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Toward a Cohesive Management of Earth's Orbital Environment: Applying Policy and Collaboration to a Design for the Present and Future

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ABSTRACT

The response to Starlink solar reflectivity by some industry leaders, scientists, and other interested actors demonstrates the ability for diverse space actors to collaborate through dialogue and innovation to solve nuanced technological problems. These efforts should be encouraged and modeled to implement a response to and prevention of future dynamics that affect Earth's orbital environment. In a separate but related context, the Federal Communications Commission ("FCC") proposed and implemented new regulations regarding orbital debris. In 2021, the final regulations on orbital debris mitigation should be adopted, published, and implemented. This context suggests that the policy climate within the FCC should be ripe for consideration of corollary regulations designed to mitigate adverse effects of satellites (e.g., solar reflectivity) on science, particularly astronomy and astrophysics, and other uses of space. Based on the foregoing, we can utilize the history of orbital debris regulation and the current climate favoring protection of Earth's orbital environment to facilitate the more expeditious adoption of regulations addressing adverse effects of satellites. But, importantly, we need the cooperation and input of the satellite industry. Beyond providing policy input, industry should be encouraged to design and implement mitigating technology. So, too, should scientists play their part in adapting to the new era of satellites and megaconstellations. And, they have done so. Everyone should also be encouraged and incentivized to share their developments. Together, the last year exhibited the potential for these independent and collective efforts to reach sound proposals for the present and future protection of Earth's orbital environment. This presentation will briefly discuss the history of orbital debris and its regulation. This will include an overview of the new FCC orbital debris regulations of 2020 and 2021. It will also address recent developments with respect to satellites and the Starlink-effect. Applying one to the other, it will identify and propose specific measures to facilitate these combined efforts of all players to ensure we protect Earth's orbital environment. In sum, this presentation will move us towards a solution that applies innate human innovation to policy, science, and technology. And, it will call for the cooperation of those in the satellite industry to join other actors to implement such a plan for the future of Earth's orbital environment and space for all humankind (and other species) that enjoy and rely on a protected space.

INTRODUCTION

Recent developments in the space economy compel the development of a cohesive approach to managing space utilization. A critical and necessary component of any approach will be the management of Earth's orbital space as a critical aspect of its environment. While intuitive, the logic of this concept remains elusive. The Federal Communications Commission ("FCC") currently interprets the National Environmental Policy Act ("NEPA") and NEPA's Council on Environmental Quality implementing regulations as only a tangent to its oversight of space operations. As such, the widespread acceptance of Earth's orbital space as integral to the Earth's environment will require a shift in paradigm thinking. That being said, recent regulatory developments and collaborative efforts to address developing novel satellite concerns suggest a design matrix for managing the present and future of space. These collaborative efforts necessarily include the satellite industry. Indeed, the response to Starlink solar reflectivity by some industry leaders, scientists, and other interested actors demonstrates the ability for diverse space actors to collaborate through dialogue and innovation to solve nuanced technological problems. These efforts should be encouraged and modeled to implement a response to and prevention of future dynamics that affect Earth's orbital environment and the management of space. This presentation seeks to discuss and provide a proposal for the means to do so.

Background and Recent Developments

The May 2019 launch of the first set of sixty (60) Starlink Satellites caught many by surprise. Or, rather, the *solar reflectivity* of the satellites caught many by surprise and prompted significant concerns. In response, thought leaders from across different spectra independently and collectively addressed these concerns on both a national and international scale. On one hand, Space Exploration Technologies Corp. (for purposes of simplicity, both Space Exploration Technologies Corp. and Space Exploration Holdings LLC shall be referred to collectively as "SpaceX") internally developed innovative and advanced technology to help mitigate the concerns emanating from within the science community. Additionally, diverse interests joined to discuss and arrive at strategic guidelines for policymakers, industry, and science to implement. Through SATCON1 and the Dark & Quiet Skies Conference ("D&QS") in 2020, these efforts moved significantly forward. Indeed, the D&QS proposals circulated within the United Nations this Spring; working groups for SATCON2 have begun discussions on further policy development; and, both SATCON2 and D&QS2 will occur later this year.

In a separate but related context, the Federal Communications Commission ("FCC") proposed and implemented new regulations regarding orbital debris. In 2021, the final regulations on orbital debris mitigation should be adopted, published, and implemented. This represents the latest and most robust chapter from over more than two decades of orbital debris policy development. The new regulations shall prove significant in mitigating orbital debris and protecting Earth's orbital environment.

