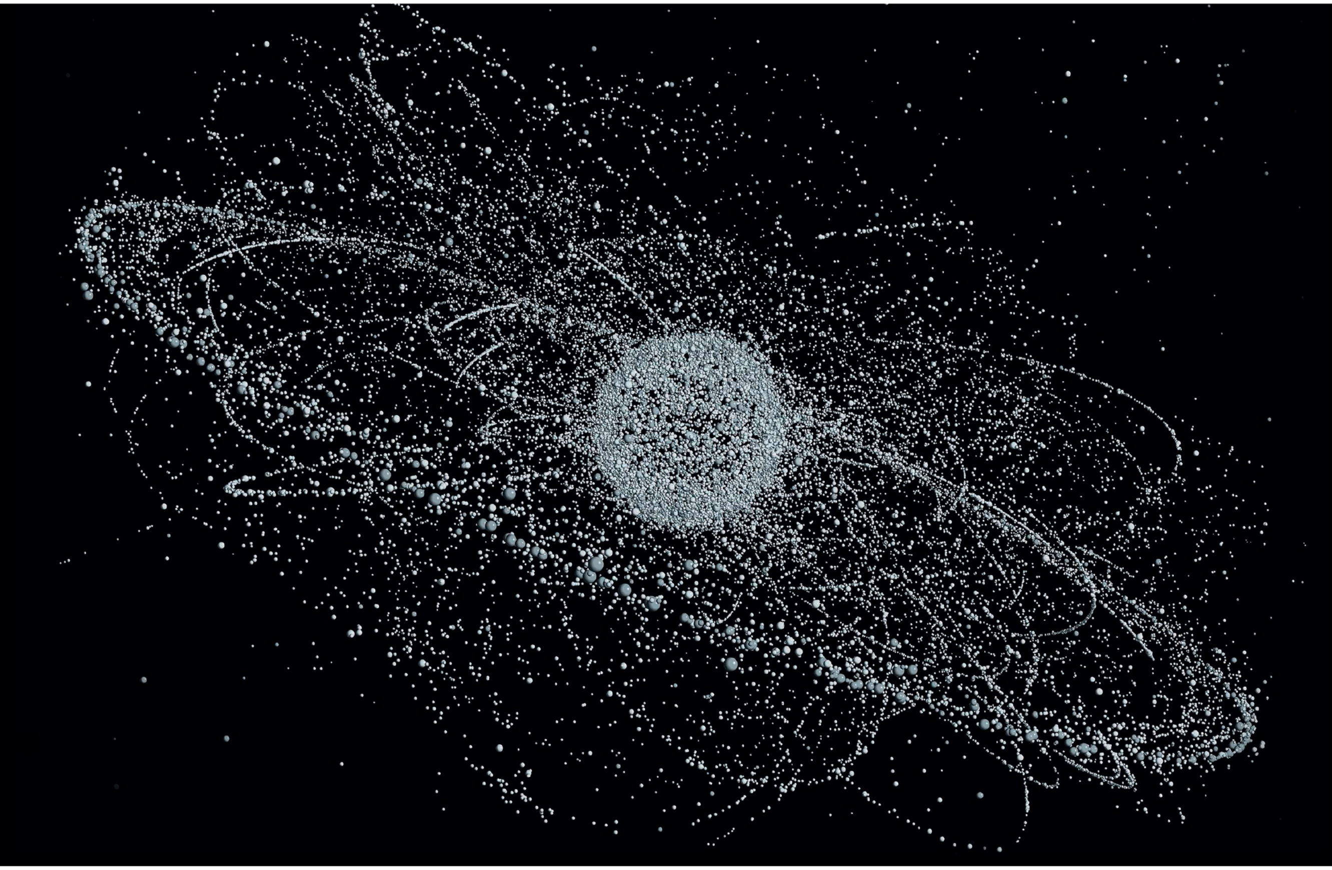
PROJECT ASTERIA 2019

SPACE DEBRIS
SPACE TRAFFIC MANAGEMENT
& SPACE SUSTAINABILITY



A COLLABORATIVE PROJECT BETWEEN
THE AIR POWER DEVELOPMENT CENTRE AND
THE AUSTRALIA NEW ZEALAND SPACE LAW INTEREST GROUP

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Cover Image

An artist's depiction of the artificial space objects, not to scale, that are both functional and non-functional and resident in Earth orbit.

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Foreword by APDC

This publication is a product of Project ASTERIA, a collaborative research initiative between the Air Power Development Centre (APDC) and the Australia New Zealand Space Law Interest Group (ANZSLIG) on a global issue that has complexity when studied from different perspectives. The collaboration between the different subject matter experts who have accepted the challenge to look at the shared problems of space debris, space traffic management and space sustainability, helps to promote a better understanding and awareness.

Orbital space missions are essential to the critical infrastructure of many states, as modern life is critically dependent on space. However, access to space and space-based systems are being increasingly challenged by the growing risks of artificial space debris. Popularly used orbits are congested with resident space objects that are space junk or fragments of junk that cannot be manoeuvred or controlled. Furthermore, collisions between and with space debris are generating even more orbital space debris.

This research project has encouraged guests from APDC and ANZSLIG to share their thoughts on the space debris issues from their different professional backgrounds. The result is this compilation of papers that highlight the risks of space debris to current and future space access and the need for a rules-based order for the sustainable use of space.

I hope that this publication will inform readers of the significance of Australian operated space situational awareness sensors and that it will encourage further research and discussion on how space debris affects space operations.

Andrew Gilbert
Group Captain
Director
Air Power Development Centre

September 2019

Foreword by ANZSLIG

A broad range of people throughout Australia and New Zealand, with a broad range of experiences, knowledge and background come together regularly to share a common interest in space law, under the banner of a group known as the 'Australia New Zealand Space Law Interest Group' (ANZSLIG). Drawing on those broad experiences, knowledge and backgrounds, ANZSLIG has been able to make a substantive contribution to raising awareness of space law within the space community as well as the public, to contribute to legislative development for the regulation of space activities and to understand space law education options in Australia and New Zealand.

Project ASTERIA 2019 is the first time that the ANZSLIG has been invited to contribute written research to published volumes. It is an honour to join the Air Power Development Centre (APDC) in a project that is intended to lead and develop space policy through public discourse. The collaboration reflects the importance of the policy issues in question not just to civil society, but also to those who bear responsibility for the security of their nation.

It is especially pleasing that the ANZSLIG has contributed to such topical issues as space debris, space traffic management and space sustainability. These exigencies are the unfortunate consequences of the growing pace of human endeavours in outer space – much more by commercial entities in recent times and into the foreseeable future, than by the military and governmental entities that dominated space activities in the past. Space infrastructure has delivered convenience, efficiency and growing prosperity to our world and our nations, but only so long as space activities can be managed sustainably. The means of such management is the crux of the policy challenge and the papers collated in this publication lay some conceptual foundations to address the policy challenge.

I thank those members of ANZSLIG who have made such a strong contribution to this publication. I recommend the publication as a whole to other ANZSLIG members (and beyond) and encourage them to consider building on this foundation in their own various fields of work within the Australian and New Zealand space communities, as well as in similar publications in the future.

Project ASTERIA presents a model for collaborative thought leadership between military and civil institutions. The ANZSLIG commends APDC for the initiative and looks forward to making future contributions in a similar way to other space policy endeavours, including with the APDC.

Duncan Blake
Wing Commander
Space Advocate & Chair, Australia New Zealand Space Law Interest Group
September 2019

About Project ASTERIA

Asteria was born during the Golden Age of Greek mythology, the period when the Titans ruled the cosmos. The Greek name αστέρια (Asteria) can be translated to mean "of the stars" or "starry one". Thus, the ancient Greeks named Asteria as the Titan goddess of shooting stars. Asteria was an inhabitant of Olympus and beloved by Zeus. In order to escape from his unwanted pursuits, she turned into a quail and threw herself from the heavens, falling into the Aegean Sea where she was metamorphosed into the island of Asteria – also known locally as the Greek island which had fallen from heaven like a star.

The visual spectacle of 'shooting stars' are the result of artificial and cosmic debris re-entering and burning up in the Earth's atmosphere. ASTERIA was therefore an appropriate name for a cooperative project between the Air Power Development Centre (APDC) and the Australia New Zealand Space Law Interest Group (ANZSLIG) that called for the research and submission of papers on the topical problems of space debris and space traffic management.

Selected papers have been edited and compiled for use as a research reference to be shared publicly with like-minded professionals interested in the design and conduct of orbital space activities, including the launch, operation, and expiration of orbiting space objects in an increasingly congested orbital environment.

About the Air Power Development Centre, Royal Australian Air Force

The Air Power Development Centre (APDC) was established by the Royal Australian Air Force in 1989. The APDC provides practical and effective analysis and advice on the strategic development of air and space power to the Chief of Air Force, the Royal Australian Air Force, and its partners.

The APDC mission is to support strategic decision-making about the future of air and space power for Air Force and its partners.

Air and space power is a cornerstone of Australia's security, and Australia's unique strategic geography means that will always be so. As the principal provider of Australia's air and space power, the RAAF is tasked with the conduct of air and space operations in pursuit of the nation's security and defence. As exponents of air and space power, all members of the RAAF have an inherent responsibility to be knowledgeable regarding the theory and doctrine of air and space power.

About the Australia New Zealand Space Law Interest Group

The Australia New Zealand Space Law Interest Group (ANZSLIG) was informally established in 2018 as a group of approximately 70 people from Australia and New Zealand, meeting monthly (in-person and remotely) on the basis of a common interest in space law, both domestic and international.

The ANZSLIG membership is drawn from the 'space community' broadly, in Australia and New Zealand, not just from what might be more narrowly described as the 'space industry'. That is, the membership reflects partisan interests in each of those sectors in how the uses of outer space are regulated, but the members of ANZSLIG are bound by a common interest in the law as a means of unifying effort in pursuit of the interests of Australia and New Zealand.

ANZSLIG brings together numerous professions with different areas of experience and expertise in international space law, domestic space legislation in Australia and New Zealand, intellectual property, regulation of the electromagnetic spectrum, export control laws, liability, contracting, military, government procurement, ethics, and other areas.

Acknowledgements

The APDC acknowledges the support provided by the following persons to realise this APDC publication project:

- Wing Commander Duncan Blake for leading the ANZSLIG efforts and coordinating paper submissions by ANZSLIG members.
- Wing Commander Michael Spencer for initiating this project and coordinating the paper submissions by APDC members and Visiting Fellows.
- The volunteer efforts of the ANZSLIG editing team, including Anna Marie Brennan, Maria Pozza, William Gloster, and Duncan Blake; and the APDC editing team, including Michael Spencer.
- Publishing and formatting by Graeme Smith.

