Comments on “Collision, Coalescence and Breakup of Raindrops. Parts I and II”

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1. Introduction

Low and List (1982a, b; hereafter referred to as LL), have described new data relating to collisions between water drops which they believe to be representative of events occurring during rainfall. With the exception of the work of McTaggart-Cowan and List (1975; hereafter referred to as ML), these experiments differ from previous ones in that they were conducted with drops falling vertically at terminal speeds. Both ML and LL have chosen to categorize each collision according to four classes of outcome, namely, coalescence, filament breakup, sheet breakup and disk breakup. By combining their data with those of ML, LL claim that the drop pairs chosen cover the range of importance for rainfall development. For the purposes of future modeling, LL have fitted analytical functions to coalescence efficiency $E_c$, the number of fragments per collision, the fraction of collisions resulting in each class of breakup, and the fragment size distributions. Kinetic and surface energy budgets were used to parameterize $E_c$. Low and List conclude that the main growth mechanism is coalescence involving the smaller drops.

While the data presented by LL are undoubtedly a useful contribution, we feel some aspects of their work require close examination. We will discuss these points in order of their appearance in LL.

2. Experimental design

a. Drop dynamics

As pointed out by Bradley and Stow [(1978a; hereafter referred to as BS(a)], it is not the drop approach angles in the laboratory frame which are significant but rather the angle between the differential velocity vector and the vertical. For example, two drops falling at a small angle on either side of the vertical collide at their equators because the differential velocity vector is horizontal. In fact, if the smaller drop in LL’s collision 5 is falling at $9^\circ$ to the vertical, then the differential velocity vector is inclined at $17^\circ$ to the vertical. On the other hand, for collision 3, the differential velocity vector would be inclined at only $2^\circ$. The fact that the differential velocity vector is nearly vertical for all LL collisions is largely fortuitous.

b. Impact geometry

Any collision between two drops is defined by their diameters $D_S$ and $D_L$ and the impact parameter $X$ (the ratio of trajectory separation to sum of drop radii). Consequently, it is somewhat surprising that LL have not presented collision statistics nor interpreted mode of breakup with reference to $X$, in spite of photographic estimates apparently being available. Further, their low hit/miss ratio does not in itself guarantee a natural distribution of $X$. It is also necessary that trajectories be centered on, and evenly distributed around, the collision region. Otherwise, weighting must be applied to correct collision statistics for bias.

3. Interpretation of results

Although LL(a) show in their Fig. 5 that their fragment numbers are similar to ML, comparison of coalescence efficiencies is a more sensitive test of equivalence of the data sets. However, our attempts to compare coalescence efficiencies from ML and LL have been frustrated by the irreconcilable statistics quoted. For example, LL’s Fig. 5 suggests one coalescence event in 72 collisions for LL, and four in 101 collisions for ML, whereas their Figs. 11–13 imply a total of 20 coalescence events and none of these coalescence efficiencies compares with those given in LL’s Table 3. Further, ML present breakup data for their total 101 collisions of type 6 and the picture is confused because 106 collisions of their entire data set are not accounted

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for. It is therefore not clear that there is adequate overlap between the two data sets, considering that LL contend the division between coalescence and no-coalescence occurs in this region. We believe that LL should present coalescence efficiencies separately for both the LL and ML experiments.

From the experimental coalescence data in Table 3 of LL(a) it appears that collision 6 is in a region where coalescence efficiency is a sensitive function of drop size. Unfortunately, it is not possible to determine from published data how the results of LL and ML were combined to obtain the value quoted. In fact, on the basis of the number of breakups quoted by ML and the numbers given in Figs. 5, 11, 12 and 13 of LL(a), it would appear that LL recorded 15 or 16 coalescence events out of 72 collisions for this drop pair. This indicates a coalescence efficiency of 0.21 for the LL data, which suggests that the dependence on collision kinetic energy excess (CKE) is much weaker and also that the ML and LL data do not match well.

