Planetary Defense Conference

PROTECTING EARTH FROM ASTEROIDS

Summary and Recommendations

from the

2007 Planetary Defense Conference

held on

March 5 – 8, 2007

at the

Cloyd Heck Marvin Center

George Washington University

Washington, D.C.

April 25, 2007

2007 Planetary Defense Conference

White Paper: Summary and Recommendations

1. Meeting Overview

The **2007 Planetary Defense Conference** was held March 5-8, 2007 at the Cloyd Heck Marvin Center at George Washington University in Washington, D.C. The primary objectives of the meeting were: to highlight current capabilities in Near Earth Object (NEO) detection, characterization and mitigation; to advance understanding of the threat posed by asteroids and comets and arrive at possible responses to an asteroid impact; and to consider political, policy, legal and societal issues that would affect our ability to mount an effective defense. The conference followed a format similar to the 2004 Planetary Defense Conference, results of which are summarized in an AIAA Position Paper.[1]

Sponsors for the 2007 event were:

The Aerospace Corporation
American Institute of Aeronautics and Astronautics
The Applied Physics Laboratory
Ball Aerospace
European Space Agency, ESA
General Dynamics
Indian Space Research Organization, ISRO
Japan Aerospace Exploration Agency, JAXA
National Aeronautics and Space Administration, NASA
Orbital Sciences Corporation
The Planetary Society
Space Studies Institute
SpaceWorks Engineering

The meeting was organized by its Steering Committee, with members listed in Attachment 1. Attachment 2 provides the conference program with the detailed agenda,

[1] “Protecting Earth from Asteroids and Comets,” AIAA Position Paper, October 2004 (see http://www.aiaa.org/content.cfm?pageid=139)

speakers and presentation titles. The meeting was attended by 145 participants, listed in Attachment 3. Copies of papers, presentation material, and videos of the presentations themselves are available at the conference web site, www.aero.org/conferences/planetarydefense.

Day 1 of the conference provided an overview of efforts to discover threatening Near Earth Objects (NEOs), defined as asteroids or comets whose orbits have perihelia of less than 1.3 Astronomical Units[2] (AU), and the subset of NEOs that pose a more immediate threat to Earth, called Potentially Hazardous Objects (PHOs). PHOs are defined as asteroids and comets that pass within 0.05 AU of Earth's orbit[3] and are large enough to cause significant damage should one impact Earth (~50 meters in diameter and larger). Day 1 presenters also discussed what we know about the composition and structure of PHOs, how such characteristics are determined, and what has been learned from recent missions to, and observations of, asteroids and comets. Briefings included a summary of the detection and characterization aspects of the recently completed study by NASA in response to congressional direction.[4] Information was also presented on NEO/PHO populations, the potential increases in their rates of discovery, and the variation of impact probability as the number of observations increases.

Presenters in **Day 2** discussed techniques that could be used to deflect or otherwise mitigate a threatening asteroid and the design of deflection and mitigation missions. Presentations highlighted how NEO composition and structure influence the effectiveness of mitigation techniques, described slow-push and quick-impulse deflection methods, and proposed techniques that could be used to break a threatening object into small fragments. Presenters also gave an overview of missions that have been proposed to actually test our ability to move an asteroid. Included in Day 2 was the presentation of deflection technique-related highlights of the NASA Report to Congress.[4]

Day 3 summarized recent work on consequences of an impact, including tsunamis and the overpressure developed during a high-speed entry into Earth's atmosphere. The latter work suggests that treating airbursts as point-source explosions may not provide the most accurate estimates of surface effects from NEO entries. Likely, hypothetical reactions of disaster and emergency response agencies and the public to warnings or to an actual impact were also highlighted using lessons learned from recent hurricane and tsunami-related disasters.

On **Day 4**, the final day, a panel of experts discussed topics such as legal issues associated with testing and implementing deflection techniques, educational aspects of NEO impact protection, and maintaining funding for an ongoing, long-term level of effort on detection, characterization and deflection. The panel also reported on ongoing efforts to develop an international decision process for NEO deflection. A second panel, made up of session chairs, discussed key points raised in each session. Meeting attendees were invited to address both panels.

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[2] Approximately the mean distance between Earth and the sun.

[3] About 7.5 million km.

[4] **Near-Earth Object Survey and Deflection Analysis of Alternatives Report to Congress**, NASA, March 2007 (available at http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf).

After the meeting, key points discussed by presenters and participants were distilled and refined by the conference's steering committee and circulated to all conference attendees for comment and discussion. Resulting consensus findings and recommendations are collected in this document.

2. Findings and Recommendations

While significant scientific and technological advances have been made since the 2004 conference and are ongoing, it is clear that providing effective planetary defense from Near Earth Objects and planning for mitigation of an impact disaster are in their infancy. Specifically, the primary findings of the conference are that:

1. While our search and discovery efforts have successfully found most of the large, "civilization-killer" 1-km and larger objects, we are just beginning to find the much more prevalent and, for that reason, more frequently dangerous objects in the 140- to 300-meter size range. An impact by an object in this size range could occur with little or no warning and could cause serious loss of life and property over a broad area.
2. Earth-based resources such as the Arecibo radar are critical for refining a PHO's orbit and providing basic information required for deflection. Arecibo has an essential role in refining the threat posed by PHOs such as Apophis.
3. Deflection of a threatening object is in the conceptual phase. We are just beginning to identify the options available to deflect an object and have yet to design or test techniques that might be used. Further, we have yet to design complete missions to deliver one or more deflection devices, and have not considered what is required to assure a high probability of success for an overall deflection campaign.
4. There are serious technical, political, policy, legal and societal issues involved in deciding whether and how to respond to a threat of a NEO impact. NEO impacts have the potential to cause disasters that would equal or exceed anything ever faced by recent civilizations. Moreover, this type of threat has never been seriously considered by any agencies that would have responsibility for responding. In addition, it is uncertain where responsibility for coordination of all aspects of the NEO threat lies, from detection to deflection to impact aftermath.
5. Understanding, analyzing, and dealing with a potential NEO threat is an international problem demanding international cooperation. Considerable work is required to develop a foundation for international cooperation and action in all areas related to planetary defense. This foundation may extend beyond defense and include benefits from international manned and unmanned space exploration.

