An Optimal Mitigation Strategy Against the Asteroid Impact Threat with Short Warning Time

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NIAC Study Objective (2011 – 2014)

To develop an innovative yet practically implementable mitigation technique for the most probable impact threat of an asteroid or comet with short warning time (i.e., when we don’t have sufficient warning times for a deflection mission)
NIAC Phase 1 Proposal (2011)

• Late intercept missions, with short warning time < 1 yr, will result in a hypervelocity arrival closing (relative) velocity of 5 to 30 km/s.
• $\Delta V = 10$ km/s requires a 96% propellant mass (300-s Isp)
• $\Delta V = 30$ km/s requires a 99.99% propellant mass ratio
• Impact velocity of nuclear explosive devices (NEDs) is limited as 300 m/s max (2005 NRC Report on NEPWs)
Precision Terminal Intercept Guidance

Terminal Guidance Begins Impact - 2 hrs for 50- to 150-m target

Camera identifies target NEO

Deployment of 10-m boom with contact fuzes and sensors

Leader S/C separates from Follower S/C

Sensors on boom detect NEO surface and Leader S/C sends a signal to initiate detonation sequence of NED

Leader S/C impacts and creates a shallow crater allowing more surface area to be exposed to NED

Launch Vehicles
- Delta IV Heavy
  1500 kg NED
  (≈ 2 Mt yield)
- Delta IV M+
  1000 kg NED
  (≈ 1 Mt yield)
- Delta II Class
  300 kg NED
  (≈ 300 kt yield)
2006 NEO Report by NASA
2010 NEO Report by NRC
Deflection

Disruption

Pulverization/Vaporization

NIAC Phase 1 & 2 Studies

2006 NEO Report by NASA
2010 NEO Report by NRC

Civil Defense

Warning Time (Years)

1 2 3 5 10 20 50 100

Ready to Launch

Build and Launch

Nuclear

10,000

1,000

100

10
The Hypervelocity Asteroid Intercept Vehicle (HAIV) mission concept of blending a kinetic impactor with nuclear subsurface explosion

7 journal articles + 30 plus technical papers

3 Ph.D. (graduated) + 3 MS (graduated) + 3 Ph.D. (current)

The HAIV mission concept should further exploit the ATLAS last alert system for active last-minute planetary defense (1 week – 3 weeks)
### ATLAS Last Alert System
(Asteroid Terrestrial-Impact Last Alert System)

<table>
<thead>
<tr>
<th>Alert Timeframe</th>
<th>Asteroid Size</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-day</td>
<td>8-m, 30-kt</td>
<td>“town killer”</td>
</tr>
<tr>
<td>One-week</td>
<td>45-m, 5-Mt</td>
<td>“city killer”</td>
</tr>
<tr>
<td>Three-week</td>
<td>140-m</td>
<td>“county killer”</td>
</tr>
</tbody>
</table>

- A $5M project started in 2013 (due to the Chelyabinsk event)
- The ATLAS is currently scanning the sky with a prototype camera and telescope, and will be fully operational in 2015-2016.
- So far, only for civil defense (evacuation)
- **One-day alert for a 8-m, 30-kt “town killer”**
- **One-week alert for a 45-m, 5-Mt “city killer”**
- **Three-week alert for a 140-m “county killer”**
NIAC Project Outcomes (2/2)

- If a HAIV/IPBM system ($\approx$ $200M - $500M) becomes ready to launch at anytime in the future,

  ✓ Given one-week warning from the ATLAS, an asteroid (> 45 m) can be intercepted/fragmented far outside the orbit of moon.

  ✓ Given three-week warning from the ATLAS, an asteroid (> 140 m) can be intercepted/fragmented far outside Earth’s gravitational field.

- Note that ALL other “non-nuclear deflection” options will require much earlier warning of at least 10 to 20 years.
Suborbital Nuclear Intercept/Pulverization Mission Scenario

Minuteman III
6.6 km/s

20 min
2,500 km

4 min

Asteroid

SM-3 IIA

AAS-2014-281
AIAA-2014-4460
PDC 2015
HAIV Design by NASA GSFC for a Flight Validation Mission ($500M)

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HAIV Design by the Mission Design Lab (MDL) of NASA Goddard Space Flight Center

Spacecraft Bus with NED Payload

10-m AstroMast Deployable Boom

Kinetic Impactor

GNC Sensors

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tests and a second trajectory correction maneuver. In addition, some initial observations of comet Tempel 1 will be attempted.

Approach Phase
The approach phase extends from 60 days before to five days before encounter. Sixty days out roughly coincides with the earliest time that the team expects the spacecraft to be able to detect comet Tempel 1 in its high-resolution camera. This milestone marks the beginning of an intensive period of observations to refine knowledge of the comet’s orbit. Regular scientific observations will be used to study the comet’s rotation, activity and dust environment.

