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The Evolution of U.S. National Policy for Addressing the Threat of Space Debris

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Abstract

Since the late 1980s, U.S. national space policy has increasingly highlighted the importance of dealing with space debris, and directed U.S. federal agencies to take specific actions to address the challenge. However, the implementation of the policy direction has been mixed. This paper provides an overview of the historical evolution in U.S. national policy on space debris, including space debris mitigation, space traffic management, and active debris removal. The paper shows that while there has been significant progress on raising awareness of the threat posed by space debris among U.S. policymakers, and taking action on implementation voluntary debris mitigation guidelines, there has been little progress on remediation of the space environment through removal of large space debris objects, despite strong scientific consensus of its importance to the long-term sustainability of the space environment. The paper discusses the lack of progress on active debris removal in the context of broader public policy models and concepts, and identifies the lack of a U.S. federal agency with clear responsibility and authority to manage the space environment as a key constraint. It recommends that future executive and legislative action on space debris consider giving an existing, or new, federal entity clear authority over on-orbit space activities and responsibility for managing the space environment.

Keywords: space debris, space policy, space sustainability, active debris removal, public policy

Acronyms/Abbreviations

Anti-satellite (ASAT)
Defense Advanced Research Projects Agency (DARPA)
Department of Defense (DOD)
Federal Aviation Administration Office of Commercial Space Transportation (FAA/AST)
Federal Communications Commission (FCC)
Geosynchronous Earth Orbit (GEO)
Inter-Agency Space Debris Coordination Committee (IADC)
Joint Space Operations Center (JSpOC)
Long-Term Sustainability of Space (LTS)
Low Earth Orbit (LEO)
Micrometeorite and Orbital Debris (MMOD)
National Aeronautics and Space Administration (NASA)
National Oceanic and Atmospheric Administration (NOAA)
NASA Innovative Advanced Concepts (NIAC)
North American Aerospace Defense Command (NORAD)
National Research Council (NRC)
Presidential Policy Directive (PDD)
Space traffic management (STM)
Scientific and Technical Subcommittee (STSC)
United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)
United States Strategic Command (USSTRATCOM)

1. Introduction

Over the last fifty years of human activities in space, there has been a growing recognition of the threat from space debris. As our use of space has grown, so has the amount of human-generated space debris we have left in orbit. The growing congestion of critical orbital regions, such as the 700 to 900-kilometer region in low Earth orbit (LEO) and the geosynchronous Earth orbit (GEO) region 36,000 kilometers above the equator, pose significant challenges for humanity's ability to derive benefits from space over the long term.

Within the United States, presidential policy directives (PDDs) are an important tool for coordinating and setting policy across the U.S. executive branch. PDDs are developed as the result of an interagency process that brings together multiple departments and agencies who have equity in a particular policy area. The final policy is signed by the President of the United States, and represents the consensus position of the administration on principles, priorities, and actions to be taken on a particular policy issue.

The Eisenhower Administration issued the first PDD establishing a national space policy in 1958 [1]. Since then, most presidents have followed suit and issued additional PDDs on national space policy and/or specific space sectors, such as transportation or remote sensing. These PDDs have formed a major component of U.S. space policy, and are a useful tool to track the evolution of space policy priorities.

This paper traces the evolution of U.S. national policy on dealing with the threat of space debris through national space policies issued by multiple administrations. It also discusses the implementation, or lack thereof, of the various actions the PDDs direct on space debris, and concludes with a discussion of why certain solutions have not had much progress in implementation as others.

2. Evolution of U.S. national policy on space debris

Since the 1960s, there has been a slow but continuous evolution in understanding of the threat posed by space debris. The scientific research on space debris was driving mainly by the need to understand space environmental risks for high-profile programs such as human spaceflight. Eventually, a combination of factors, including progress in the science and external events, led to space debris being included in presidential policy directions on space. The following sections trace this evolution from the 1960s to the 2010s.

2.1 Emerging recognition of the space debris problem

Space was not a pristine environment before humans starting launching spacecraft into orbit. The solar system is home to many asteroids that in turn created an untold number of smaller fragments, called meteoroids, through collisions with each other. Occasionally, meteoroids would re-enter the Earth's atmosphere, and become visible meteors streaking across the sky.

