the authors also provide an approximate quantitative number for the accuracy of the numerical results.

Based on the authors' results of Figs. 8 and 9, the fully developed periodic flow is achieved at $x/L = 4$ and 30 for Re = 200 and 1600 respectively for $L/H = 1$. Would the authors first quantitatively define the periodic fully developed flow, and then provide the tabular values of x/L as functions of L/H and Re for $L/H = 0.2, 0.5, 1, 2$ and 5, and the covered range of Re.

A research task remains further refining the analytical model to correlate better the performance of interrupted wall surface with the experimental results. Subsequently, the more complex heat exchanger surfaces could be analyzed. In the meanwhile, this paper by Prof. Sparrow and his colleagues serves as a reminder that the flow and heat transfer phenomena in a compact heat exchanger are too complex to analyze. A better quantitative understanding of the flow phenomena is essential for better correlations and improved heat exchanger design.

Additional Reference

10 Shah, R. K., and London, A. L., *Laminar Flow Forced Convection in Ducts*, Supplement 1 to *Advances in Heat Transfer* Series, Academic Press, New York, 1977.

Authors' Closure

We are appreciative of the perspectives conveyed by Dr. Shah's Discussion. With regard to the role of vortices and wakes, there are, assuredly, conditions where they will affect both the heat transfer and friction. On the other hand, there are conditions for which no significant effect will be felt. Perspectives on these conditions are conveyed in references [11] and [12]. In connection with the identification of the periodically developed regime in Figs. 8 and 9, there is considerable latitude depending on the selected criterion. Since all portions of a velocity or temperature profile do not develop with equal rapidity, there are various criteria that can be employed. It was for this reason that we did not quote development lengths in the paper.

Additional References

11 Kottke, V., Blenke, H., and Schmidt, K. G., "The Influence of Nose Section and Turbulence Intensity on the Flow Around Thick Plates in Parallel Flow," *Wärme- und Stoffübertragung*, Vol. 10, 1977, pp. 159–174.

12 Loehrke, R. I., Roadman, R. E., and Read, G. W., ASME Paper 76-WA/HT-30, American Society of Mechanical Engineers, New York, N.Y., 1976.

Calculation of Shape Factors between Rings and Inverted Cones Sharing a Common Axis[1]

D. A. Nelson.[2] In a recent note, Minning presented analytical results for the shape factor between inverted conical frustrums and a differential element or ring. These results should be very useful for rapid estimation of radiation from rocket plumes or flares but should find other applications as well.

The purpose of this discussion is to point out how one of Minning's results can be generalized. In his analysis of the inverted conical frustrum, Minning has chosen to express his results in terms of four variables—the cone half angle β, the height of the frustrum h, the radial location of the differential element ρ, and the vertical distance from the differential element to the extended frustrums' vertex s. In my view, this last choice is not the natural one and indeed it obscures the generality of the result expressed by equation (7). The author has also introduced a source of possible confusion by requiring that s be negative in that equation.

It appears that a better choice of variable would be the radius of the frustrum in the plane of the element or ring, which is given by $r = -s \tan \beta$. If s is thereby eliminated from equation (7) in favor of r, then it becomes clear that the cone half angle is not restricted to positive values but can be anywhere within the range $-\tan^{-1}(r/h) \leq \beta \leq \pi/2$. Now, however, one must interpret the cone half angle as the absolute value of β, whereas β itself is an angular coordinate. When it is positive, the frustrum opens in the upward direction or is inverted as discussed by Minning. When β is negative, the direction of opening is downward, thus the frustrum is in an upright orientation. The particular value $\beta = -\tan^{-1}(r/h)$ yields the upright cone configuration. Minning's equation (7) then, when properly interpreted, is valid for the complete range of shape factors between conical frustrums and a differential element (or ring) located in a plane which intersects the conical surface. The use of shape factor algebra, of course, extends the geometric configurations to which this result can be applied.

