Modeling droplet breakup in complex two-phase flows

R. Schmehl

roland.schmehl@esa.int
Aerothermodynamics Section TOS-MPA/ESTEC, European Space Agency,
Noordwijk, The Netherlands

Like many other two-phase flow applications of practical importance, fuel preparation in combustion engines is characterized by atomization and spray interaction with complex flow environments. Consequently, spray droplets are subjected to a spectrum of relative flow variations and, exceeding a certain velocity threshold, to deformation and secondary breakup. Depending on the intensity of aerodynamic forces, breakup is governed by several distinctive mechanisms: bag, multimode and shear breakup (adopting the terminology of Hsiang and Faeth [1]). Since time scales associated with these processes are often comparable or even larger than the characteristic scales of the imposed flow variations, the temporal evolution of the breakup process as well as fragment properties significantly depend on the scenario of aerodynamic loading. Thus, modeling breakup as a point event is far from reality.

The computational methodology proposed in this paper has 2 major objectives: (a) to account for relative flow variations during the breakup process and (b) to resolve the characteristic features of the different breakup mechanisms - deformation kinetics, aerodynamics and product properties - as closely to reality as possible. The implementation is based on the **dynamic deformation models** presented by Schmehl [2]: The NLTAB-model, a nonlinear variant of the classical TAB-model and the NM-model which is based on linear Normal Mode Analysis. The former concept employs a shape change of the droplet via spheroids and accounts for larger deformation amplitudes, whereas the latter concept describes arbitrary shape variations in the linear limit of small amplitudes. The stability limit is modeled by means of a critical deformation

$$y_c = 1.8 \qquad \text{(NLTAB-model)}, \qquad\qquad \alpha_c = -1.0 \qquad \text{(NM-model)}, \tag{1}$$

whereas the different breakup mechanisms are identified based on the instantaneous Weber number at the end of the deformation phase, i.e. when the critical deformation is reached,

$$\mathrm{We}_1 = 25 \quad \text{(multimode breakup)}, \qquad\qquad \mathrm{We}_2 = 65 \quad \text{(shear breakup)}. \tag{2}$$

Figure 1 illustrates a parametric reconstruction of the deformation and breakup regimes in the well-known On-We_0-map [1] using the NLTAB3-model. Regarding the influence of viscosity effects three distinct On-ranges can be identified: (a) insignificant influence up to $\mathrm{On} \sim 0.01$, (b) increasing viscous damping of maximum deformation amplitude for $0.01 \lesssim \mathrm{On} \lesssim 0.4$ and (c) coupled influence of viscous damping and droplet acceleration for $0.4 \lesssim \mathrm{On}$. The computed breakup regime transitions for the last range of large On clearly demonstrate the importance of using an acceleration-dependent aerodynamic drag coefficient $c_D(\mathrm{Re}, A)$ in contrast to the steady drag coefficient c_D.

Modeling of the gradual transitions between the typical breakup mechanisms is based on experimental data on droplets subjected to impulsive aerodynamic loading. Depending on the