This context suggests that the policy climate within the FCC should be ripe for consideration of corollary regulations designed to mitigate adverse effects of satellites (e.g., solar reflectivity) on science, particularly astronomy and astrophysics, and other uses of space. Indeed, there exists an understanding even among industry that the orbital space constitutes a part of Earth's environment and should be perceived as such. That being said, the adaptive timeline must necessarily be shorter than what occurred with respect to orbital debris. For, the number of satellites being launched continues to increase at a significant rate. There exists no time for delay. Based on the foregoing, we can utilize the history of orbital debris regulation and the current climate favoring protection of Earth's orbital environment to facilitate the more expeditious adoption of regulations addressing adverse effects of satellites. But, importantly, we need the cooperation and input of the satellite industry.

The space economy has and will continue to see substantial growth. Valued at $329 billion in 2016[1], the Space Foundation calculated the 2019 the global space economy to be $423.8 billion.[2] Of these figures, some contend that the broader satellite sector comprises 75%.[3] Moreover, the value of the smallsat sector in the next decade will be nearly double that of the last decade.[4] As to the future of the broader global space economy, some estimate its value will be $1 trillion by 2030.[5] Without question, the space industry and, particularly the satellite industry, must be included in any developments on the future management of space. Beyond providing policy input, industry actors should be encouraged to follow the lead of SpaceX and others to design and implement technology to mitigate any adverse effects of their satellites on the environment.

Entertaining a Broader Environmental Perspective

Any future policy perspective on space must include an environmental component. To put it succinctly, we should consider Earth's orbital space to be an integral component of Earth's environment and protect it as such. Of course, this approach to Earth's orbital environment has yet to be adopted in the regulatory sphere. The FCC interprets existing environmental regulations under the NEPA as having little relevance to its jurisdiction.[6] Consequently, the FCC does not perceive the Earth's orbital space as falling within the scope of Earth's environment. Although an argument exists that the CEQ regulations can incorporate Earth's orbital space within the scope of Earth's environment, the regulations do not explicitly do so.[7]

Regardless, a broader environmental perspective has emerged that incorporates Earth's orbital space into the context of Earth's environment. Indeed, Earth's natural environment logically and necessarily includes the unblemished night sky and its visible elements. As such, conduct negatively affecting the night sky necessarily imposes an adverse environmental impact on the broader Earth. For, humans are not the only inhabitants of Earth that rely upon the night sky. In 2020, the United Nations Environment Programme stated:

> For hundreds of millions of years, the web of life on land has been dependent on, and determined by, day and night, light and dark. Photosynthesis, the process by which plants grow, depends on light and dark. And all animals depend on plants for their survival.
>
> One of the less frequently reported impacts of human activity on the environment is the presence of artificial light. Lighting disrupts

> photosynthesis and the activities of insects, birds and other animals.
>
> A recent study, Light pollution is a driver of insect declines, says habitat loss, pesticide use, invasive species and climate change have all played a role in insect declines globally, but that artificial light at night is another important—but often overlooked—cause.
>
> * * * * *
>
> With artificial light increasing by around 2 per cent per year globally, light pollution has become a pertinent issue.
>
> At the Convention on Migratory Species of Wild Animals thirteenth meeting of the Conference of Parties (CMS COP13) which took place in Gandhinagar, India from 17 to 22 February 2020, delegates considered the topic for the first time following draft resolutions submitted independently by the European Union and Australia.
>
> Artificial light not only impacts insects. Turtles, seabirds and shorebirds, and ecosystems at large, are being affected.[8]

Elsewhere, scholars report that a number of animal species "use the stars as a source of directional information."[9] On this, we likely have but discovered the tip of the iceberg in terms of the species that use the night sky.[10] So, clearly, the night sky and celestial visibility also constitutes a critical component of our environment on Earth.[11] And yet, we do not see it as such.

Perhaps, the physical distance between us and the stars contributes to our limited perception of where Earth's environment ends. The same might explain why many landlocked persons think less about the effects plastics and other pollutants have on our oceans than others closer to waters. Regardless, a blind or limited perception of the Earth's environment will inevitably lead to catastrophic results. Space debris already impacted satellites[12], the Hubble Space Telescope[13], a space shuttle[14], and the International Space Station.[15] Operators maneuvered satellites to avoid collision.[16] And, the Kessler effect predicts that unfettered debris will inevitably lead to a cascading escalation of collisions that create more debris that, in turn, create more collisions. Given the effects of satellites on other objects orbiting Earth, diverse stakeholders dependent on the dark skies, and potential effects of uncontrolled reentries, it makes sense to consider Earth's orbital space as a critical component of Earth's environment needing to be protected.

This perspective needs to be advanced among policymakers and regulators. That being said, the grounds for, or wisdom of, litigation does not yet exist. Although Viasat, Inc. argues that the FCC failed to adopt an environmental interpretation that requires environmental impact assessments of satellite operations,[17] the grounds to litigate against the FCC and/or SpaceX in relation to the FCC approval of the Starlink satellite applications do not exist at this time (though, of course, this author would prefer to see the FCC require environmental impact assessments).

