Technical Comments

Reply by the Authors to G. E. Dorrington

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In his Technical Comment, Dorrington [1] raises several issues regarding the empirical natural convection correlations that are compared with computational fluid dynamics (CFD) models in our paper [2].
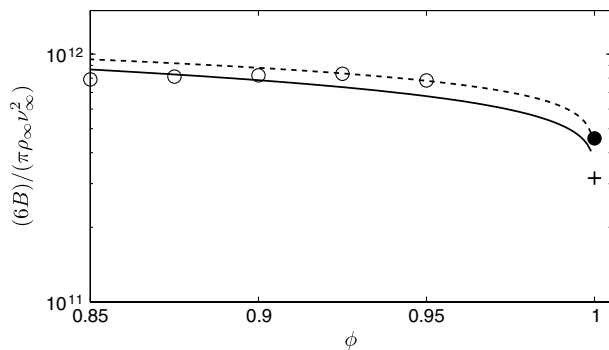

Fig. 1 Effect of gap correlation length scale on net buoyancy of the double-walled balloon. Shown here is the combined correlation for double-walled balloon with the corrected gap correlation (solid line) and the original (incorrect) formula (dashed line). The combined single-walled correlation [2] is denoted by +. Turbulent simulation results: k-ω double-walled model (open circle) and k-ω single-walled model (filled circle; $\phi = 1.0$) are also shown. Here, nondimensional heat input [2] was $\tilde{Q} = (gD^2\dot{Q})/(\rho c_p T_\infty \nu_\infty^3) = 5.97 \times 10^{14}$.

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First, for double-walled balloons, we regret that our formula for natural convection in the spherical annulus between concentric spheres promulgated an error from Holman's textbook [3]. Correction of the gap length scale used in the Rayleigh number in this correlation yields the results shown in Fig. 1 for the net buoyancy as a function of gap width ($\phi = D_i/D_o$) for double-walled balloons. The corrected correlation gives a better match with simulation results for balloons with a larger gap size, but a poorer match for smaller gaps and thus does not affect the reported conclusions [2].

Dorrington [1] also suggests the use of alternative internal and external natural convection correlations. For internal correlation, replacing the correlation of Carlson and Horn [4] with that of Hutchins and Marschall [5] only affects the laminar regime, and, as shown in Fig. 2, provides a better match with the laminar simulation results. For external convection, replacing Churchill's [6] correlation as quoted in our paper [2], with the suggested [1] modified version
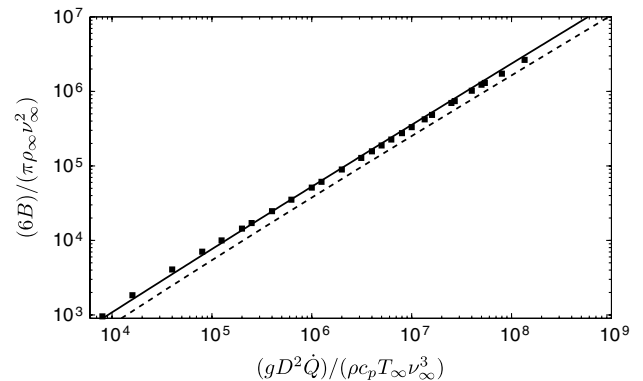

Fig. 2 Net buoyancy versus nondimensional heat input for single-walled balloons in the laminar regime. Combined correlations using the internal convection correlation of Hutchins and Marschall [5] (solid line) and that of Carlson and Horn [4] (dashed line) are compared with simulation results (filled square).
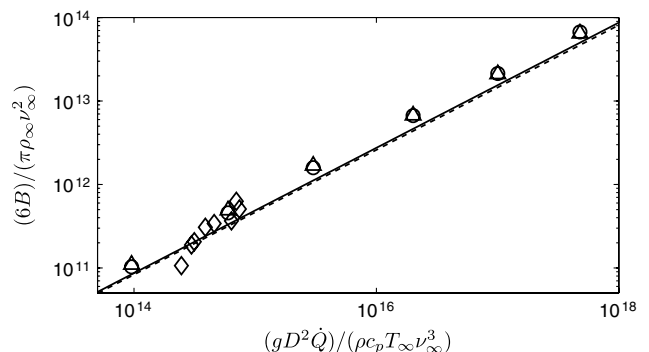

Fig. 3 Net buoyancy versus nondimensional heat input for single-walled balloons in the turbulent regime. Combined correlations for the net buoyancy versus nondimensional heat input using the external correlation of Churchill [7] (solid line) and that of Churchill [6] (dashed line) are compared with simulations for k-ε model (triangle), k-ω model (circle), and experiments (diamond).

(also by Churchill [7]) only affects the turbulent regime. As is shown in Fig. 3, the difference in net buoyancy predicted by the two formulas is quite small. For high Rayleigh numbers approaching the range of applicability to Titan Montgolfieres, our CFD simulations offer no evidence to support the superiority of Churchill's [7] alternative correlation; the shifts in the correlation curves are indeed well within the modeling uncertainties of any simulation employing turbulence models.

References

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