Beginning in the 1950s, NASA started to study the potential hazards present in the natural space environment, including meteoroids, as part of preparations for the human spaceflight program [2]. The studies included theoretical work, ground-based observation of meteors, hypervelocity impact testing on the ground of spacecraft, and flight experiments to measure the rate of actual impacts. These studies concluded that the meteoroid environment posed a real, but relatively small, risk for most spacecraft [2].

In the late 1960s, some within NASA began to wonder if scientific study should begin to shift to assessing the potential hazard from human-generated space debris. By the end of 1968, there had already been more than a dozen on-orbit fragmentations of satellites or rocket bodies, which created hundreds of pieces of space debris [3]. However, the few analyses that were done concluded that since many of the fragments were too small to be tracked by the North American Aerospace Defense Command's (NORAD) tracking network, the increased risk was "inconsequential" [2].

By the mid-1970s, interest in studying orbital debris as a possible hazard was renewed, in part due to the experiences with longer-duration missions such as Sky Lab. Eventually, the renewed interest lead to NASA scientists Don Kessler and Burton Cour-Palais publishing an influential paper that predicted significant growth in the population of human-generated space debris, and hence the collision hazard to spacecraft [4]. The major prediction of their work was that by the year 2000, the density of space debris objects would reach the point where collisions would create new space debris faster than it was pulled out of orbit through atmospheric decay. Eventually, this would lead to exponential growth in the debris population, and human-generated space debris posing more of a hazard to spaceflight than the natural meteoroids. Kessler and Cour-Palais concluded that the only effective way to prevent this scenario was to re-enter large objects at the end of their useful life, and minimize on-orbit explosions and fragmentations.

2.2 Policy focus on space debris and development of mitigation guidelines

During the 1980s, the work of Kessler and Cour-Palais, and other high-profile events, led to increased attention on space debris. According to Kessler, NASA officially created an orbital debris team in 1979 with an initial budget of $70,000 and only one full-time member [2]. Studies continued, as did on-orbit explosions and fragmentations. Three high-profile events in the mid-1980s boosted recognition of the problem significantly: NASA's decision to build Space Station Freedom, the DOD's anti-satellite (ASAT) test that destroyed the U.S. Solwind satellite and created hundreds of pieces of debris, and the 1986 explosion of a French Ariane rocket stage that created hundreds more [2]. By 1987, NASA conducting research and organizing conferences with Western Europe on the importance of minimizing the creation of debris [5].

The heightened awareness created by these events, and NASA's work, led to the first official policy statement on space debris. In 1988, President Ronald Reagan announced a new national space policy, which revised his previous national space policy from 1982. The revised national space policy included a directive that stated [6]:

> *"…all space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness."*

The 1988 Reagan National Space Policy also directed an interagency working group to develop recommendations on the implementation of the space debris policy [6], which culminated in a National Security Council report on space debris in February 1989 [7].

Subsequent national space policies continued to mention the need for addressing the threat of space debris. In 1989, the George H. W. Bush Administration issued a new national space policy that reiterated the same statement on space debris from the 1988 Reagan policy, with an additional focus on encouraging all spacefaring countries to minimize space debris [8]:

> *…The United States government will encourage other space-faring nations to adopt policies and practices aimed at [space] debris minimization.*

The George H.W. Bush National Space Policy led to the creation of bilateral working groups between NASA and space agencies in Europe, Russia, and Japan, which were merged into the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 [9].

In the 1990's, the Clinton Administration continued and expanded a policy focus on space debris. The 1996 Clinton Administration national space policy included the same language as the H.W. Bush Administration policy, but added a new focus on developing intragovernmental guidelines to minimize the creation of space debris, and working to promulgate those guidelines internationally [10]:

> *The United States will seek to minimize the creation of space debris. NASA, the Intelligence Community, and the DoD, in cooperation with the private sector, will develop design guidelines for future government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments, and systems will minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness.*
>
> *It is in the interest of the U.S. Government to ensure that space debris minimization practices are applied by other spacefaring nations and international organizations. The U.S. Government will take a leadership role in international fora to adopt policies and practices aimed at debris minimization and will cooperate internationally in the exchange of information on debris research and the identification of debris mitigation options.*

The space debris mitigation language in the Clinton National Space Policy reflected work that was already going on within the U.S. government. By 1995, NASA had already prepared a set of draft orbital debris mitigation guidelines. The draft NASA guidelines became draft U.S. Government Orbital Debris Mitigation Standard Practices, which were approved in 2001 after consultations with industry [9]. The debris mitigation standard practices were implemented for U.S. government space activities through departmental guidance and regulation, and for U.S. commercial space activities through pre-launch licensing processes.