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About the Authors

Part 1 Papers

Warrant Officer Andrew Earl

Space debris - What is it and Why Should we Care?

Warrant Officer Andrew Earl is an Air Surveillance Operator, currently serving in the Air Power Development Centre, educating the Air Force on air and space power. His operational background is in tactical space operations and remotely piloted vehicles. He was introduced to space with a posting to Denver, Colorado to work as part of the US Global missile warning system. He then formed part of the initial cadre in the operationalising of the nascent Australian Mission Processor currently situated in Adelaide.

Dr Peter Layton

Sustainable Middle Power Military Space Operations

Dr Peter Layton, PhD is a RAAF Reserve Group Captain and a Visiting Fellow at the Griffith Asia Institute, Griffith University. He has extensive aviation and defence experience and, for his work at the Pentagon on force structure matters, was awarded the US Secretary of Defense's Exceptional Public Service Medal. He has a doctorate from the University of New South Wales on grand strategy and has taught on the topic at the Eisenhower College, US National Defence University. For his academic work, he was awarded a Fellowship to the European University Institute, Fiesole, Italy.

Dr Layton is the author of the book "Grand Strategy" and as a Visiting Fellow at the APDC has written the following APDC publications:

- (2016) A New Direction for Australian Air Power: Armed Unmanned Aircraft
- (2018) Algorithmic Warfare: Applying Artificial Intelligence to Warfighting
- (2018) Tomorrow's Wars
- (2018) Prototype Warfare, Innovation and the Fourth Industrial Age
- (2018) Australia's Antarctic National Air Power

Scott Schneider

Australian Capabilities for Space Situational Awareness - Common Proposals of, and Australia's Contribution to, Space Sustainability and Security

Scott Schneider is a solicitor at Jones Harley Toole in Adelaide. His introduction to space was through the International Space University's 2017 southern hemisphere space studies program. He has maintained an interest in space education, assisting in operations such as the International Institute of Space Law's Manfred Lachs Moot and the International Space University's academic department.

Scott is party to the working table of the Australian and New Zealand Space Law Interest Group and is an administrator of the Australian Space Capability Database for the Space Industry Association of Australia. His current work focuses on identifying and addressing the needs of start-ups in Australia's space sector.

Dr William Schonberg

Some Thoughts on the Impact of Large Satellite Constellations on Space Travel and Operations

Dr William P. Schonberg, P.E., is a Professor in the Civil, Architectural, and Environmental Engineering Department at the Missouri University of Science and Technology. Dr. Schonberg is a registered professional engineer in the States of Missouri and Alabama, and has over 30 years teaching and research experience in the areas of shock physics, spacecraft protection, hypervelocity impact, and penetration mechanics. He received his BSCE from Princeton University in 1981, and his MS and PhD degrees from Northwestern University in 1983 and 1986, respectively.

Most recently, Dr Schonberg was awarded a Fulbright Distinguished Chair in Advanced Science and Technology. This award is enabling him to spend 6 months at the Defence Science and Technology Group in Melbourne, Australia, working on developing improved algorithms to more accurately predicted target response to projectile impact for a variety of engagement scenarios. While in Australia, Dr Schonberg is also on appointment as a Visiting Professor at the Royal Melbourne Institute of Technology and the APDC, where he delivered lectures and seminars on several topics, including space debris, engineering education, and the interaction between engineering and art.

Wing Commander Michael Spencer

Sustainable Space Access Depends on a Space Orbit Economy Driven by User Needs Attributing Different Values to Different Orbits

Wing Commander Michael Spencer is an Officer Aviation (Maritime Patrol & Response), currently serving in the Air Power Development Centre, analysing potential risks and opportunities posed by technology change drivers and disruptions to the future employment of air and space power. His operational background is with No 10 Squadron as P-3C Orion aircrew.

He is an Australian Institute of Project Management certified project manager, an Associate Fellow of the American Institute of Aeronautics & Astronautics, and associate member of the Australian New Zealand Space Law Interest Group. As a futurist writer at APDC, he is the author for APDC working papers and publications, including:

- (2017) Beyond the Planned Air Force (project manager and lead author)
- (2018) BPAF Series: Hypersonic Air Power (co-author)
- (2018) AFDN 1-19 Air-Space Integration
- (2019) Pseudosatellites: Disrupting Air Power Impermanence
- (2019) MQ-4C Triton: A Fifth-Generation Air Force Disruption of Maritime Surveillance (co-author)
- (2019) Dragon's Jaw: the Vietnam War target that Paved the Way to a Modern Precision Air Weapon

Professor Melissa de Zwart

Developing Effective Space Traffic Management to Promote Sustainable Uses of Outer Space

Professor Melissa de Zwart is Dean of Adelaide Law School and Deputy Director, Research Unit on Military Law and Ethics. Having developed a keen interest in the regulation and commercialisation of cutting edge technology as Manager, CSIRO Corporate Legal Service, she has published widely on internet law, intellectual property, online intermediaries, social media, surveillance, privacy and the law of outer space.

She is a Member of the Board, Space Industry Association of Australia, a Member of the International Institute of Space Law, Editor, Woomera Manual on the International Law of Military Space Operations and Regional Organiser, Manfred Lachs Space Law Moot (Asia Pacific).

Annabel Griffin

The Law of Rules: The Use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

Annabel Griffin is a partner in the KWM Canberra office with over 16 years experience working in Australia, the UK and Singapore. Annabel has built a strong satellite and ICT, procurement and project structuring practice, working with a number of government and private sector clients, such as the Department of Defence, CSIRO, the Department of Industry, Innovation and Science, the Northern Territory governments and major Australian financial institutions.

Annabel has been involved in a number of sensitive procurement and outsourcing projects, including some strategically critical government projects (at both Commonwealth and State and Territory levels) and consortium blockchain technology projects. Annabel has led key satellite projects of national significance and frequently advises clients in the technology industry, providing technical regulatory advice that is both practical and commercial. Annabel is also passionate about innovation in business and government, and is closely involved with the start-up eco-system in the ACT and around Australia.

Laura Jackson

The Law of Rules: The Use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

Laura Jackson is a law graduate in the Projects & Real Estate team in the King & Wood Mallesons Perth office. Laura has developed a strong interest in all things space over the last 3 years, particularly the emerging Australian space industry and the evolving legal challenges facing participants. Laura has worked with a variety of clients regarding compliance and navigating complex OHS regulatory landscapes.

Joel Lisk

Enforcement of Commercial Regulation in Outer Space

Joel is a PhD Candidate at the Adelaide Law School, University of Adelaide, and a Graduate in the Corporate and Commercial team of Adelaide-based national law firm, Cowell Clarke.

Joel's primary research focus is on domestic and international laws applicable commercial and civil operations in outer space, with his PhD project focused on considering international approaches to legislating for commercial activities in orbit and beyond. Joel has also undertaken research in the areas of military space activities, the applicability of general international law norms to the outer space domain, and wider general international law. Joel has presented on commercial space law and activities in a variety of fora including the International Astronautical Congress, Australian Space Research Conference, and Australian Space Industry Conference.

In the course of his employment as a Graduate at Cowell Clarke, Joel primarily works on matters of commercial concern, including corporate compliance, mergers and acquisitions, privacy, finance and security, consumer law and protection, and commercial disputes. Joel holds a Bachelor of Laws (Honours) and Bachelor of Sciences (Biochemistry and Genetics) from the University of Adelaide and has experience teaching law students in the areas of international law and advocacy.

Patrick Mackenzie

The Law of Rules: The Use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

Patrick Mackenzie is a solicitor in the Dispute Resolution team in the KWM Perth office. In his final year of studies at the University of Western Australia, he wrote an honours thesis on space debris entitled "Houston, We've Got a Problem: The Need to Reform the International Liability Mechanisms for Outer Space Activities in Response to Increasing Non-State Participation" and maintained his interest in legal aspects of space ever since then.

Mark Meegan

Earth Observation data - Climate Change monitoring

Mark Meegan is a law graduate looking for opportunities in space law. Science has always interested him as a child. He commenced a law degree at the University of South Australia to become a practising lawyer. His childhood curiosity for science led him to pursue a career in space law. In 2019, he completed the Executive Certificate of Space Studies with the International Space University. He has written several submissions to the government to advocate for space law reform. He is focused on developing his scientific literacy to better advocate for potential space clients.

Andreas Sherborne

The Law of Rules: The Use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

Andreas Sherborne is a solicitor in the Corporate M&A team in the KWM Canberra office and has experience in advising government and private sector clients on a range of matters in areas of corporate and commercial law. Andreas has a keen interest in space law, and has a detailed understanding of international and domestic liability regimes applicable to space activities.

Henry Sit

The Law of Rules: The Use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

Henry Sit is a solicitor in the Public M&A/ECM team in the KWM Sydney office, with experience in mergers & acquisitions, equity capital markets, commercial IT transactions and general corporate law. He has a broad range of commercial experience working with clients from a variety of sectors including Telstra, Netflix, Westpac and other financial institutions. Henry has a keen interest in space law, and has detailed understanding of the licensing and other requirements in the Space Activities Act 1998 (Cth).

Professor Dale Stephens

The Woomera Manual: Clarifying the Law of Military Space Operations to Promote Sustainable Uses of Outer Space

Professor Dale Stephens is a Professor at the University of Adelaide Law School. He holds a Doctor of Juridical Science (SJD) from Harvard Law School, and Masters degrees in law from Harvard Law School and Melbourne University. He spent 23 years as a Legal Officer in the Royal Australian Navy, attaining the rank of Captain and deployed multiple times to East Timor and Iraq. His final posting in the Navy was Director of Operations and International Law. He is currently Director of the Adelaide University Research Unit on Military Law and Ethics (RUMLAE), a board member of the Australian Yearbook of International Law, a member of the Governance Group of the Space Security Index and a Member of the Board of Directors and core expert of the "Woomera Manual on the International Law of Military Space Operations".

Associate Professor Matthew Stubbs

The Woomera Manual: Clarifying the Law of Military Space Operations to Promote Sustainable Uses of Outer Space

Developing Effective Space Traffic Management to Promote Sustainable Uses of Outer Space

Associate Professor Matthew Stubbs is Associate Dean (Learning and Teaching) of the University of Adelaide Law School and Editor in Chief of the Adelaide Law Review. Matthew has published widely in public international law, human rights and public law. He serves as a Core Expert of the Woomera Manual on the International Law of Military Space Operations, and is a member of the International Institute of Space Law and the Space Industry Association of Australia. Dr Stubbs' teaching, and work with Indigenous law students, has been recognized by two national teaching awards in Australia, a national teaching grant, and numerous University-level honours. His professional activities include service as Chair of the Human Rights Committee of the Law Society of South Australia and member of the National Human Rights Committee of the Law Council of Australia.

