Energy dissipation of water drops striking an undisturbed water surface

By EDMUND G. KILGORE and JOHN A. DAY, *Linfield College, McMinnville, Oregon*

(Manuscript received August 12, 1963)

ABSTRACT

The impact of water drops on an undisturbed water surface is studied by cine shadow photography. Quantitative analysis of the film data shows a quasi-exponential rate of energy dissipation away from the impact region.

1. Introduction

As more complete understanding is gained of the transfer processes which are continuously taking place across the sea–air interface it becomes increasingly possible to describe the large scale cyclic phenomena in quantitative terms. The present study has been concerned with one small aspect of this problem, namely, to determine the time rate at which the total energy carried by a falling water drop is dissipated away from the impact region.

2. Experimental

Drops of tap water were allowed to fall from a piece of standard glass tubing of 3.8 mm inner diameter supported at known heights above the surface of water contained in a small, rectangular, glass fish tank. The frequency of drop fall was regulated so that the surface was (nearly) undisturbed at the time of impact. Shadow photographs were taken in two ways, (*a*) using a Bolex H-16 cine camera "looking" at the events against a photoflood-illuminated ground glass screen, (*b*) using a 35 mm reflex camera again directed toward the bright screen, which in this case was periodically illuminated by a Strobotac flashlamp.

Knowledge of the height of fall and the dimensions of the drop yielded, on analysis, the initial total potential energy. Neglecting frictional losses incurred in fall this represented quite well the total energy carried at the moment of impact.

Work supported through the Undergraduate Research Participation Program of the National Science Foundation.

As has been shown by investigators at least as early as WORTHINGTON (1896) and more recently by KIENTZLER *et al.* (1954) the impact initiates an interesting chain of events. Fig. 1*a* shows the cylindrical shell which is thrown up around the periphery, then develops filaments which, in turn, break up into small droplets. (These are the splash-drops which are such an important erosive agent when the impact occurs in muddy water.) The expenditure of the remaining momentum of the drop results in the hemispherical cavity shown in Fig. 1*b*. The rush of water down the sides causes the production of the Rayleigh jet which, as it becomes unstable, develops one or more droplets at its upper end. Fig. 1*c* shows the jet as it first commences to develop a neck. The subsiding jet produces the volcano-shaped cavity of Fig. 1*d*. When this cavity fills it gives rise to the jetlet shown in Fig. 1*e*. An interesting underwater view corresponding in time just before Fig. 1*d* is shown in Fig. 1*f*.

The sequence described would continue for more than two cycles were it not for the rapid rate of energy loss from the impact region due both to friction and radial removal by means of the outward moving capillary waves.

3. Simplifying assumptions

Simplifying geometrical assumptions were adopted to make the computations more tractable. The initial cavity was assumed to be hemispherical at its maximum development and the jet was assumed to be cylindrical. Measurements taken from the film record yielded the total energy and time at points of