In the 2000's, the George W. Bush Administration continued the policy focus on debris mitigation guidelines established by the Clinton Administration. The 2006 George W. Bush National Space Policy included much the same language as the 1996 Clinton National Space Policy, but added more focus on preserving the space environment and including debris mitigation requirements in licensing of U.S. commercial space activities [11]:

> *Orbital debris poses a risk to continued reliable use of space-based services and operations and to the safety of persons and property in space and on Earth. The United States shall seek to minimize the creation of orbital debris by government and non-government operations in space in order to preserve the space environment for future generations. Toward that end:*
>
> - *Departments and agencies shall continue to follow the United States Government Orbital Debris Mitigation Standard Practices, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the operation of tests and experiments in space;*
> - *The Secretaries of Commerce and Transportation, in coordination with the Chairman of the Federal Communications Commission, shall continue to address orbital debris issues through their respective licensing procedures; and*
> - *The United States shall take a leadership role in international fora to encourage foreign nations and international organizations to adopt policies and practices aimed at debris minimization and shall cooperate in the exchange of information on debris research and the identification of improved debris mitigation practices.*

As a result of both the Clinton and Bush Administration policies, progress on international debris mitigation guidelines continued. The IADC continued to develop technical space debris mitigation guidelines, and in September 2007 published the IADC Space Debris Mitigation Guidelines, which represented the consensus views of the technical experts from eleven national space agencies [12]. In parallel, a working group within the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) negotiated a simplified version of the IADC guidelines, which were endorsed as voluntary measures by the full United Nations General Assembly in December 2007 [13].

2.3 Increasing challenges and the emergence of active debris removal

While the efforts of the IADC and UNCOPUOS to develop mitigation guidelines were successful, incidents in space continued to increase the amount of space debris. On January 11, 2007, China conducted an ASAT test that destroyed one of its own weather satellites at an altitude of around 860 kilometers [14]. On February 9, 2009, the Iridium 33 satellite, operated by an American company, collided with a dead Russian military satellite, Cosmos 2251, at an altitude of around 800 kilometers [15]. Taken together, the two events created more than 5,000 pieces of trackable space debris (large than 10 centimeters) in what was already the most highly congested region of Earth orbit.

The massive amount of orbital debris created by the 2007 Chinese ASAT test and the 2009 Iridium-Cosmos collision effectively reversed the reduction in space debris resulting from the debris mitigation guidelines, and prompted research to look beyond just mitigation to remediation of the space environment. New studies done by NASA and other agencies concluded that space debris remediation, mainly through removal of large space debris objects from LEO and GEO, was the only practical method to reduce the long-term collision threat to operational satellites [16].

The on-orbit events and studies prompted the Obama Administration to increase the focus on preserving the space environment in its national space policy. The 2010 Obama National Space Policy stated that the United States considers the sustainability of space to be vital to its national interests, and added a new section on "Preserving the Space Environment and Responsible Use of Space" that contained the language from the George W. Bush policy but added specific policy direction on space collision warnings, and active debris removal (ADR) [17]:

> ***Preserve the Space Environment****. For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall:*
>
> *• Lead the continued development and adoption of international and industry standards and policies to minimize debris, such as the United Nations Space Debris Mitigation Guidelines;*
>
> *• Develop, maintain, and use space situational awareness (SSA) information from commercial, civil, and national security sources to detect, identify, and attribute actions in space that are contrary to responsible use and the long-term sustainability of the space environment;*
>
> *• Continue to follow the United States Government Orbital Debris Mitigation Standard Practices, consistent with mission requirements and cost effectiveness, in the procurement and operation of spacecraft, launch services, and the conduct of tests and experiments in space;*
>
> *• Pursue research and development of technologies and techniques, through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and remove on-orbit debris, reduce hazards, and increase understanding of the current and future debris environment; and*
>
> *• Require the head of the sponsoring department or agency to approve exceptions to the United States Government Orbital Debris Mitigation Standard Practices and notify the Secretary of State.*
>
> ***Foster the Development of Space Collision Warning Measures****. The Secretary of Defense, in consultation with the Director of National Intelligence, the Administrator of NASA, and other departments and agencies, may collaborate with industry and foreign nations to: maintain and improve space object databases; pursue common international data standards and data integrity measures; and provide services and disseminate orbital tracking information to commercial and international entities, including predictions of space object conjunction.*

3. Implementation of the Space Debris Measures in the 2010 Obama National Space Policy

The implementation track record of space debris policy goals established in the 2010 Obama National Space policy has been mixed, particularly on the new additions of space collision warning measures and ADR. The following sections discuss the progress, or lack thereof, on the space collision warning measures, ADR, and international initiatives directed in the 2010 Obama National Space Policy.

3.1 Space collision warning measures

The most progress has been made on the space collision warning measures. In 2010, United States Strategic Command's (USSTRATCOM) Joint Space Operations Center (JSpOC) at Vandenberg Air Force Base expanded its screenings for potential on-orbit collisions to include all operational satellites, including commercial and foreign satellites [18]. Under a new SSA Sharing Program, the JSpOC began providing warnings of close approaches (conjunctions) directly to all satellite operators, and created a process for operators to get more detailed data on conjunctions in order to make decisions about maneuvers to reduce the risk of a collision.

More recently, the U.S. government has begun a broader conversation on dealing with the growing congestion on orbit. On May 9, 2014, the House Committee on Space, Science, and Technology convened a hearing to discuss space traffic management (STM), which included a focus on improving SSA, space debris mitigation, and future steps for ensuring the sustainability of the space environment [19]. Congress also introduced language in the U.S. Commercial Space Launch Competitiveness Act of 2015 stipulating a study on alternate frameworks for the management of space traffic and orbital activities [20]. In parallel, the White House has held interagency meetings about U.S. federal agency roles and responsibilities for oversight of space activities [21].

3.2 Active debris removal

To date, there has been little to no progress by the DOD and NASA on implementing the policy directives on developing the technology for ADR. Several reasons for this inaction are summarized in a 2011 National Research Council (NRC) study on NASA's Meteoroid and Orbital Debris Program. According to a U.S. government participant in a workshop convened by NRC, a space debris remediation plan was discussed, but not implemented, in the 2010 National Space Policy due to concerns over costs, lack of specific agency responsibility, and political concerns over the weapons-like concern of some of the ADR techniques [22].

Initially, the DOD moved to study potential options for ADR. In September 2009, the Defense Advanced Research Projects Agency (DARPA) announced a study known as Catcher's Mitt to examining the issues and challenges with removing man-made debris from orbit [23]. The study included a Request for Information for possible technical approaches and economic assessments, an international workshop co-hosted by DARPA and NASA in December 2009, and concluded in 2011. However, no follow-up actions were taken, despite the study's conclusion that U.S. military should pursue ADR [23].

The DOD's reluctance to move forward on ADR is understandable, given their bureaucratic interests. While it has the largest space budget of any governmental entity and is extremely reliant on space, cleaning up the space environment is not one of its core missions. Furthermore, the U.S. military is very sensitive to international perceptions that it is weaponizing space, not necessarily because it does not want to do so but because of the political impact such perceptions may have on domestic support in Congress and international support from its allies. Thus, the U.S. national security space community has strong concerns that any military-backed initiative for ADR may stimulate comparable programs by others in response or geopolitical complications.

The DOD is also had a shift in focus over the last few years away from concerns about space environmental threats, and towards hostile counterspace threats. The 2007 Chinese ASAT test was just one in a string of tests since 2005 that appear to be aimed at developing at least two different ASAT weapons systems. In addition, there is evidence that Russia has reactivated some of its own ASAT programs that were left fallow after the end of the Cold War, and may have used counterspace jamming capabilities in its military intervention in Ukraine. As a result, the DOD has focused a significant amount of attention to addressing the potential threat from the counterspace capabilities of potential adversaries, and less on space debris [26].

