White Paper
Summarizing Findings and Recommendations
from the
2004 Planetary Defense Conference: Protecting Earth from Asteroids

1. Overview

The Planetary Defense Conference: Protecting Earth from Asteroids was held from February 23 to 26, 2004, at the Hyatt Regency Orange County, Garden Grove, California. The meeting was sponsored by the American Institute of Aeronautics and Astronautics (AIAA) and The Aerospace Corporation, and attended by over 140 participants (see list at end of document).

The conference was held to focus on mitigating the threat to humankind posed by asteroids and comets. It is well known that there have been impacts of large Near Earth Objects (NEOs) in the past history of Earth. It is also well known that, while the probability of impact in the next month or year is small, impacts of objects large enough to seriously modify or potentially end life, as we know it, are inevitable. The conference, expected to be repeated on a periodic basis, focused on what humankind might do to deflect an approaching object.

While perhaps the most broadly focused, the 2004 conference was not the first on the topic of NEOs and the threat they pose. Conclusions and recommendations from other conferences are generally consistent with those presented here. The fact that several recommendations are repeated demonstrates that progress has been slow in this area.

The February 2004 conference featured a systems approach to NEO deflection, risk communication, and disaster response. Experts in detection of NEOs, in possible methods of deflecting a threatening NEO, in mission design, and in political, policy, law, and disaster preparedness came together to assess the current state of knowledge in each of these areas relative to mounting a successful deflection mission.

At the conclusion of the meeting, session chairs provided summaries of principal recommendations from their sessions, and participants were invited to provide their thoughts. The conference chair, session chairs, and speakers subsequently prepared this document to summarize what they believe are consensus findings and recommendations from the conference. Names and affiliations of the primary participants in the development of this document are provided. This document reflects the expert views of this group.

2. Findings and Recommendations

Findings and related recommendations are provided in the five major topic areas discussed at the conference:

A. Threat Detection and Characterization

Ongoing efforts to track and understand the nature of asteroids and comets were discussed at the beginning of the conference. Information on the size, composition, and dynamics of NEOs is critical to initially assessing and finally mitigating threats posed by these objects.

Findings:

The risk of impacts upon Earth, chiefly by Earth-crossing asteroids, is small but very real. The potential damage depends on the impactor's mass, composition, structure (e.g., whether it is a single object; approximately 1/6 of Earth-crossing asteroids as large as a few hundred meters are thought to be binary bodies), impact speed, and the location of the impact point (inhabited land, uninhabited land, or the oceans).

Impacts span a huge range in severity and frequency, and the means to predict and mitigate these impacts vary accordingly. The probability of a “dinosaur-killer” impact is about 1 in one million this century. The probability of a civilization-ending impact is larger—a bit less than 1 in 1000 this century. The probability of a small or Tunguska-class impact (near the lower size for penetration of the atmosphere, but still large enough to destroy a city) is higher still: There is approximately 1 chance in 10 of such an impact this century.

The economic and social costs of an impact are difficult to predict, but are obviously important considerations in assessing the overall threat and justifying the cost of detection and mitigation measures. Costs for funding a fully adequate search program to detect and catalog threatening objects in the 100 m class and larger and funding research to develop deflection methodologies would total perhaps $1 per year per capita. Losses caused by impact of a NEO could be incalculable.

Current search programs are of a scale that can find Earth-crossing asteroids greater than one km in diameter—e.g., those whose impacts could destroy civilization. The U.S. Government's *Spaceguard Survey*[1] plans to detect and catalog 90% of NEOs one km and larger in size by the end of 2008. A search program to locate sub-kilometer Earth-crossing asteroids has been recommended by the National Research Council (which would focus on asteroids down to 300

[1] Morrison, D. (editor), “The Spaceguard Survey: Report of the NASA International Near-Earth-Object Detection Workshop,” NASA Publication (1992).

m in size)[2] and by an internal NASA NEO Science Definition Team (which would focus on those down to 140 m)[3].