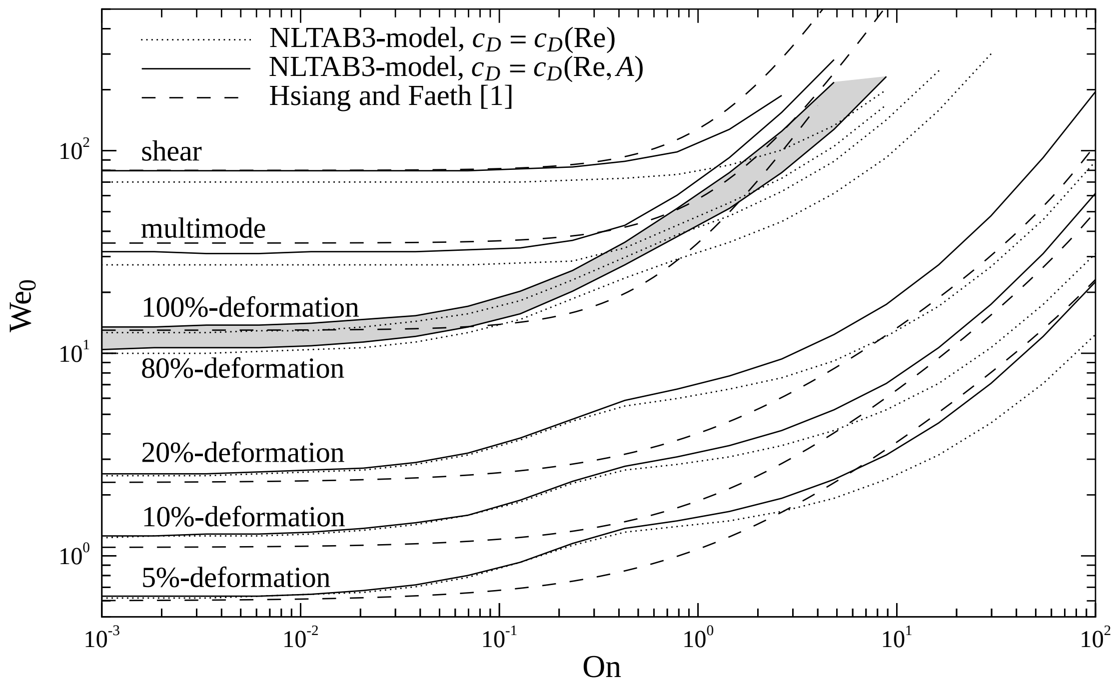

Figure 1: Droplet deformation and breakup for impulsive aerodynamic loading

value of We at the end of the deformation phase the temporal evolution in the breakup phase is prescribed according to figure 2. Between start ($t/t^* = 2-3$, where t^* is the characteristic time

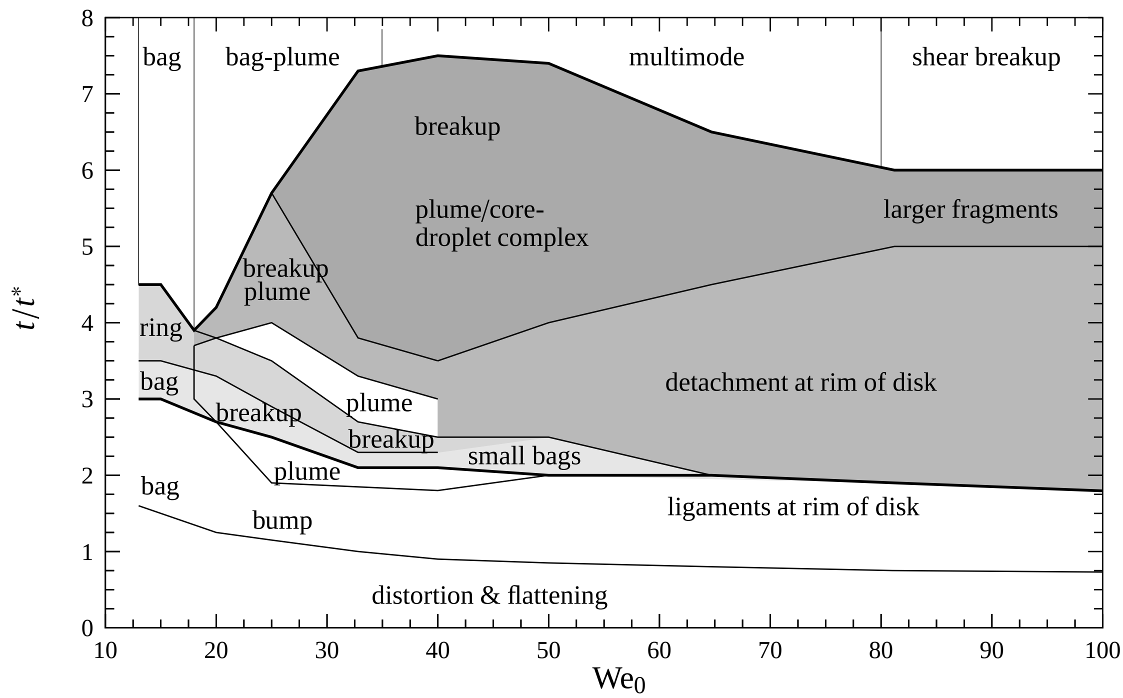

Figure 2: Temporal evolution of droplet deformation and breakup for impulsive aerodynamic loading

of droplet deformation) and end ($t/t^* = 4-7.5$) of this phase various subprocesses determine the formation of characteristic fluid structures (bag, ring, plume, etc.) and the subsequent generation of secondary fragments. The kinetics of these subprocesses, the mass re-distribution between the fluid structures and the final size and velocity distributions of the fragments are, again, based on experimental data and correlations.

To demonstrate the performance and accuracy of the proposed model implementation, the fuel preparation process in a the premix duct of a LPP research combustor is computed and compared with high resolution PDA data. This flow configuration is characterized by intensive aerodynamic interaction of a fuel sheet and a contracting air flow in a highly inhomogeneous atomization zone [3].

References

[1] L.-P. Hsiang and G. M. Faeth. Drop Deformation and Breakup Due to Shock Wave and Steady Disturbances. *International Journal of Multiphase Flow*, 21(4):545–560, 1995.

[2] R. Schmehl. Advanced Modeling of Droplet Deformation and Breakup for CFD Analysis of Mixture Preparation. In *18th Annual Conference on Liquid Atomization and Spray Systems, ILASS-Europe 2002, Zaragoza, Spain*, 2002.

[3] R. Schmehl, G. Maier, and S. Wittig. CFD Analysis of Fuel Atomization, Secondary Droplet Breakup and Spray Dispersion in the Premix Duct of a LPP Combustor. In *8th International Conference on Liquid Atomization and Spray Systems, ICLASS 2000, Pasadena, USA*, 2000.