Comet Encounter
The encounter phase begins five days before and ends one day after the impact with comet Tempel 1. This brief but very intense period includes two final targeting maneuvers, leading up to release of the impactor and its dramatic collision with the comet’s nucleus. After releasing the impactor, the flyby spacecraft will execute a deflection maneuver so that it does not also collide with the comet; the maneuver will also slow it down enough to make observations after the impact and before flying past the nucleus.

Mission Trajectory
Table 5. Preliminary launch window.

<table>
<thead>
<tr>
<th>Launch date</th>
<th>Earth departure</th>
<th>Relative velocity at intercept (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019-07-21</td>
<td>22.48</td>
<td>13.4</td>
</tr>
<tr>
<td>2019-08-02</td>
<td>11.99</td>
<td>11.5</td>
</tr>
<tr>
<td>2019-08-12</td>
<td>8.44</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Figure 10. Ecliptic plane projection of the Earth’s orbit (blue), the orbit of 2006 CL9 (violet), and the HAIV intercept trajectory (green).

Table 6. Maneuver schedule and v_budget.

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>v (m/s)</th>
<th>Time Correction</th>
<th>v Error (%)</th>
<th>v Error (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCM 1</td>
<td>26.0</td>
<td>L + 01 days</td>
<td>10</td>
<td>2.6</td>
</tr>
<tr>
<td>TCM 2</td>
<td>2.8</td>
<td>L + 10 days</td>
<td>5</td>
<td>0.140</td>
</tr>
<tr>
<td>TCM 3</td>
<td>0.3</td>
<td>L + 30 days</td>
<td>5</td>
<td>0.015</td>
</tr>
<tr>
<td>TCM 4</td>
<td>0.2</td>
<td>L + 60 days</td>
<td>5</td>
<td>0.010</td>
</tr>
<tr>
<td>TCM 5</td>
<td>0.3</td>
<td>L + 90 days</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>TGM 1</td>
<td>3.1</td>
<td>I - 90 min Nav</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TGM 2</td>
<td>0.4</td>
<td>I - 35 min Nav</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TGM 3</td>
<td>0.5</td>
<td>I - 13 min Nav</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TGM 4</td>
<td>3.5</td>
<td>I - 60 secs Nav</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Total v = 37.1 m/s
Hypervelocity Asteroid Intercept Vehicle (HAIV) Interplanetary Ballistic Missile (IPBM) Concept
Pulverization and Dispersion of a 300-m Asteroid with a 30-day Warning Time

Educational Use Only

14 Mar 2036 01:00:00.000  Time Step: 3600.00 sec
In the realm of potential planetary disasters, asteroids are among the ones to fear—like the meteorite that hit Russia today, they can inflict serious damage on Earth. With the aid of a $5-million grant from NASA, a University of Hawaii team of astronomers is developing ATLAS, a system to identify dangerous asteroids before their final plunge to Earth.

The team is on track to build and operate an asteroid detection system that will patrol the visible sky twice a night looking for faint objects moving through space. ATLAS (Asteroid Terrestrial-Impact Last Alert System) will operate up to 8 small telescopes, each fitted with cameras of up to 100 megapixels, on mounts housed at one or two locations in the Hawaiian Islands. Astronomers expect the system to be fully operational by the end of 2015.

Astronomer John Tonry compared ATLAS’s sensitivity to detecting a match flame in New York City when viewed from San Francisco. The team predicts the system will offer a one-week warning for a 50-yard diameter asteroid or “city killer” and three weeks for a 150 yard-diameter “county killer.” “That’s enough time to evacuate the area of people, take measures to protect buildings and other infrastructure, and be alert to a tsunami danger generated by ocean impacts,” Tonry said.

The typical asteroid is a “rubble pile”—a large collection of rocks and dust. Most asteroids reside in the Main Asteroid Belt between Mars and Jupiter, though some, called near-Earth objects, can orbit much closer to Earth. Sometimes the gravitational tugs from the planets in the solar system send one of the asteroids on a collision course with Earth.

Had the meteorite that hit Chelyabinsk, Russia today arrived at Earth at a different time of day, it could have hit Moscow, Belfast, Dublin or any number of other cities with a latitude similar to that of Chelyabinsk. Had the much larger asteroid 2012 DA14 that coincidentally passed by Earth on the same day been the one that hit Chelyabinsk, the entire city would have been completely destroyed. Scientists estimate that such a “city killer” impacts Earth about once every few hundred years. The most recent such impact occurred about 103 years ago—the Tunguska impact—in Siberia.

ATLAS will complement the Institute for Astronomy’s Pan-STARRS project, a system that searches for large “killer asteroids” years, decades, and even centuries before impact with Earth. Whereas Pan-STARRS takes a month to complete one sweep of the sky in a deep but narrow survey, ATLAS will search the sky in a closer and wider path to help identify the smaller asteroids that hit Earth much more frequently.

Funding from NASA’s Near Earth Observation Program will provide $5 million over five years with $3.5 million designated for design and construction in the first three years and the remainder for operating.
Thank You!