The remainder of this White Paper provides background and recommendations in five areas considered at the conference: Detection and Characterization; Deflection Approaches and Missions; Impact Consequences and Response; Political, Policy, Legal; and Public Perception and Trust.

2.1 Detection and Characterization

Significant progress has been made in detecting and tracking NEOs, with about 4600 currently known compared to ~2700 in 2004. Similarly, the number of known PHOs was about 580 in 2004 and is currently about 850. Presenters estimated that there could be over 100,000 NEOs, including 20,000 PHOs, once the smaller, 140-meter and larger objects are added to the catalog. It was suggested that as many as 10,000 new 140-meter class objects, whose Earth impact probabilities will initially be non-zero, might be discovered in the next 20 years should an effort to discover and catalog these smaller objects proceed. In addition, some NEOs are binary in nature, and accompanying bodies are themselves large enough to pose a hazard; these must also be included in deflection plans.

The 270-meter diameter asteroid 99942 Apophis continues to be an object of interest, and the calculated probability of impact has varied as additional tracking data have been utilized to refine its orbit. Presenters discussed the predicted 2029 close Earth flyby and the associated “keyhole,” the small region in space during the 2029 approach where Earth’s gravity would perturb the asteroid’s trajectory such that the subsequent 2036 encounter would be an Earth impact. A deflection effort for Apophis prior to the 2029 keyhole would require more than four orders-of-magnitude less momentum transfer than after 2029, and good tracking data during the 2012-2013 apparition of Apophis is particularly critical for refining impact probabilities and deciding whether a deflection action is required before the 2029 close approach. As a note, there may be several deflection techniques, including slow-push techniques, that could be applied prior to 2029; after that date, deflection options narrow to more energetic techniques—probably nuclear explosives. The Arecibo radar, which is scheduled for possible closure, is the most powerful instrument available for improving orbital accuracy and physically characterizing many NEOs making close passages to Earth.

A related issue is bringing appropriate assets to bear in a cost-constrained environment. For example, the NASA report to Congress noted that there are civil and U.S. Department of Defense assets that could be leveraged for the NEO detection task. There may also be international resources that should be integrated into these efforts.

One potential requirement for PHOs might be "tagging" the object to permit precise tracking for several years. The Planetary Society is conducting a global competition for a mission design to place a transponder on an asteroid, with a $50,000 privately funded prize. Results from this competition should be studied as a first step for future considerations of tagging. This competition may be a model for encouraging creative ideas for other aspects of planetary defense.

There is continuing scientific uncertainty about the internal structure of NEO objects, with spacecraft imagery indicating that some smaller bodies are not solid, monolithic bodies, but so-called “rubble piles”—accumulations of smaller objects and debris held together by little more than their own self gravity. These physical properties are important for assessing the effects and effectiveness of deflection and mitigation options. Missions to asteroids may be the only way such issues can be resolved.

U.S. and Japanese missions to asteroids and comets are providing invaluable information on these bodies. Presenters detailed results of the Japanese Hayabusa mission to asteroid

Itokawa and the proposed European Don Quijote mission. The Hayabusa spacecraft is returning to Earth in 2010, hopefully with small samples of Itokawa obtained when it touched down on the asteroid's surface. Don Quijote is being planned to send an orbiter to an asteroid, where it will observe the effects of a kinetic impact on the object and on its orbit.

Recommendations

2.1.1. **Immediately initiate actions to locate threatening objects in the 140-meter to 1-km size range.** Objects smaller than 1 km, while certainly not "civilization killers," are large enough to cause local devastation and large loss of life. Perhaps more significantly, objects of this class are much more likely to strike Earth during future decades than are larger objects. The 1908 Tunguska event, caused by the entry of a NEO estimated to be 30-50 meters in diameter, leveled over 2000 sq km of Siberian forest—an area larger than the Washington, D.C. metropolitan area. Current technology limits our ability to detect and track many objects this small, but ground-based telescopes could, if adequately funded, discover and track a high percentage of potentially threatening 140-meter class NEOs in a reasonable time at a relatively low cost.[4] The addition of a space-based infrared survey telescope could significantly increase the discovery rate and provide improved estimates of NEO sizes.

2.1.2. **Characterize Apophis and refine its orbit during the 2012-2013 apparition.** Asteroid 99942 Apophis is the first known and tracked NEO that will pass close to Earth and present a real threat of impact within the next 30 years. The 2012-2013 apparition presents the opportunity to substantially improve orbital predictions and determine whether the threat warrants future deflection action.

