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The Need for a United Nations Asteroid Deflection Treaty to Establish a System for Trustworthy Mission Design and Execution

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Abstract: One promising technique for deflecting a near Earth object headed for an impact with the Earth is to use low thrust devices (several Newtons) for long periods of time (several years). During the time thrust is applied to the object, the initial impact point moves slowly across the surface of the Earth until it "lifts off", i.e., the path of the object becomes tangential to the Earth's surface. This path across the Earth is the locus of instantaneous impact points from the initial (act of God) point until the point of liftoff. The course of this "deflection path" is an act of humankind, albeit one determined by the minimization of fuel and time to liftoff. The deflection path may cross many political boundaries between the initial and end points. Further compounding the implied policy issues is the fact that lateral (non-optimal) movement of the path can be generated by the expenditure of additional fuel, e.g., to minimize risk to specific population concentrations. Public concern will arise at both the planning and execution stages of this process. The public policy implications of this situation call for the development of rational planning criteria through international mechanisms *prior to* the detection of a pending impact by a near Earth object.

Preamble

Given three reasonable assumptions and a modicum of scenario thinking the need for such an international regime becomes self-evident.

The three assumptions are:

1. A substantial near Earth object has been detected and tracked and has been determined to be on a collision course with Earth,
2. The orbital parameters of the asteroid have been well enough established to identify a specific impact point and time of impact, and
3. A low-thrust system to rendezvous, dock with and deflect the asteroid is, or will soon be, available to cause it to miss the Earth

1. Background

Detection. The Spaceguard Survey [2], involving astronomers and observatories around the world, is detecting new near Earth objects (NEOs [3]) at a current rate of about 10 per week. NASA, in testimony before the US Congress, committed to the goal of detecting 90% of NEOs greater than 1 km. in diameter before the end of 2008 [4]. Over 640 of an anticipated total population of 1000-1100 have now been detected.

While a collision with an asteroid of this size or larger would threaten human civilization, collisions with asteroids smaller by a factor of 10 would be substantial and threaten local and regional populations [5, 6, 7]. A 100 meter diameter asteroid would have the equivalent impact energy of a 100 megaton nuclear weapon. Since the expected population of NEOs of this size is approximately 200,000 the collision rate is considerably higher than those that threaten society as a whole. An impact by a 100 meter NEO is anticipated on the order of every 2-4000 years [8].

Impact Determination. Optical telescopes designed for survey purposes generally perform the initial detection of NEOs [9]. Confirmation of these initial findings and refinement of the orbits by subsequent optical measurements are performed by a combination of professional and amateur astronomers on a worldwide basis. Generally, within a matter of weeks following initial detection, the orbital parameters of a newly detected NEO are well enough known to determine whether a collision is to be expected within the next 100 years.

Active radar is being used with increasing frequency to investigate the physical characteristics of known NEOs and to significantly increase the precision of the knowledge of their orbits [10]. Radar data typically reduce the positional errors in NEO orbit predictions by several orders of magnitude, allowing impact predictions to be reliably forecast out to several hundred years.

More significant, should an impact be predicted, it is anticipated that refined radar and astrometric data would enable the prediction of a precise impact time and geographic location well in advance of the actual impact. Assuming an impact is predicted it is reasonable to believe that adequate time would be allocated to determine these data using the world's best observing facilities.

Deflection. Active systems for deflection of NEOs on collision courses with Earth have been casually discussed for several decades [11]. Little substantial work, however, has been done to date. Nevertheless, given the success of the increasingly capable detection programs the development of such a capability is being actively considered by concerned professionals familiar with the NEO challenge and the emerging space power and propulsion technologies [12].

Detonating a nuclear explosion in the near vicinity of a NEO would create an impulse slightly deflecting the object from its undisturbed path, and may be the only available technique for short warning times. For the expected warning times of a decade or more, however, concerns about the abuse of nuclear weapons in space and the multitude of uncertainties about the response of the NEO to the explosion have triggered strong objections to this proposal [13].