NASA's organizational support for ADR has been tepid at best, as a result of both budget concerns and NASA's fiefdom-like structure. Three different NASA field centers – Ames Research Center in California, Johnson Space Center in Texas, and Goddard Space Flight Center in Maryland, all indicated a strong interest in being the "center of excellence" for space debris within NASA, partly because they saw it as a potential source of additional funding. Each of the three centers has a different focus, largely as a function of its broader expertise and mission set, and competes with the others as to who should be the main player on space debris.

Partly as a result of this competition between centers, and partly due to broader budget constraints, NASA's recent budget submissions reflect an increased rhetorical focus on space debris, but little actual monetary commitment. The term "space debris" did not even appear in NASA's fiscal year 2009 (FY09) budget estimate, as it was considered to be a small part of operations and protection for both the Space Shuttle and the International Space Station (ISS) [29]. Beginning in FY10, NASA included a specific reference to space debris, and outlined efforts to conduct scientific studies to characterize the near-Earth space debris environment, assess its potential hazards to current and future space operations, and identify and implement means of mitigating its growth, but did not provide a dedicated budget line for doing so [30].

Since 2011, NASA has invested a small amount of money in research and development for ADR technology. A NASA Innovative Advanced Concepts (NIAC) Phase I award was given out in 2011 to study Space Debris Elimination. Throughout 2011 and 2012, NASA began to review proposals for ADR concepts, culminating in a $1.9 million contract to a company in 2013 to develop the technology for an electrodynamic tether that could remove debris from LEO, but the funding was not continued past FY14 [31]. In 2016, NIAC awarded another Phase I contract to Aerospace Corporation to develop the concept for its two-dimensional "brane" spacecraft for orbital debris removal [32].

While these small research and development grants are a step in the right direction, NASA has also decided to set strict limits on its investment in carrying research and development of ADR technologies forward. In June 2014, NASA formally adopted a policy to limit its ADR efforts to basic research and development of the technology up to, but not including, on-orbit technology demonstrations [33]. It is believed that the main reason for this limitation was an unwillingness by NASA to take on a potentially costly major new initiative without additional funding from Congress.

3.3 International initiatives

Internationally, the United States has focused its multilateral diplomatic efforts to address space debris and the space environment on participation in the Working Group on the Long-term Sustainability (LTS) of Outer Space Activities under the Scientific and Technical Subcommittee (STSC) of UNCOPUOS. The Working Group was created in 2010 to examine and propose measures to ensure the safe and sustainable use of outer space for peaceful purposes and for the benefit of all countries [34]. In June 2016, the Working Group on LTS reached consensus on an initial set of 12 voluntary guidelines for enhancing space sustainability based on existing best practices [35]. The guidelines endorsed by the LTS Working Group include promoting sharing of information on space debris and investigating measures to manage the space debris population. The LTS Working Group plans to continue to discuss 16 additional guidelines, with the hope of reaching consensus by 2018.

The United States has also engaged in a series of bilateral engagements on SSA data-sharing. Following the 2010 National Space Policy, USSTRATCOM was given authority to lead negotiations with commercial satellite operators and foreign governments on data-sharing agreements. As of August 2016, USSTRATCOM had signed agreements with eleven foreign governments, two international organizations, and more than commercial entities [36]. These bilateral agreements provide the policy framework for which the United States can exchange SSA data with foreign governments and commercial satellite operators to support both space debris monitoring and collision warning, and national security needs.

4. Space debris in the context of broader public policy theories

Public policy theory may provide insights on the mixed progress in implementing the space debris measures in U.S. national space policy. The following sections provide a brief overview of major models in public policy on how policy change happens, and what these models imply for achieving progress on the issue of space debris.

4.1 Punctuated equilibrium and alignment of policy streams

The field of public policy has defined several underlying concepts that impact how public policy issues are addressed [37]. The first is that policy-makers operate under the constraint of "bounded rationality," which prevents them from considering all problems and all solutions at all times, and forces them to choose specific issues to address. Policy-makers also tend to pay disproportionate attention to specific policy issues, sometimes addressing an issue more than they rationally should, and sometimes less so. The public policy system includes power brokers and interest groups, who try to maintain their privileged position in the network and frame issues to their advantage.

