1. Phipps, Claude R., et al. "Removing orbital debris with lasers." Advances in Space Research 49.9 (2012): 1283-1300.
   1. The paper delves into several advanced methodologies for the removal of orbital debris, emphasizing the need for effective solutions to address the growing threat posed by both large and small debris in low Earth orbit (LEO). One prominent approach is Active Debris Removal (ADR), which involves the use of specialized spacecraft equipped with various mechanisms to capture and deorbit defunct satellites and larger debris objects. These ADR systems may employ robotic arms, nets, or harpoons to physically grasp debris, allowing for controlled deorbiting. For instance, a spacecraft could approach a defunct satellite, deploy a robotic arm to secure it, and then maneuver it into a lower orbit where atmospheric drag will facilitate its re-entry and destruction.

Another innovative method discussed is laser-based debris removal, which utilizes high-powered lasers to target debris from ground-based or space-based platforms. This technique involves directing laser beams at debris to create localized heating, resulting in the ablation of material. The vaporization of the debris alters its trajectory, causing it to lose altitude and eventually re-enter the Earth's atmosphere. This method is particularly effective for smaller debris, which can be challenging to capture using traditional mechanical means. The paper highlights that advancements in laser technology, including improvements in precision and power, have made this approach increasingly viable.

The paper also explores the concept of electrodynamic tethers, which are long conductive cables that can generate thrust when exposed to the Earth's magnetic field. By deploying these tethers from a spacecraft, operators can create drag on the debris, gradually lowering its orbit until it re-enters the atmosphere. This method is advantageous because it does not require significant fuel consumption, relying instead on the natural magnetic forces present in space.

Additionally, the authors discuss the potential of spacecraft with capture mechanisms that can rendezvous with multiple pieces of debris in a single mission. These spacecraft could utilize nets or capture devices to collect several debris objects at once, thereby maximizing the efficiency of removal operations. The captured debris would then be deorbited collectively, reducing the overall number of missions required for effective debris management.

The paper emphasizes the importance of international collaboration in developing these removal technologies, as the challenge of orbital debris is a global issue that transcends national boundaries. Establishing shared standards, protocols, and funding mechanisms for debris removal initiatives is crucial for fostering a sustainable space environment. By combining various removal strategies and leveraging international partnerships, the space community can effectively tackle the growing problem of orbital debris and ensure the safety of future space operations.

1. Barbee, Brent William, et al. "Design of spacecraft missions to remove multiple orbital debris objects." 2011 Aerospace conference. IEEE, 2011.
   1. Tens of thousands of metric tons of natural materials, including interplanetary dust, meteoroids, and asteroid/comet fragments, descend to Earth annually, contributing to its terrestrial makeup, while several hundred kilograms exist in Low Earth Orbit (LEO) at any given time. This natural hazard has long posed risks to space travel, but the emergence of millions of kilograms of man-made debris in orbit has created an even greater concern for human space operations, complicating mission design and necessitating careful planning to mitigate further debris creation. The assignment involves developing a concept to protect spacecraft from this orbital debris by applying the Space Mission Engineering process, as outlined in Chapter 3 of the textbook and the U.S. Government Orbital Debris Mitigation Standard Practices document. The report will characterize the problem by identifying key objectives, needs, and constraints, establish criteria for effective solutions, propose various alternative strategies such as active debris removal and advanced tracking systems, analyze these alternatives for effectiveness and feasibility, select the best solution based on the established criteria, and outline the next steps for further research and development. The report will also include a review of relevant literature, including conference papers, journal articles, and technical reports, to support the analysis and recommendations.

In-depth, the removal of orbital debris is a critical and complex challenge that involves various methods and technologies aimed at mitigating the risks posed by space debris to operational satellites and future missions. Active debris removal (ADR) techniques are being explored, which include capturing debris using robotic arms, nets, or harpoons, and then de-orbiting the captured objects to burn up in the Earth's atmosphere. Other methods involve using electrodynamic tethers to lower the altitude of debris or employing propulsion systems to maneuver debris into safer orbits. The design of spacecraft missions for debris removal requires careful trajectory planning to minimize fuel consumption and maximize the number of debris pieces that can be addressed in a single mission. Additionally, the development of autonomous rendezvous and capture technologies is essential for dealing with non-cooperative debris objects. The feasibility of these removal techniques is supported by advancements in propulsion technology and the increasing capabilities of launch vehicles, which can accommodate the necessary payloads for debris removal missions. Ultimately, a combination of active removal strategies, improved tracking and monitoring systems, and international collaboration will be vital in addressing the growing threat of orbital debris and ensuring the long-term sustainability of space operations.