2.1.3. **Support the operation of facilities critical to NEO discovery, orbit determination, and tracking.** Discovery and precision orbit determination are the critical first steps in characterizing a NEO threat and initiating a mitigation action. Facilities and capabilities for collecting and quickly processing discovery data are essential. The planetary radar at Arecibo is a unique national asset. The facility has the world's best capabilities for determining the orbit of Apophis, as well as estimating its size and spin state, detecting accompanying bodies, helping resolve uncertainties in impact probability and projecting the scope of impact damage. But plans call for this asset to be shut down and rendered unavailable during the 2012-2013 apparition of Apophis. Its use during this period is very important for determining whether Apophis will be a serious threat to Earth in 2036. A similar need for this or an equivalent asset will exist as additional new objects are discovered.

2.1.4. **Initiate a program in collaboration with planetary science objectives for the in-situ characterization of PHOs.** The effectiveness of deflection techniques is strongly influenced by the physical characteristics of the target NEO, yet we do not have a good understanding of the range of properties with which we might have to deal. Characterization missions, related to both general and specific threats, are required to provide insight into the nature of the objects we may need to deflect. Small and micro-spacecraft technology should be considered to reduce costs and enable multiple characterization missions. International collaborative missions to achieve these goals should be encouraged.

2.1.5. **Release the full 272-page "2006 Near-Earth Object Survey and Deflection Study"[5] to the public.** This report contains more detailed data and analysis supporting the NASA NEO Analysis of Alternatives Report to Congress[4] and is an excellent benchmark for the current state of knowledge on NEOs and their discovery and deflection options.

2.2 Deflection Approaches and Missions

Sometime in the future a credible NEO threat will be identified and actions will be required to prevent an impact disaster. As noted, we are very early in the development of technologies and techniques that could be used for such action.

Potential options identified in the NASA Report to Congress and discussed at the conference vary from slow-push techniques such as the gravity tractor and mass driver to more energetic impulsive techniques like kinetic impactors and nuclear explosives. Of course, technological development and verification is required for each, and the nuclear explosive option also requires addressing substantial public and international concerns.

In addition to technology developments related to the implementation of a deflection technique such as a gravity tractor or nuclear explosive, each option also has mission design-related issues that must be addressed. For example, in many cases a kinetic impactor will approach the NEO at a very high relative velocity, and thus will require rapid, accurate, and autonomous trajectory control. Similarly, slow-push techniques require rendezvous and long-term operation either attached, or in close proximity, to the target NEO. All options also have limitations imposed by the availability of launch vehicles and the demand for high reliability.

The 2004 conference discussed mission reliability and it was noted that to achieve the overall objective of deflecting an approaching object away from Earth with high reliability, a deflection campaign might include multiple launches of the same vehicle design. Further, since a common fault might be present in a single mitigation approach, a deflection campaign might actually consist of deflection attempts using two or more independent techniques.

The possibility of synergism between two deflection techniques was discussed from the perspective that a deflection campaign might incorporate both a slow-push and a more energetic technique to increase overall reliability. Some noted, for example, that a deflection campaign might utilize a slow-push technique as primary, with a quick-impulse technique as backup; others suggested a quick-impulse technique as primary, with a slow-push used to "clean up" the results. Of course, the mission timeline, cost effectiveness and overall probability of success of the campaign will factor into related decisions.

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[5] **2006 Near-Earth Object Survey and Deflection Study, Final Report**, NASA HQ, PA&E, December 28, 2006.

In all cases, we must be able to determine a new orbit after (or during, in the case of a slow-push technique) execution of a deflection attempt. The time required for establishing a new orbit must be included in the overall mission design and features that might be used to improve the accuracy of the post-execution orbit, such as placing a transponder on the object or maintaining a spacecraft on station nearby, were proposed.

The possibility was also raised that a deflection action might successfully avert a specific impact, but might increase the possibility of an impact at some future date. Design of a mission for a specific deflection must consider and minimize this possibility.

Recommendations

2.2.1. **Research, characterize and demonstrate technologies associated with the most promising impulsive and slow-push techniques.** Except for some technologies that might be used for impulsive missions, very little work to characterize deflection techniques has been done. Research is required to move these techniques from concepts to viable options for NEO deflection. Research should identify technologies critical to each method. Research should also consider approaches that might be synergetic and improve the overall certainty of a deflection mission. Included should be microgravity experiments to illustrate the response of NEO materials to impacts or to methods that might be used to attach or couple to the surface of such objects in microgravity conditions (i.e., attaching transponders or other instrument packages).

2.2.2. **Identify and pursue opportunities to demonstrate potential deflection technologies during characterization missions that are in formulation or early development.** At present, designers of deflection missions must allow for large uncertainties in the response of a target NEO to a deflection attempt, and additional research is required to increase confidence in our ability to predict and control the effectiveness of a deflection attempt. Compatible opportunities during characterization missions should be identified to demonstrate potential deflection technologies (e.g., attaching transponders, testing kinetic impactors, using low-impulse ion engines and slow-push techniques, etc.). The European Space Agency's Don Quijote mission is an example of the type of mission that might be used to characterize a NEO and to test deflection technologies.

2.2.3. **Develop and document complete designs of a deflection campaign, including launch vehicle and payload requirements, ground support requirements, overall mission reliability, mission timelines and milestones, and costs.** Our ability to <u>deliver</u> a deflection option to a threatening NEO with a high probability of success must also be considered in detail. Results of these studies would feed into an overall NEO deflection plan and help develop a roadmap for the architecture of a deflection campaign using current and near-term technology and capabilities. This plan should be updated on a periodic basis.