Within the field of public policy, there are two major models that are often used to understand how change occurs, or does not occur. The first model, developed by Frank Baumgartner and Bryan Jones, is known as punctuated equilibrium, and focuses on conflict between policy monopolies in setting and controlling the agenda on a policy topic [38]. Policy monopolies tend to form between bureaucracies (the executive branch), the legislative branch, and powerful interest groups. A policy monopoly tries to control the agenda for a specific set of issues, and maintain a positive policy image for their approach. The resulting status quo, or equilibrium, can be disrupted by outsiders successfully mobilizing a wave of criticism from alternative interest groups, problems, and approaches. If successful, the challengers create a new monopoly, which sets a new equilibrium until the next disruption.

The second major model is the policy streams model developed by John Kingdon [39]. Instead of focusing on agenda setting conflict and mobilization, the policy streams model focuses on the mechanics of the overall decision-making agenda. Public policy decision-making has three components: the "problem stream" of issues that rise to the attention of policymakers; the "policy stream" of the community that creates policy alternatives to solving a problem; and the "politics stream" of the coalition building and bargaining techniques that push an issue onto the national agenda. Under the streams model, policy change happens when all three streams align, and a "policy window" opens. However, misalignment of the streams – such as a policy community failing to define useful solutions while there is political interest in addressing it, or the lack of significant interest in addressing a problem that does have a good solution – will prevent change from occurring.

Both models have applicability to the space debris problem. The evolution of policymaker interest in space debris can be seen as a series of shifts in the underlying interest groups, which have driven periods of sudden change. Early on, research in space debris was driven by the need to better understand the space environmental risks involved in human spaceflight. That in turn drove NASA, and in particular Johnson Spaceflight Center, to be the early center of power on space debris, along with its associated Congressional committees. But a major shift occurred after the 2007 Chinese ASAT test and the 2009 Iridium-Cosmos collision, in which the U.S. military took a stronger role in preventing collisions between all satellite operators, and in space debris issues in general. And at the moment, there is the beginning of a potential new disruption being driven by the increasing commercial use of space, which may lead to a new policy monopoly on space debris in the near future focused on ensuring and managing the economic development of space.

At the same time, the policy streams model also appears to have been at play in the historical evolution of U.S. national policy on space debris. The research done by NASA scientists on identifying the problem and possible solutions was not immediately implemented in policy. Rather, it took a series of external events to raise awareness of the issue among policymakers, and the beginning of interagency discussions on revising national space policy, to align the policy streams and create the window for change. The policy streams model also provides insight in understanding the lack of progress on space debris remediation. The failure of the solution stream to produce politically- and economically-acceptable ADR capabilities is likely a major reason why remediation has yet to garner significant support from policymakers. It will likely take the development and demonstration of practical ADR techniques before the policy window on remediation has a chance at opening.

4.2 The power of bureaucracy in motivating policy change

Despite the progress made over the last few decades, there are still significant gaps in current U.S. government efforts to address space debris. The first major gap has been on allocation of resources. Most of the progress on implementing national policy on space debris has been in areas that did not require allocation of significant budgets by NASA or the DOD. NASA continues to fund basic research on the space debris population, but the amount is too small to break out into a separate budget. All told, NASA's entire annual budget dedicated to space debris probably amounts to several million dollars, a paltry sum out of a total annual budget of nearly $18 billion.

While the DOD has recently shifted a significant amount of money to deal with space threats, the vast majority of it appears to be directed at the counterspace threat and not dealing with space debris. A U.S. Government Accountability Office report published in October 2015 estimated that the DOD spends approximately $1 billion per year on SSA [40], but much of the motivation for that spending is the broader SSA mission to collect intelligence on foreign space capabilities and detect threats to U.S. space assets. Even if the entire amount were spent on tracking and mitigating space debris, it would still represent around 1/20th of the estimated more than $22 billion reportedly spent on U.S. national security space each year [41].

