drop size derived from edge measurements [5], and also from indirect measurements of the spray cone angle [6]. These modeling efforts indicate that the downstream spray drop size is not sensitive to the assumed initial drop size [6]. However, as will be seen in the present study, this is because drop coalescence phenomena have an important effect on the downstream sizes within those solid-cone sprays.

In hollow-cone sprays, coalescence is less important and therefore the downstream drop size could be expected to depend on the assumed initial drop size. The purpose of the present study was to assess the implications of inadequate knowledge of the initial drop size and to establish the importance of secondary atomization phenomena within the spray (due to drop breakup).

MODEL

The governing equations and the numerical solution method of the model are described by Amsden et al. [2]. An explicit numerical method is used with acoustic subcycling to solve the 3-dimensional gas conservation equations and a Lagrangian treatment is applied to the drops. Stochastic parcel injection is used to represent the spray drops for computational efficiency. In the present computations, the gas phase mass, momentum and energy equations were supplemented by a $k-\epsilon$ turbulence model which accounts for turbulence diffusion [5,7]. The computational drops exchange mass, momentum and energy with the gas using the dense spray correlations of O'Rourke and Bracco [8]. Droplet dispersion due to turbulence is modeled using a random walk method [9]. The walk durations are related to the drop residence time within an eddy or to the eddy lifetime, whichever is smaller. Drop collision and coalescence are also included in the model [8].

The injected drop size for hollow-cone spray computations was specified using an atomization model that is derived from a stability analysis of liquid sheets [10]. This analysis gives

$$SMR = 8.4 \ C^{-3/2} \ \xi \ (\rho_2/\rho_1)^{1/2} \qquad (1)$$

where SMR is the Sauter Mean Radius,
ξ is the sheet breakup length,

$$\xi/\delta = C \ \{(\frac{\rho_1}{\rho_2})(\frac{\sigma}{\rho_2 U^2 \delta})(\frac{h}{\delta})\frac{1}{\tan \theta}\}^{1/3}$$

and ρ_1 and ρ_2 are the liquid and gas densities, respectively, and σ is the surface tension. θ is the cone angle, δ is the poppet seat diameter, h is the sheet thickness at the nozzle exit, and U is the injection velocity. A χ^2-distribution was assumed for the injected drops. The atomization model used for solid-cone spray computations was that of Reitz and Bracco [11].

Drop breakup was modeled starting from the correlations given in the review by Nicholls [12] where two breakup regimes are identified: bag breakup when

$$We=\rho_2 w^2 r/\sigma > 6.0 \ ; \qquad (2)$$

(We is the Weber number) (the factor 6.0 was taken in Eq. (2) as a representative value. Literature values vary between 3.6 and 8.4) and stripping breakup when

$$We/\sqrt{Re} > 0.5 \qquad (3)$$

where the Reynolds number $Re=2wr/\nu$, ν is the kinematic viscosity and r is the drop radius.

The lifetimes of unstable drops are

$$t_1 = D_1 \ \left[\frac{\rho_1 r^3}{\sigma}\right]^{1/2} \qquad (4)$$

$$t_2 = D_2 \ \frac{r}{w} \ (\rho_1/\rho_2)^{1/2} \ , \qquad (5)$$

for the bag and stripping modes, respectively. The bag breakup time, Eq. (4), is assumed to be proportional to the drop natural frequency. In Eq. (5), w is the relative velocity between the drop and the gas and the constant D_2 is of order unity [12].