



Bombs, flyin' high. In-flight dynamics of volcanic bombs from Strombolian to Vulcanian eruptions.

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Bomb-sized (larger than 64 mm) pyroclasts are a common product of explosive eruptions and a considerable source of hazard, both from directly impacting on people and properties and from wildfires associated with their landing in vegetated areas. The dispersal of bombs is mostly modeled as purely ballistic trajectories controlled by gravity and drag forces associated with still air, and only recently other effects, such as the influence of eruption dynamics, the gas expansion, and in-flight collisions, are starting to be quantified both numerically and observationally. By using high-speed imaging of explosive volcanic eruptions here we attempt to calculate the drag coefficient of free-flying volcanic bombs during an eruption and at the same time we document a wide range of in-flight processes affecting bomb trajectories and introducing deviations from purely ballistic emplacement. High-speed (500 frames per second) videos of explosions at Stromboli and Etna (Italy), Fuego (Guatemala), Sakurajima (Japan), Yasur (Vanuatu), and Batu Tara (Indonesia) volcanoes provide a large assortment of free-flying bombs spanning Strombolian to Vulcanian source eruptions, basaltic to andesitic composition, centimeters to meters in size, and 10 to 300 m/s in fly velocity. By tracking the bombs during their flying trajectories we were able to: 1) measure their size, shape, and vertical component of velocity and related changes over time; and 2) measure the different interactions with the atmosphere and with other bombs. Quantitatively, these data allow us to provide the first direct measurement of the aerodynamic behavior and drag coefficient of volcanic bombs while settling, also including the effect of bomb rotation and changes in bomb shape and frontal section. We also show how our observations have the potential to parameterize a number of previously hypothesized and/or described but yet unquantified processes, including in-flight rotation, deformation, fragmentation, agglutination, and bouncing of volcanic bombs.