Acronyms and Abbreviations

ANU	Australian National University
ANZSLIG	Australia New Zealand Space Law Interest Group
APDC	Air Power Development Centre
ASAT	Anti-satellite
ATM	Automated Teller Machine
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
CRC	Cooperative Research Centre
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FCC	(US) Federal Communications Commission
G20	Group of Twenty international forum
GCOS	Global Climate Observing System
GEO	Geostationary Earth Orbit also Group on Earth Observations
GEOSS	Global Earth Observation Systems of Systems
GHG	greenhouse gas
GPS	Global Positioning System
HDTV	high-definition television
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordination
ICAO	International Civil Aviation Organisation
ILC	International Law Commission
IMO	International Maritime Organisation
INMARSAT	International Marine/Maritime Satellite
ITU	International Telecommunication Union
LEO	Low Earth Orbit
MARPOL	International Convention for the Prevention of Pollution
MEO	Medium Earth Orbit
MEPC	Marine Environmental Protection Committee
MILOMOS	Woomera Manual on the International Law of Military Space Operations
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NEO	Near Earth Object
NOAA	National Oceanic and Atmospheric Administration
NORAD	(US) North American Air Defence
NRAO	National Radio Astronomy Observatory

PSLV	(India) Polar Satellite Launch Vehicle
RAAF	Royal Australian Air Force
SARSAT	Search and Rescue Satellite Aided Tracking
SCO	Space Climate Observatory
SSA	Space Situational Awareness
SSN	(US) Space Surveillance Network
SSNID	(US) Space Surveillance Network Identification
STM	Space Traffic Management
UNFCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
WMO	World Meteorological Organisation

Part I

Space Activities

Space Debris: What is it and Why Should We Care?

Andrew Earl

Introduction

The Earth orbital space environment, and the artificial machines deployed into those orbits, have together incrementally become strategically significant to the vast majority of the global population and the critical infrastructures they need to assure the functioning of their modern societies. The societal 'need' for safe and assured access to the near earth environment has created a new market that is proliferating space based services. Coupled with the step-change reduction in the cost of space launches, and small satellite buses, recent years have seen an escalation of interest by new actors to participate and operate in the space environment.

The United Nations Treaty on Outer Space was ratified in 1967.[1] At that time only large government bodies were able to fund the expertise and technologies necessary to launch an object beyond the Earth's atmosphere; in 2019 'Space as a service' is the new accepted and affordable reality, which now includes in excess of thirty five private corporations manufacturing launch vehicles for government and commercial use.[2] Space activities have proliferated and one hallmark of the accumulating and increasing effects of human activities in space is orbital debris.

The purpose of this paper is to inform readers on the fundamental scientific and operational issues surrounding space debris in the Earth orbital environment.

Orbital mechanics 101 – the fundamentals

The altitude required to keep an object in an orbital trajectory is governed by Earth's gravitational field. An object travelling overhead at approximately

100kms above the Earth's surface, with a speed of approximately 7 to 8 km/sec will have adequate kinetic energy to continually freefall over the Earth's horizon but never hit the Earth; it is continually being pulled back towards the Earth by its gravitational pull but misses and will naturally continue along a circular trajectory around the Earth.[3] It is essentially 'falling' with a forward velocity at the same rate as the curvature of the earth falls away beneath it.

While this paper is a discussion on space debris, it's worth first discussing the most commonly used orbits, and what objects are generally launched to fill these orbits, since there is a myriad of reading resources on the intricacies of orbital mechanics. However, some of the orbits are more popular for space missions than others and this is reflected in the distribution of space debris across the different orbit altitudes. There is not an internationally accepted standard for orbit designations.

Low Earth Orbit – LEO

LEO is the range of orbital altitudes that are spread from approximately 160km up to about 1000 km above earth, with a repeating orbital period of about 90 minutes to conduct a single orbit.[4] Because of these orbital altitudes, the field-of-view of LEO satellites have a relatively small sensor footprint on the ground which moves as quickly as the satellite passes overhead.

A single satellite might eventually cover the entire surface, after a few days of satellite passes, as the Earth rotates beneath the orbit. However, if global coverage is required concurrently all over the globe, as is needed with communications systems, then a large number of satellites are required to be spread throughout an orbiting constellation.[5]

LEO is the cheapest of these three orbits for a space launch rocket to access due to its proximity to the ground; it requires the least energy to propel a satellite into orbit, needs less power to transmit data back over the short distances to Earth, and provides high resolution imaging through its optical and radar sensors at a lower cost for the same reasons.[6] These characteristics are exploited by the design of the NOAA Search and Rescue Satellite Aided Tracking (SARSAT) to provide 24/7 continuous global coverage for monitoring the emergency beacons carried by travellers, aircraft, and ships, etc, and activated when in distress.[7]

The human spaceflight mission with the International Space Station is situated in a LEO orbit at about 400 km.[8] Owing to the characteristics of LEO, this orbit is ideal for cheaper space launches for its extensive program of lifting many heavy payloads, for recovering the astronauts to Earth, and for the constant and necessary telecommunications to Earth. However, it is notable that SpaceX Starlink[9] and Amazon.com Project Kuiper[10] are planning to inhabit this orbital region with new mega constellations, raising concerns for the safety of the ISS and its human occupants.

Medium Earth Orbit – MEO

The MEO region sits above the LEO orbital region and reaches out to approximately 35,000 kms. The footprint for sensors deployed into MEO is superior to LEO allowing for less satellite buses to achieve more of a global coverage (eg the GPS constellation operates with 31 vehicles[11] to provide continuous global coverage). The dwell time for a MEO satellite is measured in hours, generally the higher the altitude the longer the dwell time. MEO is also commonly used for communication satellites in polar orbits. The most significant uses of MEO are for global communications relay systems (eg INMARSAT[12]) and global navigation satellite systems (eg GPS).

Geosynchronous Earth Orbit - GEO

The GEO orbital region sits above MEO at 35,786 kms above the earth's surface and is a fixed altitude rather than a large band of space.[13] The key characteristic of the GEO orbit is that, to a user on Earth, a GEO satellite appears to be stationary overhead, since the GEO satellite is orbiting around the Earth at the same rate as the Earth is turning about its centre. In order to achieve this a GEO orbit must be on the equatorial plane, which is aligned with the Earth's equator.

The GEO orbital period length is almost 24 hours (matching the rotation of the Earth). At this distance, a GEO sensor has a field-of-view that is almost able to capture the whole visible side of the Earth. Compared to MEO, only three GEO satellites, spread around the geostationary belt are needed to provide coverage to locations between 81 degrees north and south[14], within with which the majority of the Earth's population exists. Because the satellite does not appear to move, the infrastructure required in ground stations is simplified as antennas aren't required to track moving targets. GEO is commonly used for communication and Earth observations, including weather satellites.[15]

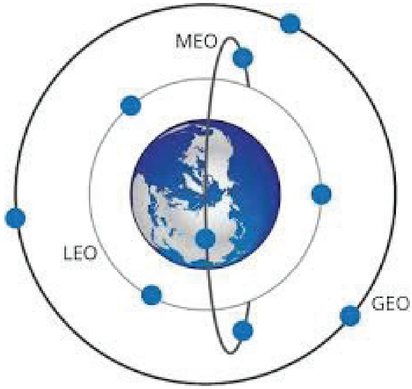


Figure 1: Example of various orbital trajectories[16]

Kessler Syndrome

In 1978 Kessler and Cour-Palais published a paper titled *Collision frequency of Artificial satellites: The creation of a debris belt*[17] , this paper postulated that if past growth in the numbers of space debris (remember this was 1978, the first satellite was orbited in 1957) continued at the same rate, then the growth of small debris would rise exponentially, and disastrously on its own, even without the additions of new objects from additional space launches and missions. This rapid increase in space objects was postulated on the basis that collisions occurring between space objects on orbit will break them up into a larger number of smaller objects, which then continue on to collide with other objects to create even more smaller objects. The postulation of a natural phenomenon that could increase the numbers of space objects was a concern for the increasing risks and hazards associated with on-orbit collisions with valuable space missions and human spaceflight.

Up until 1978, only state actors were adding to the space catalogue with large and expensive launches, the paper's authors could not predict the current availability and cost point of orbital assets and 40 years later, academics agree that 'Kessler syndrome' has played a significant part in the current debris on orbit.[18] In 2018 the number of space launches exceeded 100 many of these hosting multiple payloads.[19] This number is set to increase as the likes of SpaceX and Amazon.com look to establish massive constellations

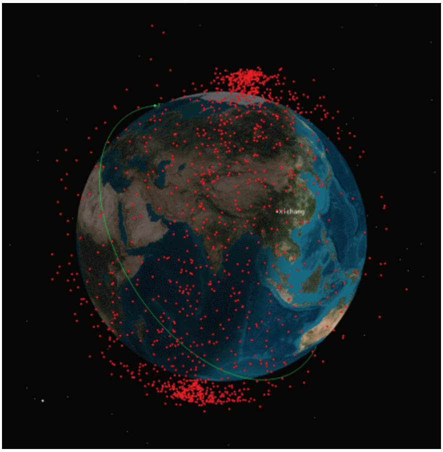
Chinese Anti-Satellite (ASAT) weapons test, January 2007

In January 2007 the Peoples Liberation Army launched a modified DongFeng-21 ballistic missile with a kinetic kill vehicle from Xichang launch centre.