Premature litigation can easily result in adverse rulings that reverberate for years to come. Moreover, litigation – particularly against an agency – can push away the involvement of actors critical to developing a cohesive approach to managing space. Consequently, prior to resorting to tenuous arguments in litigation, a better use of motivation, resources, strategy, and tactics would be directed toward solidifying a regulatory framework that protects the interests of everyone and includes explicit environmental protections. Recent agency developments provide the foundation to do so.

Modernizing Space Regulations

Over the last few years, the United States implemented updates to its regulation of the space sector across agencies. In 2020, the National Oceanic and Atmospheric Administration ("NOAA") published its final rules overhauling the licensing of private remote sensing space systems.[18] Similarly, the Federal Aviation Administration ("FAA") implemented new launch and reentry regulations through its Office of Commercial Space Transportation ("OCST").[19] Most recently, the Federal Communications Commissions ("FCC") initiated a review and overhaul of its regulations related to satellites and the mitigation of space debris.[20]

This broad regulatory overhaul should encourage the space industry to adopt and implement a forward-thinking approach to satellite design and operations. Indeed, as the space sector continues to grow (perhaps exponentially), there will be an increasing need for dynamic regulatory responsiveness. A prescient perspective derived from an understanding of existing regulatory and industry dynamics can enable a company to be "ahead of its time" and absorb future requirements into its processes well before an implementation deadline. An examination of the FCC's recent space debris regulations and the UN's recent recommendations with respect to dark skies demonstrate the viability and practical wisdom of incorporating regulatory compliance into the design process.

United States FCC Space Debris Mitigation Rules

For nearly two decades, international and domestic policymakers examined the growing problem of space debris. In the early 1990s, the United States, Russia, Japan, and the European Union created the Inter-Agency Space Debris Coordination Committee ("IADC") which issued guidelines to countries on mitigating space debris.[21] The United Nations ("UN") Committee on the Peaceful Uses of Outer Space ("COPUOS") soon followed with its guidelines published through the UN Office for Outer Space Affairs ("UNOOSA").[22] Although the United States participated in the development of international guidelines, its domestic efforts at implementing substantial space debris regulations proceeded at a much slower pace.

In fact, though the Clinton Administration began examining the issue in 1993, the FCC only issued broad proposed regulations in 2002. Although a subsequent report followed in 2004, the FCC did not issue substantive *proposed* regulations until 2018 after nearly a 15-year period of dormancy.[23] Then, in 2020, the FCC issued certain final regulations while also seeking additional comment on other proposed rules.[24]

Among the final rules adopted in 2020, those focused on collision avoidance particularly demonstrate the practical need to consider mitigation issues at the satellite design stage. As an example, with respect to transit through the International Space Station (ISS) orbit, the FCC states:

> The Commission proposed . . . that for any NGSO space station deployed above the International Space Station (ISS) and that will transit through the ISS orbit either during or following the space station's operations, the applicant provide information about any operational constraints caused to the ISS or other inhabitable spacecraft and strategies used to avoid collision with such spacecraft. The Commission explained that normal operations of the ISS could be disrupted or constrained by collision avoidance maneuvers that the ISS would need to perform to avoid satellites transiting through the ISS orbit.[25]
>
> We conclude that it is in the public interest to adopt the proposed disclosure requirement. *The statement must describe the design and operational strategies, if any, that will be used to minimize the risk of collision and enable the operator to avoid posing any undue operational constraints to the inhabitable spacecraft.* Commenters agree that special protections should be afforded to inhabitable spacecraft. We find that requiring this information will help to ensure that the applicant has taken into consideration the inhabitable spacecraft, and will provide information in the public record to help the Commission and other interested parties, such as NASA, determine if there are any potential issues with the applicant's operations vis-à-vis the ISS or other inhabitable spacecraft. NASA states that disruption to ISS operations may be lessened if a spacecraft in the process of disposal through atmospheric reentry remains active and able to maneuver until the apogee is below ISS altitude. We conclude that the benefits in assuring the safety of human life in space and minimizing disruption to the operations of inhabitable spacecraft outweighs any additional cost to applicants in preparing such a disclosure.[26]

(emphasis added). Indeed, the FCC continued to discuss more specific disclosures regarding the maneuverability of space stations:

> [and] . . . noted that this could include an explanation of the number of collision avoidance maneuvers the satellite could be expected to make, and/or any other

> means the satellite may have to avoid conjunction events, including the period both during the satellite's operational lifetime and during the remainder of its time in space prior to disposal.[27]

Stating that most commenters agreed with the disclosure, the FCC adopted the notice requirement.[28] Considering these two requirements alone, a license applicant must then disclose and discuss the means by which the satellite can maneuver (if at all) to avoid collisions with other objects in space. This necessarily involves an understanding of the satellites' physical capabilities. For, the response should be more than a minimalist indication whether these capabilities exist. And, in fact, the best discussion will emanate from a design perspective that included these aspects from the mission origin, specification, and manufacturing.

