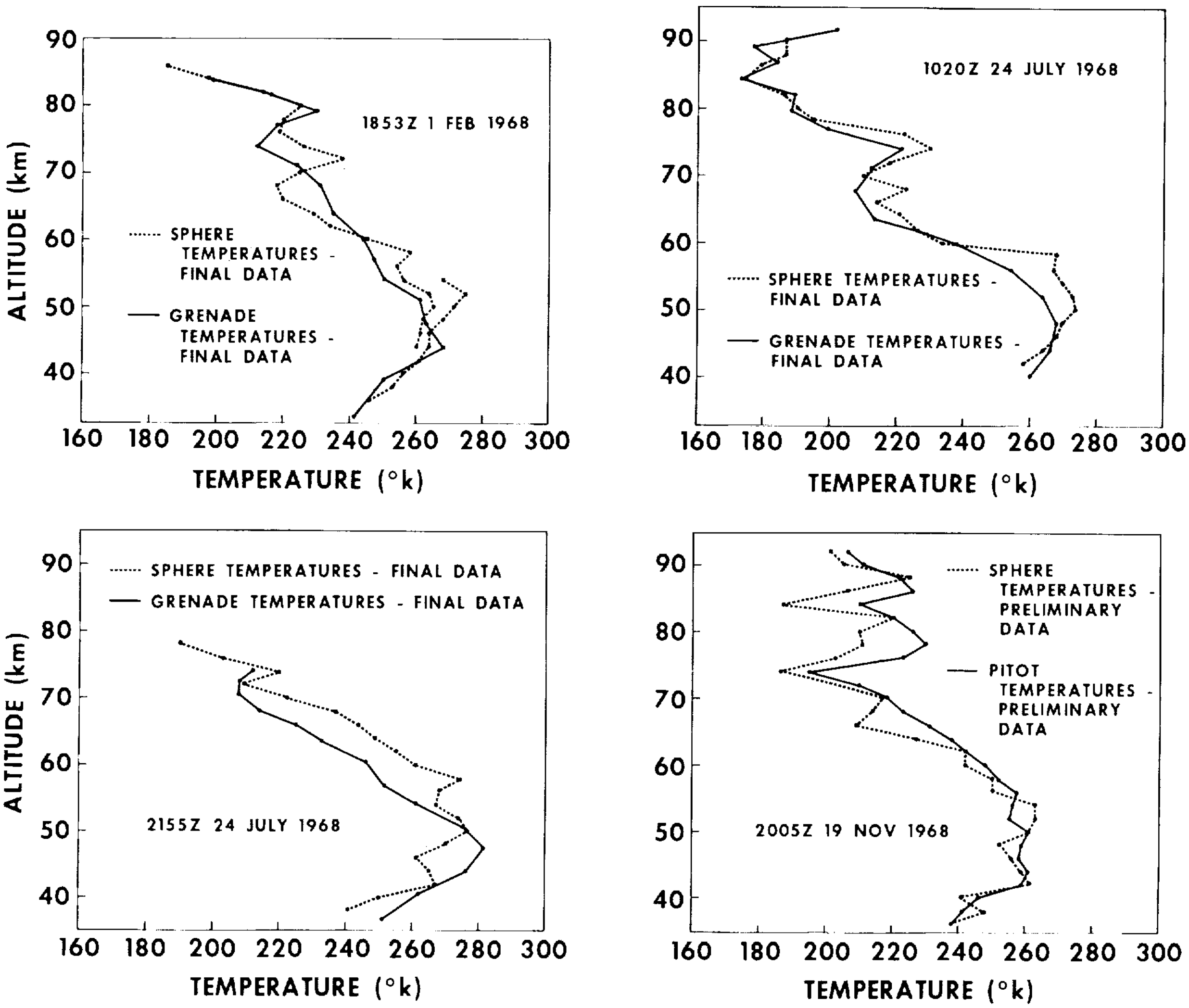

Figure 3.- Temperature data as derived from sphere and grenade or pitot-tube experiments versus altitude.

