JOURNAL OF PROPULSION AND POWER
Vol. 25, No. 6, November–December 2009

Technical Comment

TECHNICAL COMMENTS are brief discussions of papers previously published in this journal. They should not exceed 1500 words (where a figure or table counts as 200 words). The author of the previous paper is invited to submit a reply for publication in the same issue as the Technical Comment. These discussions are published as quickly as possible after receipt of the manuscripts. Neither AIAA nor its Editors are responsible for the opinions expressed by the authors.

Comment on "Atomization Characteristics of Impinging Liquid Jets"

Essam A. Ibrahim*
Alabama A&M University, Normal, Alabama 35762

DOI: 10.2514/1.46212

RYAN et al. [1] advanced a comprehensive study of the atomization of impinging-jet injectors which involved both experimental and modeling efforts. As they pointed out, even though their model was quite successful in providing predictions of atomization characteristics in the laminar flow regime, the model predictions exhibited notable disagreement with their drop size data under turbulent flow conditions. Ryan et al. [1] postulated that the discrepancy was due to the fact that their model considered only the effects of aerodynamic waves on atomization and did not include the contribution of the impact waves referred to by Dombrowski and Hooper [2]. Jung et al. [3] owed the lack of agreement to the utilization of various orifices with different materials, inner surface roughness, and treatment quality of orifice holes in Ryan et al.'s [1] experiments. Although these justifications are valid, they are not sufficient to explain the fact that Ryan et al.'s [1] model predicted drop sizes that were, in some cases, twice as large as their measured counterparts especially at high Weber number. It will be shown in this comment that the discrepancy mainly stems from the nature of the data employed in the model verification rather than the model's accuracy, at least for the experimental range investigated.

Kang and Poulikakos [4] reported experimental measurements for drop sizes versus impingement angle, jet velocity, orifice diameter, and liquid properties for turbulent impinging-jet atomization. An interesting feature of their work is that they documented length-mean d_{10}, Sauter-mean d_{32}, and mass-median-mean d_{MMD} diameters of spray drops. As their measurements indicate, the magnitudes of these diameters can be quite different. Ryan et al.'s [1] published drop size measurements were made at a single spatial location of 16 mm along the sheet centerline, meaning that they correspond to length-mean diameters. In general, most experimental studies focus on measuring the more commonly used Sauter-mean diameter. As can be seen from Figs. 4 and 5 of Kang and Poulikakos [4], the length-mean diameter d_{10} is much smaller than the Sauter-mean diameter d_{32}, which in turn is smaller than the mass-median diameter d_{MMD}. Therefore, it is apparent that a major source of the overestimation of Ryan et al.'s [1] model predictions compared to turbulent atomization data may originate from the use of measurements of length-mean drop diameter rather than Sauter-mean diameter.

Received 1 July 2009; revision received 19 July 2009; accepted for publication 24 August 2009.

*Associate Professor, Mechanical Engineering Department. Associate Fellow AIAA.

To test the preceding hypothesis, comparisons between Ryan et al.'s [1] model predictions and Kang and Poulikakos's [4] drop Sauter-mean diameter data documented in Figs. 4a and 4b of their paper are illustrated in Figs. 1 and 2 of this comment.

Figure 1 contrasts drop diameter estimates given by Ryan et al.'s [1] model against the length-mean and Sauter-mean diameter measurements of Kang and Poulikakos [4] plotted in Fig. 4a of their article for $\theta = 30$, 45, 60 deg ($2\theta = 60$, 90, 120 deg), $d_0 = 1.016$ mm, and $U = 12.0$ m/s (corresponding to $We = 2010$), where θ is half the impingement angle, U is the mean liquid velocity, and We is Weber number based on liquid properties, mean liquid velocity, and orifice diameter d_0. The length-mean and Sauter-mean drop diameters are made dimensionless by dividing by the orifice diameter. The model predictions are computed according to Eq. (14) of Ryan et al. [1] for the same experimental conditions used in their study and properties of liquid water injected into atmospheric air.

As evident from Fig. 1, the model predictions agree quite favorably, qualitatively and quantitatively, with the measurements of Sauter-mean drop diameter. The agreement between model predictions and data for length-mean diameter is far less favorable. The model predictions are somewhat improved at higher impingement angles for the Sauter-mean diameter. Whereas the Sauter-mean diameter decreases with increasing impingement angle, the length-mean diameter measurements appear to be insensitive to it. The results in Fig. 1 confirm that the discrepancy between Ryan et al.'s [1] model predictions and their drop size data based on length-mean diameter reported in their original article could very well be a consequence of not employing the Sauter-mean diameter in their comparison.