2.3 Impact Consequences and Response

Many small objects enter Earth's atmosphere on a daily basis and a few yield fragments that survive to reach the surface as meteorites. While some small object entries lead to airbursts and most are harmless, an otherwise harmless but brilliant bolide (fireball) in the wrong place could be mistaken for an attack, potentially causing a dangerous response. Quick notification of such events, should they be detected, would help avert such consequences.

Larger objects enter less frequently, but the effects increase as size increases. As noted earlier, the 1908 Tunguska event occurred after an airburst of a 30- to 50-meter-diameter object, which caused widespread devastation. The energy released had previously been estimated in the range of 10 to 20 megatons. More recent estimates suggest that the energy released could have been as low as 3 to 5 megatons.[6] An entry of this size is estimated to occur once every 1000 years on average.[7] The statistical likelihood of such an entry this century is 1 in 10.

Based on responses to past disasters, predictions are that an impact would result in initial confusion at all levels of leadership. The lack of understanding of the characteristics of a major impact event and impaired command and control are likely to result in delayed initial response efforts and resulting additional loss of life and suffering. As noted by Michael Chertoff, Secretary, U.S. Department of Homeland Security, in his testimony to the Select Committee Hearing after the Hurricane Katrina disaster: "This tragedy 'once again' emphasized how critical it is that we ensure our planning and response capabilities perform with seamless integrity and efficiency in any type of disaster situation—even one of cataclysmic nature."

Recommendations

2.3.1. **Conduct an Impact Response Exercise—a well-scripted and well-designed tabletop exercise, driven by improved gaming, modeling and simulation resources to increase understanding of the evolution of an impact disaster and demands on response agencies and communication systems.** For many natural disasters, agencies responsible for assisting those affected conduct simulations involving all segments of disaster response to identify issues and develop solutions. An unexpected NEO impact should be added to the set of disasters simulated. The disaster could be either from an ocean impact, where the effects could be experienced by a long expanse of coastline and possibly affect several or many nations, or from a land impact. The simulation would focus on effects of a 50- to 140-meter class NEO, a size that would likely impact without warning. Ideally, the exercise would involve all stakeholders that would be involved in a response, including local and national governments, military organizations, disaster responders, and members of the press.

2.3.2. **Incorporate the NEO hazard into the mandates of agencies, both national and international, that are charged with addressing very large-scale natural and man-made catastrophes.** Nations should assess the risk relative to natural

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[6] Boslough, M., "Low-Altitude Airburst Contribution to the Impact Hazard," presentation at 2007 Planetary Defense Conference, March 2007.

[7] Brown, P., et al, "The flux of small near-Earth objects colliding with the Earth," ***Nature*** **420**, 294-296, 21 November 2002.

and man-made hazards, and encompass the NEO response within existing national and international frameworks that address the more familiar hazards, ensuring that emergency response capabilities are suited to dealing with NEO-related scenarios.

2.3.3. **Conduct additional research to advance understanding of the relationship between NEO size and event consequences.** This relationship is critical for setting the lower limit of our detection efforts and making the decision to initiate a deflection campaign or other mitigation efforts. Previously, NEO explosions above Earth's surface (events believed typical of a class of smaller NEOs) have been treated as point-source explosions. New information indicates that the shock and flow field generated throughout the entry trajectory may be important contributors to ground effects (tsunamis, etc.). Additionally, an impact could release an electromagnetic pulse that could interrupt communications among disaster responders. We may not yet understand the complete nature of the hazard associated with PHO impacts and the dependence of impact consequences on object size.

2.4 Political, Policy, and Legal

An asteroid impact could occur anywhere on the globe at any time, so planetary defense has implications for all humankind. All nations on Earth should be prepared for this potential calamity and work together to prevent or contain the damage. That said, there is currently very little discussion or coordination of efforts at national or international levels. No single agency in any country has responsibility for moving forward on NEO deflection, and disaster control agencies have not simulated this type of disaster.

Providing funding over the long term was also seen as a challenge. Much of the work in virtually all areas of planetary defense has been done on individuals' own time and initiative. There is a need for ongoing studies and peer-reviewed papers to improve our knowledge in this area, as well as to increase the credibility of the issue and the public's trust in our ability to respond. The reality is that NEO deflection or disaster mitigation efforts may not be required for decades or longer, so governments, which are focused on more immediate concerns, may not be willing to commit sufficient recourses to this type of work. Determining the appropriate level of this work and funding such activities over the long term is seen as a major issue.

In addition, major legal and policy issues related to planetary defense need to be resolved. An example is liability for predictions that prove false or deflection missions that only partially work or fail completely, resulting in an impact. Other examples include:

- A prediction is made that an impact may occur in a specific area, and residents and businesses that might be affected leave. Are there liabilities associated with the loss in property values if the prediction is wrong?
- A nation makes a deflection attempt, but it fails to change the object's orbit enough to miss Earth. Is that nation now responsible for the damage inflicted?
- A NEO threat demands the nuclear option, but public perception is that the possibility of a launch failure and subsequent damage is more acute than the

threat from the NEO. What are the liabilities and political and policy implications associated with a launch failure during a deflection mission?

These types of issues should be discussed and resolved before they are raised by a serious threat.

Recommendations

2.4.1. **Develop an international protocol for use in situations when critical decisions relating to threat and disaster mitigation are required.** Given the global nature of the consequences, it is unlikely that one country will decide on its own whether to take action. There must be international involvement in decision-making and in whatever actions are decided. Discussions on how these decisions will be made should begin while there is no specific threat. Principles and protocols for the process of communication and dissemination of information about potential impacts, and the implementation of necessary mitigation measures should be negotiated and agreed to at an international level. These protocols should identify roles and responsibilities of key players and include a means to notify governments and the public of all hazards of a regional or global nature.