Comets are much harder to deflect due to their long-period orbits, short warning times, high velocities, and the non-gravitational forces on them—venting as comets approach the sun causes small, random deflections of their orbits, making accurate hazard predictions impossible and creating uncertainties in the nature of comets. Fortunately, the hazard from comets appears to be a very small fraction of the overall risk. Future conferences should continue to address the difficult but important task of detecting and mitigating comets.

Adequate warning time is a requirement to enable design and implementation of a mission to deflect a threatening object, and accurate detection and tracking are essential. Uncertainty in the risk of Earth impact decreases the likelihood that a mitigation mission could be proposed, funded, and successfully completed.

NASA currently has the responsibility to find and track NEOs. But there is no formal process in place for forwarding notice of a high-priority threat to agencies responsible for civil defense. Nor do civil defense agencies have plans for responding to such notices. In addition, no national or international organizations or agencies are responsible for the more general problem of protecting the planet from impacts. Most organizations likely to be involved if a threat is detected are not even aware of this natural hazard.

Recommendations:

1. Review current international amateur and professional efforts related to detection, timely sharing of survey data, astrometric follow-up, orbit calculation, and physical characterization of potentially threatening asteroids and comets, and develop recommendations for improving coordination of, and support for, these NEO activities.

2. Efficiently survey and catalog 100-m-class NEOs. The central conclusion of the NASA Science Definition Team report on NEOs is that the global residual hazard (that which will remain after completion of the current *Spaceguard Survey*) is reducible by relatively inexpensive telescopic and/or spacecraft systems. Such systems can rapidly retire most of the residual hazard for a fraction of the hazard's fiscal costs. However, a substantial increase in the funding base beyond the current level of NASA funding (~$4.0 million per year) is required to accomplish this survey of sub-kilometer asteroids, and this funding must be maintained into the future to watch for long-period comets and rogue asteroids.

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[2] "New Frontiers in the Solar System: An Integrated Exploration Strategy," Solar System Exploration Survey, Space Studies Board, Division on Engineering and Physical Sciences, National Research Council, 2003 (see http://books.nap.edu/html/newfrontiers/0309084954.pdf)

[3] "Study to Determine the Feasibility of Extending the Search for Near-Earth Objects to Smaller Limiting Diameters," prepared by Near-Earth Object Science Definition Team, August 2003 (see http://neo.jpl.nasa.gov/neo/neoreport030825.pdf).

3. Encourage the development of creative ideas for detecting and cataloging potentially threatening long-period comets.

4. Develop and fund ground-based techniques (including planetary radar) as well as missions to several asteroids to gather information that contributes to designing deflection missions. Critical information includes object sizes and dynamics, object types (e.g., binary), characteristics of surface and sub-surface materials, responses to explosive forces, and characteristics relating to attaching a spacecraft or other large structures to NEOs. This information is important not only for mitigating NEOs but also for enriching our scientific knowledge of asteroid properties.

5. Establish a formal protocol for disseminating information regarding NEOs when the probability of impacting Earth exceeds specified thresholds.

B. Mitigation Options and Mission Designs

Several options for deflecting a threatening NEO were presented at the conference. These options are in various states of maturity—some might be available within a few years, others might require decades of development and testing before they could be used to move an approaching object. In some cases, technology developed for other space missions might be applied to moving an asteroid. Proposed approaches included using nuclear explosions or mirrors to ablate small amounts of material from the asteroid's surface, deflecting the object with a high-speed impactor, and attaching to the asteroid a high-efficiency electric propulsion system (whose development would be beneficial for a variety of deep space missions). Participants generally agreed that we need a test program to confirm our ability to move threatening asteroids in a controlled fashion.

Findings:

The feasibility and method used to deflect an oncoming object depend on its size, spin state, and composition (e.g., solid body, loose aggregation of smaller bodies, binary body), as well as the time available to effect a change in the object's orbit. The range of all of these parameters is very great—the deflection means must be flexible enough to adapt to the particular NEO that threatens.

Nuclear explosives and kinetic impactors (for small NEOs) are possible options in the short term, though the effectiveness of either technique is uncertain, given the lack of appropriate testing for a mission of this type. The response of a NEO to a nearby nuclear explosion or a high-speed impact might be better understood from testing and with better information on the nature and composition of NEOs. (Current international agreements forbid testing or use of nuclear explosives in space, even for peaceful purposes. The effect of nuclear explosions could potentially be tested using non-nuclear means.) Use of nuclear devices would face significant political hurdles that could delay or derail a deflection effort.

