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DISCUSSION

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Kannberg and Davis address two important points in the design and analysis of multiple-port diffusers: (1) What is the mechanism of jet merging and how to model it? (2) What is the effect of jet merging on the mixing capacity of such diffusers?

(1) The lateral merging of the individual jets emanating from the diffuser nozzles appears to be a complicated process. As the jet boundaries approach each other, the space for the entrainment flow is limited between the jets leading to low pressure zones and dynamic attachment effects. The turbulent diffusion characteristics change from an axisymmetric shearing zone to a two-dimensional one. Clearly, jet integral techniques, with their assumptions of jet similarity and hydrostatic pressure distribution, can describe this transition in an approximate fashion only. Kannberg and Davis' profile specification in the transition region represents a reasonable approach in this direction and has advantages over Koh and Fan's earlier model, inasmuch as it avoids abrupt changes in the center line temperature prediction. Questions, however, remain as to the choice of the entrainment coefficient (two- or three-dimensional value) and the assumptions of a turbulent Prandtl number of unity, which is in contradiction with experimental observations on jets and plumes. The pressure effect on the merging process caused by ambient currents is even more difficult. The form drag assumption, equation (34), proposed by the authors seems a tenuous one in view of the complicated geometry. Such model deficiencies, however, could be corrected through the best-fit choice of the drag coefficients, at least within the parameter range of the author's experiments.

(2) The basic argument of the two-dimensional slot diffuser concept, as used in the model by Jirka and Harleman [4], is that beyond the line of merging the flow field of the actual multiple-port diffuser is equal to that of a slot discharge. Or in other words, the initial three-dimensional details have no distinguishable effects at longer distances. This concept is physically reasonable, as the equivalent slot diffuser has the same kinetic energy input per unit length, which is ultimately expanded in turbulent jet mixing. This behavior of laterally limited jets is in analogy with the nozzle shape effects on free turbulent jets in which, after a certain characteristic distance, the initial shape effects are no longer felt and all jets approach an wxisymmetric shape (Sforza, et al. [22][2], experiments by Yevdjevich reported in [21]). The equivalent slot concept is useful for diffuser classification as the number of governing parameters is reduced. It has been found of sufficient accuracy for multiple-port diffusers by Liseth [8] and more recently by Buhler [23]. The lack of agreement which is indicated by Kannberg and Davis' experiments may be due to equipment effects, since the horizontal momentum input of the jets is likely to cause some circulation and possibly re-entrainment in a finite size laboratory facility. This may account for the lower centerline temperatures which were observed.

Finally, some caution has to be expressed regarding Kannberg and Davis' introductory claim that their analysis is applicable for the predictions of condenser heat discharges from electric power generation. In fact, the low buoyancy of such heated discharges in combination with the limiting water depth at usual disposal sites gives rise to dynamic instabilities in form of a recirculating eddy extending over the entire water depth. This discharge condition cannot be analysed by means of simple buoyant jet models as proposed by the authors. Stability criteria, which depend on relative water depth, discharge Froude number and angle, have been developed by Jirka and Harleman [4, 24] and are plotted in Fig. 10. Multiple-port diffuser designs for condenser heat discharge generally fall into the unstable discharge range. The practical application of the stable range, in which the authors' model is applicable, relates to sewage and blowdown diffusers, usually with higher buoyancy and lower flowrates.

