New Perspectives on the NEO Threat and Other Reasons to Consider Asteroid Deflection/Fragmentation

Mark Boslough
Sandia National Labs
Albuquerque, NM

Asteroid Deflection Research Symposium 2008
October 23-24, 2008

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.
Red Storm simulation

2005 simulation was for concept demonstration: not intended to be realistic option
New perspectives on the impact threat

1. Some nuclear deflection strategies are better: Multiple low-yield shallow bursts are best.

2. Low-altitude airbursts dominate residual threat: Mitigation should be for ~hundred m asteroids.

3. Recent controversies in impact science: Credibility of community requires solid research.

4. Total asteroid threat is diminishing: Mitigation not justified for NEO protection alone.

5. Better reasons to consider asteroid deflection: Geo-engineering and space resources.
1. Nuclear deflection

- Best way to couple energy and momentum is buried nuclear burst (direct consequence of scaling laws)
- For a given total yield, multiple bursts are better than single burst (direct consequence of scaling laws)
- Non-weaponizable impact-triggered fission device is possible in principle
- Impact-triggered fission device would make multiple low-yield shallow bursts feasible
Numerical simulations of momentum coupling

- Three prongs of analysis: Numerical simulations, analytic models, scaled experiments.
- 2D parameter studies, sensitivity analysis, and intuition (require workstation computing).
- 3D models quantify effects of heterogeneities, strength, fracture, and spallation that are not amenable to either scaled experiments or analytical models (require capability computing).

2D workstation-class problem

Example:
1 kiloton surface burst in an intermediate-strength 100-meter diameter dunite disk \((m=10^9 \text{ kg})\) couples \(3 \times 10^8 \text{ kg} \cdot \text{m/s}\), but spalls material off the back surface.

3D capability-class problem

Example:
For known 3D geometry, internal structure of Itokawa must be assumed. Over what range of parameters can momentum be coupled to Itokawa without breaking it?
Golevka deflection: 100 kt explosion, 5 m deep
1 billion computational cells, Red Storm
2. Low-altitude airbursts

- The relative threat from low-altitude airbursts (LAAs) is increasing
- Our understanding of LAAs is improving
- The next destructive NEO will almost certainly be a LAA
- “100/100/100 event”: (~100 m, ~100 Mt, ~1/100 chance this century)
- 100/100/100 event will dominate threat after survey is complete
- Time for technology development is similar to threat reduction time
- There are other reasons to deflect/fragment small asteroids
- Technology should be focused small (~few hundred meter) asteroids
The nature of the impact threat is changing.
There are two types of Low-Altitude Airburst

1. The explosion generates a fireball that descends rapidly but does not reach the ground. Most of the damage at ground level is mechanical, due to the blast wave. This occurs for explosions between about 1 and 10 Mt, and may occur on time scales of several hundred years. The only known example is 1908 Tunguska event.

2. The fireball is much larger and descends all the way to the surface. The damage is dominated by high-temperature thermal radiation. The threshold yield is about 10 Mt, depending on other parameters, and they recur on time scales of several thousand years. The best putative example is the Libyan Desert Glass event, 29 million years ago.
There are two types of Low-Altitude Airburst:

- Type 1: Tunguska
- Type 2: Libyan Desert
Type 1 airburst simulation: 5 megaton
Type 2 airburst simulation: 15 megaton
Type 1 LAA: “Tunguska-Type”
Type 1 LAA: “Tunguska-Type”
Consequences of Type 1 airburst

Krinov, 1963
Modeling Type 1 airburst

90% on flat land (healthy forest)
30% on flat land (healthy forest)
90% on flat land (unhealthy forest)
30% on flat land (unhealthy forest)
90% on ridge tops (unhealthy forest)
30% on ridge tops (unhealthy forest)

Wind speed (m/s)

Surface velocity at 1.00e+01 seconds

Map view
velocity shading
first 115 seconds
5 Mt explosion at 12 km above surface, 35° entry angle

Tunguska treefall map (Longo et al, 2005)  
Wind speed map (this study)
Type 2 LAA: “Libyan-Desert-Type”
Consequences of Type 2 airburst
Modeling Type 2 airburst