There is difficulty in accepting the statement made by LL that Eqs. (4.5) and (4.6) describe the coalescence efficiency $E_c$ using the "... most fitting simple combination of physical quantities which may be involved in the process." Although their Fig. 7 does demonstrate a good fit, parameters of this fit are heavily dependent on $E_c$ derived for collision 6, and the 5μJ cutoff-value for $E_T$ relies critically on compatibility between the two data sets. Neither the quadratic term nor the exponential term in Eq. (4.5) have a clear physical justification for collisions between large drops. Following the arguments of LL, we find that a simpler expression involving the ratio of excess energy $E_T$ to the binding energy $S_c$ is

$$E_c = 1 - 0.67(E_T/S_c)^{0.36}. \quad (1)$$

Calculated values of $E_c$ are compared with observed values in Fig. 1 for both expressions and it is clear that Eq. (1) describes the data equally well. Although both expressions fit the coalescence data adequately, there are real dangers in extrapolating from any non-physical model. For example, the contours of $E_c$ derived from Eq. (1) differ markedly from those shown in Fig. 8 of LL, as is demonstrated in our Fig. 2.

As noted above, LL have neglected $X$, which is one of the three fundamental collision parameters, and rotational effects arising from conservation of angular momentum have been ignored. We have thoroughly treated the total collision energy budget in BS(a,b),
from which it may be shown that the change in combined mechanical and surface energy, $E_T(X)$, is

$$E_T(X) = CKE \left[ 1 - \frac{5}{2} \frac{D_S^3 D_L^3 (D_S + D_L)^2}{(D_S^3 + D_L^3)^{8/3}} X^2 \right] + \Delta S_z.$$  

(2)

This is based on the assumption that, in general, coalesced masses will be rotating. Considering all possible collisions, we obtain from Eq. (2) the ratio of $\bar{E}_T/\bar{E}_T$ shown in Fig. 3, where $\bar{E}_T$ is the mean value of $E_T(X)$ and $\bar{E}_T$ is the value $E_T(0)$ used by LL. The large departures from unity conclusively show that any physical model must include rotational effects so that, whereas $\bar{E}_T$ may be an adequate parameter in fitting LL data, expressions of the kind LL used in Eq. (4.5) and our Eq. (1) cannot be extrapolated.

The models considered above are based on the excess energy which must be dissipated in order for a spherical drop to result from the collision. Since distorted drops do not necessarily disrupt, the reference sphere concept only approximates reality when both impacting drops are small. Also, drops falling at terminal speed will in general be distorted even before impact and although LL stress the need to conduct experiments using realistic speeds, they have neither addressed this factor in their parameterizations nor in any discussion of the results.

Both ML and LL have chosen to classify collisions according to four possible outcomes, namely, coalescence and three modes of breakup. While the distinction between coalescence and breakup is unambiguous, the division of breakup modes into filament, disk and sheet forms is necessarily subjective. Since this division does not facilitate modeling of the physical process, there seems no advantage in individually parameterizing probability, fragment numbers and fragment distributions for each mode. Rather, this method of division leads to poor statistics; thus, for collision 4, LL have fitted one of their Gaussian distributions to a total of only 11 fragments. However, classification of results according to impact parameter would yield data more appropriate for modeling, providing of course, enough collisions were studied.

Finally, there are two points relating to the fragment distributions. First, the use of Gaussian and log-normal distributions qualitatively appears to be reasonable but we do have reservations regarding the fitting of as many as 58 parameters to the data presented by LL. Although this practice has resulted in good fits to their data, we believe that in this particular case extrapolation is statistically unsound. Second, on the basis of their fragment-diameter presentation, LL infer that the main growth mechanism is coalescence involving the smaller drops. However, it is possible that partial coalescence is a significant growth mechanism for all larger drops [see BS(a)]. Those breakup events in which the larger drop grew at the expense of the smaller drop are unfortunately not identifiable within the broad class intervals of drop diameter used by LL.

4. Summary

The raw data obtained by LL provide potentially useful information on drop collisions, but do not conclusively show that previous experiments involving relative drop velocities are invalid. It also remains to be proven that the ML and LL data can be merged. The data would have a wider applicability to modeling if collision classification included the impact parameter rather than using a subjective classification based on collision outcome. Omission of both rotational effects and a good physical model precludes extrapolation of results to cover all interactions.

REFERENCES