The payload reached a terminal velocity of approximately 8 kilometres per second towards an aim point of a defunct 750 kilogram Chinese weather satellite, the FengYun-1C, which was in polar orbit at an altitude of approximately 865 kilometres.[a]

The subsequent kinetic impact resulted in two orbital bodies (kill vehicle and satellite) multiplying into approx. 2000 trackable objects (golf ball size or bigger) and up to 35,000 debris particles all within low earth orbit.[b]

Personnel in the International Space stations have on two occasions been forced to take shelter in the Soyuz module and in 2012 the ISS was forced to alter its orbit to avoid debris as orbital debris from the FY-1C breakup has come within dangerous proximity to the station.[c]



ISS orbit in green, orbital debris from the Chinese weapons test against FY-1C in red

a Kelso, T (2007). *Analysis of the 2007 Chinese ASAT Test and the Impact of its Debris on the Space Environment.* Technical Papers, 8th Advanced Maui Optical and Space Surveillance Technologies Conference, Maui, HI (Vol. 7). Online at https://celestrak.com/publications/AMOS/2007/AMOS-2007.pdf. Accessed 22 August 2019.

b ibid.

c Spark, J (2012). *ISS Dodges Chinese ASAT Debris.* Space Safety Magazine. Online at www.spacesafetymagazine.com/news/iss-forced-dodge-chinese-asat-debris/. Accessed 22 August 2019.

in LEO which, if not actively managed the exponential aspect of 'Kessler Syndrome' becomes even more significant when 'debris begets debris.'[20]

Satellites are delicate, precision objects and launch cost is calculated by weight.[21] The addition of these potential hazards in the space environment will require satellite buses to install additional shielding in order to protect the precious payload from damage caused by debris fields. This will serve to complicate the satellites, leading to the inevitable downstream cost to an organisation's bottom line.[22]

The rapidly falling price of space launch

The 2011 cost to launch NASA's space shuttle into LEO was approximately US$54,500 per kilogram. In 2018, the price quoted for a SpaceX Falcon launch was US$2,720 per kilogram.[23] This represents a step change in the availability and affordability of launching an object into low earth orbit, which as a result has allowed private corporations to seriously consider the use of space based systems in their business planning. Historically, when technological advancements become more affordable they become more prolific. The space environment is not unique in this compounding phenomena (as the price of mobile technology decreased the increase in e-waste has become a global problem).[24]

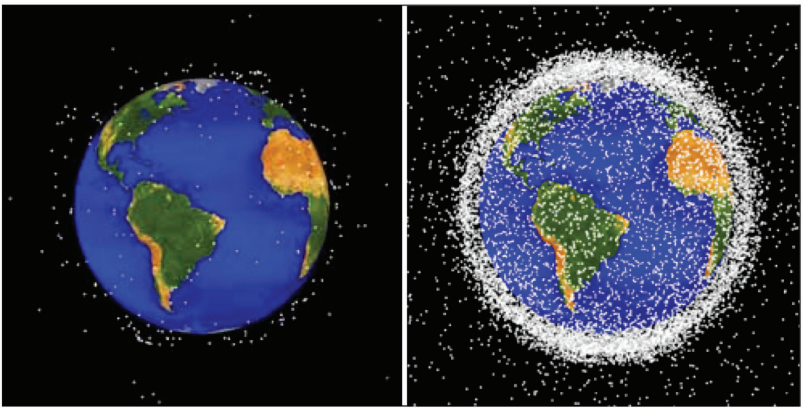


Figure 3: Tracked debris from 1963 (L) to 2013 (R)[25]

Amazon.com: Project Kuiper

Amazon.com has published plans to launch and sstain a constellation of approximately 3,000 low earth orbit satellites in order to provide high-speed broadband internet to the entire globe – 'The goal here is broadband everywhere'.[a]

The planned constellation will consist of three layers of satellites:

- 784 satellites at 585 kilometres altitude,
- 1296 satellites at 609 kilometres altitude,
- 1156 satellites at 629 kilometres altitude,

This will also include a network of twelve earth stations across the globe for satellite control and downlink.[b]

This plan represents an enormous capital outlay, Amazon is currently one of the biggest companies on the globe, and one of the few that can afford this expenditure, Morgan Stanley have suggested that this project represents a $100 billion dollar opportunity for the company.[c] Corporations that take on this investment will be the catalysts to generate a step change in the provision of internet services to the world.

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b Porter, J (2019). *Amazon will launch thousands of satellites to provide internet around the world.* The Verge. Online at www.theverge.com/2019/4/4/18295310/amazon-project-kuiper-satellite-internet-low-earth-orbit-facebook-spacex-starlink. Accessed 22 August 2019.

c Zacks Equity Research (2019). *Amazon Sees $100 Billion Opportunity in Project Kuiper.* Yahoo! Finance. Online at https://finance.yahoo.com/news/amazon-sees-100-billion-opportunity-125212837.html. Accessed 22 August 2019.

Running parallel to cheaper launch capability is the ever increasing miniaturization of electronics[26] and mechanical systems to perform similar functions as the traditional but larger, more expensive 2-tonne class satellites. This dual phenomena has proliferated the interests and deployments into space of small-sized, high-resolution, near real time cubesat missions.[27] It is now becoming commercially viable to launch large constellations of low earth orbit and networked satellites, using disposable cubesats and the more that companies invest in this technology, the lower the launch cost will become and the more it will be used and proliferated.[28]

SpaceX has US FCC approval to deploy a 12,000 satellite constellation into LEO, commencing with the first sixty prototype satellites launched in 2018.[29] Just Amazon.com and SpaceX alone represent an increase of up to 15,000 additional objects in LEO, and there are a number of other companies exploring near earth orbit for commercial use (Google, Planet Labs etc). As discussed above in examining the Kessler syndrome, particularly in LEO, unregulated business represents a danger to all users of this orbit and risks the commercialization of space with the associated complication of the UN Outer Space Treaty text of 'space shall be free for exploration and use by all the states.'[30]

How long do they stay in orbit?

Vanguard 1 is listed in the US Space Surveillance Network catalogue as SSNID #00005.[31] It was only the fifth satellite, when launched in 1958 to be inserted into the big clear sky that was outer space. It remains as the longest orbiting man-made object and seems to dwell in an orbit that Goldilocks would have liked – not too high, not too low; not too much unbalanced pushing and shoving from Earth's gravity, Sun and Moon; and positioned to comfortably ride out big and little space weather events and still remain comfortably in orbit – all without station-keeping manoeuvres because its on-board systems expired in 1964.

Current prediction calculations estimate that the lifetime for Vanguard 1 to remain in orbit is only about 240 years[32] , after which current known atmospheric drag effects and orbital perturbations are likely to drag it down for re-entry and atmospheric burnup, or not.

Vanguard 1 orbits alongside derelict and operational satellites, and trackable orbital space debris. Objects are listed in the US Space Surveillance Network catalogue and include sensor lens caps, spent rocket boosters, fragments resulting from catastrophic satellite failures or collision, exploding pressurised rocket fuel containers, satellite collisions, and anti-satellite weapons tests and hand tools dropped by astronauts servicing the ISS.

What can we do about it?

There is a growing body of research looking at ways to minimise and mitigate the space debris problem. These are generally split into two groups. The first approach is 'space situational awareness' (SSA) - this being our understanding of what's in our near space environment. SSA is the more evolved of the two approaches to identify space objects with a large number of sensors spread throughout the globe resulting in a comprehensive space catalogue, there are both private and government organisations adding to the global knowledge base.[33]

Generally, ground based systems consist of radar and/or electro-optic sensors, space based sensors are usually electro-optic, and function more efficiently than ground based electro-optic sensors due to their altitude and lack of atmosphere to look through. The second approach (and one that should run concurrently) to mitigate space debris is active recovery and deorbiting, this is nascent technology at the time of writing with a University of Surrey consortium orbiting an experimental satellite as part of exploring removal technologies.[34] This satellite is hosting 3 technologies, a harpoon, a net and a drag sail, and successfully deployed its net in September 2018.[35] While still in early development, the implications for this technology are wide reaching, the ability to remove or deorbit space debris, particularly if it poses a risk to life, represents the next phase in the evolution for human management of the near space region.

There have also been a number of experiments using laser energy to irradiate orbital particles (generally up to 10cm in diameter) in order to nudge them into a decaying orbit in order to create the conditions for re-entry and subsequent burn up, several companies have tested ground based models of this technology.[36]

Conclusions

The conundrum of space debris has hitherto been an unseen issue for the wider community - as long as mobile phones continue to stream content, ATMs continue to dispense money and vehicles can navigate cities, the issue of assured access to the space environment has not been a headline grabber.

Current plans for mega constellations launched and maintained by corporations rather than sovereign nations will generate significant legal and responsibility disputes.

- Who is responsible for making a company clean up its debris in an environment no-one 'owns'?
- If it's not cost effective for shareholders, why would they bother?
- Who's responsible for Space traffic management, who has 'right of way' on orbit?

The extrapolation of Kessler syndrome and its cumulative effect on particles in orbit, if not carefully considered as the availability of launch capabilities increases exponentially will eventually lead to a tipping point where the expectation and safety of an orbital slot is not guaranteed.

The issue of space debris is a global one and one that will require space faring nations to come together to 'protect the commons'. If there is a less than global approach, then the chances of success are significantly reduced and inevitably the assured use of the space environment will be denied to all.

At this stage the academic modelling for space debris is centred on the peaceful use of space. This paper has not included any discussion on counter space programs, nor the implications of belligerent (or worse, nefarious) space faring entities acting in a hostile manner. Needless to say that in that instance the free and guaranteed use of space while currently congested, would be exponentially harder to manage and assure.

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Some Thoughts on the Impact of Large Satellite Constellations on Space Travel and Operations

William P. Schonberg

Introduction

The modern Space Age arguably began in 1957 when the USSR launched Sputnik, the first man-made satellite, into Earth orbit. The US followed shortly thereafter with its own rocket-launched satellite, Explorer I. Since that time, the number of space-faring nations has steadily increased. Table 1 shows the year in which various countries could be said to have joined this rather exclusive club. To be included in this list, the rocket used to launch the satellite must have been produced by the launching country.

Country	Satellite	Rocket	Location	Date
Soviet Union	Sputnik 1	Sputnik-PS	Baikonur, USSR	4 Oct 1957
United States	Explorer 1	Juno I	Cape Canaveral, US	1 Feb 1958
France	Astérix	Diamant A	Hammaguir, Algeria	26 Nov 1965
Japan	Ohsumi	Lambda-4S	Uchinoura, Japan	11 Feb 1970
China	Dong Fang Hong I	Long March 1	Jiuquan, China	24 Apr 1970
England	Prospero	Black Arrow	Woomera, Australia	28 Oct 1971
ESA	CAT-1	Ariane 1	French Guyana	24 Dec 1979
India	Rohini D1	SLV	Sriharikota, India	18 July 1980
Israel	Ofeq 1	Shavit	Palmachim, Israel	19 Sept 1988
Ukraine	Strela-3	Tsyklon-3	Plesetsk, Russia	28 Sept 1991
Russia	Kosmos 2175	Soyuz-U	Plesetsk, Russia	21 Jan 1992
Iran	Omid	Safir-1A	Semnan, Iran	2 Feb 2009
North Korea	Kwang-myŏngsŏng-3	Unha-3	Sohae, North Korea	12 Dec 2012

Table 1. List of First Orbital Launches by Country[1]

The rate at which rockets are launched into space has remained relatively constant between 1960 and 1990, at approx. 150 launches per year; fiscal contractions and geo-political realignments undoubtedly contributed to a drop in the annual rocket launch rate to approx. 100 launches per year for the next 20 years or so. Following after the year 2010 or so, however, there has been a marked increase in the number of private satellite launches, which has resulted in a significant net increase in the annual rocket launch rate. In total, since 1957 there have been approx. 9,000 rocket launches delivering a variety of payloads to various altitudes above the Earth. Figure 1 below shows a summary plot of the annual number of launches per year from 1957 to 2017.