The second major gap is the lack of any progress on space debris remediation. Despite near consensus in the scientific community on the need for space debris remediation, the United States does not have a strategy to develop the technology to do so, nor is there a strong push from either the DOD or NASA to request funding from Congress to support development of remediation technologies. The lack of a request is likely because space debris does not clearly fall into either organization's "job bucket," resulting in a lack of organizational motivation to take on a mission that might result in cuts to other missions that are deemed higher priorities.

The lack of organizational push is seen more clearly in comparison to the national security community's budgetary and programmatic push for more space protection efforts. The DOD has clear organizational mission and responsibility to protect its space assets. The DOD has also demonstrated significant competence in working with Congress to convince key committees of the need for increased spending on space protection. A recent news report cited one Congressional staffer as having said there were more classified briefings on counterspace threats in 2013 and 2014 than the last decade combined [42]. These briefings are also designed to take advantage of the current Republican control of Congress, as it is the party most likely to be concerned about national security threats and amenable to increased military spending.

Although the term "bureaucracy" may have a negative connection in the public mind, it is also a tool that can be wielded to positive effect. In his classic work on the subject, Anthony Downs defined a bureaucracy as a rational, goal-seeking group of individuals motivated by self-interests, which can be created when a government decides there is a need to perform a new function [43]. James Wilson expanded upon this idea, noting that one of the main tasks of a bureaucracy is to create autonomy by identifying its role and purpose as unique and separate from other bureaucracies, and to obtain the resources to sustain its functions [44].

The on-going discussions on STM may provide an opening to change bureaucratic incentives on space debris. Part of the interagency and Congressional discussions is whether or not to give on-orbit authority to a civil federal agency, and whether this authority extends to managing the space environment.

One option would be to give the authority to an existing agency. Although NASA might seem a suitable candidate due to its long-standing focus on orbital debris research, its lack of regulatory authority creates a challenge for implementing other aspects of STM. Other candidates, such as the Federal Communications Commission (FCC), National Oceanic and Atmospheric Administration (NOAA), and Federal Aviation Administration Office of Commercial Space Transportation (FAA/AST), do have regulatory authority over some aspect of space activities. However, none have existing scientific or operational expertise with space debris and SSA.

Although not yet definitive, the general consensus is that the FAA/AST might be the most suitable candidate. In April 2016, Congressman Jim Bridenstine unveiled a proposal for an American Space Renaissance Act, which included language moving the Commercial Space Transportation Office (AST) from its current position within the Federal Aviation Administration to a separate office under the Department of Transportation, and giving it authority to regulate private sector activities in space [45]. Expanding the responsibilities of AST to include management of the space environment could provide the necessary bureaucratic incentive to drive investment in ADR technologies, and developing a more holistic strategy to dealing with space debris.

Another option would be to create a new civil agency that has broad oversight over many different aspects of space activities. Such an agency might be modeled after the U.S. Coast Guard, which has responsibility for safety and efficient use of the environment, a mix of regulatory and law enforcement powers, and domain awareness capabilities [46].

But the concept of a "Coast Guard for space" or "Space Guard" faces significant bureaucratic and institutional challenges to becoming reality. It would require convincing the bureaucracies with existing authorities and budget over space to give up their power to the new entity, which in turn would need to develop its own competency and capabilities. Such a massive bureaucratic change is among the most difficult and challenging public administration tasks, as exemplified by recent attempts within the United States to create the Department of Homeland Security, the Office of the Director of National Intelligence, and United States Cyber Command.

6. Conclusions

Over the course of the last thirty years, successive U.S. presidential administrations have reaffirmed, and increased, the focus on dealing with space debris in national policy. There is a clear movement over time in implementation of national mitigation guidelines, international mitigation guidelines, broader discussion on space sustainability, and improving SSA and collision warning measures. However, while national policy has recognized the importance of developing remediation capabilities such as ADR, there has not been significant progress in doing so. To date, U.S. efforts on space debris remediation have been limited to studies by both NASA and the DOD, and relatively small research and development contracts from NASA. The lack of progress is likely due to organizational and political factors, including the lack of clearly defined responsibilities, budget constraints, and a political predilection for national security. Broader theories of how public policy change occurs, and how bureaucracies function, can provide insights into changes that could result in improved progress on dealing with space debris. Among the changes that should be considered is giving an existing, or new, federal agency explicit authority over on-orbit activities and management of the space environment.

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