Wind speed (m/s)

Surface velocity at 5.00e+00 seconds

Map view velocity shading first 120 seconds

90% on flat land (healthy forest)
30% on flat land (healthy forest)
90% on flat land (unhealthy forest)
30% on flat land (unhealthy forest)
90% on ridge tops (unhealthy forest)
30% on ridge tops (unhealthy forest)
15 Mt explosion at 18 km above surface, 35° entry angle

Tunguska treefall map (Longo et al, 2005)

Wind speed map (this study)
100 Mt explosion, 90° entry angle

Temperature at 3.56 seconds

Temperature shading

Kelvin

5500
5000
4500
4000
3500
3000
2500
2000

1 km
100 Mt explosion, 90° entry angle

Wind speed shading
Animated version for National Geographic documentary “Ancient Asteroid”
Meteor Crater impact was a low-altitude airburst

Less than 30% of the initial energy made it to the surface (Melosh & Collins, 2005)
9.0 Mt initial KE, 2.5 Mt formed crater, 6.5 Mt explosion in air
The physics of airbursts

Shoemaker-Levy 9 comet crash: Jupiter, 1994
Shoemaker-Levy 9 impact, July 1994

Visible From Earth
Behind Jupiter

Cloud Tops

This is a robust result
Shoemaker-Levy 9 impact, July 1994

This is a validated result
View from Earth

Shoemaker-Levy 9 comet crash: Jupiter, 1994
Plumes and line explosions on Earth
3 MT impact source produces high velocity “ballistic fireball”

3 MT explosion source produces high velocity “buoyant fireball”

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>80</th>
<th>100</th>
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<tbody>
<tr>
<td>420 m/s</td>
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<td>225 m/s</td>
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</table>
Pancake model: Earth’s atmosphere protects us from low-altitude airbursts


\[
m \frac{dv}{dt} = -\frac{1}{2} C_D \rho A v^2
\]

\[
q \frac{dm}{dt} = -\frac{1}{2} C_H \rho A v^3
\]

\[
r \frac{d^2r}{dt^2} = \frac{1}{2} C_D \frac{\rho}{\rho_m} v^2
\]

A stony asteroid deposits essentially all of its kinetic energy above 7 km. In this model the energy deposition curve is sharply peaked because of the mutually-reinforcing effects of atmospheric drag and deformation. Subsequent modeling has been based on point-source explosions and nuclear weapons effects.
The "point source explosion" model is a poor approximation.
Movies: Difference between explosion and impact

5 megaton point explosion at 5 km altitude: first 20 seconds
Movies: Difference between explosion and impact

5 megaton point explosion at 5 km altitude: first 20 seconds

Box dimensions: 8.4 x 15 km
Movies: Difference between explosion and impact

5 megaton impact airburst at 5 km altitude: first 20 seconds

Time = 10.02 seconds

15 kilometer box
Movies: Difference between explosion and impact

5 megaton impact airburst at 5 km altitude: first 20 seconds

Box dimensions: 8.4 x 15 km
Impact-Induced Vortex Rings

5 megaton impact airburst at 5 km altitude generates stack of supersonic white-hot “mega-tornado” rings

Red: inward rotation
Blue: outward rotation

Sustained supersonic flow melts and ablates surface
Impact-Induced Vortex Rings

5 megaton impact airburst at 5 km altitude

Box dimensions: 3 x 4 km
Animated version for National Geographic documentary “Ancient Asteroid”

This video was shown as justification for Younger-Dryas extinction impact hypothesis at 2007 Spring AGU, Acapulco:

http://www.youtube.com/watch?v=I2ld-lohrPw&feature=PlayList&p=741568C2D58A9793&index=1

This idea is based on simulations of Boslough and Crawford (1997) but is not physically realistic as shown in this animation. There is no viable mechanism to generate a cluster of fragments with this spacing.
Tutankhamun’s Fireball (Ancient Asteroid)
3. Recent impact controversies

Two new papers

Gasperini et al. (2007) “A possible impact crater for the 1908 Tunguska Event”

- Viable hypothesis
- Only evidence is circumstantial
- Have not found any theoretical support

Firestone et al. (2007), “Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling”

- Not a viable hypothesis
- Evidence is very weak
- Completely inconsistent with physics of impacts and airbursts
The Lake Cheko Controversy

“A possible impact crater for the 1908 Tunguska Event” Gasperini et al., 2007
The Lake Cheko Controversy

Lake Cheko photography: Discovery Channel

Impact crater or just a lake?