Given the foregoing, two important narratives emerge for the satellite industry. To begin with, industry must be involved in and comment upon the development of regulations affecting their operations. To be sure, the efforts of the FCC to mitigate orbital debris should be applauded. Moreover, industry certain participated in the comment period on the proposed regulations. Nonetheless, industry must continue to participate as the regulatory process identifies metrics and criteria applicable to satellite operations.

As to the second narrative, the satellite industry should embrace these regulatory developments early in the design process. As an example, a satellite manufacturer and/or operator should consider maneuverability options at the design stage. Indeed, given the concern to mitigate space debris and the implicit regulatory desire that satellites possess the ability to avoid collision through physical maneuvers, a satellite manufacturer should incorporate maneuverability into the design and manufacture of the satellites. This would be accompanied by design specifications that address the regulatory requirement. In this way, if the manufacturer does not also serve as the satellite operator for a particular mission, it could provide the operator or license applicant the documentation to complete the specific discussion as to these capabilities in the license application. In any case, the decision on such mechanisms should be well documented.

The applicability of design foresight can be seen elsewhere in the new FCC regulations. In a separate but related requirement, a license applicant must discuss any potential release of liquids from the space station that could pose a risk to other satellites through collisions.[29] The FCC noted that "there has been increasing interest in use by satellites (including small satellites) of alternative propellants and coolants, some of which would become persistent liquids when released by a deployed satellite."[30] It thus expected "that the orbital debris mitigation plan for any system using persistent liquids should address the measures taken, including design and testing, to eliminate the risk of release of liquids and to minimize risk from any unplanned release of liquids."[31] Considering comments that argued not all droplets would cause concern, the FCC limited its notice requirement to those liquids that would persist in the environment and pose a risk. For further guidance, the FCC elaborated:

> *[T]he the applicant will determine whether any liquids have a chemical composition that is conducive to the formation of persistent droplets*. If so, then the applicant will disclose that fact to the Commission. The main consideration in making this determination is whether the liquid, if released into space, will disperse through evaporation, or remain in droplet form, as is typical of some ionic liquids, such as NaK droplets. *If the applicant determines that released liquids will not persist due to evaporation or chemical breakdown, for example, then the applicant need not address the release of such liquids.* We conclude that asking applicants—who have the most information regarding the operational profile of the mission and characteristics of the potentially released substances—to assess the risk will address the commenters' concerns that such a requirement may be overinclusive or premature. *We clarify that this rule would apply to any liquids, not just propellants. In addition, we clarify that this rule will apply equally to release of liquids throughout the orbital lifetime.* We further conclude that the benefit of identifying potential risks associated with use of certain liquids, if such liquids could become long-term debris objects, outweighs any costs to operators in assessing the chemical composition of any liquids to determine the physical properties of such liquids

following release into the orbital environment.[32]

Given the foregoing, a satellite manufacturer must consider the type of liquids used with the satellites, their chemical components, the likelihood such components will produce droplets, and whether these create a risk for collision.[33] A focus on these issues at the licensing stage alone will be insufficient and inefficient. In such a case, the applicant – whether itself or through the satellite manufacturer – would still need to determine the specific effects of the liquid. Should the results of that assessment require – or minimally strongly suggest – modifications to the liquid composition or handling, any design and manufacturing changes might be very well too late. Depending on the costs, such redesign might also threaten the mission. Given the foregoing, there clearly exists practical wisdom in considering space debris regulations early in the design stage.

Lest one believe that an applicant need merely allude to the characteristics regardless of outcome (Some parties have sought reconsideration and more specificity as to when a license application would be denied), the FCC also proposed specific metrics by which to gauge a satellites collision avoidance possibilities. For example, the FCC "proposed that applicants for NGSO satellites . . . state whether the probability that their spacecraft will collide with a large object during the orbital lifetime of the spacecraft will be less than 0.001 (1 in 1,000)."[34] Where a satellite system incorporates collision avoidance maneuverability, this presumption could be zero.[35] Similarly, the FCC discussed implementing a metric of .01 (1 in 100) to avoid collisions with small debris or meteoroids. It stated:

