IMPACT

Detlef Lohse, Raymond Bergmann, Rene Mikkelsen, Christiaan Zeilstra, Devaraj van der Meer, Michel Versluis, Ko van der Weele, Martin van der Hoef, and Hans Kuipers
Faculty of Science and J. M. Burgers Centre for Fluid Dynamics, University of Twente, 7500 AE Enschede, The Netherlands

(January 5, 2004)

According to Shoemaker, the "impact of solid bodies is the most fundamental process that has taken place on the terrestrial planets" [1], as they shape the surfaces of all solar system bodies. A lot of information on this process has been extracted from remote observations of impact craters on planetary surfaces [2]; experiments however with large enough impact energies as compared to the energy stored in the ground are difficult. We approach this problem by *downscaled* experiments and by corresponding discrete particle numerical simulations: The idea is to fully *decompactify* very fine sand which then at impact of a steel ball behaves fluid-like. Thus, we are in the gravity-dominated regime. The series of events is as follows: On impact of the ball, sand is blown away in all directions ("splash") and an impact crater forms. When this cavity collapses, a *granular jet* [3, 4] emerges and is driven straight into the air. A second jet goes downwards into the air bubble entrained during the process, thus pushing surface material deep into the ground. The downward jet will therefore considerably change the layering of the sediments underneath a crater, as it provides a mechanism how surface material can be transported deep into the ground. This suggested mechanism may shed new light on the sediment layering data found underneath the Chicxulub crater, which is a source of major controversy [7, 8]. The entrained air bubble rises slowly towards the surface, causing a granular eruption. In many cases the collapsing jet leaves a *central peak* in the crater, just as observed in craters of the terrestrial planets. The upward jet will strongly contribute to the transfer of planetary matter into space [5]. In addition to the experiments and discrete particle simulations, we present a simple continuum theory to account for the void collapse leading to the formation of the upward and downward jets. We show that the phenomenon is robust and even works for *oblique* impacts: the upward jet is then shooting *backwards*, in the direction where the projectile came from.

[1] E. M. Shoemaker, in *Impact and Explosion Cratering*, edited by D. J. Roddy, R. O. Pepin, and R. B. Meril (Pergamon Press, New York, 1977), pp. 1–10.
[2] E. Pierazzo and H. J. Melosh, Ann. Rev. Earth Planet. Sci. **28**, 141 (2000).
[3] S. T. Thoroddsen and A. Q. Shen, Phys. Fluids **13**, 4 (1996).
[4] R. Mikkelsen *et al.*, Phys. Fluids **14**, S14 (2002).
[5] J. D. O'Keefe and T. J. Ahrens, Science **198**, 1249 (1977).
[6] A. M. Walsh, K. E. Holloway, P. Habdas, and J. R. de Bruyn, Phys. Rev. Lett. **91**, 104301 (2003).
[7] J. Smit, Ann. Rev. Earth Plan. Sci. **27**, 75 (1999).
[8] G. Keller *et al.*, J. Geol. Soc. **160**, 783 (2003).

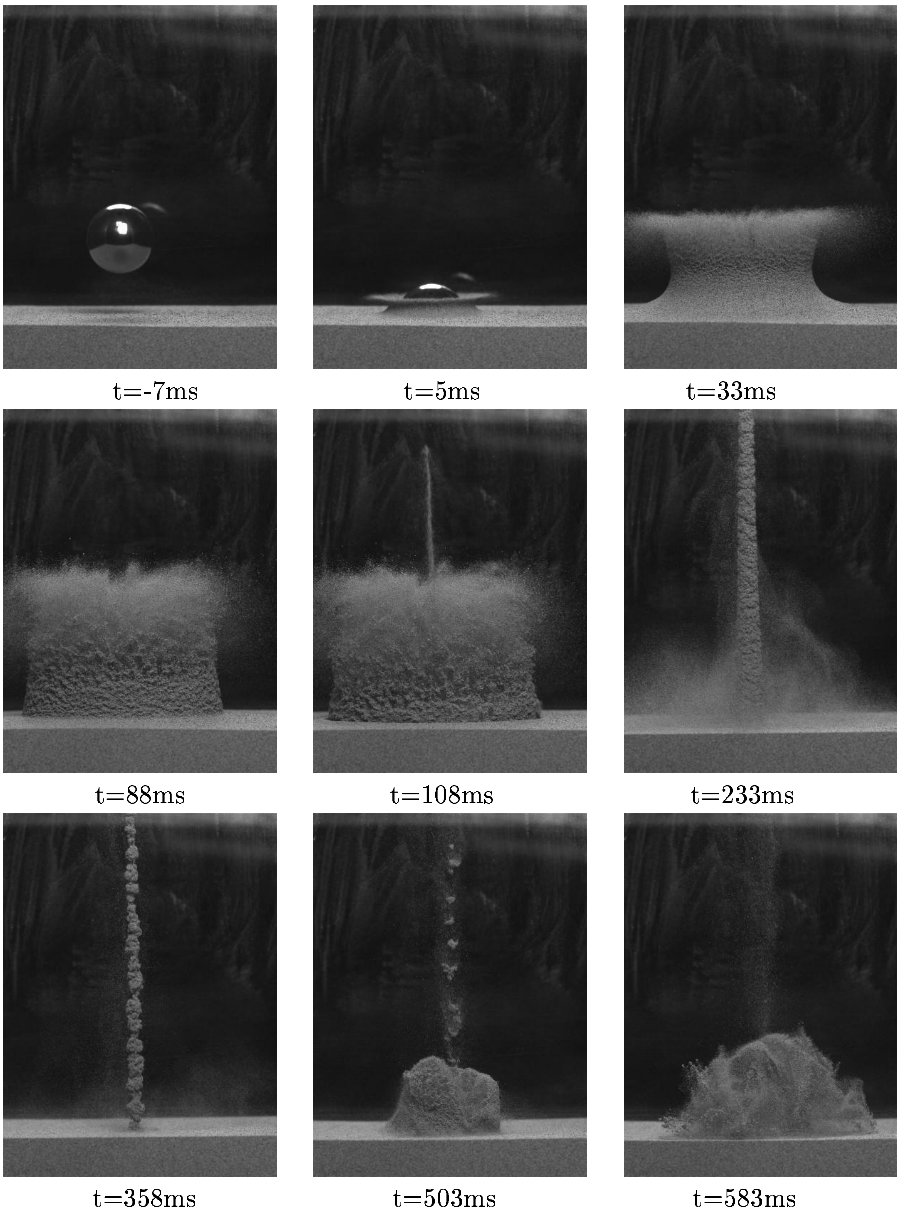

FIG. 1. Jet formation after the impact ($v_0 = 2.43m/s$) of a steel ball of $R_0 = 1.25cm$ on loose very fine sand. The jet in this experiment exceeds the release height of the ball. Frames 2-4: splash; frames 5-6: a jet emerges; frame 7: clustering within the jet; frames 8-9: granular eruption at the surface.