Other deflection options, such as electric propulsion and laser ablation, have been proposed, but at current spending levels, many years would be required to develop these technologies to the point where they could be used for a NEO deflection mission. If we wish to avoid the launch of nuclear explosives into space, the development of these alternative technologies for NEO deflection should have increased priority.

The mission requirement for a NEO deflection effort (e.g., "reduce the probability of Earth impact to less than 1 in a million") will drive the design of the deflection mission. The possibilities of launch failure, sensor failure, and off-nominal performance by satellite and deflection systems, as well as uncertainties in the properties of the NEO, must be recognized and factored into the overall design of the mission.

To date, we have not demonstrated that we can actually deflect a NEO in a controlled way using any of the suggested mitigation techniques.

Recommendations:

6. Conduct mission design studies to characterize requirements for short-, medium-, and long-range missions. These studies would compare current capabilities with mission requirements and help to identify and prioritize technology research and development goals. For example, we may be required to lift a heavy load to space for some deflection missions. Will we have appropriate launch capabilities? These studies would also help guide experiments that might be included in upcoming asteroid and comet missions.

7. Examine mission design, political, and policy issues involving the use of nuclear explosives for NEO deflection.

8. Identify and characterize promising non-nuclear means of deflection.

9. Establish the reliability requirement for a NEO deflection mission to insure that the overall probability that the object will impact Earth is less than some defined value (e.g., less than 1 in a million).

10. Develop realistic decision and funding timelines for deflection missions, emphasizing critical political, funding, and mission milestone decisions.

11. Conduct tests of deflection techniques leading to a demonstration of an ability to move an asteroid.

C. Public Information and Communications

Empirical studies in the social sciences can be brought to bear on public interaction and information aspects of the NEO impact problem, and the resulting information needs to be shared with the physical science and engineering communities. Knowledge of how the public responds to natural disasters (and to warnings of disaster) is obviously useful in developing an overall notification, warning, and response plan.

Findings:

People often remain calm and perform rationally when confronted with an immediate threat or disaster, and are reasonably tolerant of false alarms as long as they are kept informed. People will seek multiple sources of reliable information should they learn of a warning. If communications about the hazard are to be judged credible by the public, leaders and organizations must begin work now to establish that they are trustworthy. Social science research indicates that a top-down, command-and-control approach to communications is not always best. This finding is relevant to communicating the risk before a real threat is identified, and it is relevant to communicating the risk should a real threat be discovered.

Good science fiction and other popular entertainment have helped and can continue to help raise the awareness of the public to the NEO hazard. However, science fiction based on bad science and engineering might mislead the public and contribute to the "giggle factor" sometimes associated with planetary defense studies. One approach to improving the treatment of the NEO threat and possible mitigation approaches in the media is to make available scientifically accurate presentations, including visuals and explanations, to the media, the press, and leadership.

The potential impact of an asteroid or comet is an international issue, and we need international means to deal with it.

Recommendations:

12. Apprise the public in an accurate and authoritative way of possible threats and potential actions that might be taken. The Torino Scale and other tools to portray the threat to the public should be reviewed with the goal of improving communications with the public and with decision makers. Warnings must maintain public trust by presenting information using specific, relevant, and consistent terms. It may not be effective to define the threat in probabilistic terms. The public must view the sources of information as objective and trustworthy. The information released should be supported by experts in relevant fields. Social scientists should assist in the development of these protocols.

13. Apply lessons learned from major disasters to help us understand our ability to mitigate a disaster caused by a NEO impact. Determine whether some NEO impact scenarios are already covered by existing plans for earthquake, tsunami, or other disasters.

14. Bring evidence of previous NEO impacts to the attention of the public to increase awareness that impacts do happen and that the possibility of future impacts should not be ignored.

15. Demonstrate to the public that something can be done about a NEO hazard. A demonstration mission to change the orbit of a non-impacting NEO in a controlled fashion is one way to accomplish this.

