Order-of-Magnitude Physics – Lab 5

Guidelines:

- You can switch scribes between parts (a)–(f).

Problem 1. Chelyabinsk

On 15 February 2013, a near-Earth asteroid exploded near the Russian city of Chelyabinsk.

The meteor entered the atmosphere nearly horizontally (about 10 degrees from the horizontal).

About 1,500 people were injured, mainly from broken glass from windows that were blown in.

Estimate (in whatever order you prefer):

(a) the **overpressure required to shatter the windows (see photograph on video screen)**, in units of bars (1 bar = 1 Earth atmosphere);

(b) the **altitude at which the meteor started to break apart**, in km. Here it is helpful to know that the Chelyabinsk meteor was a stony (not iron) asteroid and therefore weak: its failure stress was roughly a factor of 10 smaller than that of ordinary terrestrial materials (a consequence of being battered by asteroid-asteroid collisions over billions of years in space);

(c) the **energy** of the explosion, in standard bomb units of kilotons of TNT;[1]

(d) the **radius** of the incoming asteroid (a.k.a. meteoroid);

(e) the **time it took for most of the meteor to vaporize** and thus the **length** of the fireball trail it left behind;

(f) **whether people would be knocked off their feet** by the explosion.

Hint 1: Pressure is energy density.

Hint 2: Is a blown-in window more like a horizontal branch or more like a vertical tree? As we discussed last Thursday, this question matters for the moment arm of the buckling torque.

Hint 3: Think Sedov-Taylor and assume the explosion is "adiabatic", i.e., ignore radiative cooling (the term "adiabatic" is misleading because entropy is not conserved in the explosion). Adiabatic explosions do work on the surrounding medium: they convert energy into pressure and bulk wind velocity, in roughly equal measure.

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[1]For comparison, the Hiroshima nuclear bomb had a yield equivalent to 16 kilotons of TNT.