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Analysis Three Approaches for Coping with Asteroid Impact: Impact of Aircraft, Nuclear Explosion, and Gravitational Traction

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Abstract:
The impact of an asteroid on the Earth may lead to catastrophic consequences, so it is necessary to explore effective approaches for protection. This paper aims to analyze the defense strategies against an asteroid impact on the Earth, focusing on three methods: impact of aircraft, nuclear explosion, and gravitational traction. This paper first outlines the basic characteristics of asteroids and their potential risk of impacting the Earth. Subsequently, it analyzes the status quo, advantages and disadvantages, and applicable conditions of the three defense methods. It is found that aircraft impact is mature but time-consuming. Nuclear explosions are fast and effective but carry political and radiation risks. Gravitational traction is safe and stable but takes a long time. Different approaches apply to different types of asteroids and warning times, and these factors need to be considered comprehensively when choosing. This paper then discusses the exploring directions for improvement of the various methods and points out possible future trends, including technology convergence and multinational cooperation. Finally, the importance of choosing the appropriate methods of defense based on the size of the asteroid and the warning time is emphasized.

Keywords: Aircraft, Nuclear Explosion, Gravitational Traction.

1. Introduction

Asteroids are objects in our solar system that move around the sun but are much smaller in size and mass than the planets [1]. Humans have now discovered more than a million asteroids in space, and they are mainly concentrated in the asteroid belt [1]. Of these, more than two thousands are considered potentially hazardous [2]. And for a variety of factors, an asteroid's orbit can be deflected to hit the Earth, and this can generate a lot of heat, causing forest fires, tsunamis, or earthquakes.

Asteroid impacts on the Earth are common, and the international peer-recognized Earth Impact Database

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published by the Planetary and Space Science Center (PASSC) at the University of New Brunswick shows that there are a total of 190 confirmed craters worldwide. Some of the impacts that have occurred have had serious consequences. The Tunguska Explosion, which occurred in 1908, is widely believed to have been caused by a meteorite impact [3]. Peekskill, which crashed into the Earth in 1992 and caused an explosion, is believed to have been an asteroid with a radius of less than 70 cm [4]. The 2013 asteroid impact in Chelyabinsk injured more than 1,600 people [5]. The damage from a larger asteroid falling on a densely populated area would be enormous. Therefore, it is necessary to take defensive activities against asteroid impacts. Many defense methods have been proposed, some of which are more mature and experimental, some of which have been simulated, and some of which are still in the theoretical and conceptual stage. However, all of these methods are relatively independent, and there are fewer studies linking different methods. In fact, each means of defense has its own advantages and disadvantages, and the size of the asteroid, speed and other factors are also different. Therefore, it is important to analyze different ways of defense and discuss their applicability. There are several ways to cope with an asteroid impact, and three of the more feasible ones are aircraft impact, nuclear explosion, and gravitational traction or propulsion [5]. The purpose of this paper is to analyze the characteristics of these three methods, explore their relations with each other, and discuss their different applications .

This paper will analyze each of the three methods by summarizing the current researches and information on each of these methods. It illustrates the current development of the three methods and their respective advantages and disadvantages. The purpose of this paper is to improve people's ability to make scientific and rational decisions and choose the most effective coping strategies when facing the crisis of an asteroid impact.

2. Aircraft Impact

Aircraft impact is the method of hitting a dangerous asteroid with an aircraft at a very high speed to give momentum to the asteroid, thus changing its direction and speed of motion, which is abbreviated as the impact method in the following. In addition, various properties of the asteroid such as material, structure, etc. affect the efficiency of the impact, so it is necessary to launch a probe to obtain information about the asteroid before performing the impact [6]. For the effectiveness of the impact method, the momentum gained by the asteroid will be greater than the momentum carried by the vehicle, because some asteroid fragments will fly into space [7]. The impact method is relatively mature and there are some experiments or specific examples of program design.

