Reply

G. D. NASTROM[1]

Aeronomy Laboratory, NOAA, Boulder, CO 80303

14 March 1981 and 30 May 1981

Massman correctly points out that our equations for the dynamic response of a balloon to its environment become the same under certain special conditions. He further states that my formulation of this problem of balloon vertical motions is more general than the one he used. For example, neglecting balloon volume changes when solving the equation of motion has the same relative effect as increasing the static stability of the atmosphere. This can be seen in my Eq. (9), where setting the volume change term to zero has the same effect as making the lapse rate more stable. However, it should be kept in mind that we both have incomplete formulations because we both neglect the thermodynamic properties of balloons, as explained next.

All flexible balloons expand and contract due to changing superpressure as they oscillate in the vertical. The gas inside the balloon changes temperature with these volume changes, but usually at a different rate than the temperature of the ambient air changes. Thus, a temperature gradient develops between the balloon and the air, leading to heat exchange. This heat exchange leads to further volume changes of the balloon, and has the effect of another drag force on the balloon. By comparing numerical integration solutions of the balloon's equation of motion both with and without thermodynamic effects, I concluded that they could be ignored for the small boundary-layer tetroons I was studying. However, "thermal drag" effects may not be negligible for all balloon systems, and must be considered on a case-by-case basis. Further, one must consider that if the radiation environment of the balloon changes periodically, then the balloon's skin, and hence internal gas temperature, will also change leading to vertical oscillations even in a calm atmosphere. For example, raising the temperature of a 150 cm tetroon at 900 mb by 1°C will cause it to rise ~15 m. The effect on other balloon systems is likely different. The point is that all calculations of vertical balloon motion should take account of thermodynamic effects.

Massman correctly calls attention to my apparently vague use of the term "low stability". My graphical results are given for three atmospheric lapse rates: adiabatic, isothermal, and the lapse rate at St. Cloud on 31 October 1978 ($6°\mathrm{C\ km^{-1}}$; the U.S. Standard Atmosphere lapse near 900 mb is $\sim 6.5°\mathrm{C\ km^{-1}}$). Thus, as my curves for isothermal and for $6°\mathrm{C\ km^{-1}}$ are very similar, "low stability" means a lapse rate greater than $6°\ \mathrm{km^{-1}}$. Massman's data seem to suggest that for TWERLE balloons "low stability" is greater than $7°\mathrm{C\ km^{-1}}$.

When the atmospheric changes of wind and density are monochromatic then the forcing terms in the balloon's equation of motion [my Eq. (4)] contain only odd harmonics, so by the principle of harmonic balance the solution must be a series of odd harmonics.

---

[1] NRC-Postdoctoral Research Associate.