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Time-dependent plume pinch-off with reducing driving source conditions in uniform environments

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It has been observed that under certain conditions a plume rising from a buoyancy source can cause the formation of individual rising thermals. The transition from plumes to thermals occurs whenever a source, due to its very low thermal conductivity, is unable to provide its surface with sufficient buoyancy flux to compensate for the buoyancy taken away by the growing plume. Such conditions result in the existence of horizontal pressure gradients, due to the local cooling at the surface, that cause the plume to pinch off[1]. Plume pinch-off plays a central role in many atmospheric, oceanographic and geological processes. Such unsteady thermal convection currents have been observed in some very high Reynolds number convection patterns such as in the atmospheric boundary layer that are driven by the solar heating of the Earth's surface, in the ocean in Polar Regions that sink from the buoyancy flux caused by the ejection of salt during seawater freezing, and in the Earth's outer core that are created by the inner core's heat flux.

Conditions under which plume pinch-off can occur are investigated both in top-hat and Gaussian profiles, and a theoretical model is suggested based on Scase *et al.* (2006)[2]. Following the approach of Witham & Phillips (2008)[3] it is assumed that the turbulent ambient fluid not only is entrained by the plume, but is also extraining fluid from the plume. It is illustrated that by decreasing the source strength, plume pinch-off can occur.

In the steady case, solutions in a Gaussian framework are shown to agree with the qualitative description of Witham & Phillips (2008)[3] in a top-hat framework. Near a buoyancy source, where vertical plume velocity is greatest, entrainment is dominant and the plume width increases whilst the density difference between the ambient and plume fluid decreases. Away from the source, the entrainment weakens because of the reduction in plume velocity while the convective velocity (i.e., the characteristic velocity of the background turbulence) remains constant. At a certain height, extrainment balances entrainment and the plume width stops growing. Further in height, extrainment dominates over entrainment and the rate of plume growth reduces with height. Eventually, the plume width becomes zero as the density difference between the two fluids vanishes. This steady plume appears to have a 'tear drop' shape.

In addition, the time-dependent solutions in top-hat and Gaussian profiles predict that by decreasing the source strength from an initial to a final value, the upper region of the plume (further from the source) lies almost unaffectedly on the 'tear drop' envelope described by the steady solution, whereas the lower region (closest to the source) necks inwards. Eventually, the plume breaks off into a thermal rising individually in the upper section and a growing plume in the lower section. As time evolves, the plume grows to attain a steady solution which is similar to the initial plume profile. Due to the dominance of the extrainment of plume fluid to the background fluid, the thermal continuously undergoes reduction in size.

[1] HUNT, J. C. R., VRIELING, A. J., NIEUWSTADT, F. T. M. & FERNANDO, H. J. S. 2003 *J. Fluid Mech.* **491**, 183 – 205.
[2] SCASE, M. M., CAULFIELD, C. P., DALZIEL, S. B. & HUNT, J. C. R. 2006 *J. Fluid Mech.* **563**, 443 – 461.
[3] WITHAM, F. & PHILLIPS, J. C. 2008 *J. Fluid Mech.* **602**, 39 – 61.