The Asteroid Impact and Deflection Assessment (AIDA) mission is the first experimental mission for asteroid defense conducted in cooperation between Europe and the United States. The mass of the vehicle is more than 300 kg and the speed is 6.25 km/s [7]. The target of the experiment was the smaller asteroid of a set of binary asteroids. This decision was made to more visibly observe changes in the target's orbit [7]. The AIDA mission was divided into two parts: the DART mission and the AIM mission. Ultimately, the experiment resulted in the DART mission being very effective at deflecting the target's orbit, as the asteroid gained substantially more momentum than that carried by the aircraft [8]. Finally, telescopes and radars on Earth confirmed that the DART impact shortened the binary's orbital period by 33.0 ± 1.0 minutes [8].

In addition, Luo mentions a method of coordinated impact using multiple aircraft, mainly those already deployed in Earth orbit [9]. This method reduces the preparation time and is suitable for hazardous asteroids that are not warned too far in advance or for hazardous asteroids where other methods have failed to intercept them. This appropriately mitigates the disadvantage of the long preparation time required by the impact method.

Overall, the impact method to deflect an asteroid's orbit is relatively well established and is the only method for which there are actual experiments. However, this method also has some uncertainties [10]. Both the characteristics of the asteroid itself and the instability of the impact mission can result in an uncertain outcome, and in some cases, the impact mission may only be able to land the asteroid in a relatively sparsely populated and safe area, rather than completely deflecting it from Earth's orbit [10].

3. Nuclear Explosion

The nuclear explosion defense method involves launching a nuclear bomb to explode at a dangerous asteroid, thus changing the asteroid's orbit or directly shattering it. The nuclear explosion method is the most efficient, especially if the warning time is very short [11]. A nuclear explosion can blast a large amount of loose material off the surface of an asteroid, thus giving the asteroid momentum. Experimental results show that the momentum generated by a nuclear explosion will be much larger than that generated by an aircraft impact [12]. So the nuclear explosion method is very effective. In a simulation experiment, a nuclear explosion produced a velocity change of 2.18 meters per second on an asteroid, while an aircraft impact produced a velocity change of 0.49 meters per second on the same asteroid [13]. Bombs can be detonated close to an asteroid, or they can be detonated on the surface of an asteroid or underground to generate more momentum. However, underground detonation requires more complex calculations, and the momentum generated by detonation close is already significant, so detonation close to the asteroid is a more appropriate method [6]. In addition, for smaller asteroids, other chemical bombs work well [6]. Because surface features can affect the effectiveness of the explosion, like the impact method, detection before the explosion is necessary [6].

Nuclear explosions as a very effective means of defense also have many potential risks. Firstly, many fragments produced by the breakup of an asteroid may have radioactive materials, which are likely to cause harm if they fall to Earth. Numerical simulation results show that the underground explosion caused serious damage to the outer shell of the asteroid, but the core was largely unaffected, and a large number of cracks appeared in the outer shell, but most of the cracks did not extend to the surface, and thus did not lead to the complete fragmentation of the shell [13]. However, the explosion caused a large amount of debris to fly out, and these large fragments may pose a threat to the Earth, the risk of which needs to be assessed [13]. This risk can be substantially reduced under certain conditions. If the explosion is carried out many years before the expected impact, the fragments of the asteroid will reach a safe radiation value before they reach the Earth, and at the same time, the number and size of the fragments will not be too large [12]. However, if the explosion is taken shortly before the impact, the risk of debris harming the Earth will be high [12].

Another potential danger is that using a nuclear explosion to deflect an asteroid's orbit would mean breaking many of the treaties that already exist about nuclear weapons [14]. If these treaties were to be broken, then it would likely result in a violent nuclear war or non-nuclear weapon conflict [14]. In other words, there are both disadvantages and advantages to a nuclear explosive defense, but there is no specific analysis that can measure the circumstances under which the use of nuclear weapons would outweigh the disadvantages, probably because the risks associated with the use of nuclear weapons are difficult to determine. However, the use of nuclear explosions must be necessary when nuclear weapons are the only defense available and other methods are ineffective, such as when an asteroid is too large or the warning time is too short [14].

Currently, all the methods related to nuclear explosions remain in the theoretical stage without actual experiments, but the nuclear explosion method is theoretically feasible to a very high degree.

