Ames Research Center

Simulation-Based Height of Burst Map for Asteroid Airburst Damage Prediction

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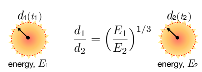
Overview

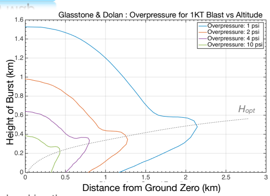
Entry and breakup models predict that airburst in the Earth's atmosphere is likely for asteroids up to approximately 200 meters in diameter. Objects of this size can deposit over 250 megatons of energy into the atmosphere. Fast-running ground damage prediction codes for such events rely heavily upon methods developed from nuclear weapons research to estimate the damage potential for an airburst at altitude. (Collins, 2005; Mathias, 2017; Hills and Goda, 1993). In particular, these tools rely upon the powerful yield scaling laws developed for point-source blasts that are used in conjunction with a Height of Burst (HOB) map to predict ground damage for an airburst of a specific energy at a given altitude. While this approach works extremely well for yields as large as tens of megatons, it becomes less accurate as yields increase to the hundreds of megatons potentially released by larger airburst events. This study revisits the assumptions underlying this approach and shows how atmospheric buoyancy becomes important as yield increases beyond a few megatons. We then use large-scale three-dimensional simulations to construct numerically generated height of burst maps that are appropriate at the higher energy levels associated with the entry of asteroids with diameters of hundreds of meters. These numerically generated HOB maps can then be incorporated into engineering methods for damage prediction, significantly improving their accuracy for asteroids with diameters greater than 80-100 m.

1 Improving the Height of Burst (HOB) Map

- With no buoyancy or other length scales, point sources blasts are self-similar
- Yield scaling allows us to relate overpressures between blasts of different strengths



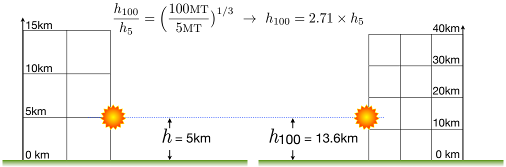
$$\frac{d_1}{d_2} = \left(\frac{E_1}{E_2}\right)^{1/3}$$



- Buoyancy introduces an additional length-scale breaking the self-similarity of the blasts -- can be neglected for "small" blasts (< 5-10MT) since:
  - Propagation times are short so acceleration due to gravity doesn't have time to act.
  - Distances are small as compared to the scale-height of the earth's atmosphere (~7-8km).

e.g. **Yield scaling predicts** that a 100 MT blast at a burst height of 13.6 km will have the same scaled ground overpressure as a 5 MT blast detonated at an altitude of 5 km

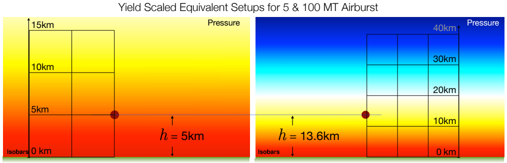
$$\frac{h_{100}}{h_5} = \left(\frac{100\text{MT}}{5\text{MT}}\right)^{1/3} \rightarrow h_{100} = 2.71 \times h_5$$



2 Introducing Buoyancy

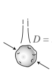
- **Buoyancy** enters through the pressure gradient due to gravity, $\partial p/\partial z$. This introduces a second characteristic length: the **scale height of the atmosphere.**
- With this second length scale, the two blasts are no longer strictly self-similar.
- When the scale height (7-8 km for Earth) is large compared to the blast footprint, buoyancy effects are small.
- However, at the high energy levels associated with asteroids whose diameter is greater than about 100m, these effects can be significant.
- Here is the yield scaled equivalent setup for the 5 & 100 MT airburst in (1) *with buoyancy.* Note that while the blasts themselves are similar, the background pressure gradient in the atmosphere is significantly steeper at the larger yield.

Yield Scaled Equivalent Setups for 5 & 100 MT Airburst

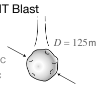


- These correspond roughly to:

Diameter = 52 m
Speed = 16 km/sec
ρ = 2.50 g/cc

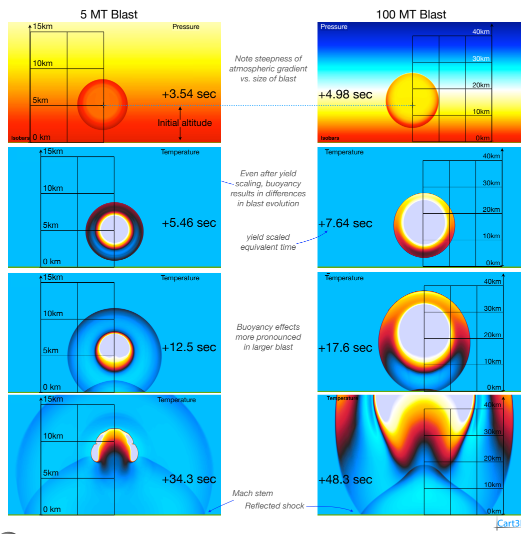


Diameter = 125 m
Speed = 18 km/sec
ρ = 2.50 g/cc



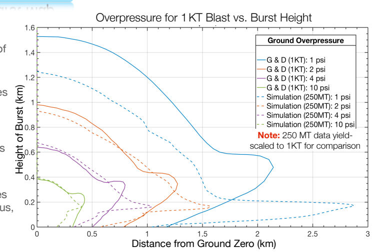
3 Blast Evolution

- The similarity parameter $\frac{d^5 \rho_o}{t^2 E} = \text{Const}$ establishes the time scale equivalence between two blasts.
- For 5 and 100MT, this implies $\left(\frac{t_2}{t_1}\right)^2 = \frac{\rho_{o2}}{\rho_{o1}}\frac{E_1}{E_2}\left(\frac{d_2}{d_1}\right)^5$ giving $\frac{t_2}{t_1} = \frac{t_{100\text{MT}}}{t_{5\text{MT}}} = 1.4079$
- The increase in time scale compounds the effects of buoyancy. Not only is the pressure gradient steeper, but it acts over a longer period of time.
- As an example, compare 5 & 100 MT blasts. In the image sequence below, burst height, length and time scales have been sized to provide yield scaled equivalent snapshots of the blast evolution.
- Buoyancy modifies the ground overpressure footprint, resulting in different damage predictions



4 Updated Height of Burst Map

- Used simulation to numerically generate HOB maps for blasts of various yields at dozens of altitudes
- Buoyancy significantly decreases the height of the "bulge" associated with H_{opt},
- This can increase the radius of lethal overpressures for airbursts of asteroids in the 100-200m range.
- Since the ground footprint scales with the square of the blast radius, estimates of the effected population are significantly improved.



Outcome

The probabilistic risk tool (Mathias, 2017) now interpolates between appropriate numerically generated HOB maps to give improved prediction of ground footprint for larger entry energies. Since large asteroids typically have lower burst heights, these predictions can be significantly effected by the steep gradients seen in the HOB map above. This modified risk tool was used for analysis supporting NASA's Science Definition Team's work to quantify the threat posed by Near Earth Objects.

Acknowledgements

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