Sensitivity of Airburst Damage Prediction to Asteroid Characterization Uncertainty

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Physics-Based Impact Risk Model

Asteroid Characterization → Input Parameter Distributions

Monte Carlo Sampling

Initial Conditions

Flight Integration
(meteor equations of motion, ablation)

Airburst Altitude
(peak energy deposition)

Fragment-Cloud Model
(breakup and energy deposition)

Blast and Radiation Propagation

Thermal Damage
(3rd degree burns)

Impact Coordinates

Overpressure Damage
(Peak overpressure ≥ 4 psi)

PHA Measurements
- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

Impact Parameters
- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

Local Land Impact Casualties
(Gridded population within largest damage area)

Global Effects Casualties
(Percentage world population killed by climatic effects)

Initial Conditions

Input Parameter Distributions

Monte Carlo Sampling

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Fragment-Cloud Model (FCM)

- Analytic model of asteroid entry/breakup to estimate energy deposited in the atmosphere
- Combines progressive breakup of independent fragments and “pancaking” debris clouds.

**Entry flight:** integrates meteor equations of motion and ablation

\[
\begin{align*}
\frac{dm}{dt} &= -0.5 \rho_{\text{air}} v^3 A \sigma \\
\frac{dv}{dt} &= \rho_{\text{air}} v^2 A C_D / m - g \sin \theta \\
\frac{d\theta}{dt} &= (v/(R_E+h) - g/v) \cos \theta \\
\frac{dh}{dt} &= v \sin \theta
\end{align*}
\]

**Fragmentation when pressure > strength**

\[ \rho_{\text{air}} v^2 > \text{strength} \]

**Each break yields:**
- Multiple independent, identical fragments (baseline 2)
- Debris cloud of specified mass fraction (baseline 50%)

**Fragment strengths increase with decreased size**

\[ S_2 = S_1 (m_1/m_2)^\alpha \]

**Clouds broaden and slow under common bow shock**

\[ v_{\text{dispersion}} = v_{\text{cloud}} (3.5 \rho_{\text{air}} A / \rho_{\text{cloud}})^{1/2} \]

Energy deposition computed as change in total KE of all fragments/clouds as a function of altitude.

Airburst at altitude of peak energy deposition.
Sensitivity to Parameter Variations, 70m Diameter

Baseline vs. Variation:

- Avg. pop. vs. Local gridded pop.
- 70m vs. H-mag 23.5 (~30-150m)
- 3400 vs. Meteorite distribution
- 1e-8 vs. 1e-9 – 1e-7 (uniform)
- 21 vs. 12 – 30 km/s (uniform)
- 45° vs. 0° – 90° (weighted)
- 5.05 vs. 0.1 – 10 MPa (uniform)
- 0.03 vs. 10^{-4} – 10^{-2} (uniform)
Sensitivity to Parameter Variations, 140m Diameter

**Casualty Sensitivities, 140m**

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. pop.</td>
<td>Local gridded pop.</td>
</tr>
<tr>
<td>140m</td>
<td>H-mag 22 (~65-310m)</td>
</tr>
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Impact Risk Distribution

- Sample risk posture: track any size with at least a one-in-a-million/year chance of causing damage above a threshold level of 4 (10^4 affected people).

Absolute Damage Exceedance by Size Threshold
Stony Asteroids

~75m threshold
Absolute Size & Damage Thresholds

- Damage threshold pushed to smaller H-magnitude equivalent diameters, driven by potential for actual asteroid to be larger than assumed from average albedo conversion.
- For sizes that tend to cause little-to-no damage, potential to be larger than assumed has greater risk impact than potential to be smaller.

**H-Mag Size**

**Direct Diameter**