4. Gravitational Traction

In the gravitational traction approach, an aircraft is used to hover over an asteroid for an extended time, using gravity to pull the asteroid to deflect its orbit. This method is still at the theoretical and computational stage, with no real experiments. The advantage of this approach is a more precise change of the asteroid's orbit [6]. This can drastically mitigate the uncertainty. Moreover, gravitational traction is not affected too much by the material or structure of the asteroid's surface, so there is no need to survey the surface of the asteroid as carefully as in the previous two approaches, and there is no dangerous asteroid debris [15]. The disadvantage of this method, however, is that it requires a long traction time, usually lasting several years. A way to shorten the hauling time is to increase the attraction; NASA has proposed the idea of an Enhanced Gravity Tractor (EGT), which mines rock on the surface of an asteroid to increase the mass of the tractor [15]. Multiple tractors can also be used to increase the total traction. Gao proposed another way to increase traction by first impacting another asteroid to deflect its orbit, and then using that asteroid to attract the threatening asteroid. This approach does not have a direct impact or damage on the hazardous asteroid, thus avoiding further threats to the Earth from hazardous debris.

5. Discussion

The three methods mentioned above currently have some limitations. Among them, the impact method should be developed in the direction of shorter warning times. In addition, there is a great deal of uncertainty associated with aircraft or nuclear explosions due to accuracy issues. Therefore, future research should focus on improving the accuracy of aircraft navigation to reduce the potential danger and uncertainty of the impact method [10, 14].

The main problems that need to be solved in the nuclear explosion method lie in two aspects. First, the most basic and important limitations of nuclear explosions are political and social [14]. Politically multinational coalitions to improve and refine nuclear weapons treaties are important, as well as improving security capabilities to minimize the activities of terrorists. A safe and stable political environment is a fundamental prerequisite for nuclear explosive methods to enter practical use. Secondly, improving early warning capabilities to shorten the warning time is also an important way to reduce the uncertainty of nuclear weapons. The most significant development in gravitational traction technology is to increase the mass of the tractor. Among them, the method of sampling on the surface of asteroids is promising. In addition, to compensate for their

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respective shortcomings, a combination of multiple technological approaches to defense may become the dominant method in the future.

In conclusion, the differences in hazardous asteroids are mainly reflected in two aspects: size and warning time. The energy and the time required for different approaches to defense are also different. Therefore, when choosing the appropriate approach of defense, the main consideration is the size of the asteroid and the warning time. Drube also mentioned a similar classification and summarized the following Figure 1 [7].

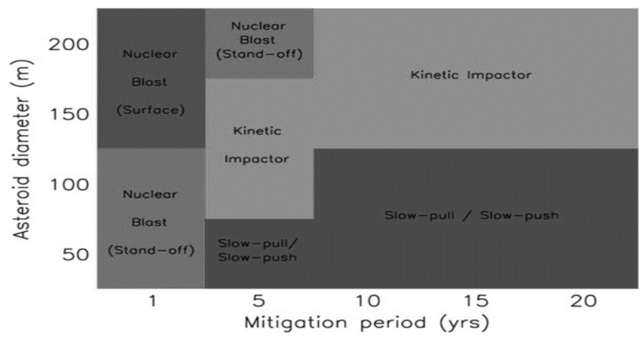

Fig. 1 The best choice of space-mission mitigation methods, according to the results of a NEOShield trade-off study by Astrium (UK), is shown here based on the size of the potential impactor and the time available for deflection of the NEA. "Mitigation period" is defined as the time between the start of the spacecraft's interaction with the asteroid and the predicted date of the impact of the NEA on the Earth. Slow-pull and slow-push techniques include the gravity tractor in addition to alternative approaches studied in less detail within NEOShield, such as the ion-beam shepherd and laser ablation. For NEAs much larger than 200 m or mitigation periods shorter than a few years, nuclear blast deflection is deemed the best option. For objects smaller than 50 m, no space missions are foreseen, and "civil defense" actions (i.e., sheltering and evacuation measures) would probably be most appropriate (Figure credit: S. Eckersley (NEOShield, Astrium Limited, UK) and D. Perna (NEOShield, Observatoire de Paris, LESIA))

Fig. 1 The relationship between defensive approaches, warning time, and asteroids size [7].

