Laminar Gas Jets in High-Temperature Atmospheres

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Abstract

Numerical and asymptotic methods are used to describe the structure of low-temperature laminar gas jets discharging into a hot atmosphere of the same gas in the limit of small jet-to-ambient temperature ratios $\varepsilon = T_j/T_o \ll 1$. The boundary-layer approximation is used to describe the slender steady solution that emerges for moderately large values of Reynolds number $Re = \rho_o U_j a / \mu_o$, where U_j represents the exit jet velocity, a is its characteristic transverse dimension (the initial radius for the round jet and the initial half-width for the planar jet) and ρ_o and μ_o are the ambient values of density and viscosity. In the limit $\varepsilon \rightarrow 0$, heat conduction cannot modify significantly the temperature in the cold gas, leading to a two-region flow structure consisting of a neatly defined unperturbed cold jet for $r < r_f(x)$, where $T = T'/T_o = \varepsilon$ and $u = U'/U_j = 1$, surrounded by a hot gas. These two region are separated by a transition layer where $T - \varepsilon \sim \varepsilon$ and $1 - u \ll 1$.

In planar jets, axial convection and radial transport balance in the surrounding outer gas in a region whose radial extent increases continuously with downstream distance according to $(r - a) \sim \sqrt{x}$. The same balance is found in the thickening transition layer separating the outer region from the unperturbed core, which remains centered at $r = a$, with a thickness that increases continuously with distance according to $r - a \sim \varepsilon^{(1+\sigma)/2} \sqrt{x}$. Both regions merge at distances $x \sim \varepsilon^{-(1+\sigma)} Re a$ where $T - \varepsilon \sim 1 - u \sim \varepsilon$ at the jet axis. In this far field, transverse gradients of temperature and velocity are very small and, consequently, large distances of order $x \sim \varepsilon^{-2} Re a$ are required to achieve axial values of T and $1 - u$ of order unity.

In round jets, a thickening layer of very low density gas surrounds initially the jet front, which remains at $r = a$, much like the planar jet. However, for $x \gg Re a$ axial convection becomes negligible and a quasi-steady balance settles outside the jet as the mass emerging from the jet decreases, meanwhile the front remains at $r = a$. At distances $x \sim \varepsilon^{-(1-\sigma)} (\log \varepsilon^{-1})^2 Re a$ the front starts to move radially towards the axis as the cold gas is ablated from the cold jet surface. The front, that thickens as $r - r_f \sim \varepsilon^\sigma \log \sqrt{x}$, reaches the center of the jet at $x \sim \varepsilon^{-1} \log \varepsilon^{-1} Re a$.

REFERENCES

1. Abramowitz M, Stegun A. Handbook of mathematical functions. New York: Dover, 1965
2. Tarifa C S, Crespo A, Fraga E. A theoretical model for the combustion of droplets in super-critical conditions and gas pockets. *Astronautica Acta*, 1971; **17**: 685-692
3. Pai S I. Axially symmetrical jet mixing of a compressible fluid. *Quar Appl Math*, 1971; **10**: 141-148
4. Pai S I. Fluid Dynamics of Jets. Toronto: Van D Nostrand Company, 1954