> . . . the NASA Standard . . . states that for each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post-mission disposal maneuver requirements does not exceed 0.01 (1 in 100). The revised ODMSP includes a similar provision. Our current rules require a statement that operators (both GSO and NGSO) have assessed and limited the probability of the satellite becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control or prevent post-mission disposal. Generally, operators have provided information regarding spacecraft shielding, redundant systems, or other designs that would enable the spacecraft systems to survive a collision with small debris. Some operators have been providing the information specified in the NASA Standard, calculated using the NASA Debris Assessment Software.[36]
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> * * * * *
>
> NASA notes that this particular agency requirement, when applied to NASA missions, has been achievable and cost-effective with shielding, use of redundant systems, or other design or operational options.[37]
>
> * * * * *
>
> We conclude that incorporating the NASA Standard-derived metric into our rules for NGSO[38] applicants is in the public interest as it provides more certainty for operators regarding an acceptable disclosure of risk specifically related to collisions with small objects. We conclude that the benefits of this approach are worth the efforts of operators in performing an additional calculation in preparation of their orbital debris mitigation plan, because this calculation may be completed using the NASA Debris Assessment Software or a comparable or higher fidelity assessment tool, and many applicants already conduct this assessment.[39]

To be sure, many of the FCC regulations require disclosure of a satellite's physical capabilities to meet certain specific metrics. There may be a point where the FCC denies an applicant that, albeit compliant with the disclosures, fails to demonstrate it met the desired metrics and capabilities to avoid collisions.[40] This possibility behooves a forward-looking company to consider technologies that will meet the requirements.[41]

In fact, the consideration of these issues and the resulting potential impact on the orbital environment should occur initially in the satellite design stage and continue through the manufacturing process; must be described in the licensing application; and should be revisited throughout the lifecycle of the satellite. To facilitate this, counsel should concurrently inform various teams within the satellite manufacturers of the specific disclosure requirements. There should be open discussion on how to incorporate these disclosure requirements into the design and manufacturing process. In so doing, this compliance by design will effectuate the profitability of the companies and ensure more efficient regulatory compliance.

Thus, given the recent accelerated regulatory movement to mitigate orbital or space debris,[42] manufacturers of satellites and other space stations will be best served by incorporating existing and anticipated regulatory requirements into their design and manufacturing process. This regulatory "compliance by design"[43] shares a number of benefits associated with the broader concept of "manufacturing by design." In July 1988, Daniel E. Whitney wrote that "[s]trategic product design is a total approach to doing business."[44] In his article, Whitney explained how businesses benefit from adopting such an approach to manufacturing efficiency.

Applying similar principles, and by adopting a "compliance by design" approach to manufacturing in the space sector, satellite manufacturers and operators will more efficiently prepare for the licensing and regulatory process. Of more direct fiscal importance, they will inevitably benefit from the cost savings derived from this approach. And, of no less significance, they will become better stewards in protecting the future of Earth's orbital environment. This stewardship can be clearly observed in SpaceX' efforts to work with the astronomy community to address its satellites' solar reflectivity.

Mega-Constellations, Dark Skies, and Astronomy

During the comment period on the FCC's proposed space debris mitigation regulations, an unanticipated issue emerged. In May 2019, SpaceX launched its first set of sixty (60) Starlink satellites.[45] The solar reflectivity of the Starlink satellites caused many people to observe streaks of light across the night skies.[46] While to some a novelty, it caused significant concern among astronomers given the impact on astronomical optical[47] observations as reflected in this DECam image from the Blanco 4-meter telescope.

The number of satellites anticipated in the Starlink and other mega-constellations only exacerbated these concerns. Since then, the astronomy and broader scientific community collaborated with industry representatives to address these issues.[48] In 2020, the United Nations hosted a conference that included the issue of satellite solar reflectivity in a broader discussion of dark skies.[49] The report produced by the Dark & Quiet Skies Conference ("D&QS") provides substantial background and recommendations arising from substantive discussions among many diverse thought leaders.[50]

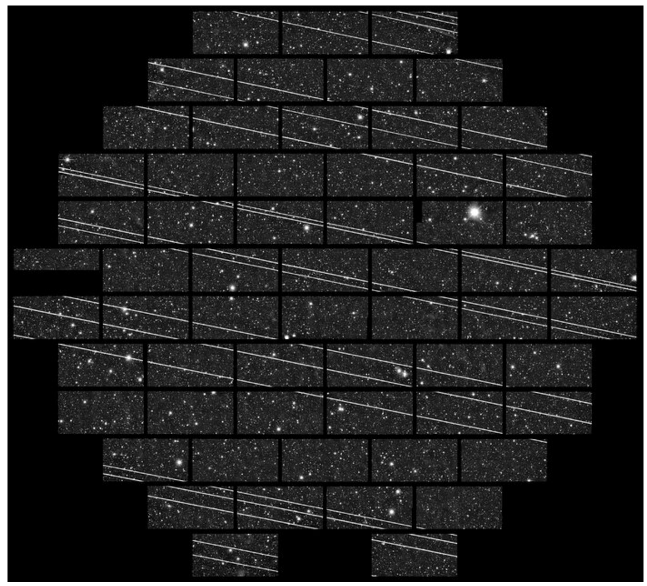

Figure 1: DECam Starlink Image

CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey

The report provided specific recommendations across the relevant actors in the space community. These included observatories[51], domestic[52] and international[53] policymakers, the astronomy community[54], science funding agencies[55], and industry[56]. As to the industry, the recommendations focused on awareness and outreach, mission design, satellite operations, and satellite design.[57] On this latter point, the report recommended that industry:

> Design satellites to minimize overall brightness at all orbital phases, dynamic variations, and specular flares when observed from the ground. Investigate and implement all commercially reasonable design and operational measures to reduce average brightness from diffuse reflection as much below 7 visual magnitude as

possible. Reflected sunlight ideally should be slowly varying with orbital phase to be fainter than 7.0 Vmag +2.5 × log(SatAltitude / 550 km), or equivalently, 44 × (550 km / SatAltitude) watts/steradian, as recorded by high etendue (effective area × field of view), large-aperture ground-based telescopes.

* * * * *

Conduct reflectance simulation analyses on satellite designs and perform Bi-directional Reflectance Distribution Function (BRDF) measurements on satellites as part of development activities.

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Provide greater detail on antenna power density fluxes, beam patterns and out of band sidelobes across the range of operating frequencies, than provided for ITU and regulator filings. Design satellites to have sidelobe levels that are low enough that their indirect illuminations of radio telescopes and radio quiet zones do not interfere, individually or in the aggregate.[58]

Considering the history of space debris regulations, we could expect that regulators will (or at least should) adopt metrics reflecting the D&QS recommendations. Given the inclusion of diverse actors and perspectives in developing the recommendations (including industry), this could occur more quickly than with space debris. In fact, the rapid advancement of technology and satellite deployment[59] compels this necessity. To that end, the D&QS report also provided recommendations for national policymakers and regulatory agencies to:

Formulate satellite licensing requirements and guidelines that take into account the impact on stakeholders, including astronomical activities, and that coordinate with existing efforts in relation to radio astronomy and space debris mitigation.

* * * * *

Develop inquiries and recommendations that encourage flexible technology that can better share spectral resources while ensuring protection of sensitive radio astronomy operations. Consider study of and incentives for new transmitter requirements toward a dynamic approach where coordination could be automated and based on the frequency of the scientific observation being taken and the direction in the sky where the radio telescope is pointed. Coupled with dynamic spectrum hopping and other techniques, these types of dynamic models could enhance spectrum efficiency and replace the current static model of quiet zones that assume fixed transmitter requirements based on a given set of parameters.

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Satellite operators should be encouraged to share the details of their radio systems to a much greater extent than contained currently in public filings with the International Telecommunications Union or radio spectrum regulators that support their authorization or licensing.

* * * * *

Formulate licensing requirements that take into account the location of radio quiet zones and radio telescopes, such that satellites can avoid direct illumination of these areas.[60]

With respect to national standards agencies, the D&QS report recommended they:

Develop spacecraft systems and operational standards that take into account the impacts on astronomical science. Areas include reflectivity of surface materials, brightness of space objects, telemetry data, and spurious antenna emissions.[61]

Although these latter recommendations speak to policymakers, the implementation of these recommendations will directly impact satellite manufacturers and operators. Consequently, the satellite industry should anticipate the implementation of these (or similar) regulations and incorporate their effect into satellite design. Among industry leaders, SpaceX stands out in this regard. Even without regulatory imperative, SpaceX collaborated with members of the astronomy community and developed its VisorSat[62] technology to mitigate the solar reflectivity of its Starlink satellites.

The US is Not Alone

Clearly, the history of cooperation related to space debris and, most recently, solar reflectivity demonstrates the broader international aspects of these issues. However, it should be noted that individual countries other than the United States have also begun to address space debris domestically in one form or another. In 1999, France issued the CNES Standards Collection, Method and Procedure Space Debris – Safety Requirements through its space agency.[63] Since 1999, Russia has issued and updated space debris standards.[64] In 2005, Canada incorporated aspects of space debris mitigation in its Canadian Remote Sensing Space Systems Act. Despite the recent criticism of the errant CZ-5B R/B rocket stage, China developed its standard and guidelines at least as early as 2005.[65] Other countries state that they follow the international guidelines without necessarily having developed standards or regulations domestically. Consequently, mitigating space debris does not represent merely a United States initiative. Thus, the recommendations provided herein apply to a satellite manufacturer in any jurisdiction.