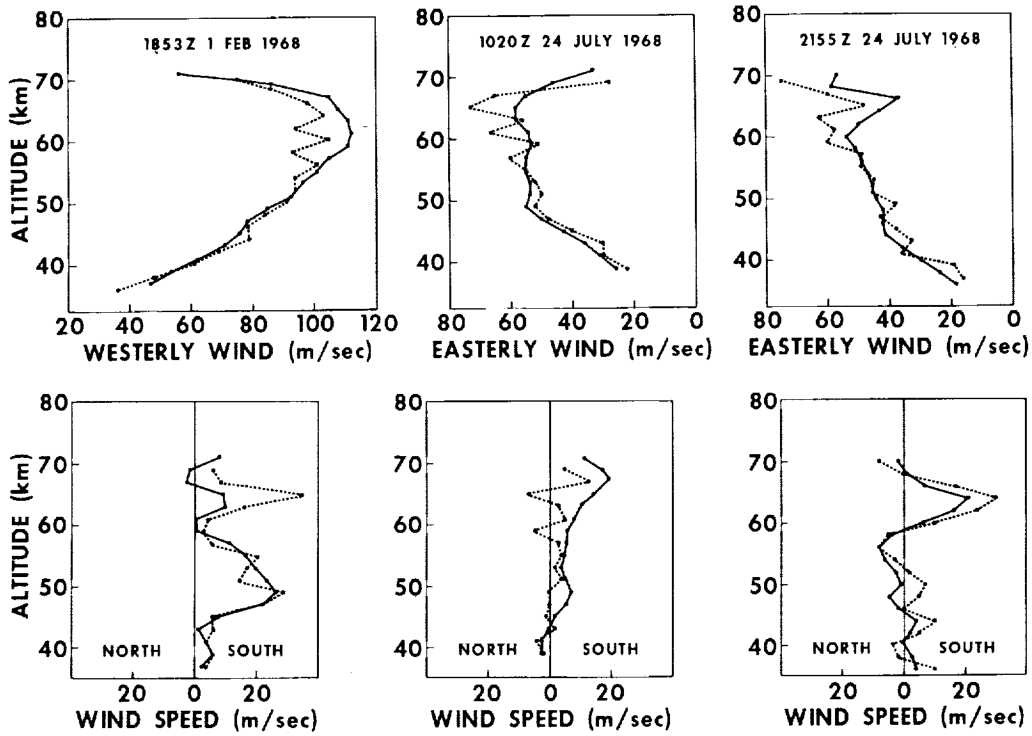

Figure 4.- Wind data, in meridional and zonal components, as derived from sphere and grenade experiments versus altitude.

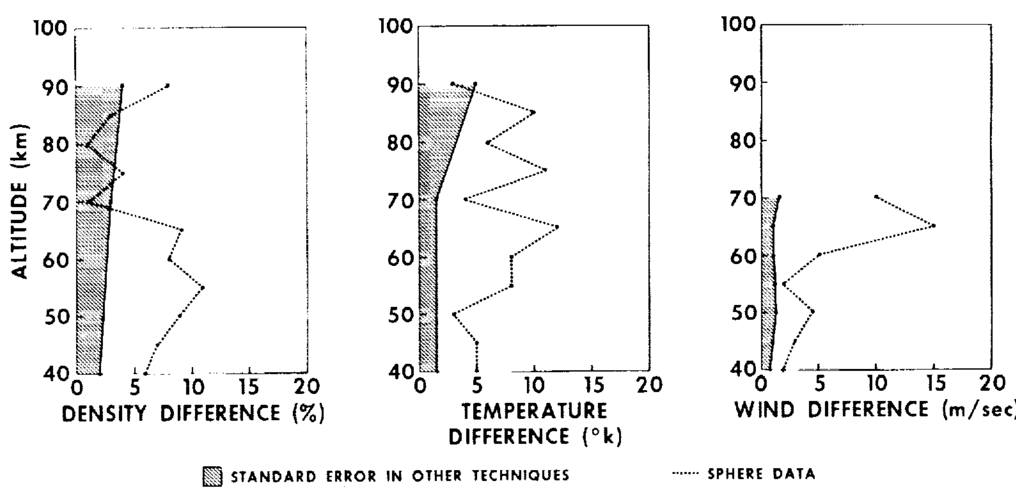

Figure 5.- Summary of density, temperature, and wind data differences. The zero-line data are an average of the grenade and pitot tube, the cross-hatched area represents the error estimated with these data, and the dotted line represents the data from the sphere experiments.