2.4.2. **Increase international collaboration on efforts aimed at detection and characterization, mission planning, and research related to deflection.** One concept suggested is to establish a Planetary Defense Coordinating Committee (PDCC) where nations can discuss and coordinate research efforts at the technical level. The group might be similar to the current Inter-Agency Space Debris Coordinating Committee (IADC)[8] where space agencies of 11 nations meet to address the issue of man-made debris. The PDCC would be chartered to coordinate NEO research activities and provide technical recommendations supporting legal and policy decisions.

2.4.3. **Develop and implement a mechanism to maintain funding for critical technologies and efforts over the long term.** Establishment of a trust fund or foundation should be considered to ensure uninterrupted financial support for research related to planetary defense.

2.4.4. **Develop a framework for the use of nuclear explosives for NEO deflection before a credible threat is identified.** The nuclear option for NEO deflection is sure to raise concerns among the public and governments, but this option would be necessary for the largest NEOs, or for NEOs that don't respond as predicted to non-nuclear techniques, or for those discovered too late to utilize other options.

2.4.5. **Develop international agreements limiting the liability related to making impact predictions or to taking or not taking action on a NEO threat.** In its discussions about NEOs, the international community should develop agreements regarding specific limitations of liability for taking or not taking actions, and for making predictions about NEO threats. At present, there may be potential liabilities related to specifying a threat and to taking a deflection action. For

[8] http://www.iadc-online.org

example, the mere forecast of an impact could have tremendous implications for the value of land and for businesses in the impact zone; a failed or ineffective deflection attempt could result in a subsequent impact and serious damage to the original threat area or possibly another area.

2.5 Public Perception and Trust

Low probability disasters come to the attention of policy makers and become part of the national and international agenda as the result of focusing events.[9] These are infrequent, sudden and harmful events that become known to the public and to the government simultaneously. As attention-grabbers, they initiate a push to "do something" about redressing the situation and preventing its recurrence. A hurricane, earthquake, major oil spill or technological catastrophe can generate a "spike" in interest that typically peaks in a few weeks in the media and in a few months in governmental deliberations and then dissipates as other issues come to the fore. Typically it produces a two-year window of opportunity for preparing for similar disasters, a window that closes slowly in the absence of another focusing event.

Progress occurs when there is an organized community of scientists and policy experts who push for new legislation during the window of opportunity. Such "policy entrepreneurs" have been highly successful promoting useful legislation following earthquakes, with the result that construction standards have improved consistently over the past hundred years. For example, earthquake policy entrepreneurs were instrumental in the drafting of the National Earthquake Hazard Reduction Act (NEHRA) of 1977. The key is a motivated and organized group of policy advocates that presses for efforts to mitigate the hazard and not just speed the flow of post-disaster relief.

While no NEO impact disastrous to society has occurred yet, significant NEO detections and even low-level threat warnings provide windows of opportunity for educating the public and decision makers on the nature of this recently recognized problem. Additionally, major projects, such as developing a new NEO warning or mitigation system, may have focusing effects and further our mitigation efforts.[10] In presenting risk, we must treat the threat seriously and act through established protocols that are understandable by the public.

Recommendations

2.5.1. **Engage and sustain the interest of professionals and practitioners from the social and behavioral sciences.** Even as effective detection and deflection strategies depend upon the best available knowledge from astronomy, physics, and engineering, effective warning and recovery depend upon utilizing the best

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[9] Birkland, Thomas A. *After Disaster: Agenda Setting, Public Policy, and Focusing Events*. Georgetown, DC: Georgetown University Press, 1997.

[10] Lowry, William. "Potentially Focusing Projects and Policy Change." *The Policy Studies Journal*, Vol. 34, no. 3, 313-335.

available knowledge from anthropology, psychology, sociology, political science, risk communication and related disciplines.

2.5.2. **Develop a strategy for educating elected and governmental officials and the public on the nature of the NEO threat and what to expect in regards to NEO detections and warnings.** The strategy should include ways to present sober, realistic assessments of the facts during periods of potential high risk and subsequent risk reduction efforts after refined orbit determinations are arrived at. The strategy should also consider enhancing understanding of our current abilities to discover threats and the potential for impacts to happen anytime without warning. One suggestion is to provide or enhance Internet sites to show how threats evolve and to illustrate possible action scenarios. A protocol for actions and notifications should be developed for threats that exceed predefined thresholds.

2.5.3. **Examine how social factors such as individual and group psychology, culture, and political and religious beliefs might affect the decision to move forward on a NEO deflection effort.** Individuals approach problems from a variety of viewpoints, and these factors are likely to be involved in discussions and decisions related to planetary defense and disaster recovery. Experts involved in NEO science and technology must also be aware of these aspects of the problem—particularly when they are informing the public, decision makers or potential funders about their research implications. A periodic survey on issues related to planetary defense may be a way to track progress in public understanding.

3. Summary

The 2007 Planetary Defense Conference focused on the current state-of-the-art of planetary defense-related technologies and legal, policy, political, and public-response issues that would affect the decision to mount a deflection campaign or to respond to a NEO-related disaster. The broad sponsorship of the conference indicates that planetary defense is increasingly being accepted as a legitimate issue and goal internationally and domestically.

The 19 recommendations presented in this White Paper are a result of presentations and discussions at the conference and subsequent interactions among conference participants. The hope of participants is that the recommendations contained herein will encourage serious, long-term efforts to develop and test technologies and to debate and enact policies that support protecting Earth from the threat of Near Earth Objects.