Alternative deflection concepts being considered involve the use of low levels of thrust for long periods of time to generate enough velocity change to cause the NEO to miss the Earth [14]. These systems assume that a decade or more of warning time will be available in order to permit the successful deployment, rendezvous and deflection time required to achieve the planned result. In many instances, whether utilizing an indirect, stand-off system (mirror, laser, etc.) to boil off surface material, or direct thrusting by a docked system (mass driver, plasma engine, etc.), the thrusting technique requires a year or more of continuous application to achieve the necessary velocity change.

These low thrust systems appear to have the additional advantage that the extremely low accelerations involved are not likely to disrupt the integrity of the NEO. This concern has emerged recently with the recognition that many of these objects are extremely tenuous. Indeed, some recently characterized NEOs appear more to be closely associated piles of rubble than solid bodies [15]. Very low acceleration deflection systems, therefore, appear to be desirable.

Policy Implications. Once a deflection system to protect the Earth from NEO impact has been developed the policies to be applied to both its planned use and control over it once deployed come into play. The development of these policies *prior to the detection of a pending impact* is critical.

One has only to realize that, given a thrust profile lasting a year or more, the instantaneous impact point (i.e., the current impact point if thrust were to terminate) will slowly migrate across the surface of the Earth from its initial deterministic point to the point of "liftoff" (i.e., where the trajectory of the NEO becomes tangential to the Earth's surface). While the shape of this track across the Earth will vary considerably based on many factors, its path will nonetheless be defined by the specific thrust profile used to deflect the asteroid.

Since the possibility of propulsion system failure exists throughout the deflection operation, the resultant new impact point will have been defined by human choice and not by an "act of God". In fact, during such a deflection operation all points along the resultant path will be placed at some increased risk during the operation due to, inter alia, potential propulsion system failure.

While the default logic for the specific path will likely be the minimization of fuel required, or alternatively the minimum time to liftoff, such logic may not prove wise or acceptable should the resultant path cross over or pass close by a major world city or populated area. Indeed, choosing a slightly modified (non-optimal) thrust profile might enable the path to either miss, or cross over, a given country on its way to the liftoff point.

Clearly the question of how this path is chosen and how and by whom the agreed thrust profile is executed is of enormous local and international import.

Proposal. This paper proposes that a trustworthy system of mission planning and execution be established to assure that both the mission design and its execution fulfill the collective will of the people of the Earth. Since the initial deterministic point of impact, and to a lesser extent, the risk path from there to liftoff, could cross any point on the planet, it is assumed that this international agreement would be established under United Nations auspices.

2. Mission Design Protocol

Trustworthy mission design must take into account the value judgment of people affected by the decisions made. Since the potential exists, prior to the detection of a pending asteroid impact, that anyone on Earth might affected, it is reasonable to assume that the criteria by which a deflection path is chosen should be developed by a representative international body with broad participation.

The default risk path is the fuel optimum path required to move the impact point from its origin to a point where the NEO just grazes the Earth's surface (neglecting the atmosphere). The default path is therefore, by definition, the shortest and fastest path available to liftoff.

This deflection path (or risk path) is generally a gently curving line (approximately east-west) with a maximum length of about 90 degrees of arc. The specifics of this nominal path are complex and dependent on the orbital parameters of both the Earth and the asteroid. Forcing this path to curve laterally in order to avoid specific geographic locations will be very expensive and will increase the overall risk of an Earth impact in order to realize a slight benefit to any particular population.

Nevertheless, since fuel consumption is the primary cost, the actual path chosen will most likely take into consideration the minimization of risk to specific population concentrations along the route to liftoff. Substantial judgment will have to be applied in determining an acceptable algorithm that balances risk exposure against increased burn time, fuel requirements and launch costs. An additional factor that should be considered is the relationship between total mass at docking with the asteroid and any increased complexity and decrease in mission success probability as a result thereof.