Principles and Steps Toward a Framework

Given recent regulations governing the operations of satellites from various agencies within the United States, the recommendation for additional regulations to mitigate adverse effects of solar reflectivity, and the potential for new issues to arise, a more cohesive perspective to the future of space operations in Earth's orbital space seems warranted. In fact, a critical and timely opportunity exists to develop a broader framework within which to manage the future of space. Toward that end, there exists certain steps that can facilitate this occurring:

Actors' Participation

To begin with, all actors that enjoy and use space should become involved in the future management of space. Of course, this extends beyond industry to include the broader public, amateur astronomers, and those appreciative of the dark and quiet skies. For purposes of this article, the focus remains more on industry and professional participation. However, diverse opportunities exist for individuals to participate in the future management of space. This can involve local efforts to regulate light pollution. It could involve advocacy with policymakers. In fact, individuals can file their own comments to regulatory proceedings. Organizations also provide opportunities for individual advocacy. For example, the International Dark-Sky Association operates an advocate network. Additionally, those actors already involved should encourage others to participate and facilitate widespread outreach.

Environmental Component

Earth's orbital space must be recognized as a critical component of Earth's environment. Space debris exists and brings with it substantial risk to commercial operations and human spaceflight. Irresponsible acts in space can exacerbate these issues by creating substantial amounts of debris. Additionally, careless spacecraft operations produce terrestrial risks as well (e.g., the errant CZ-5BR rocket stage came close to impacting inhabited portions of Earth).[66] With the emergence of Starlink, it became evident that satellite and space operations at various orbital altitudes affect the operations of others on Earth. Science also continues to discover the reliance on space and the night sky by other species. Thus, any sound discussion and regulation of space necessitates the understanding that Earth's orbital space constitutes a part of Earth's environment.

Government Structure

Space permeates varied regulatory agencies. With launch and reentry the purview of the FAA, Earth remote-sensing governed by NOAA, satellite operations within FCC jurisdiction, public-private partnerships working with NASA, ISS endeavors proceeding through NASA, ITAR and EAR enforced by the Departments of State and Commerce, respectively, CEQ implementing NEPA, and multiple other agencies involved in nuanced aspects of space operations, there should be a synthesis and coordination among efforts to regulate space within the United States. This does not mean a single agency governing all operations. Rather, there should be a commission of sorts – still within the Executive Branch – that ensures a consistent regulatory approach to space governance.

This same commission could also coordinate and collaborate with international counterparts.

There must also be continued support for and coordination with UN COPUOS and UNOOSA.

Industry "Compliance By Design"

Industry should adopt a forward-thinking approach to the future of managing space. In conjunction with an environmental perspective, a prescient company can become innovators and lead the industry. Moreover, by anticipating the design modifications necessary for regulatory compliance, these companies develop strategic advantages over competitors. Thus, regulatory compliance should not be viewed as a burden but a strategic opportunity. Particularly, where a company participates in the development of proposed policies, the company increases its strategic footing even further.

Industry Self-Governance

Industry self-governance should be encouraged. However, it should not be relied upon alone. Rather, it must exist in harmony with government regulatory efforts.

Innovation

Industry actors should be encouraged to design and implement technology to mitigate any adverse effects of their satellites on the environment. Indeed, the management of Earth's orbital space as part of our environment protects the fiscal concerns of the space industry. Consequently, it makes economic sense for the space industry to innovate and develop technologies that preserve and protect the orbital environment. As argued elsewhere, this should be infused within the design and manufacturing process. It should not become a regulatory afterthought.

International Cooperation

Similarly, states should participate in the development of international guidelines and standards. Individuals should participate in efforts to help develop them (of course, individuals cannot engage in state diplomacy on behalf of their government; however, they can act as individuals and become involved in efforts to develop proposals for international policy). But, as with industry self-regulation, the states should not rely solely upon international efforts. Rather, international policies must exist in conjunction with domestic regulatory efforts.

ITAR/EAR

ITAR and EAR should be analyzed to facilitate innovation and international cooperation while also protecting the interests of the United States.

Regulatory Efforts

Individual states should regulate space operations within their jurisdictions. Using the United States as an example, these efforts may be diversified among agencies (e.g., FAA, FCC, NOAA, etc.). In such a case, a systematic approach to such efforts should exist to coordinate among agencies. All regulatory proposals should be available for public comment. Additionally, regulators should hold hearings allowing public input as well as seek contributions from experts to facilitate the development of standards and/or the adoption of existing proposals.

SmallSat Participation

Some might suggest that some of these issues may not affect the nanosat or smallsat industry communities as much. For example, it could be argued that smallsats simply do not contribute to solar reflectivity. Nonetheless, lest regulations be developed applicable to smallsats without the participation of the smallsat industry, it behooves those in any sub-sector within the satellite industry to participate. Indeed, regulators may not always carve out exceptions for smaller actors. This could lead to burdensome (if not prohibitive) regulatory requirements.

Standards

As mentioned in a few circumstances above, interested actors should contribute to the development of acceptable standards that can reach a broad consensus (understanding that unanimity will be ever evasive). These standards can be developed independent of the regulatory process. In fact, an independent approach may be able to more quickly adopt proposed criteria than the typical bureaucratic regulatory process (e.g., SATCON and D&QS). Toward this end, the author directs interested parties to view current FCC proposed regulations for space debris and the standards from SATCON and D&QS on solar reflectivity cited *supra*.