Conference Steering Committee

V. Adimurthy	Associate Director, Vikram Sarabhai Space Centre, Indian Space Research Organization, India
William Ailor	(General Chair) Director, Center for Orbital and Reentry Debris Studies, The Aerospace Corporation, US
Mark Barrera	Engineering Specialist, The Aerospace Corporation, US
Ivan Bekey	President, Bekey Designs, Inc., US
Elizabeth Carter	American Institute of Aeronautics and Astronautics, US
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A.C. Charania	Senior Futurist, SpaceWorks Engineering, Inc. (SEI), US
Lee Clarke	Associate Professor, Rutgers University, US
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David Dearborn	Lawrence Livermore National Laboratory, US
Louis Friedman	Executive Director, The Planetary Society, US
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David Morrison	Senior Scientist, NASA/Ames Research Center, US
Steve Ostro	NASA Jet Propulsion Laboratory, US
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Rusty Schweickart	Chairman, NEO Committee, Association of Space Explorers; B612 Foundation; Former Astronaut, US
Lee Valentine	Executive Vice President, Space Studies Institute, US
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Massimiliano Vasile	Lecturer, Department of Aerospace Engineering, University of Glasgow, Scotland, UK
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Anatoly Zaitsev	Director General, Planetary Defense Center, Russia

ATTACHMENT 2: CONFERENCE PROGRAM

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

Monday, March 5, 2007

Introduction & Welcome
Bill Ailor, The Aerospace Corporation

Keynote: Simon P. "Pete" Worden, Director, NASA Ames Research Center

SESSION 1A: Discovery & Characterization
Chair: David Morrison, NASA Ames Research Center

Poster Papers

Corrections for Initial Masses of Large Fireballs from the Canada Network, M.I. Gritsevich, V.P. Stulov (Not present, submitted paper)

An Analysis of the Correction Problem for the Near-Earth Asteroid (99942) Apophis=2004 MN4, V.V. Ivashkin and C.A. Stikhno (Not present, submitted paper and presentation)

Planetary Cosmogony of the Solar System: The Origin of Dangerous Meteoroids, Alexander V. Bagrov (Not present, submitted paper and presentation)

The Impact of Deep Impact, Jeffrey Van Cleve

Current NASA Discovery/Characterization Efforts: The Recommendations of the 2003 SDT Report and the December 2005 Congressional Request
Donald Yeomans, NASA Jet Propulsion Laboratory

December 2006 Report to Congress on the Next Generation of Search and Characterization
Lindley Johnson, NASA Headquarters

Evaluation of Present and Future Ground-Based Surveys and Implications of a Large Increase in NEA Discovery Rate
Alan Harris, Space Science Institute

NEO Warning Times for NEAs and Comets
Paul Chodas, NASA Jet Propulsion Laboratory

NEO Alert Frequency, the Evolution of Impact Probabilities, and Keyhole Dynamics
Steven Chesley, NASA Jet Propulsion Laboratory

March 5-8, 2007
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SESSION 1B: Discovery & Characterization
Chair: Donald Yeomans, NASA Jet Propulsion Laboratory

Poster Papers

Covariance Analysis of Near Earth Objects (NEOs), Vannaroth Nuth, et al

Comet Threat Mitigation Approaches & Challenges, James A. Marusek

NEAT: Near Earth Asteroid Trailblazer Characterization Mission, David Morrison, Julie Mikula, Kevin Martin

Near-Earth Asteroid Rendezvous Missions with the Orion Crew Exploration Vehicle, M.A. LeCompte, et al

Radar Reconnaissance of Near Earth Asteroids
Steve Ostro, NASA Jet Propulsion Laboratory

Results of the Hayabusa Mission to NEA Itokawa
Makoto Yoshikawa, Japan Aerospace Exploration Agency

To What Extent Can NEAs be Grouped by Their Common Physical Characteristics?
Richard Binzel, Massachusetts Institute of Technology

Internal Structures of NEOs
Erik Asphaug, University of California at Santa Cruz

Near Earth Asteroid Characterization Missions
David Morrison, NASA Ames Research Center

Planetary Defense Conference
PROTECTING EARTH FROM ASTEROIDS

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

Tuesday, March 6, 2007

Keynote: Michael Simpson, President, International Space University

SESSION 2: Deflection Techniques
Chair: David Lynch, The Aerospace Corporation

Poster Papers

Evaluating the Effectiveness of Different NEO Mitigation Options, Mark G. Schaffer, A.C. Charania, and John R. Olds

Blast Designs for NEO Destruction, Leslie Gertsch, Jason Baird, and Paul Worsey

Head-On Impact Deflection of NEAs: A Case Study for 99942 Apophis, Bernd Dachwald, Ralph Kahle, B. Wie

Dynamical Characterization and Stabilization of Gravity Tractor Designs for NEO Impact Risk Mitigation, Eugene G. Fahnestock, Daniel J. Scheeres

Gas-Blast Orbit Modification, Guy F. Cooper

Deflection of Near Earth Objects by Means of Tethers, V.A. Chobotov and N.Melamed

Gravity Tractor
Ed Lu, B612 Foundation

Nuclear Deflection
Steve Patenaud, Lawrence Livermore National Laboratory

Impact Deflection of Potentially Hazardous Asteroids Using Current Launch Vehicles
Jesse Koenig, SpaceDev Inc.