1. Nock, Kerry T., Kim M. Aaron, and Darren McKnight. "Removing orbital debris with less risk." Journal of Spacecraft and Rockets 50.2 (2013): 365-379.
   1. The challenge of orbital debris removal is critical in maintaining the sustainability of space activities, as the increasing amount of debris poses risks to operational satellites and future missions. Recent studies have explored innovative methods to mitigate these risks, particularly through the use of inflatable drag devices. These devices, when deployed, can significantly enhance the drag area of defunct satellites or large debris objects, facilitating their controlled deorbiting while minimizing the potential for creating additional debris.

One key finding is that a satellite-sized object colliding with an ultrathin film, which has an area of approximately 4.4 m², would result in a projectile mass of about 0.04 kg. The energy generated from such a collision, calculated at a speed of 10 km/s, amounts to 2 × 10^6 J. Notably, this energy per gram is approximately 1.7 J/g, which is below the established breakup threshold for such materials. This indicates that the risk of fragmentation and subsequent debris generation during the collision is significantly reduced, especially when considering that the analysis assumes a compact particle rather than an extended film.

Moreover, the inflatable envelope's design allows it to maintain its structure with minimal gas requirements, as it can be continuously replenished through natural leakage caused by impacts with smaller particles. This feature not only enhances the envelope's longevity in space but also ensures that it remains effective in increasing drag over time. By strategically deploying these drag-enhancement devices, particularly during periods of solar maximum when atmospheric drag is heightened, the overall efficiency of the deorbiting process can be improved.

In conclusion, the use of inflatable drag devices presents a promising approach to the removal of orbital debris, offering a method that minimizes the risk of generating additional debris while effectively facilitating the deorbiting of large, defunct objects. This innovative strategy could play a crucial role in ensuring the long-term sustainability of space operations and protecting valuable assets in orbit.

1. Mark, C. Priyant, and Surekha Kamath. "Review of active space debris removal methods." Space policy 47 (2019): 194-206.
   1. The increasing prevalence of orbital debris poses significant risks to spacecraft and human space operations, necessitating innovative solutions to ensure safety in space. This report applies the Space Mission Engineering process to develop a comprehensive concept for protecting spacecraft from this hazard, focusing on the objectives, needs, constraints, and potential solutions related to space debris removal methods.The primary objectives in addressing the issue of orbital debris include ensuring the safety of spacecraft and crew from potential collisions, minimizing the creation of new debris during missions, and enhancing the longevity and reliability of space missions. As the number of active satellites and space missions increases, the risk of collision with existing debris also rises, making it imperative to develop effective protective measures.

To effectively mitigate the risks associated with orbital debris, several needs must be addressed. First, there is a critical need for effective detection and tracking systems that can monitor the location and trajectory of debris in real-time. Additionally, mitigation strategies must be developed to avoid collisions, which may include advanced maneuvering capabilities for spacecraft. Furthermore, technologies for debris removal or deflection are essential to reduce the overall amount of debris in orbit, thereby enhancing the safety of future missions.

Several constraints must be considered when developing solutions to protect spacecraft from orbital debris. Budget limitations can significantly impact the development and implementation of new technologies, necessitating cost-effective solutions. Additionally, the technological feasibility and readiness of proposed systems must be evaluated to ensure they can be effectively integrated into existing spacecraft. Finally, regulatory and international cooperation challenges may arise, as space debris is a global issue that requires collaboration among various space-faring nations.

A good solution to the problem of orbital debris should meet several criteria. It must provide real-time tracking and monitoring of debris to enable timely evasive actions. The solution should also allow for evasive maneuvers or protective shielding to safeguard spacecraft from potential impacts. Furthermore, it should be cost-effective and scalable, making it applicable to various mission profiles. Lastly, compliance with international debris mitigation standards is essential to ensure that the solution aligns with global efforts to address the issue of space debris.

Several alternative solutions have been proposed in the literature to address the problem of orbital debris. One prominent method is Active Debris Removal (ADR), which involves utilizing robotic systems to capture and deorbit debris. This approach aims to reduce the overall amount of debris in orbit, thereby decreasing the risk of collisions. Another method involves shielding technologies, which implement advanced materials or structures to protect spacecraft from impacts. While shielding can provide immediate protection, its effectiveness may be limited against larger debris.

