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Defense Strategies and Development Status of Near-Earth Asteroid Impact on the Earth

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Abstract:

The impact of asteroids on the Earth has always been a matter of great concern in the fields of astronomy and planetary science. It is one of the causes of many biological extinction events in the history of the Earth. In recent years, with the rapid development of science and technology in various countries, human beings' research and detection capabilities on asteroids impacting the Earth have been significantly improved. This article starts with how to destroy asteroids and change their orbits and conducts research on near-Earth asteroid defense technologies to analyze the basic principles of three defense technology approaches. The first is the OTM/HOTM method, which focuses on solving the changes in materials under real impact conditions in a unified framework, which significantly improves computational efficiency in multiple dimensions. The second is to establish a magnetic plasma sail-asteroid combination model for simulation calculations and change the orbit of the asteroid through the interaction between the "magnetic bubble" and the plasma in the solar wind. The third is to use multiple interceptors to directly collide with weak characteristic points on near-Earth asteroids to make them non-threatening. Based on the current status and development ideas of asteroid defense technology, combined with the existing technical foundation, this article discusses suggestions for developing effective asteroid defense and briefly describes the current status of the development of near-Earth asteroid defense.

Keywords: asteroid, planet crushing, orbital deflection, model and method, development status.

1. Introduction

Asteroid impacts on the earth have always been a potential threat to human survival and development. Planetary defense is a hot research field in the world and a major security demand of various countries. Near-earth asteroids or near-Earth comets are near-Earth objects with perihelion $q \leq 1.3AU$ and aphelion

$Q \geq 0.983$ AU. According to their orbital characteristics, they can be divided into Apollo types (orbital semi-major axis $a \geq 1.0$ AU; $q \leq 1.0167$), Ardenne type (a< 1.0AU; $Q \leq 1.0167$), and an Amore type (1.0167< q<1.3AU) asteroid [1]. Among them, the orbits of Apollo and Ardenne near-Earth asteroids will intersect the Earth's orbit, and there is a risk of impact. Even though the orbit of the Amore type asteroid is currently located in the low-Earth orbit outside the orbit of the Earth, many years later, they are likely to evolve the above two types of near-Earth asteroids that intersect the orbit of the Earth, thereby posing a threat to the Earth and bringing disaster. A near-Earth asteroid impact could wreak havoc on global ecosystems. For example, in 1908, an asteroid about 50 meters in size exploded over Tunguska with an explosion equivalent to 20 million tons of TNT, destroying more than 2,000 square kilometers of forest [2]. A larger asteroid impact could be devastating to human civilization. For example, in the Cretaceous period 66 million years ago, a 12-14 km asteroid hit the Earth, causing major changes in the Earth's environment and climate, resulting in the extinction of 75% of non-bird species, including dinosaurs [3].

Relative to floods, tornadoes, earthquakes, and other natural disasters, the impact of asteroids on the Earth is global destruction. However, with a series of measures, asteroid impact on Earth is completely avoidable. The research on this content can help people to better construct a comprehensive and practical protection framework, and provide more effective countermeasures for human society in the face of such celestial threats. Therefore, the space agencies of various countries actively carry out international cooperation, such as the International Asteroid Early Warning System (IAWN), which is an international organization established to deal with the threat of asteroid impact on the Earth and is responsible for monitoring and defense of near-Earth asteroids [4, 5]. As early as the 1990s, Western countries represented by the United States researched asteroid defense, and explored technical means such as kinetic energy impact and nuclear explosions. Since 2000, a variety of technical means such as gravitational traction, ion beam migration, tugboat, and laser ablation have been proposed [6].

This paper studies the effective defense strategies against the extreme natural disaster of potential asteroid impact on Earth in the future and briefly evaluates the feasibility of implementation and future application prospects of these strategies.

