NOTES AND CORRESPONDENCE

Comments on "Case Studies of a Convective Plume and a Dust Devil"

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The paper by Kaimal and Businger (1970) is an important contribution to our observational knowledge of plumes and dust devils in the planetary boundary layer. I should like to suggest, however, that the interpretation given by the authors, while undoubtedly correct in some aspects, is deficient in ignoring the three-dimensional structure of the plumes. Recent aircraft measurements by Lenschow (1970) have shown evidence that in horizontal cross section plumes are considerably longer in the downwind (downshear) direction than across the flow. In part this is certainly because they are strongly bent over, as shown by Kaimal and Businger, but in any case it might be suggested that a two-dimensional model is insufficient.

The authors state that any theory suitable for explaining their plumes should incorporate: "1) the sharp frontal boundary at the back of the plume, 2) the dissimilar shapes of the w and T traces within the plume, 3) the slope of the plume, 4) the entrainment mechanism, and 5) the momentum and energy balance within the plume." I would like to suggest that a slightly modified version of Scorer's bent-over plume model (Scorer, 1959) adequately satisfies all the above requirements which are solidly required by the data.

Scorer's model, illustrated in Fig. 1 (from Scorer, 1968), was intended to explain the shape of a buoyant smoke plume coming out of a stack in a neutral atmosphere with a mean flow. He assumed that to a first approximation the bent-over plume could be approximated by a line-source thermal, and laboratory work on the latter was performed by Richards (1963). The modifications required to convert the model to one of natural plumes are to allow the entire plume to drift at some velocity corresponding to the mean flow very close to the surface and to admit a non-negligible magnitude of decaying residual turbulence in the plume environment. The effect of the latter, as shown by Turner (1963) and Telford (1970), is to reduce or eliminate the spread angle of the plume by "detrainment," probably mainly along the sides of the plume.

In a bent-over plume, as so modified, parcels of air entering near the bottom will engage in a helical motion around each side of the plume. The front of the plume, that portion advancing into fresh environment, is sharp and corresponds to the apparent rear edge for a stationary observer. The maximum upward vertical motion occurs at the center but consists substantially of entrained air, while the warmest air will be in the nearly stagnant flow nodes in each half of the plume. This is

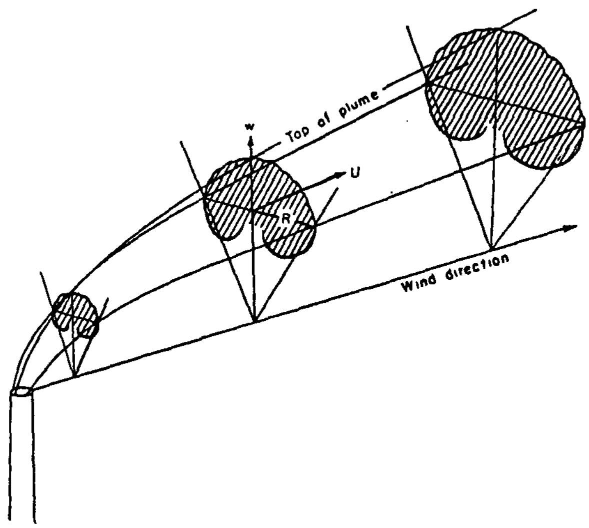

FIG. 1. The width of a bent-over hot plume in a neutral turbulence-free environment as a function of its height above an origin close to the chimney top. The diagram shows three similar sections transverse to the wind, the size being proportional to height above the origin (from Scorer, 1968).

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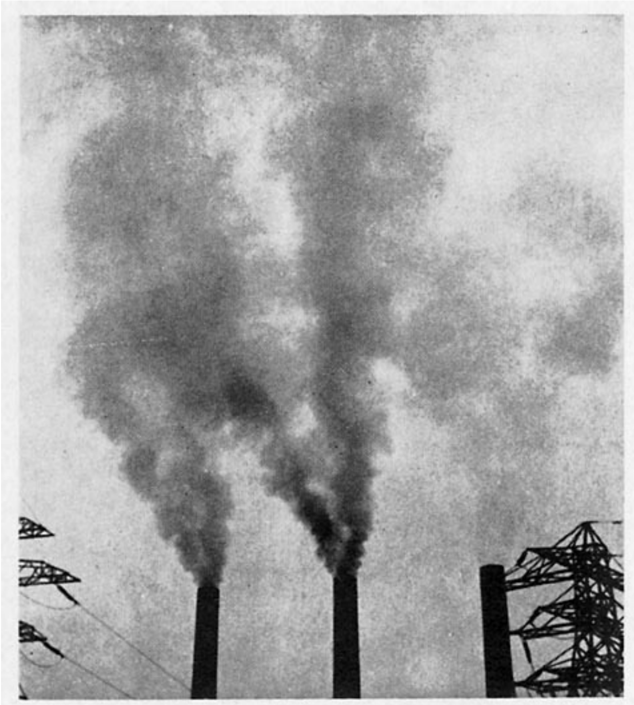

Fig. 2. Bent-over plumes seen from below. The buoyancy causes a bifurcation which is always seen in a smooth wind but which is often disrupted by more intense eddies in the surrounding air (from Scorer, 1968).

shown by Scorer's photograph (Fig. 2) of smoky plumes, where it can be assumed that smoke density is proportional to temperature. The sides of the plumes, while still warmer than the environment, will be descending, and additional descent occurs in the near environment around the plume. Thus, T and w are not too highly correlated, although obviously a net positive correlation exists.

The only clear discrepancy of the above model with the results of Kaimal and Businger is in their measured positive momentum flux. In a bent-over plume in a shearing environment it seems that the rising air in the plume centers must always have a horizontal velocity characteristic of levels below its position, and vice versa for the air in the sinking edges. This would correspond to negative momentum flux as defined by Kaimal and Businger. If the data must be attacked in order to admit the theory, this seems an adequately weak spot. A careful perusal of the u, w and $\overline{u'w'}$ records shows that the total positive contribution to the latter (which only occurred at the higher of the two altitude levels presented) was associated with a period of high u both inside and outside the thermal at its rear. The problem here is what to use for $\bar{u}$, and if the value used by the authors were increased somewhat, the magnitude of $\overline{u'w'}$ would either decrease or reverse sign. In any case a proper evaluation of momentum transport should include not only the rising center but also the sinking edges of the plume, which are undoubtedly more difficult to recognize from chart records.

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