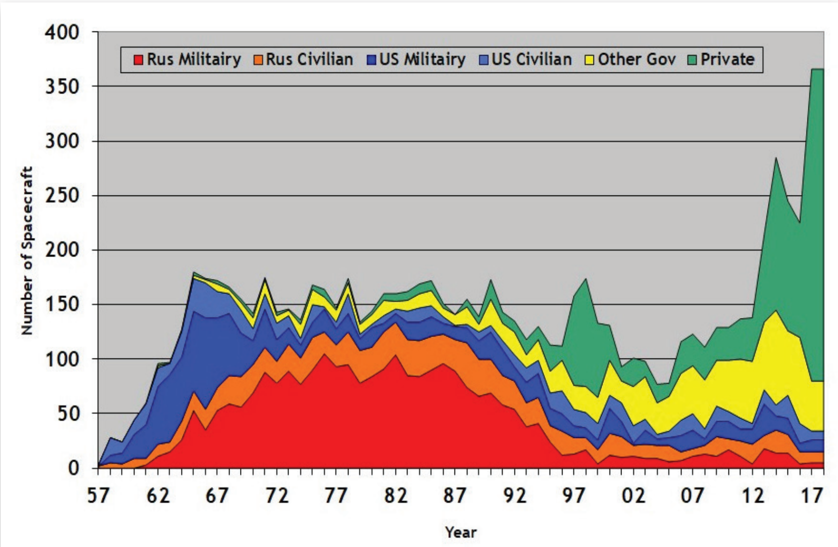

Figure 1. Number of Spacecraft Launched, 1957-2017[2]

As of the writing of this paper, of these approx. 9,000 satellite launches there remain 2,062 operational satellites in Earth orbit.[3] Figures 2 and 3 show the locations of these satellites and their general functions. It can be seen from these figures that approx. 2/3 of these satellites are in low earth orbit (with an additional 1/4 in GEO), and that the purpose of about 1/3 of the currently still operational satellites is some kind of communication, with another roughly 1/3 for earth observation.

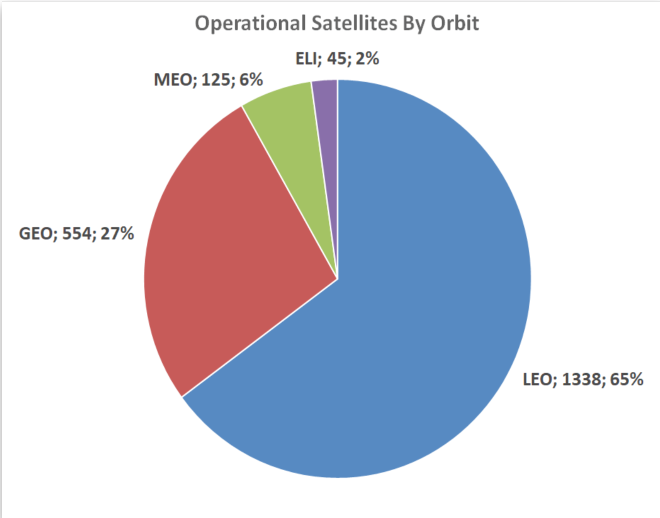

Figure 2. Location of Operational Satellites by Orbit as of April 2019

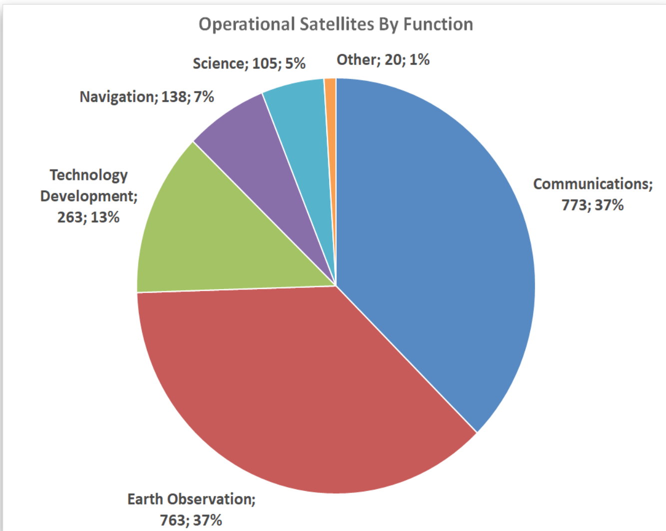

Figure 3. Function of Operational Satellites as of April 2019

Traditionally designed satellites typically carry a price-tag of several USD$million, and take many years to build and ultimately launch. By necessity, then, to make these investments of time and money worthwhile, these satellites have very long life-spans. Interestingly enough, it is very likely that satellites designed and built this way could become obsolete before they are even launched! Furthermore, if one of these satellites suffers a malfunction or collides with a defunct satellite or spent rocket booster, that satellite could be lost, rendering its operator/owner completely without the benefits and services that were provided by the satellite. Alternatively, constellation satellites are expected to be much cheaper, can be built a lot quicker, and if one is lost, a replacement can be inserted to fill the void relatively easily and quickly.[4]

This paper provides an overview of some of the possible impacts that the deployment of large satellite constellations might have on space programs and operations. Pros and cons of such constellations are discussed, including their use in disaster relief, bringing information to parts of the world that is currently not able to access the internet, increased close encounters with other functional space assets, and a much expanded catalog of tracked objects in Earth orbit. Whether we are space travelers or space scientists, we will all have to increase our space situational awareness if all of the planned satellite constellation deployments come to fruition. Of course, in the end, I believe that we should strive to take advantage of this inevitable technological development for our benefit – we should be pro-active, be smart and be involved!

Satellite Constellations

Individual satellites provide limited coverage areas – either narrow bands (if in LEO) or small circles (if in GEO) – whereas a satellite system, or constellation, provides a much more extended coverage area. Furthermore, the demand for ever-faster broadband internet connections is maxing out the capabilities of today's satellites. This demand is fueled by a variety of commercial, personal, military applications, including Netflix, streaming video games, HDTV, etc. The proliferation of inter-connected satellites in the form of constellation addresses both of these issues.

Of course, small satellite constellations already exist – about 15 companies and/or programs have placed into earth orbit approx. 175 satellites for communication, weather-monitoring, disaster management, and navigation purposes. However, according to plans made public as of this year, we can expect approx. 22,000 new satellites in earth orbit sometime in the next decade! SpaceX expects to launch over 12,000, Boeing around 3,000, and OneWeb around 2,000 new satellites into the ever more crowded regions of earth orbit. Table 2 below summarizes the satellite launch plans announced by various companies and organizations over the past few years.

Company	Launch Plans
SpaceX	4,425 satellites in Phase I
	7,518 satellites in Phase II
Samsung	up to 4,600 in LEO
Amazon	up to 3,236 LEO satellites
Boeing	up to 2,956 satellites to LEO
OneWeb	up to 1,320 LEO satellites, 720 to MEO
China Aerospace Science & Tech	up to 320 satellites
Russian Space Systems	up to 288 satellites
Sky & Space Global	up to 200 satellites
China Aerospace Industry Corporation	up to 156 satellites
Telsat	two constellations of 117 satellites each
LeoSat Enterprises	up to 108 satellites
Planet	at least 67 satellites in LEO

Table 2. Satellite Constellation Launch Plans as of April 2019[5]

Thus far, OneWeb launched its first six satellites in February, 2019; SpaceX its first 60 in May, 2019. The question naturally arises regarding what potential benefits can these new large satellite constellations can provide, as well as what are some of the potentially detrimental side effects they may have as well.

Just how many satellites are needed for a constellation? For global coverage, several satellites will be needed at different orbits, including LEO, MEO, and GEO. After all, GEO satellites cannot “see” Polar Regions. The number of satellites needed can be approximated using non-overlapping spherical hexagons, and depends on planned orbital altitude, coverage area, and other considerations.[6]

Figure 4 below shows what a satellite constellation might look like for a relatively small number of satellites in the constellation.

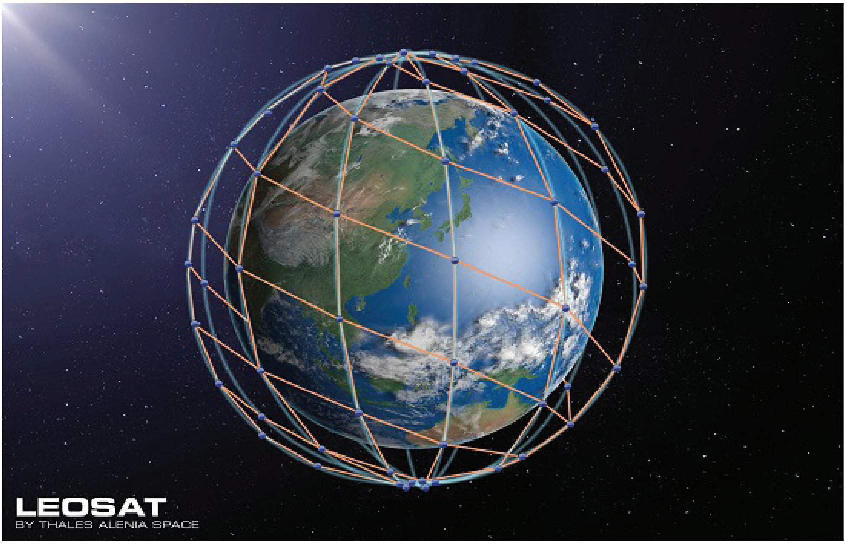

Figure 4. **LeoSat Data Network Constellation**[7]

While the function of many of the satellites will be communications, there are indeed a number of benefits that can be derived from such constellations. For example, to name a few:

1. The basis for many of the benefits lies in the capability of a satellite constellations to provide a space-based world wide web. No longer limited by fibre capacity of hampered by repeated atmospheric interference, a space-based world wide web will be able to provide improved internet access and communication to places where now the internet is slow or non-existent and reliable communication is difficult, at best. The huge expense associated with fibre-based communication infrastructure will be absent as well in a space-based system.[8]
2. A variety of satellites with different capabilities will provide better assistance with disaster management. No single satellite can gather, process, and provide information for all types of events - different situations need data collected in different wavebands. For example, agricultural droughts require optical and near infrared sensors, while tracking a hurricane or monitoring flooded areas beneath clouds require microwave sensors. Landslide investigations require accurate

high-resolution digital elevation models, while thermal imagery is needed for fires or volcanoes. Disaster managers need satellites with sensors that collect data in all regions of the electromagnetic spectrum, a capability that a sensor network distributed across a suite of satellites should be able to provide.[9]

3. Astronomical studies can be performed without atmospheric interference, leading to more reliable information obtained without a need for significant signal or image processing or correction. For example, the BRITE (BRIght-star Target Explorer) / CANX-3 (Canadian Advanced Nanosatellite eXperiment-3) project, comprised of scientists from the University of Toronto, TU Graz, Universität Wien, University of British Columbia, and l'Université de Montréal, has as its objectives as:

    (a) photometric observations brightest stars in the sky, and
    (b) the study of low-level oscillations & temperature variations in such starts. The anticipation is that the precision of observations made from beyond the Earth's atmosphere will exceed that of ground based observations by a factor of ten or more.[10]

There is also the potential that the deployment of 22,000+ satellites could negatively affect space travel and either on-going or otherwise planned space operations. For example:

1. There will be an increase in the possibility of on-orbit impact, either by a piece of space junk on a constellation satellite, or by a constellation satellite on another satellite (functioning or not). As a first-of-its-kind data point, 5% of the SpaceX Starlink satellites failed to deploy or function properly (ie 3 out of the launched 60).[11] These are now part of the catalogued of space junk that is tracked by North American Air Defense (NORAD) and other organizations that have space situational awareness and traffic management as part of their charter. An untold number of studies performed by investigators all over the world continue to demonstrate the highly destructive nature of such impacts, and the highly deleterious effects such impacts have on space travel and space operations.
2. There will be more clutter in the catalogue of space objects, resulting an increase in the number of close-approach warnings. Figure 5 shows the growth in the NORAD catalogue of trackable

space objects. At present, there are approx. 19,000 such trackable objects – the addition of 22,000+ satellites in the various planned constellations will effectively double the number of tracked objects in Earth orbit. Using today's warning thresholds, more than 25,000 warnings could be issued each day, all of which must be adjudicated by the operators that receive them. At that rate, decisions regarding orbital adjustment firings may need to be every 3 to 4 seconds every 24 hours.

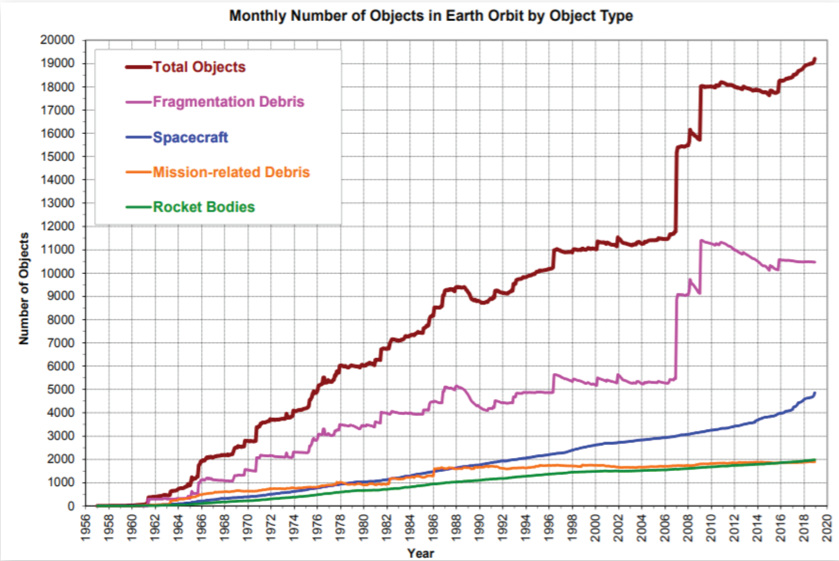

Figure 5. Increase in the Population of Tracked Space Objects, 1957-2019[12]

3. There proliferation of new radio and other band telemetry signals will undoubtedly result in signal interference in radio astronomy programs. The greatest potential for interference is from those satellites having downlink frequencies near those of prime interest to radio astronomers. Some of the proposed LEO-based satellite constellations are also of particular concern because their lower orbit allows their transmissions to reach radio astronomy receivers at high relatively power levels.[13] This, of course, can wreak havoc on equipment that is designed and built to receive exceedingly faint

signals from the far reaches of the universe. Figure 6 below shows the effect of a passing satellite on the radio imagery of a nearby start.

Implications for Future Science and Engineering Activities

Much like the "mini'-satellite constellations already in earth orbit, the planned "mega"-satellite constellations are likely to be game-changers for future earth-based and space-based science and engineering operations. On earth, for example, as a result of the much wider coverage afforded by future satellite constellations, it will be much easier to develop, implement, and maintain a 'round-the-clock engineering design operation, whether it be for buildings or bridges or whatever. Global coverage would also allow for subsidiaries to not have to be located within a relatively narrow equatorial band of land; rather, they can be located pretty much on any land mass that has satellite coverage. This will certainly spawn new commercial "tax-free" zones as new nations compete to be a part of such engineering enterprises.

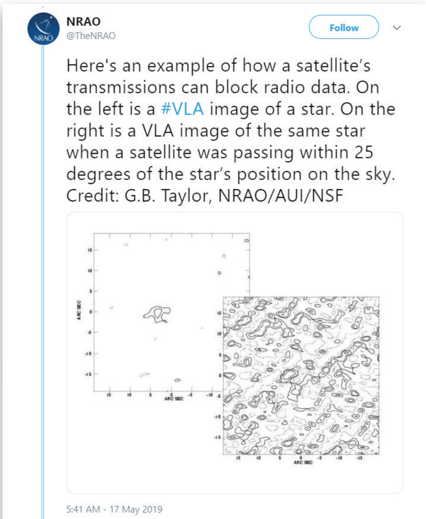

Figure 6. Image from NRAO's Twitter Feed Showing the Effect of Satellite Transmissions on a Star's Radio Imagery

Of course, much like for earth-based operations, space-based operations will need to have redundancies and contingencies in place in the event that a satellite is lost due to either natural or human activities. Of course, human activities that result in the loss of a satellite could be either accidental (e.g. collision with a meteoroid or a piece of space debris) or deliberate (e.g. a hostile action by another company or country in order to cripple the operation of a particular network). Entirely new legal frameworks, most of which will by necessity be international in scope, will likely need to be developed to accommodate such possibilities, and to ensure that the rights and assets of all participants are protected.

It is also incumbent on satellite constellation owners and operators to be mindful of their legacy in space. Such constellations will need to be designed (and costed) to either operate in perpetuity (with scheduled replacements, etc), or to have a graceful exit from the orbital stage upon completion of their missions. The population of earth-orbiting space debris, despite the good intentions and the improvements in spacecraft design of the space faring community as a whole, has continued to increase almost unabatedly. The presence of tens of thousands of new satellites in earth orbit has a great potential to make things seriously worse for everyone, including the owners / operators of those satellites. Great care must be taken to properly design, launch, track, and operate each and every satellite in any given constellation, and then to dispose of it when no longer needed.

Finally, the implications of the presence of such constellations on other space-related or space-based operations (e.g. space science, earth science, astronomy and astrophysics, to name a few) must be not only recognized by their owners/operators, but actively protected so as to not interfere with their activities. The quest for knowledge regarding the origins of life, our solar system, galaxy and universe remain, but can be severely hampered by the presence of thousands of earth orbiting satellites.

Constellation owners/operators must be prepared to share sufficient information about their networks (not only positions, etc but also broadcast frequencies, for example) so that astronomers can plan around them when making their observations. Additionally, satellite constellations can actually be of great service to the scientific community thanks in part to their location. As such, the owners/operators of these constellations can engender much good will throughout the scientific community if partnerships and collaborations develop across discipline and application boundaries.

Concluding Comments

In recent years, several companies have announced plans to launch several thousand satellites of their own, mainly for communication purposes, but also to provide a sort-of space-based world wide web. According to plans made public, we can expect approx. 22,000 new satellites in earth orbit sometime in the next decade.

This paper has discussed some of the benefits can these new large satellite constellations can provide, and what possibly deleterious effects they might have on other space activities and operations. Possible benefits include delivery of the internet and more reliable communications in parts of the world where both are limited, at best, improvements in disaster relief planning and operations management, and improved scientific observation capabilities.

Negative effects include an increase in the likelihood of impacts by space objects, and increasingly cluttered catalog of trackable space objects, and interference with ground-based radio astronomy investigations. However, good engineering and good science that is properly exercised in the design, construction, and deployment of satellite constellations should be able to lessen these negative effects and allow more and more of the world's population to benefit from their proper operation.

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Sustainable Middle Power Military Space Operations

Peter Layton

'Space is big. Really big.'

—The Hitchhiker's Guide to the Galaxy, 1979[1]

It turns out *The Hitchhiker's Guide to the Galaxy* was wrong, at least as regards near-Earth space. This zone between about 160-40,000km above the earth's surface is not limitless at all. This area is better conceptualised as a 'commons', an area others can't be excluded from accessing or using.[2] This near-earth space commons offers benefits so compelling that some 60 nations now operate more than a thousand military and civilian satellites there, and growing. In 2017, there was a 100% increase in the total number of spacecraft deployed; in 2018 there was a record-setting 114 orbital launch attempts.[3]

Such exploitation generates problems. Orbits are not just crowded by increasing numbers of functioning satellites but also by debris arising from earlier space missions and accidents. The debris problem is acute with some 23,000 man-made objects larger than 10cm in orbit, and another 100 million pieces of less than 1mm.[4] Worse, the quantity grows about 10% a year.[5] This debris is orbiting at extremely high speeds meaning that even collisions involving a very small object can cause a satellite to fail and must be avoided whenever practical. Indeed, the manned International Space Station is actively manoeuvred to avoid space debris impact when necessary. In addition, there is also congestion in the electromagnetic spectrum with satellites operating too close together interfering with each other's radio signals.[6]

Such issues simply reflect typical 'tragedy of the commons' concerns. In these common-pool resource situations, where users are self-interested, governance is ineffectual and there are no incentives to restrict usage, over-exploitation leading to environmental degradation is to be expected.[7] The real fear is that on earth such a process leads to long-lasting environmental damage that seriously impacts all users. Such a scenario now seems to be emerging in near-earth space. The sustainability of space operations over the longer term is becoming threatened, particularly in the well-used, in-demand Low Earth Orbit (LEO) between 160-2000km.[8]

This article aims to develop a strategy that middle powers like Australia could potentially use to achieve sustainable military space operations over the longer term. The first section examines the emerging difficulties to sustaining military space operations, the second discuses the implications of these difficulties, the fourth some conceptual changes necessary and the conclusion a possible middle power military space strategy. The article addresses military not civilian space operations, focuses on the space segment operating in space rather than ground facilities or terrestrial military forces, and only considers unmanned satellite systems.