D. Political and Policy Considerations

A deflection mission requires political and policy-level support. A deflection mission with a short time frame would require substantial investment and might require nuclear devices (whose use currently is forbidden in space). Clearly, an authority would need to be in charge of the effort, and preparations for evacuation and other mitigation efforts would need to be made in the case that the deflection effort was unsuccessful. There would be substantial issues related to international participation in a deflection effort and possible disaster mitigation.

Findings:

At present, there is no formal chain of responsibility for planetary defense. Potential applications of existing and new projects to possible planetary defense use are not currently explored or encouraged. Outside of NASA, there are no established guidelines or protocols for notifying authorities or the public of impact possibilities or even for identifying where such notices should go. No detailed studies of potential disaster scenarios related to NEO impacts have been conducted. Finally, governments have a legal obligation to institute effective plans to prevent this type of harm, and failure to take prompt and meaningful action could result in monetary liability or violation of public international and domestic law.

Recommendations:

16. Explore political and policy-level decisions and decision time lines for various deflection scenarios (short-term, long-term, nuclear, non-nuclear). Assess potential public and government concerns and responses to a potential threat and subsequent deflection effort. Consider how a deflection effort would be managed in the face of public expectations and uncertainty.

17. Find (or create) an organizational/governmental home within the U.S. government for the NEO issue. NASA, DoD, DoE, FEMA, DHS, and perhaps a newly formed Space Corps of Engineers based on the Army Corps of Engineers model have been suggested as possibilities. In June 2000, AIAA[4] recommended establishment of an "interagency office charged with dealing with all aspects of Planetary Defense" and further recommended that a "senior level inter-agency working group be formed to define the appropriate makeup and reporting structure of the planetary defense organization, develop a roadmap leading to its implementation, and procure funding for its support." A subsequent AIAA Position Paper[5] reiterated this recommendation.

18. Assess which lessons can be learned from major disasters that would apply to a NEO impact disaster. We need a systematic and thorough review of how the substantial literature on disasters and risk communications can inform NEO-related policy.

19. Begin a dialog among nations and international institutions to characterize the challenges implicit in worldwide planning and execution of future deflection missions.

20. Develop contingency plans and processes for NEO mitigation. Understanding and solving policy issues before they need to be invoked would greatly enhance our ability to mount a successful deflection mission.

3. Summary:

This conference is the first of a series on the threat posed by Near Earth Objects, possible techniques and missions for deflecting an oncoming object, and political, policy, and disaster-preparedness issues associated with NEO deflection. The conference produced several recommended actions, the foremost being that we need to: 1) begin trust-building efforts so that claims that the NEO hazard is important will be considered credible by the public, even though we recognize that the probability of a disastrous impact is small; 2) increase our efforts to detect threatening objects and to determine the detailed physical and compositional properties of NEOs; and 3) move forward on means to deflect a threatening object.

A key recommendation, consistent with previous AIAA Position Papers, is that a chain of responsibility be clearly and publicly defined for detecting and warning the public of threats, and mitigating those threats. These threats are real, and efforts to coordinate information and activities related to detecting and mitigating them should begin now.

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[4] Tagliaferri, Edward, "Dealing with the Threat of an Impact of an Asteroid or Comet on Earth: The Next Step," AIAA Position Paper, June 2000.
[5] Tagliaferri, Edward, Warren Greczyn, Lawrence Cooper, "Addressing the Comet and Asteroid Impact Threat: A Next Step," AIAA Position Paper, July 2002.

Considerable work needs to be done to ensure that threats can be detected early and that the means available for deflection are known to be effective.

Future impacts by comets and asteroids are a certainty. Such impacts could have severe consequences—even ending civilization and humanity's existence. Life on Earth has evolved to the point where we can mount a defense against these threats. It is time to take deliberate steps to assure a successful defensive effort, should the need arise.

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The individuals below contributed to the development of this document by presenting their ideas at the conference or by participating directly in the document's preparation. The findings and recommendations are based on discussions held during the meeting and are believed to represent consensus opinions of those in attendance; however, some may not reflect the opinions of all individuals listed below or all attendees. Findings and recommendations are personal opinions and are not intended to reflect the opinions of listed organizations.

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