Policy and Collaboration as Design

Among the foregoing, collaboration must be considered the paramount factor to any effective design for the management of space in the future. Beyond theoretical underpinnings of inclusiveness, the last two years witnessed diverse groups of people collaborating with one another to reach compromise and solutions on significant and complicated technical issues related to satellite solar reflectivity.

Of course, SpaceX stands out for the lengths to which it went in developing technology that mitigated the solar reflectivity of its satellites. SpaceX iterated once with DarkSat. Determining that DarkSat created adversely affected the satellite, it continued to innovate and developed VisorSat. Since determining its viability, all Starlink satellites include VisorSat.

Of course, SpaceX did not need to do engage in such efforts. Yet, it did. By working cooperatively and diligently to mitigate the adverse effects of its product, SpaceX serves as a role model. That being said, SpaceX possesses resources that many other satellite and space companies lack. As such, not every company can invest such funds in "after-the-fact" mitigation research.

How then can other companies avoid the *need* to do so? Compliance by Design. To begin with, a company should thoroughly understand the regulations. This understanding should permeate the corporate structure such that compliance becomes an integral design component. But, beyond mere regulatory understanding, a forward-thinking company will become engaged in the regulatory development process. This involves more than mere lobbying a certain perspective. It involves working with others and understanding their concerns; sharing capabilities and limitations (e.g., what could work and what will not work); and, innovating. By engaging in this process, the company can obtain foresight and implement changes in the design process before they become required.

In essence, the engagement involves collaboration. Beyond the investment in technology, SpaceX and other industry actors engaged with astronomers, academics, astrophysicists, scientists, lawyers, and others to understand the problems, identify potential solutions, discuss solution viability and preference, and reach proposed metrics and recommendations. Moreover, the solutions necessarily involved changes within all of the interested communities. They targeted the astronomy community, the satellite industry, policy makers, and other interested actors. By engaging with the process, industry contributed to the proposed metrics and provided insight into technical possibilities. They helped shape and obtained an understanding of possible regulatory changes.

In this context, the recent FCC space debris mitigation regulations provide a construct through which future regulations relating to solar reflectivity mitigation (and other future issues) may be written. The FCC regulations bring specific metrics and requirements, rather than mere regulatory lip-service or articulation that the issue has been considered. Moreover, the regulations themselves, a wealth of comments and exists containing valuable intelligence and insight that can be used voluntarily to develop designs preempting later concerns.

The proposed metrics for solar reflectivity mitigation certainly could find their way to the FCC. A more policy-focused SATCON2 will occur this Summer. A second Dark & Quiet Skies may be on the horizon for Fall. There may very well be increased international support for guidelines that can facilitate regulatory adoption. Additionally, more domestic advocacy could occur as the issues become more prominent. Moreover, given the collaboration of the diverse actors, the proposed metrics and recommendations could very well find publication and implementation much sooner than it took the FCC to address space debris.

Of course, beyond specific topics with the FCC, a broader regulatory change must occur. The CEQ must implement regulations that compel agencies to perceive the Earth orbital space as an integral component of the Earth's environment. While we can persuade the FCC to modify its existing interpretation on its own, as with industry-regulation, the issue cannot simply be left to FCC interpretation (of course, the existing interpretation dates significantly prior to the current FCC). A broader perspective must be implemented throughout the space regulatory regime.

But again, all this requires collaboration and discussion. It also requires an available audience among agencies. With the FCC's recent efforts relating to space debris, it appears ready and willing to help define a positive future for a shared space. Combined with efforts of other agencies to update their space regulations, the space community's collaborative efforts to compromise and share the night sky, a framework for defining the future of space can be at hand.

CONCLUSION

Space may serve as the ever expansive opportunity for humankind to explore and satiate its innate desire to discover. Space may indeed be our final frontier. Yet, to properly govern the exploration, exploitation, and use of space, a cohesive framework to space management must be adopted and implemented. To begin with, a framework must be grounded in the concept that Earth's orbital space constitutes a critical component of Earth's environment. Our use of space affects other actors in the same environment (risk of collision) and terrestrially on Earth (uncontrolled reentry, astronomy, enjoyment of dark & quiet skies). Additionally, terrestrial species rely upon space in their natural activities. Moreover, we need to understand that, though vast, the space around Earth remains finite with a risk of collision ever-increasing as the number of satellites grows. Consequently, we need parameters to govern our use of space. These parameters will arise from an intricate and complimentary framework of international policies, industry self-governance, and domestic regulations. In developing a foundation to support this developing framework, we should use recent United States regulatory and international collaborative efforts as a model. More so, we need the participation of all space actors – particularly those in the growing space economy – to help define the future of space.

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