2. Defense technology and application

2.1 Method

There are two basic methods of asteroid defense: One is to use some means to break the asteroid into pieces, so that the debris can avoid Earth, or to break up pieces small enough to be harmless to Earth. There are also many different ways to smash asteroids, such as nuclear explosions, conventional explosions, collisions, and so on. Another is to change the asteroid's orbit so that the two never meet again.

If scientists use nuclear weapons, high-tech lasers, or a massive object to hit an asteroid or use some other technology to smash it into pieces, then mankind can save the Earth easily. However, these proposed methods are not only expensive but also do not have a complete guarantee of eliminating invading asteroids.

2.2 OTM/HOTM

Whether there is a simple and feasible way to solve these problems, and how to simulate the results of these situations. In this paper, various complex physical phenomena occurring in materials under some limiting conditions were preliminarily discussed by the developed ESCAAS ultimate mechanics simulation platform [7]. OTM (Optimal Transponation Meshfree) is an explicit incremental Lagrangian meshfree method for dynamic shock problems. To solve the hot-fluid-structure coupling problem, he adopted a theoretical framework based on the variational principle. Based on OTM, by introducing the energy conservation equation and the variational constitutive of hot-fluid-structure coupling, he extended the Hot 0ptimal Transportation Meshfree (HOTM) method with strong thermal coupling. Further, the massively parallel OTM method (pOTM) has been implemented by combining the distributed multi-process parallelism and the shared memory multi-thread parallel strategy [8]. The focus of OTM/HOTM is to be able to solve the material changes in real-impact situations within a unified framework (Figure 1). It emphasizes that the method covers three aspects, basic theory, computational method, and material model. In terms of basic theory, an important point is the introduction of the coupling of heat and mechanics, which can automatically describe the phase transition process of matter according to the form of energy and can be extended to the general problem of energy propagation and dissipation. In terms of algorithms and models, the so-called grid-free method is adopted, in which the material element deforms according to the deformation of the material, and a so-called EigenFracture crack propagation algorithm is adopted, using the energy release rate as the criterion,

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which is mathematically strict and practically accurate.

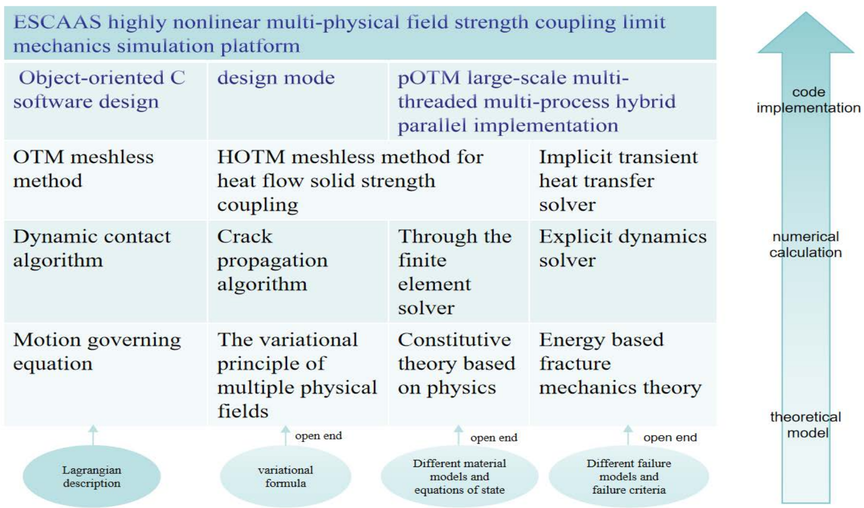

Fig. 1 Theoretical framework of ultimate mechanics simulation based on OTM [7]

"Real and efficient", the real is that a variety of complex physical phenomena can be taken into account, and efficient is that multi-threaded multi-parallel strategies can be calculated on a large scale, both fast and accurately. In terms of material failure, it overcomes the shortcomings of traditional crack growth numerical methods such as grid correlation, non-convergence, and the inability to characterize the real deformation and physical failure mechanism of materials. It also liberates the constraint of the grid, so it overcomes the difficulties caused by the grid distortion in dealing with large deformation problems by the Laplace method [9]. OTM/HOTM greatly improves computing efficiency in many dimensions. OTM/HOTM method can not only simulate the kinetic energy impact of asteroids but also simulate the process of asteroid nuclear explosion interception. This method provides relevant theoretical and technical support for asteroid defense means, and has a promising prospect.