Response of NEO to Mitigation Techniques
Keith Holsapple, University of Washington

Deflection Aspects of NASA's Analysis of Mitigation Alternatives Study
Vern Weyers, NASA (retired)

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

SESSION 3: Deflection Missions & Technology
Chair: Gianmarco Radice, University of Glasgow

Poster Papers

Very Short Reaction Time, Low Delta V, Non-Nuclear Mitigation of Some NEOs: A Case Study, Ivan Bekey

Sticking Thrusters into Asteroids from Permanent Bases at L1 and L3, Claudio Maccone

Probabilistic Design of a Planetary Defense System, Jason Sherwin, Jan Osburg and Dimitri Mavris

Spacecraft Mission Design For The Destruction Of Hazardous Near-Earth Objects Via Distributed-Energy Explosives, Brent William Barbee and Leslie Gertsch

Opportunities for Deflection of Asteroid Threats, Warren G. Greczyn, David F. Chichka

Optimal Trajectories for NEO Deflection Missions
Max Vasile, University of Glasgow

Energy Requirements for Intercept and Rendezvous of Potentially Hazardous Asteroids
Alisa Hawkins, The Aerospace Corporation

Industrial Assessment for the Don Quixote Mission
Ian Carnelli, European Space Agency

Scenarios for Dealing with Apophis
Donald Gennery, Consultant

Hovering Control of a Solar Sail Gravity Tractor Spacecraft for Asteroid Deflection
Bong Wie, Arizona State University

Optimal Impulsive Deflection Analysis and Mission Scenarios for Asteroid Apophis
Brent Barbee, Emergent Space Technologies

Multiple Mass Drivers as an Option for Asteroid Deflection Missions
John Olds, SpaceWorks Engineering

Near Earth Object Mitigation Options Using Exploration Technologies
Robert Adams, NASA Marshall Space Flight Center

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

Wednesday, March 7, 2007

Keynote: Bill Burrows, Director, Science and Environmental Reporting, New York University

SESSION 4: Impacts & Effects
Chair: Clark Chapman, Southwest Research Institute

Poster Papers

Quasi Three-Dimensional Modeling of Tunguska Comet Impact (1908), Andrei E. Zlobin (Not present, submitted paper)

Entry of the Tunguska Cosmic Body into the Atmosphere: Final Decision, V.P. Stulov (Not present, submitted paper)

Comet and Asteroid Threat Impact Analysis, James A. Marusek

Overview of Asteroid Impact Phenomenology
Clark Chapman, Southwest Research Institute

Low-Altitude Airburst Contribution to the Impact Hazard
Mark Boslough, Sandia National Laboratory

Tsunamis from Asteroid Impacts in Deep Water
Galen Gisler, University of Oslo

Impact Tsunami Hazard—My Best Guess
Steven N. Ward, University of California, Santa Cruz

Human Hazards from Impact Effects
Steven Chesley, NASA Jet Propulsion Laboratory

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

SESSION 5: Preparing the Public
Chair: Caron Chess, Rutgers University

Poster Papers

Impact Disaster Preparedness Planning, James A. Marusek

Financing a Planetary Defense System, William F. Mitchell

The NEO Hazard: Interfaces between Scientists and the Public
Clark Chapman, Southwest Research Institute

Preliminary Observations Regarding Preparedness and Response to the Denver Asteroid Impact Event
Richard Davies, Executive Director, Western Disaster Center

Planetary Defense in the Context of Current Approaches to Societal Security
Geoffrey Sommer, Homeland Security Institute

A Tool for Assessing the Consequences for Populations and Infrastructure resulting from an Asteroid Impact
Nick Bailey, Astronautics Research Group, Southampton University

Composure and Panic in Time of Catastrophe: An Empowerment Approach to NEO Disaster Management
Albert A. Harrison, Department of Psychology, University of California, Davis

Information is Not Enough
Caron Chess, Sociology Department, Rutgers University

Planetary Defense Conference
PROTECTING EARTH FROM ASTEROIDS

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

Thursday, March 8, 2007

Keynote: René Oosterlinck, Director of External Relations, European Space Agency; Professor, Ghent University

SESSION 6: Panel Discussion: Political & Policy Issues
Chair: Richard Crowther, Rutherford Appleton Laboratories, UK

International Policy Issues
Rusty Schweickart, Association of Space Explorers Committee on NEOs

Legal Aspects of Planetary Defense Issues
Frans von der Dunk, Space Law Research, International Institute of Air & Space Law

The Domestic Politics of Planetary Protection
John Logsdon, Director, Space Policy Institute, George Washington University

Paper 4
Makoto Yoshikawa, Japan Spaceguard Association

Paper 5
Michael Simpson, International Space University

Planetary Defense as a Major Rationale for Human Spaceflight and Exploration
Alain Dupas, Director of Strategic Studies, College de Polytechnique, Paris

Paper 6
Christopher Chyba, Professor of Astrophysics and International Affairs, Princeton University

Panel Discussion

March 5-8, 2007
The Cloyd Heck Marvin Center
Washington, D.C

SESSION 7: Panel Discussion: Findings & Recommendations

Panel Discussion

Moderator: Bill Ailor, The Aerospace Corporation

Rep. of Session 1 - Donald Yeomans, David Morrison
Rep. of Session 2 - David Lynch
Rep. of Session 3 - Mark Barrera
Rep. of Session 4 - Clark Chapman
Rep. of Session 5 - Albert Harrison
Rep. of Session 6 - Richard Crowther