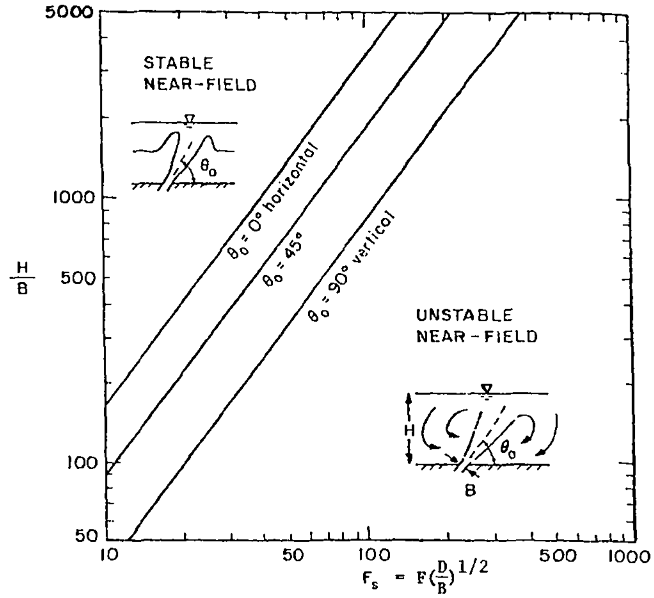

Fig. 10 Stability of the flow field for multiport diffusers discharging into shallow water as a function of slot densimetric Froude number F_s, relative water depth H/B, and discharge angle, θ_0. ($B = D^2\pi/4L$ is the equivalent slot width); after Jirka and Harleman [24]

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Authors' Closure

We appreciate Dr. Jirka's taking time to comment on the analysis and results of this paper. We agree with much of what he has said, but feel a few points need to be further clarified.

A unity turbulent spreading parameter was introduced into the analysis to make the smooth merging of both temperature and velocity easier. The authors realize that this may not be exactly the case but

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[2] Numbers in brackets designate Additional References at end of discussion.

it is felt that the errors introduced are minor in light of the complexity of the problem.

The equivalent slot concept is a useful approach in analyzing the characteristics of certain multiport discharges, but as with most simplified analyses, the limits of use should be understood. The fundamental premise behind the equivalent slot is that beyond the point of merging the plumes from a row of equally spaced jets become the same as the plume from a slot jet having the same mass and momentum flux per unit length as the multiple jets. This presumes that up to the point of merging, the mixing mechanisms of the two are the same, and of course they are not. The effect of this difference on the ultimate dilution would be minor if the major portion of the dilution occured after merging. This would either be for large distances away from the point of discharge or for closely spaced discharge ports. Most researchers realize this. For example, Liseth [8] suggested the use of an equivalent slot for closely spaced ports and only attempted to compare results at $y/L = 80$. For an $L/D = 10$, this at a $y/D = 800$. At this point the dilution is so great that the excess temperature, regardless of how it is calculated, is usually no longer of interest.

In the near and intermediate field where most of the data reported in this paper were taken, the story is different. One of the causes of this difference is the development length. To illustrate, consider a diffuser with 1-ft dia ports spaced 10-ft apart discharging into stagnant water. The jets for this system merge about 30 ft from discharge and have a development length where the temperatures begin to decay of about 6 ft. The equivalent slot for this system has a width, B, of 0.08 ft. Therefore, at the end of the actual single jet development zone where the excess temperature is of the order of 1.0–0.8, the equivalent slot is at an s/B of 75 where it predicts an excess temperature of the order of 0.2.

In addition to the development zone problem, entrainment is also different for the two systems. Entrainment has been suggested as $2\pi(0.082)bu_c$ and $2(0.16)Lu_c$ for the round and slot jets, respectively [3]. For the example case considered in the foregoing, the slot jet entrainment is $3.2u_c$ while the round jet entrainment varies due to plum growth from $0.26u_c$ at discharge to $2.6u_c$ at merging. Thus, even though a multiport discharge merges into essentially a two-dimensional plume where the individual character of the original jets no longer exists, its properties are different from those of a plume that originated from a slot. As a result, the authors feel that the indiscriminate use of the equivalent slot to model multiple port diffusers could lead to gross errors.

We agree with Dr. Jirka that the present model should not be used in shallow stagnant receiving water where surface effects and instabilities are present. In flowing ambients, however, even at low velocities these effects are reduced and in some cases eliminated. In many cases the receiving water is sufficiently deep to use the model to predict the major portion of the plume's characteristics.