2.3 Magnetic Plasma Sail

In the problem of changing the orbit deviation of near-Earth asteroids, it can establish a magnetoplasma sail-asteroid assembly model for simulation calculation [10]. The magnetic plasma sail propulsion technology was proposed by Winglee et al., which increases the range of magnetic fields in space by injecting plasma based on pure magnetic sail. After receiving the signal from the near-Earth asteroid exploration system, when the solar wind interacts with the magnetic field, the magnetic pressure and dynamic pressure of the solar wind particles balance each other, forming a bow shock wave [11]. This bow shock enables the exchange of momentum between the solar wind and the magnetic field, which converts momentum into pressure acting on the "magnetic bubble". The establishment of a magnetic field in space and the expansion of the magnetic field through the emission of plasma, that is, the formation of a "magnetic bubble", through the interaction of the "magnetic bubble" and the plasma in the solar wind, it can change the orbit of the asteroid (Fig. 2) [10].

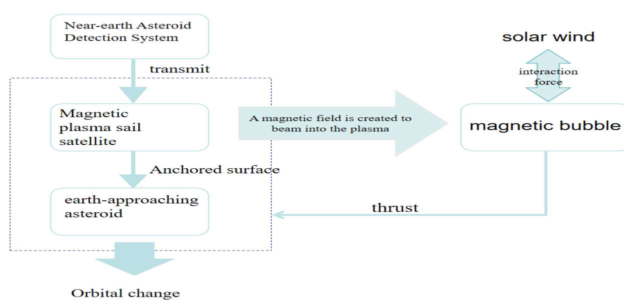

Fig. 2 Flow of near-Earth asteroid orbit control method using solar wind magnetic sail mechanism [10]

The simulation experiment of the magnetoplasma sail-asteroid assembly shows that the optimal value of thrust is always the maximum value that can be achieved, so it is necessary to increase the thrust size. Not only that, the optimal Angle is determined according to the different simulation times, so it needs to determine the action time in advance when carrying out asteroid defense so that it can accurately get the Angle transformation range of the electromagnetic coil. In this simulation experiment, it is also found that the maximum offset of the magnetoplasma sail-asteroid assembly increases with the increase of the simulation time, and the offset will not change significantly until the simulation time reaches a certain amount. Therefore, when using this technology for asteroid defense, there is a need for faster and earlier detection of near-Earth asteroids with impact threats to the Earth and timely strategies to take action [10].

The results show that under certain conditions, this method can make the maximum orbital offset of the target asteroid reach the order of a million meters after 20 cycles, which has certain application potential and prospects.

2.4 Multi-Interceptor Defensein

In the absence of a long-term slow defense strategy, it is necessary to implement a short-term fast strategy for near-Earth asteroid impact. By using multiple interceptors to directly collide multiple weak feature points on a threatening near-Earth asteroid, the asteroid can be crushed to make it non-threatening, and the orbit of the asteroid can be significantly changed to no longer intersect with the Earth's orbit, thus eliminating the threat of the asteroid to the Earth [12].