Emerging Problems

Advances in technology are dramatically lowering the costs of space operations. This new affordability is democratising space, at least in the sense of allowing many more countries and commercial entities to become directly involved. In Australia this development is often labelled Space 2.0.[9] Under this nomenclature, Space 1.0 is seen as the domain of great powers and large companies with advances shaped mainly by strategic concerns. In contrast Space 2.0 is seen as involving most nations, new start-up companies and universities, and shaped mostly by commercial imperatives.

In general Space 2.0 technologies are those associated with the fourth industrial revolution with its stress on continual innovation.[10] The Space 2.0 approach has lead to lower cost launch systems and an emphasis on developing ever-smaller satellites that are ever-more capable. With small satellites more can be inserted into orbit in a single launch. The current record set in 2017 involved India's PSLV-C37 inserting 101 nano-satellites into orbit, 96 for two US companies, one each for Dutch and Swiss companies and one each for universities in Israel, Kazakhstan, and the UAE.[11]

This launch reflects the conceptual shift away from large, expensive, long-life satellites operating in geosynchronous orbits (35,786km) to the 'small, cheap and many' approach using smallsats (< 500kg) operating in LEOs.[12] Two examples of this approach are the planned OneWeb and SpaceX broadband communications satellite constellations. OneWeb plans to have some 600 smallsats (each 150kg) in orbit, replacing each every five years and building some 40 each month.[13] SpaceX has its first 60 smallsats (each 230kg) in orbit, initially growing to 400 but with regulatory approval for 12,000.[14]

Smallsats are themselves getting smaller. Nano-satellites are typically hand-sized, weigh less than 10kg and can do much that traditional large satellites once did.[15] They are typically quick to build, launched into LEO, have a short life of 3-4 years and have a cost of less then US$1m. Accordingly, about half the satellites now operational are nano-satellites, some 580 overall.[16]

New Zealand's Rocket Lab, a start-up company presently launching from Mahia Peninsula on the North Island, offers an indication of how the various factors combine. The company-designed two-stage rocket is constructed using carbon-composites and includes ten engines built using additive manufacturing; the rocket can insert about 220kg into orbits of 300-700km for about $5m.[17] A June 2019 mission delivered seven satellites, the 56kg BlackSky Global-3 and six nano-satellites: two US Special Operations Command Prometheus's, two Swarm Technologies SpaceBEEs, the University of Melbourne's educational program's ACRUX-1 and a classified package.[18]

Such performance at an affordable cost means middle powers are increasingly interested in space-based systems. Strategically, military space activities are simply a continuation of terrestrial politics by other means.[19] Accordingly, military forces seek to achieve their assigned political objectives through using the space commons to the extent necessary, while simultaneously denying it to adversary forces to stop them achieving their political objectives. In so mimicking earthly military practice, space becomes simply a location in which during conflict friendly activities are protected and hostile ones attacked. Achieving this may be usefully conceptualised as involving: space situational awareness (SSA), space control and assured access to space.[20]

SSA provides an understanding of the space environment. In peace or war, SSA is crucial to allow warning of approaching debris in sufficient time to allow friendly satellite orbits to be adjusted to avoid a collision. The RAAF has an embryonic SSA capability that includes a C-band space surveillance radar and a Space Surveillance Telescope.[21] There are plans for a 5-6 station Optical Space Surveillance SSA network across Australia with the initial facilities at Mount Stromlo and Exmouth Gulf already completed.[22] Beyond national SSA coverage, Australia has a partnership with Canada, New Zealand, France, Germany, the United Kingdom and the United States in the Combined Space Operations Initiative that shares SSA data.[23]

Space control involves both defensive and offensive measures. Defensive measures involve actively or passively protecting friendly space capabilities from attack or interference. These measures can include making satellites difficult to detect and track, hardening them from electronic or physical attack, manoeuvring them away from approaching threats and building redundancy by having multiple satellites in orbit.

Offensive measures involve attacking adversary space capabilities. Soft kill measures can include lasers to blind a satellite's imaging sensors, high-power microwave transmissions to interfere with a satellite's electrical systems or jamming ground communications' links.[24] Soft kill systems are much cheaper and easier to develop and employ than hard kill systems but their effectiveness is difficult to predict, varying greatly with the satellite being engaged.[25]

Hard kill measures are not just technically more difficult but their use is also problematic. Modern Anti-Satellite (ASAT) weapons are either exo-atmospheric Ballistic Missile Defence missiles (US, Russia and Israel) that have a secondary anti-satellite capability or optimised direct ascent ASAT systems (China and India). China's 2007 and India's 2019 ASAT missile tests highlight the problems using such weapons pose.

China's ASAT test destroyed the 750kg FY-1C polar orbiting weather satellite at an altitude of 865kms. This created the largest ever manmade loud of debris comprising some 2000 trackable fragments and about 150,000 debris particles; many will remain in orbit for several decades.[26] In 2011, some passed within 6km of the International Space Station.[27] The Indian test targeted the 740kg Microsat-R at an altitude of 280km created about 400 fragments (60 trackable) and another 6000 debris particles; most will de-orbit within three years.[28]

A small space war that involved destroying 30 satellites is estimated to increase overall orbital debris by about a factor of four; a major war with 100 satellites destroyed might lead to an increase of over 1250 percent.[29] The small war case then would see about 80,000 fragments larger than 10cm in orbit, and another 400 million pieces of less than 1mm, most in LEO. A large war case would create an immense debris problem.

The debris created directly by the ASAT tests is only part of the predicament. Space debris continually increases due to the Kessler Syndrome where debris collides with other debris and there is a cascading effect creating ever more. An example was the 2009 accidental collision between an operational Iridium 33 satellite and the defunct Cosmos 2251 at an altitude of 789km and a velocity of 42,120 km/h. More than 2,000 pieces of debris measuring at least 10 cm in diameter were created along with thousands of smaller pieces.[30] The anticipated deployment of large smallsat constellations into LEOs will further exacerbate existing Kessler Syndrome concerns were already more debris is created each year than de-orbits.

Moreover, ASAT technology could quickly proliferate. The Space 2.0 concept of smallsats and low cost launches suggests that middle-powers could now feasibly develop and employ their own ASATs. Smallsats could be deliberately crashed into adversary satellites in orbit or be orbited nearby and electronically jam them. Some consider the 2007 close fly-by of the International Space Station by China's 40kg BanXing smallsat a test of co-orbital ASAT interception technology where the satellite catches up to its target after several orbits.[31]

The final piece of the doctrinal mix is assured access to space. This requires having a national launch capability or ready access to an allied one. Space 2.0 technologies now make this practical for example with the New Zealand Rocket Lab facility already in service and plans underway for an Australian austere launch capability on the Gove Peninsula.[32]

Implications

Paradoxically, while Space 2.0 technologies are making space more affordable they are also making space-based systems increasingly vulnerable. Satellites in LEO can no longer rely on their location for protection. They can be made more robust and resilient but their survival is not guaranteed in peace or war. In peace, accidental collisions with space debris are a constant concern; in war, adversaries may now try to deliberately damage satellites. Satellites are like sand castles: 'difficult to build but easy to destroy.'[33]

Major powers can already intercept satellites. In the near future, given Space 2.0 technologies, middle-powers will be able to field similar capabilities if they wish. Crucially the debris caused by any satellite interceptions during a conflict is unlikely to be able to be contained or be limited to the combatants only. This debris can be expected to adversely affect impact all nations' use of space for military and civilian purposes. In a space war, neutrality will provide no protection.

The issue of guaranteed satellite survivability becomes even more problematic when the Kessler Syndrome is taken into account. LEO congestion is now reaching a stage in terms of debris quantity that, considered mathematically, random collisions could already set off a cascade. Dr Ben Greene, Chief Executive of the Space Environment Management CRC worries that:

> A catastrophic avalanche of collisions that would quickly destroy all satellites is now possible…. In the worst case, two satellites would collide and the debris from those satellites would be directly in the path of more satellites in a very short space of time. They would then generate more debris and very quickly the avalanche would grow until everything was colliding with everything and space would become uninhabitable for satellites for hundreds of years.[34]

In today's LEOs this is a low probability, high consequence event. However, the probabilities increase as more satellites are launched, and if there is a conflict involving deliberate satellite destruction. An approach to try to avoid the latter is through agreeing appropriate international laws that proscribe physical attacks on satellites.

Russia and China have proposed a treaty banning weapons in space but this has floundered on definitional precision, as any satellite can be a weapon, and the difficulties of verification. Australia and others prefer Transparency and Confidence Building Measures that construct norms of responsible space behaviour.[35] Neither approach appears likely to provide a high probability that satellites will be inviolate in time of conflict.

Moreover, there is an underlying fundamental problem with governing a commons: the difficulty of enforcing compliance. Elinor Ostrom's Nobel prize-winning work on commons governance devised several criteria associated with enforcement. This included monitoring of compliance, self-enforcement by the groups using the commons, graduated sanctions for non-compliance with the severity of sanctions varying with the offense's severity and context, and access to rapid, low-cost arenas to resolve conflict.[36]

Space activities reflect terrestrial politics, as noted earlier. Accordingly, in the contemporary anarchical international system with its underlying assumption of increasing great power competition and conflict, it seems improbable that Ostrom's criteria can be meet in terms of space commons governance. It seems unlikely that the more than 60 nations using space will agree to be bound by such rules or approve a rigorous enforcement regime.

As an example of the difficulties of sole reliance on legal constraints, the People's Republic of China is a party to the Outer Space Treaty. However, China did not warn the space community nor consult internationally before destroying the FY-1C satellite in 2007. Indeed, China did not even admit to the ASAT test for about a month. On the other hand, the international community did not enforce sanctions against China for its actions albeit some used diplomatic channels to protest.[37]

Conceptual Changes

The sustainability of space-based systems over the longer term is questionable. Instead, satellites are perhaps best considered as expendable systems with an unpredictable life span. In times of peace, normal satellite reliability uncertainties would apply combined with the debris dangers elaborated. However, during a crisis, satellites may now be considered potential targets for soft or hard kill attack as part of a measured approach to signalling national intent and concern.