It takes little imagination to visualize the extreme political and social controversy if we wait for a specific impact to become known before developing the path deviation criteria. Clearly this algorithm should be developed at the earliest possible time and before an impending impact is detected, with broad, informed input from national representatives. The outcome of this effort might best be embedded in an international treaty to ensure broad accountability and acceptance of its implications.

Nonetheless the actual fuel available for deflection once at the asteroid will depend on choices made during the design of the mission. This indeterminate variable can easily be accounted for, without additional controversy, if it is built into the path deflection algorithm from the outset. In other words, a family of risk paths can be produced with fuel available at the initiation of the deflection maneuver as the independent variable.

Finally, a path deviation algorithm should be developed as soon as possible since the detection rate of smaller but significant near Earth objects will likely increase rapidly in the near future.

3. Mission Execution Protocol

Execution of the thrust profile to cause the instantaneous impact point to follow the selected path must also be performed in a trustworthy manner. Specific responsibility for the conduct of the mission may well, of practical necessity, remain with a national entity. Nevertheless the mission as a whole, and the command system for executing the deflection thrust profile in particular, must incorporate safeguards specified by a treaty regime. A monitoring body to ensure compliance with the safeguard agreements may have to be created in order to assure adequate public trust.

An early realization of the potential of such a deflection system for abuse, whether by "negligence, fanaticism or madness" (Sagan, 1992) appeared in the form of the deflection dilemma [16]. This dilemma arises in the recognition that if one can deflect an incoming NEO such that it misses the Earth, one can as well deflect a NEO that would otherwise miss the Earth such that it now hits the Earth, presumably in a particular location.

The power of the deflection dilemma argument decreases dramatically as the acceleration available for deflection decreases. In the case under consideration, where the thrust is very low and the targeted end point is 0.4 Earth radii above the surface, the opportunity for malicious use is minimized. Nevertheless, the opportunity for abuse and the underlying human characteristics that concerned Sagan, et al still remain a challenge while the instantaneous impact point is slowly guided off the Earth.

Two components of this challenge come immediately to mind. The first is the necessity for independent information systems to ensure that, during the deflection maneuver, full knowledge of all critical parameters (e.g., spacecraft systems, guidance and navigation) is available in real time to a monitoring body. The second is that the monitoring body must have, at a minimum, full review and veto power over any commands sent to the deflecting spacecraft by the operating agency.

While there may be acceptable means for assuring that the pre-determined thrust profile is being properly commanded without the monitoring body assuming de-facto control, the regime will have to be negotiated with great care and wide participation in order for the world public to trust the system.

This is clearly a challenging task since the few space faring nations of the world are powerful, and such intrusive oversight will not be easily negotiated. Nevertheless, without such robust and trusted oversight by a body representative of transnational interests, widespread social disruption and even panic may ensue. One has simply to realize that the controlling agency is moving a ticking multi-megaton bomb through the neighborhood and might just decide to stop at any time. Worse yet, without airtight thrust profile command control, the operating agency will be able to select anew which neighborhoods to traverse, despite prior agreements.

A obvious but controversial answer to this possibility is that full control be assigned to the international monitoring body, making it a monitoring and control authority. Whether or not a less intrusive, yet acceptable arrangement can be negotiated will only be known as the result of serious consideration and debate. This consideration should begin as soon as possible since there is clearly a long way to go and the time may be running short.

Conclusion

It is crucial to realize that the appropriate time-window to negotiate these international agreements is not the time available until an impact occurs, but rather the time available until an impact is predicted. Since new Earth approaching asteroids are discovered every day, initiation of this effort should begin as soon as possible. By design, the worldwide NEO detection programs automatically and immediately publish the discovery of asteroids and their impact probabilities in the open literature. When specific knowledge of an impact exists, it will be known by the world public in real time. It seems highly likely that, when that time comes, there will be widespread public expectation that these matters will already have been resolved.

It is therefore urged that an appropriate international forum take up these matters at the earliest possible time. While there are many technical details not yet known, or even knowable, the general outlines and essence of the challenge are clear now, and more than adequate information is available to establish the basic design of the required protocols.

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