Airbursts - from Tunguska to Chelyabinsk

Natalia Artemieva

Planetary Science Institute, Tucson AZ; Institute for Dynamics of Geospheres, RAS, Moscow

Airburst (incorrectly called an “explosion”) is a sharp release of meteoroid’s energy into the atmosphere causing generation of strong blast waves. Airbursts are closely related to meteoroid’s fragmentation which occurs if a dynamic loading exceeds meteoroid strength. The 1908 Tunguska event represents the largest recorded example of an airburst event on Earth to date, with a magnitude estimates ranging from 3 to 5 Mt up to ~10–20 Mt [1-3]. Recent airburst above Chelyabinsk area was probably the largest since the Tunguska time with estimated energy of 100-500 kt. Theoretical calculations coupled with ground- and satellite-based observations of airbursts suggest that the Earth is struck annually by a objects of energy 2–10 kt [4,5].

Numerical methods and hydrocode in use. Methods describing meteoroid’s motion through the atmosphere include: 1) a system of differential eqs. to describe describing deceleration, ablation, and fragmentation into separate fragments [6] or “pancaking” [7]; 2) full-scale hydrodynamic modeling of a high-velocity gas flow (Mach number ~ 50) around the meteoroid [2,3,6]. SOVA code [8] is a 3D Eulerian code that models multidimensional, multi-material, large deformation, strong shock wave physics. SOVA includes a general treatment of viscosity for modeling viscous flow with Newtonian or Bingham rheology. Compared to other hydrocodes used to model high-velocity impacts SOVA has the advantage of including a two-phase hydrodynamics procedure that describes condensed particles and their momentum-energy exchange with gas.

Tunguska event 1908. The peculiar butterfly shaped pattern of the surface damage has been explained by an interaction of atmospheric shock waves with the surface and has been reproduced repeatedly in experiments and in three-dimensional physical models. Models and observations of Shoemaker-Levy 9 comet impact on Jupiter in 1994 helped to understand what happened to the Tunguska body. First of all, it was deformed, disrupted, and transformed into tiny droplets as it entered the atmosphere. The hot rarified atmospheric wake worked like a chimney forcing numerous particles into the upper atmosphere. A 400-km-diameter plume was formed within a few minutes and then splashed back spreading the projectile material along the dense lower atmosphere to distances of up to several thousand kilometers. Substantial amounts of water-vapor have been transported from the troposphere into the usually cold and dry mesosphere. Strong upper atmospheric winds transported this giant cloud all the way to Northern Europe within ~20 hours, creating extremely bright polar mesospheric clouds.

Chelyabinsk event 2013. On the early morning of February 15, 2013, thousands of people observed a bright flash in the sky over the city of Chelyabinsk. The flash was followed by a powerful sonic boom which destroyed windows across the area of ~ 5000 km^2 injuring more than 1500 people. Numerous video recordings of the event have allowed to reconstruct the trajectory and fragmentation history. The size (15-20 m) and energy of meteorite (100-500 kt) were estimated based on its infrasound signal, the energy of the brightest flash, and ground effects. Only a small fraction of the total mass was found near Chelyabinsk — mainly just tiny pieces with the largest fragment weighting ~3 kg.

References: [1] Vasiliev N.V. 1998. *Planetary and Space Science* 46:129–150. [2] Boslough M. and Craawford D. 1997. *Annals of the NY Academy of Sciences* 82: 236-282. [3] Shuvalov V. abd Trubetskaya I. 2007. *Solar System Research* 41:220-230. [4] Brown P. et al. 2002. *Nature* 420:294–296. [5] Bland P. abd Artemieva N. 2003. *Nature* 424: 288-291. [6] Artemieva N. and Shuvalov V. 1991. *Journal of Geophysical Research* 106: 3297-3310. [7] Chyba C.F. et al. 1993. *Nature* 361:40-44.[8] Shuvalov V. 1999. *Shock waves 9:*381-390.