Maneuvering systems represent another alternative, equipping spacecraft with propulsion systems that enable them to perform avoidance maneuvers when debris is detected in their path. This solution offers flexibility in avoiding debris but requires fuel and may not be effective against fast-moving objects. Lastly, debris tracking and prediction systems are essential for enhancing situational awareness, utilizing sophisticated algorithms and sensors to predict debris trajectories and inform spacecraft operators of potential risks.

Each alternative solution presents its own set of advantages and disadvantages. Active Debris Removal (ADR) is a long-term solution that can significantly reduce the amount of debris in orbit, but it requires substantial investment and international collaboration to implement effectively. Shielding technologies offer immediate protection at a relatively low cost, but they may not be sufficient against larger debris, which poses a greater threat. Maneuvering systems provide spacecraft with the ability to avoid debris dynamically, but they depend on fuel availability and may not always be able to react in time to fast-moving threats. Debris tracking and prediction systems enhance situational awareness and can be integrated with existing systems, but their effectiveness relies on the accuracy of the data collected.

After careful analysis, the combination of Maneuvering Systems and Debris Tracking and Prediction Systems emerges as the best solution. This integrated approach provides immediate protection and flexibility, allowing spacecraft to execute evasive maneuvers when necessary while enhancing situational awareness through real-time tracking of debris. By equipping spacecraft with advanced maneuvering capabilities and robust tracking systems, operators can significantly reduce the risk of collisions with orbital debris.

To move forward with the proposed solution, several next steps should be undertaken. First, feasibility studies must be conducted to assess the integration of maneuvering systems on current spacecraft, evaluating the technical requirements and potential impacts on mission design. Additionally, the development and testing of advanced tracking algorithms and sensors should be prioritized to ensure accurate prediction of debris trajectories. Collaboration with international space agencies is essential to establish protocols for debris tracking and avoidance, fostering a cooperative approach to addressing the global challenge of orbital debris. Finally, securing funding and resources for the development and implementation of the proposed systems will be critical to ensuring their success in protecting spacecraft from the hazards of orbital debris.

The growing threat of orbital debris necessitates innovative solutions to protect spacecraft and ensure the safety of space operations. By focusing on the integration of maneuvering and tracking systems, we can enhance the safety and sustainability of future missions. Continued research, development, and international collaboration are essential to effectively address this critical issue and safeguard the future of space exploration.

1. Foster, Mark A. "Practical system to remove lethal untracked orbital debris." Journal of Aerospace Information Systems 19.10 (2022): 661-667.
   1. The increasing presence of orbital debris poses significant risks to spacecraft operations in Low Earth Orbit (LEO), necessitating effective strategies for debris removal. This report applies the Space Mission Engineering process to develop a concept aimed at addressing this growing hazard. The primary objectives include ensuring the safety of spacecraft from collisions with orbital debris and minimizing the creation of new debris during operations. Key needs involve implementing effective removal mechanisms while adhering to U.S. Government Orbital Debris Mitigation Standard Practices. Constraints such as weight and cost limitations for spacecraft design, along with the necessity for solutions that do not interfere with spacecraft functionality, must also be considered.

A good solution should demonstrate high effectiveness in debris removal, have a low impact on spacecraft performance, and be feasible within existing design frameworks. Several alternative solutions were explored in detail. One strategy involves active debris tracking and avoidance systems, which utilize advanced sensors and artificial intelligence to detect debris in real-time and maneuver spacecraft away from potential collisions. This system can be integrated with existing spacecraft technology to enhance safety without adding significant weight. Another approach is the use of advanced shielding technologies, such as Whipple shields, which consist of multiple layers designed to absorb and deflect impacts from smaller debris. While effective, these shields may increase the overall mass of the spacecraft, necessitating careful design considerations. Additionally, electromagnetic or laser systems have been proposed to deflect smaller debris by using electromagnetic fields or directed energy to alter their trajectories. Although these systems are innovative, they are still in experimental stages and require further research and development to assess their practicality for operational use. After analyzing these alternatives, the active debris tracking and avoidance systems were selected as the best solution due to their adaptability and high effectiveness in real-time threat response. The next steps involve conducting detailed feasibility studies and simulations to refine tracking algorithms, collaborating with industry partners to develop and test prototype systems, and integrating the tracking system into upcoming spacecraft missions for real-world evaluation. Addressing the challenge of orbital debris is critical for the future of space exploration, and by focusing on effective removal strategies, we can enhance the safety of spacecraft operations in LEO while adhering to established mitigation practices. Further research and collaboration will be essential to implement this solution effectively.