Figure 2 depicts Ryan et al.'s [1] model drop diameter predictions versus the length-mean and Sauter-mean diameter data of Kang and Poulikakos [4] presented in their Fig. 4b for $\theta = 45$ deg ($2\theta = 90$ deg), $d_0 = 1.016$ mm, and $U = 12.0$, 15.4, and 19.1 m/s (corresponding to $We = 2010$, 3310, 5091, respectively). It is visible in Fig. 2 that Ryan et al.'s [1] model is capable of generating much closer predictions of the measured Sauter-mean diameter rather than the length-mean diameter. Therefore, the trend observed in Fig. 1 is further affirmed by the findings of Fig. 2. The agreement between the model predictions and either mean diameter measurements is enhanced at lower Weber number. This is expected becuase, as

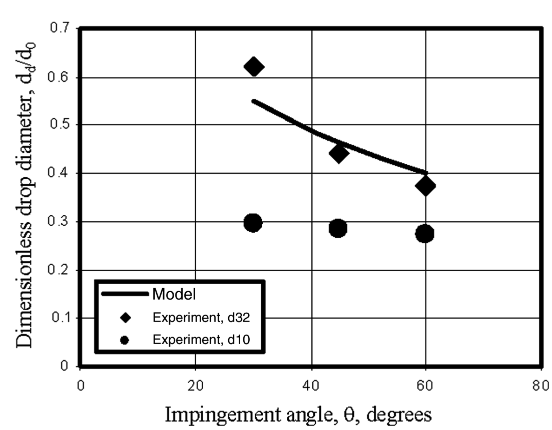

Fig. 1 Comparison of model predictions with experimental data.

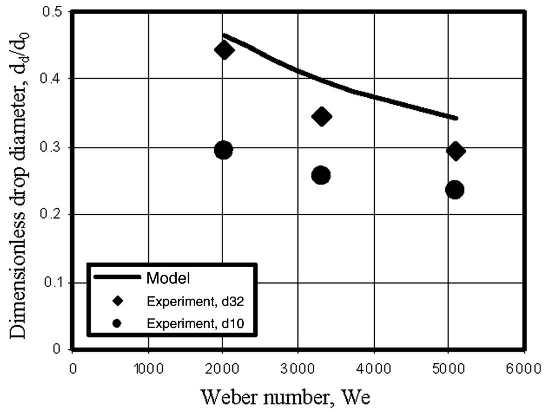

Fig. 2 Comparison of model predictions with experimental data.

Weber number is increased, turbulence becomes more prominent and the model's inability to account for turbulence phenomena becomes more of a liability.

It is worth noting that the nonlinear model of Ibrahim and Outland [5] turns out almost identical results as that of Ryan et al. [1] for the computations encountered in Figs. 1 and 2. This is quite interesting because the two models' predictions deviated in the range of parameters investigated in Ibrahim and Outland [5]. However, the reason behind these events might be that, for $We > 2000$, the predictions of two models converge, as can be attested from Figs. 10 and 11 of Ibrahim and Outland [5]. It is therefore surmised that the nonlinear effects are surpassed by turbulence effects in the range of experimental data exploited in the present Comment.

The results elucidated here offer no assurance that current aerodynamic-based models can be used to render reliable predictions of turbulent impinging-jet atomization at Weber number higher than that examined. Therefore, an effort to develop a rigorous model that incorporates impact wave influence on atomization under turbulent flow conditions, such as that begun by Anderson et al. [6], is highly warranted. However, until such a model is available, the present comment can benefit today's designers, whose only option is to apply the readily available modeling tools to guide their decision making.

References

[1] Ryan, H. M., Anderson, W. E., Pal, S., and Santoro, R. J., "Atomization Characteristics of Impinging Liquid Jets," *Journal of Propulsion and Power*, Vol. 11, No. 1, 1995, pp. 135–145. doi:10.2514/3.23851

[2] Dombrowski, N., and Hooper, P. C., "A Study of the Sprays Formed by Impinging Jets in Laminar and Turbulent Flow," *Journal of Fluid Mechanics*, Vol. 18, No. 3, 1964, pp. 392–400. doi:10.1017/S0022112064000295

[3] Jung, K., Khil, T., and Yoon, Y., "Effects of Orifice Internal Flow on Breakup Characteristics of Like-Doublet Injectors," *Journal of Propulsion and Power*, Vol. 22, No. 3, 2006, pp. 653–660. doi:10.2514/1.20362

[4] Kang, B. S., and Poulikakos, D., "Holography Experiments in a Dense High-Speed Impinging Jet Spray," *Journal of Propulsion and Power*, Vol. 12, No. 2, 1996, pp. 341–348. doi:10.2514/3.24034

[5] Ibrahim, E. A., and Outland, B. E., "A Nonlinear Model for Impinging Jets Atomization," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 222, No. 2, 2008, pp. 213–224. doi:10.1243/09544062JMES710

[6] Anderson, W. E., Ryan, H. M., and Santoro, R. J., "Impact Wave-Based Model of Impinging Jet Atomization," *Atomization and Sprays*, Vol. 16, No. 7, 2006, pp. 791–805. doi:10.1615/AtomizSpr.v16.i7.60

K. Frendi
Associate Editor