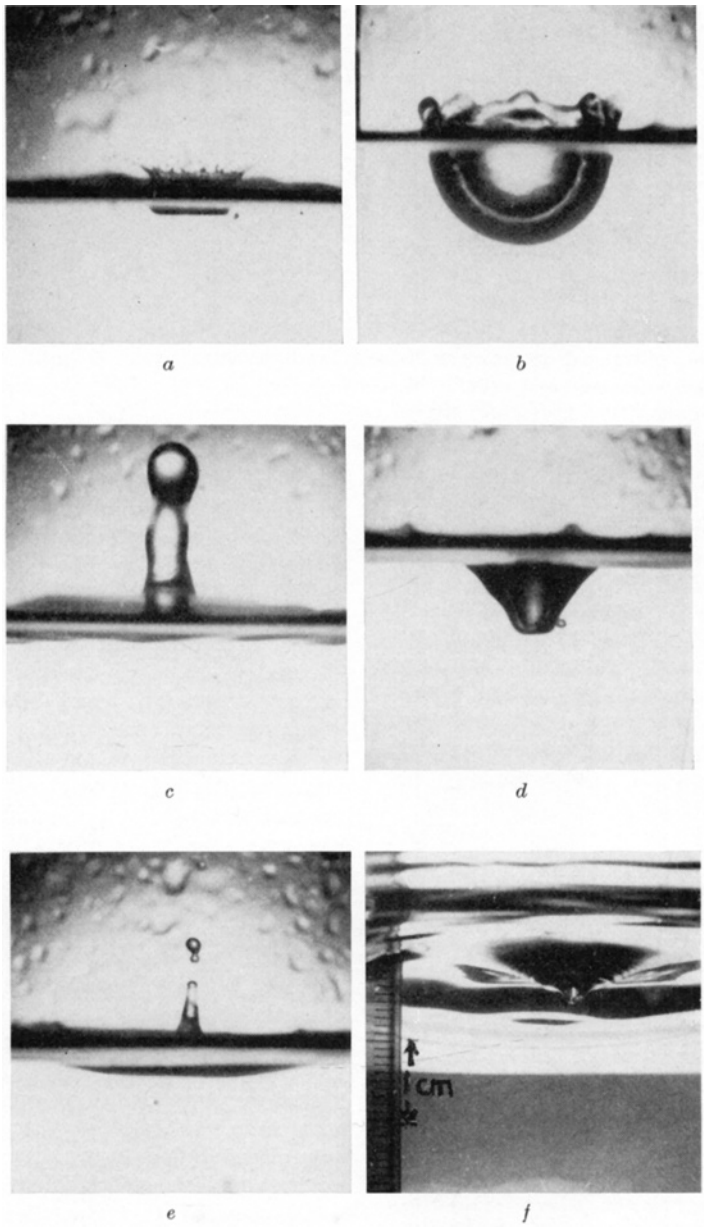

FIG. 1. A composite series of photographs taken at and just below the water level showing several stages in the dissipation of the energy carried by the original drop. Fall height is 47.5 cm. (*a*) shows the splash effect produced immediately upon impact; in (*b*) the cavity is hemispherical and the crest of the first capillary wave is near its maximum; (*c*) shows the Rayleigh jet at its maximum height with the first jet drop nearly detached; (*d*) illustrates the volcano shape of the second cavity which fills and produces the jetlet (*e*); (*f*) is an under-water view of the surface just before the time of (*d*).

maximum development of cavity and jet. In the cases in which unstable jets yielded individual droplets, the total potential energy of the drops was computed from their trajectories and the total surface energy from the droplet dimensions. The increase in surface energy manifest in the first capillary wave was measured by using the equivalent area of a rectangular cross section toroid of the same radius as the cylindrical wave.

4. Results

Plotting the total energy against time for the four heights of fall yields the results shown in Fig. 2. These curves show a rapid rate of dissipation of the initial energy carried by the drop away from the impact point at an initial rate approximating 153 milliwatts for case 4. Uncertainty in the measurement of wave amplitudes made it impossible to differentiate between the amount of energy transmitted away from the impact point by the wave motion and the amount of energy which was dissipated as heat.

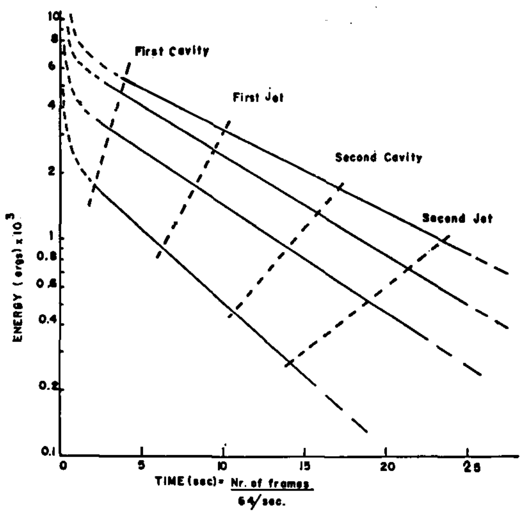

FIG. 2. Total energy as a function of time. Initial energy corresponding to fall heights of 12 cm, 52 cm, 102 cm and 152 cm are 10.6×10^3, 39.3×10^3, 82.3×10^3 and 114.0×10^3 ergs. Zero time corresponds to the impact instant.

REFERENCES

KIENTZLER, C. F., ARONS A. B., BLANCHARD, D. C., WOODCOCK, A. H., 1954, Photographic investigation of the projection of droplets by bubbles bursting at a water surface. *Tellus*, **6**, pp. 1–7.

WORTHINGTON, A. M., 1896, Impact with a liquid surface. *Phil. Trans. of Roy. Soc.* London, p. 139.