Closing Comments

Bill Ailor, The Aerospace Corporation

2007 Planetary Defense Conference
George Washington University
March 5 - 8, 2007

First Name	Last Name	Title	Company
Paul	Abell	Research Scientist	NASA JSC
Robert	Adams	Advanced Propulsion Technologist	NASA-Marshall Space Flight Center
Vipparthi	Adimurthy		Indian Space Research Organization
William	Ailor	Principal Director	The Aerospace Corporation
Robert	Arentz	Advanced Systems Manager	Ball Aerospace and Technologies Corp.
Erik	Asphaug	Professor	UCSC, Earth and Planetary Sciences Dept.
Nick	Bailey		University of Southampton
Priyankar	Bandyopadhyay		Indian Space Research Organization
Anne	Barbance		European Space Agency (ESA)
Brent	Barbee	Aerospace Engineer	Emergent Space Technologies, Inc.
Mark	Barrera	Systems Engineer	The Aerospace Corporation
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Phil	Berardelli		ScienceNow
Richard	Binzel	Professor	M.I.T.
Mark	Boslough	Technical Staff	Sandia National Laboratories
Steve	Brody	Vice President	International Space University (ISU)
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Bill	Burrows		New York University
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Joe	Carroll		Tether Applications, Inc.
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Steve	Chesley		NASA/JPL
Caron	Chess		Rutgers University
Paul	Chodas		JPL
Christopher	Chyba	Professor	Princeton University
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Guy	Cooper	Sr. Engineer	QI-Solutions, Inc.
Richard	Crowther		RAL
Germano	D'Abramo		IASF-INAF / ESA
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David	Desrocher	Owner	SAS, Inc
Mario	Di Martino		INAF - Osservatorio Astronomico di Torino
Bill	Douthitt		National Geographic Magazine
Dave	Dunham		Johns Hopkins University-APL
David	Dunham		Applied Physics Laboratory
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2007 Planetary Defense Conference
George Washington University
March 5 - 8, 2007

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Louis	Friedman	Executive Director	The Planetary Society
Genziana	Frigo		Politecnico di Milano
Tom	Gardner	Senior Principal Syatmes Engineer	Raytheon
Don	Gennery		Consultant
Leslie	Gertsch	Sr. Research Investigator / Assistant Professor	University of Missouri-Rolla
Adeel	Ghayur		University Institute of Information Technology
Galen	Gisler	Senior Researcher	University of Oslo
Rob	Gold		Johns Hopkins University-APL
David	Goodwin	Physical Scientist	U.S. Dept of Energy (DOE)
Warren	Greczyn		SPARTA, Inc.
Alan	Harris		Space Science Institute
Albert	Harrison	Professor Emeritus	UC Davis
Alisa	Hawkins	Technical Staff	The Aerospace Corporation
Keith	Holsapple	Professor	University of Washington
David	Huntsman		NASA
Lindley	Johnson	NEO Observation Program Scientist	NASA, Planetary Sciences Division Science Mission Directorate
Tom	Jones	Member	Association of Space Explorers
Jesse	Koenig	Spacecraft Engineer	SpaceDev, Inc.
Gregory	Konesky	V.P., R&D	SGK Nanostructures, Inc.
Ekkehard	Kuehrt		DLR
Rob	Landis		NASA Johnson Space Center
John	Logsdon	Director, Space Policy Institute	George Washington University
Ed	Lu		Nasa
David	Lynch		The Aerospace Corporation
Claudio	Maccone		International Academy of Astronautics
James	Marusek	Physicist/Engineer	Impact
Christopher	McKay	Scientist	NASA Ames Research Center
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David	Morrison		NASA
Vannaroth	Nuth		The Aerospace Corporation
John	Olds	CEO	SpaceWorks Enginerring, Inc.
Rene	Oosterlinck		ESA
Paul	Ostdiek		Johns Hopkins University-APL
Steven J	Patenaude	Scientist	Lawrence Livermore National Laboratory
Glenn	Peterson		The Aerospace Corporation
Claude	Poux	Graduate Student	Columbia Univ. Grad. School of Journalism
Margaret	Race		SETI Institute
Harold	Reitsema	Director, Advanced Systems	Ball Aerospace and technologies Corp.
Andy	Rivkin		Johns Hopkins University-Applied Physics Laboratory
Irving	Robbins	Director	Astrophysical Observatory CSI-CUNY
Joan Pau	Sanchez Cuartielles		University of Glasgow
Mark	Schaffer	Project Engineer	SpaceWorks Engineering, Inc.
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2007 Planetary Defense Conference
George Washington University
March 5 - 8, 2007

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Geoffrey	Sommer		Skybase
Tim	Spahr	MPC Director	SAO
Ben	Stahl	Student	Georgia Institute of Technology
Robert	Strong	Director	Near Earth Object Foundation
Edward	Tagliaferri		The Aerospace Corporation
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Frans G.	von der Dunk		International Institute of Air and Space Law
Marc	Warburton		SAIC
Steven	Ward		UCSC
Brian	Weeden	Captain	1st Space Control Squadron
Vern	Weyers	Aerospace Consultant	Retired
Bong	Wie	Professor	Arizona State University
Rodney	Wilks	Space Exploration Manager	ATK
Bobby	Williams	Director	KinetX, Inc. SNAFD
Pete	Worden	Center Director	NASA Ames Research Center
Donald	Yeomans		Jet Propulsion Laboratory
Makoto	Yoshikawa	Associate Professor	JAXA/JSGA
Andrei	Zlobin	Expert	Federal Agency of Sport, Russia
Alan	Zucksworth	Aerospace Engineer	U.S. Air Force