3. Current Status of Astrological Monitoring

After the comet impact in 1994, the United States increased its funding and infrastructure construction in areas such as planetary monitoring and defense technology research. It has established an integrated monitoring network for space and Earth and is a technology leader and major contributor to the search and monitoring of near-Earth objects. The Pan STARRS (Panoramic Survey Telescope and Rapid Response System) is an ongoing celestial monitoring program consisting of an array of four 1.8-meter telescopes for observation. The PS1 telescope is located at the summit of Haleakala volcano in Maui, Hawaii, while other observation points may be at the Mauna Kea Observatory or Haleakala volcano in Hawaii. These four telescopes will simultaneously observe the same celestial region, producing a resolution equivalent to that of a 3.6-meter telescope. The Pan Star Program is operated by the Institute of Astronomy at the University of Hawaii and will establish a database of celestial bodies with a minimum magnitude of up to 24, observing the entire sky and expecting to discover many new celestial bodies. Its prototype telescope (PS1) officially conducted full-time scientific observations on May 13, 2010. The Discovery Channel Telescope is the fifth largest astronomical optical telescope in the United States, which was put into use in 2012. Its main objectives are to investigate small objects in the Kuiper Belt, study comets, investigate the structure and evolution of small galaxies, and study stellar populations. At present, ground-based optical telescopes in the United States are developing towards larger apertures, larger fields of view, and faster response times. In addition, the United States has built two ground-based radar stations for planetary exploration, one of which is the Arecibo Observatory located in Puerto Rico, in the Caribbean region of the United States. It can detect asteroids with a diameter greater than 1 km within a range of 3.5 × 107 km. The other is the NASA/JPL Goldstone Solar System Radar located in Goldston, California, which can detect asteroids with a diameter greater than 1 km within a range of 1.5 × 107 km [13, 14].

The current situation in the field of international near-earth monitoring and early warning is: that the United States is leading, followed by Europe, Russia, and Japan are opening up their way, and the near-earth celestial monitoring network is being improved. Although human beings have made some progress in detecting and exploring asteroids, they still need to overcome many technical and operational challenges. Asteroids are usually weak in brightness and small in size, which requires navigation sensors to have the ability to imaging dark and weak targets, which poses challenges to the accurate identification of target asteroids. In the planetary defense mission, even if the probe successfully hits the asteroid, the detailed investigation after the impact and the close-range survey of the crater require subsequent probes, which brings technical limitations to countries. Space exploration missions are accompanied by complex and difficult tasks, including factors such as budget and time. Some space missions require a lot of time and resources. Defending asteroids is a potential threat to the Earth, which requires the joint efforts of the international community. Therefore, there are the following suggestions: strengthen monitoring and early warning, establish a global near-Earth asteroid monitoring network, improve the ability to detect and track asteroids and ensure that potential threats can be detected and evaluated on time. It is necessary to develop a disaster relief plan after the impact to reduce possible casualties and economic losses. Asteroid defense is a global challenge that requires the joint participation and cooperation of all countries. The international community should strengthen information sharing, technology exchange, and joint research to jointly improve defense capabilities. Continue to promote technological innovation and explore new defense concepts and technologies to deal with various types of asteroid threats.

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4. Conclusion

In recent years, research on defense against near-Earth asteroids has been a hot topic. Although the impact of near-Earth asteroids or comets on Earth is a rare phenomenon, once it occurs, it can cause serious harm to human production and life. Through the analysis in this article, it can be concluded that current simulations of asteroid impacts can provide relevant theoretical and technical support for asteroid defense against kinetic energy impacts, it's also possible to increase the orbital offset by establishing a magnetic plasma sail asteroid combination model and to use multiple interceptors to collide with asteroids. The following insights have been drawn from the planning of asteroid defense missions: research on asteroid warning is very important, as the length of asteroid warning time plays a decisive role in the success or failure of asteroid defense and the choice of methods. It is recommended to establish an asteroid tracking, monitoring, and early warning system as soon as possible to prevent potential problems. Moreover, key new technologies are needed for asteroid defense strategies. Many countries have insufficient technological reserves in the field of asteroid exploration, therefore, corresponding technological breakthroughs should be carried out as soon as possible for some key new technologies. Asteroid prevention is not just a matter for one country, it should be given global attention. In the process of asteroid defense missions, not only does it take a long time and the scale of the mission is large, but the cost is also enormous. Therefore, countries must work together to not only share the task but also promote the establishment of a global joint asteroid defense system. International cooperation will be the future development trend.

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