First post-expedition conference: Vanavara

First look: Submersible camera videos!
The Lake Cheko Controversy

“Anfinogenov spindles” (Anfinogenov, 1966)  Multiple explosions (Boslough, 2008)

Have not been able to find a physically-reasonable model that creates airburst consistent with Tunguska treefall pattern and crater consistent with Lake Cheko. Airburst modeling does not disprove the hypothesis, but does not support it either.
The odds that a potentially devastating space rock will hit Earth this century may be as high as one in 10. So why isn’t NASA trying harder to prevent catastrophe?”

By Gregg Easterbrook

A team of researchers led by Richard Firestone, of the Lawrence Berkeley National Laboratory, in California, recently announced the discovery of evidence that one or two huge space rocks, each perhaps several kilometers across, exploded high above Canada 12,900 years ago.

If, as Boslough thinks, most asteroids and comets explode before reaching the ground, then this is another reason to fear that the conventional thinking seriously underestimates the frequency of space-rock strikes—the small number of craters may be lulling us into complacency.

Given the scientific findings, shouldn’t space rocks be one of NASA’s priorities? You’d think so, but Dallas Abbott says NASA has shown no interest in her group’s work: “The NASA people don’t want to believe me. They won’t even listen.”

The Atlantic article was very misleading
The Megafauna Extinction Controversy

R.B. Firestone et al. (2007), "Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling'.

Not consistent with physics of airbursts

Bear skull, Krasnoyarsk

Russian poster at Tunguska 2008 conference, Moscow

Firestone et al., 2007 (poster, AGU Fall Meeting)
4. The asteroid threat in perspective
The asteroid threat in perspective

Alan Harris,
“What Spaceguard Did”
Nature 453, 2008

<table>
<thead>
<tr>
<th>Cause</th>
<th>Expected deaths per year*</th>
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<tr>
<td>Type 1 airburst</td>
<td>10 (&lt;1 per year in US)</td>
</tr>
<tr>
<td>All asteroids</td>
<td>80 (~4 per year in US)</td>
</tr>
<tr>
<td>Climate change</td>
<td>150,000 – 300,000</td>
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<td>Air Pollution</td>
<td>600,000</td>
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<td>Malaria</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Traffic accidents</td>
<td>1,200,000</td>
</tr>
<tr>
<td>HIV/AIDS</td>
<td>2,100,000</td>
</tr>
<tr>
<td>Tobacco</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

*Asteroid estimates from Harris (2008).
All other estimates from the World Health Organization.
5. Better reasons for NEO deflection

The rate of climate change is exceeding the most extreme expectations: Huge uncertainty in climate projections is analogous to uncertainty in NEO orbits
Climate change threat is ~ 10,000 times greater

...when probability distribution function for climate sensitivity is treated the same way as probability distribution function for NEO impact

Threat = Probability x Consequences
NEO capture for space resources or geo-engineering

Low-energy pathways allow capture of object into Earth orbit (Marsden and Ross, 2005)
Global climate change mitigation: More urgent than impact mitigation by $\sim 10^4$

- Captured asteroids can be fragmented and used to create engineered orbital debris ring, or placed at L1 for shadow.
- Changes in incoming solar radiation and atmospheric opacity modify Earth’s climate.
- Rapid changes in Earth’s climate are observable in geologic record.

Climate simulations

Conclusions

1. Multiple low-yield shallow bursts are most effective nuclear deflection method.

2. Primary mitigation goal should be for Type 2 airburst prevention.

3. Credibility of community requires skepticism and solid research.

4. Deflection not justified for NEO protection alone.

5. Geo-engineering and space resources are vastly better reasons to develop deflection technology.
Questions?