In general, if the warning time is too short or the asteroid is too large, approaches that can generate higher energy such as explosions or impacts are necessary, whereas with more warning time or if the asteroid is very small, gravitational pulling methods can be used.

6. Conclusion

There are a large number of asteroids in our solar system, and some of them have the potential to crash into the Earth and cause natural disasters or heat that can adversely affect humans. There have been some impacts throughout history, and they have demonstrated the immense energy carried by meteorites. Therefore, to deal with potential asteroid impacts, scientists have proposed several solutions, including aircraft impacts, nuclear explosions, and gravitational traction or propulsion. The effectiveness and feasibility of these approaches are being continuously researched and explored to minimize the huge losses that may be incurred.

This paper summarizes and analyzes the current research progress for these three asteroid defense methods and discusses the advantages and disadvantages of each method. The advantage of vehicle impact is that the technology is more mature and relevant experiments have been carried out. However, the disadvantage is that it takes a longer time to design the mission program. The nuclear explosion method is the most effective and fastest option, but at the same time, the potential dangers are obvious. A nuclear explosion could lead to some political conflict, and radioactive debris could further threaten the planet. Gravitational traction is the safest and most stable method, and the uncertainty is minimal. The disadvantage, however, is that due to the small traction force, it is necessary to continue the traction mission for up to several years.

Various defensive methods still need further research and experimental support to enhance their effectiveness and feasibility. In particular, how to find the best balance between technological maturity, political risk, and timeliness of implementation is an important direction for the development of future asteroid defense programs. In addition, international cooperation and coordination will also be key to responding to the asteroid threat and ensuring that the global response to the asteroid impact crisis continues to improve.

References

[1] Asteroids. Wikipedia, 2024. (Accessed: 30 August 2024).

[2] Wu W. Response to risk of near-earth asteroid impact. Chinese Journal of Engineering Science, 2022, 24(2): 140.

[3] Deacon E. L. The 1908 Tunguska Explosion. Weather, 1982, 37(6): 171–175.

[4] Graf Th., et al. Exposure history of the Peekskill (H6) meteorite. Meteoritics & Planetary Science, 1997, 32(1): 25–30.

[5] Drube L., Harris A. The NEOSHIELD project for near-earth

object impact threat mitigation. In: International Seminars on Nuclear War and Planetary Emergencies, 48th Session, 2016: 559–568.
[6] Drube L. Neoshield – a global approach to near-earth object impact threat mitigation. In: Handbook of Cosmic Hazards and Planetary Defense, 2014: 1–22.
[7] Cheng A. F., et al. Asteroid impact and deflection assessment mission. Acta Astronautica, 2015, 115: 262–269.
[8] Cheng A. F., Agrusa H. F., Barbee B. W., et al. Momentum transfer from the DART mission kinetic impact on asteroid Dimorphos. Nature, 2023, 616: 457–460.
[9] Luo Y. Multisatellite task allocation and orbit planning for asteroid terminal defense. Aerospace, 2022, 9(7): 364.Rumpf C. M., et al. Deflection driven evolution of asteroid impact risk under large uncertainties. Acta Astronautica, 2020, 176: 276–286.
[10] Meshcheryakov S. A., Lipnitskii Yu. M. Estimated efficiency of the deflection of a dangerous space object using an explosion or impact. Technical Physics, 2015, 60(1): 26–30.
[11] Aleksandrova A. G. The preventive destruction of a hazardous asteroid. Astronomy Reports, 2016, 60(6): 611–619.
[12] Han P. Numerical study on asteroid deflection by penetrating explosion based on single-material ALE method and FE-SPH adaptive method. Aerospace, 2023, 10(5): 479.
[13] Baum S. D. Risk–risk tradeoff analysis of nuclear explosives for asteroid deflection. Risk Analysis, 2019, 39(11): 2427–2442.
[14] Mazanek D. D., et al. Enhanced gravity tractor technique for planetary defense. NASA Technical Reports Server (NTRS), 2015.
[15] Gao Y. A kinetic impact strategy for deflecting an asteroid to form a gravity tractor system with a potentially hazardous asteroid.