With respect to this latter point, one may note, as was done for a cylinder by Sparrow, et al. [1] that the shape factor in question can be considered as the sum of two parts—one being a circular segment and, in this case, the other being a tilted triangular plate frustrum. Since the former is known [2], the latter can be readily obtained and subsequently expressed in variables more suitable for that configuration. This, of course, introduces new possibilities too numerous to mention.

Finally, since Minning does not mention any analytical checks of his result, it is pointed out that, when $\beta = 0$, it reduces to a form equivalent to that for the cylinder [1].

[1] By C. P. Minning, published in the August, 1977 issue of the JOURNAL OF HEAT TRANSFER, Vol. 99, No. 3, pp. 492–494.

[2] The Aerospace Corporation, El Segundo, CA 90245.

Additional References

1 Sparrow, E. M., Miller, G. B., and Jonsson, V. K., "Radiating Effectiveness of Annular-Finned Space Radiators, Including Mutual Irradiation between Radiator Elements," *Journal Aerospace Sciences*, Vol. 29, 1962, pp. 1291–1299.

2 Sparrow, E. M., "A New and Simpler Formulation for Radiative Angle Factors," ASME JOURNAL OF HEAT TRANSFER, Vol. 85, 1963, pp. 81–88.

Author's Closure

I appreciate Dr. Nelson's pointing out that the applicability of equation (7) is broader than originally indicated in my paper. I also agree with his contention that my original choice of variables is not the most convenient for the applications he has in mind. However, from the standpoint of clarity and visualization of the geometry, I find the use of both positive and negative values of β to be no less confusing than the use of both positive and negative values of s.

An alternate expression that avoids this confusion can be derived by substitution of the relation $r = -s \tan\beta$, as suggested by Dr. Nelson, and the relation $\alpha = (\pi/2) - \beta$ into equation (7). The result is as follows:

$$F_{dA_1-A_2} = \frac{\cos\alpha}{\pi}\,\mathrm{Tan}^{-1}\left[h\sqrt{\frac{1+\cot^2\alpha}{\rho^2-r^2}}\right] + \frac{1}{\pi}\,\mathrm{Tan}^{-1}\left[\sqrt{\frac{\rho+r}{\rho-r}}\right]$$
$$+ \frac{(h\cot\alpha + r)^2 - \rho^2 - h^2}{\pi\sqrt{[(h\cot\alpha+r)^2+\rho^2+h^2]^2 - 4\rho^2(h\cot\alpha+r)^2}}$$
$$\times\,\mathrm{Tan}^{-1}\left[\sqrt{\frac{[(h\cot\alpha+r)+\rho]^2}{[(h\cot\alpha+r)-\rho]^2}\cdot\left(\frac{\rho-r}{\rho+r}\right)}\right]$$

In this expression, α is the angle between the plane of dA_1 and the sloping side of the conical frustrum. Values of α are always positive and lie in the range $0 \leq \alpha \leq \pi$. For $0 \leq \alpha < \pi/2$, the frustrum opens upward away from the plane of dA_1. For $\pi/2 < \alpha \leq \pi$, the frustrum opens downward toward the plane of dA_1. The special case, $\alpha = \pi/2$, corresponds to a vertical cylinder. For $\pi/2 < \alpha \leq \pi$, this expression is comparable to the analytical results derived by Holchendler and Laverty [1] for the same geometry.

Another interesting case is the situation where $\rho = r$. Here the alternate expression reduces to

$$F_{dA_1-A_2} = \frac{1}{2}[1 + \cos\alpha]$$

where it is seen that for $\alpha = \pi/2$, $F_{dA_1-A_2} = 0.5$, which is the well-known result for a circular cylinder.

Additional References

1 Holchendler, J. and Laverty, W. F., "Configuration Factors for Radiant Heat Exchange in Cavities Bounded at the Ends by Parallel Disks and Having Conical Centerbodies," ASME JOURNAL OF HEAT TRANSFER, Vol. 96, No. 2, 1974, pp. 254–257.