The recent destruction of a US Global Hawk unmanned air vehicle by an Iranian Surface-to-Air Missile system may be a portent. The US did not forcibly respond because destroying an unmanned system had much different connotations to engaging a manned platform. Such considerations suggest that a satellite failing during a crisis will create some uncertainties; is the failure due to an engineering problem, a debris impact or a deliberate attack? If the latter, does this foreshadow a sudden widening of hostilities? Is it a *casus belli*?

Surprisingly, in actual conflicts between middle-powers satellites are probably safer in that both sides will have incentives to demonstrate restraint. The middle powers will both wish to continue using space-based systems and also be trying not to expand the conflict by undertaking actions detrimental to the international community. However, this mutual deterrence may not hold in circumstances where one or both sides have great power allies keen to provide support in a less provocative but still militarily effective manner.

In large wars involving great powers and their attendant allies, outcomes darken. There will be strong incentives to attack others' satellites using soft or hard kill systems. Mutual deterrence may hold initially but as one side perceived it was losing, military escalation to regain the strategic initiative would be inevitable. As unrestricted submarine warfare erupted in both World Wars, so a similar process could be anticipated to lead to widespread attacks on satellites.

Over all these abstract discussions of peace and war hangs the spectre of the Kessler Syndrome. The probability of such an occurrence is low but steadily increasing. Mathematics may yet impose a reality of its own for, in highly dynamic systems, improbable events sometimes occur.

Middle-power space activities need to be undertaken cognizant of the uncertainties surrounding their long-term sustainability. In particular, robustness and resilience need to be included as important criteria when designing military space systems. Various possibilities exist.

Instead of having one large satellite, a constellation of many smallsats would be more robust. Even if some are successfully attacked, the constellation will gracefully degrade not catastrophically fail. In so doing, it seems sensible to also harden the individual satellites against soft-kill systems, such as laser dazzle weapons or electronic jamming, able to engage multiple satellites. Another approach would be inserting satellites into higher orbits beyond the crowded LEOs; this would give longer warning times of approaching debris or interceptors allowing manoeuvring.

In this, manoeuvrability appears an important general design requirement to improve sustainability. Manoeuvring a satellite reduces its vulnerability to debris and soft and hard kill systems and is useful in all circumstances.[38] Furthermore, having a manoeuvre capability means that during a crisis, satellites can be quickly moved so as to delay any adversary attacks while new orbital parameters are determined. The trade-off for including propulsion systems on a satellite is that this reduces the space and weight available for sensor or communication payloads but this appears necessary.

In terms of resilience, the key system design criterion appears being able to quickly replace damaged satellites. Rapid reconstitution implies assured access to space with a launch on demand capability. The fourth industrial revolution manufacturing approach offers considerable potential for this in terms of being able to quickly build rockets and satellites when necessary. To be feasible though the rockets and satellites need to be designed under, and manufactured inside a fourth industrial revolution process.[39] While rockets and satellites then might not need to be stockpiled for use *in extremis*, the ability to move to rapid manufacturing would need to be maintained.

In considering insertion into specific orbits, launch location can be crucial. In this, Australia has some advantages because of its continental size and latitudinal spread. In that regard, Gilmour Space Technologies is developing mobile launch capable rockets around fourth industrial revolution manufacturing techniques and able to insert smallsats into LEOs.[40]

Conclusion

Space 2.0 technologies, military doctrines and the different issues discussed suggest a strategy that middle power militaries could adopt to improve their space activities' sustainability across peace and war. Such a strategy might have four elements:

1. **Space Situational Awareness.** SSA's continual monitoring of the space environment is fundamental to providing the intelligence necessary to both protect friendly satellites in peace and war, and attack adversary assets if circumstances require.
2. **Defensive Space Control.** Satellites can be made more resistant to debris and hostile action through careful design and manufacture. While there are cost and performance penalties associated with including protective measures, sustainability considerations mandate them. Defensive measures such as manoeuvrability rely on good SSA to be effective.
3. **Offensive Space Control.** Soft kill measures would be useful to develop. However, given their effectiveness is ultimately unknowable until conflict begins, it might be prudent to limit expenditure to allow other elements to be more fully funded. While hard-kill systems are becoming practical for middle-powers, the development costs involved, their limited utility and their adverse impact on the space environment suggests they not be acquired. Middle powers could better press for adoption of international laws or norms that make hard-kill satellite weapons less likely to be employed.
4. **Assured Access to Space.** Hardening satellites can make them more robust but having a resilient military space capability requires being able to replace satellites when and as required. Space 2.0 technologies are making middle power assured access to space practical.

The final piece of the strategy is to not be overly reliant on space-based systems. Such systems are force multipliers in war, and in peace confidence builders through being able to accurately assess other's military capabilities. Nevertheless, the growing debris problem and the impact of Space 2.0 technology proliferation suggests that space activities may not be unsustainable over the longer term or in time of major war. Total reliance on space-based assets would be unwise.

The strategy aims to deter by demonstrably being able to deny an adversary the ability to achieve their strategic objectives by attacking friendly space-based systems. The combination of SSA, offensive and defensive space control, and assured access makes an adversary's task much more difficult and success uncertain. Having an ability to function without space further reinforces deterrence by denial. Paradoxically, in being able to fight wars without needing to use space, our use of space becomes more sustainable.

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Sustainable Space Access Depends on a Space Orbit Economy Driven by User Needs Attributing Different Values to Different Orbits

Michael Spencer

"Space, space technologies and space data are becoming increasingly important to the functioning of the modern economy. They support future economic growth, and assist business with cost savings and advancements. For example, they assist in agriculture with targeted crop spraying and precision planting, through to improving the products and services Australians enjoy every day including phone coverage, precision mapping, food availability, and health".[1]

—Australian Space Agency (2019)

Introduction

'Space access' enables space users to launch rockets, lift launch satellites and their mission payloads into space, insert them into Earth orbit, and perform space missions designed to achieve specific outcomes. Space access can be achieved through national government-funded programs or commercial service-providers and has become a common element included in the models of many states that regard space-based services as essential to their critical infrastructure for sustaining national power, including national security. It is a self-evident truth, drawn from studying the Earth orbital environment, that "Space is a finite resource — just like the atmosphere, and the water, and the Earth" - Dr W Schonberg.[2]

Space actors wanting to deploy more space missions into the orbital space environment are face increasing contest and competition for access to preferred orbits in a loosely regulated space access and orbit allocations. The numbers of new objects being inserted into orbits, resulting from the human space activities (including satellites and debris), exceeds the numbers and rates that objects are vacating the orbits, and this varies across the different bands of useful orbit altitudes.[3] As a consequence, orbital congestion is a growing problem for the sustainable use of the space environment, leading to different orbital altitudes having different economic values based on the increasing scarcity of their availability and accessibility. This, combined with the risks of on-orbit collisions with uncontrolled space debris, is driving competition and contests for commonly preferred orbits. Figure 1 depicts the uneven distribution of space objects across popularly used low-Earth orbital altitudes, compared with the numbers of new satellites proposed in future megaconstellations, driving tension between the design options for the satellites which are dependent on the available orbital altitude.

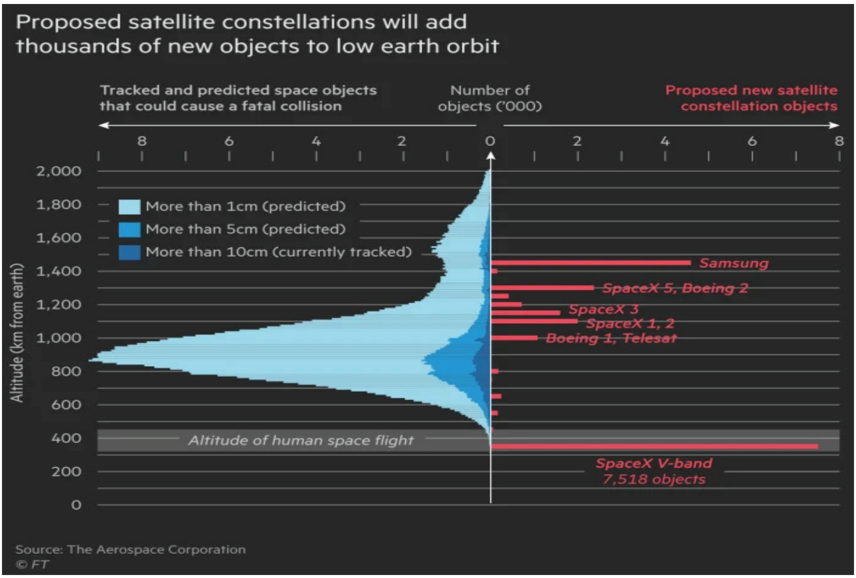

Figure 1. Depiction of trackable space objects compared to numbers of satellites in new constellation proposals.[4]

The economic value of space orbits

The dependency of critical state and corporate infrastructures on space missions illustrates clearly the linkages between the assured access to preferred orbits and economic prosperity and security assurance. However, the uncontrolled space debris threatens assured access to a clear orbit and reliable performance of a space mission.

Space missions are performed by orbiting payloads carried by satellite buses. Satellites are lifted into an orbital location defined by the both the orientation of a circular trajectory and a specific position on that trajectory. Orbital trajectories within particular regions of orbits are more valued than others as a consequence of common space missions requiring similar orbital locations. The uncontrolled and growing congestion on some orbits is driving competition for access to particular orbits similar to an economic competition for limited resources. Of note, similar issues are being experienced in the aviation industry as commercial aircraft with comparable performance characteristics seek commercial advantage by utilising routes and altitudes that are becoming increasingly congested.

An economic outcome is at stake: monetary and non-monetary values depend on the space mission which, in turn, depends on access to the orbit needed to optimise the mission outcomes noting the risks from congestion throughout the orbital environment. The perceptions of uncontrollable risks from orbiting space junk gives varying values to different orbits can be based on on-orbit collision risks with space debris and unintended interference from other space missions operating nearby (eg electromagnetic interference by a satellite transmitter in low-Earth orbit that passes between a geostationary satellite and its ground station; sun reflections from the solar panels on a satellite passing between a deep space object and a ground based optical sensor). Thus, particular orbital regions are made more popular because the orbital altitude can optimise the performance and functions of a space mission.

An imbalance in the space economy equation

The demands and congestion in different orbits vary with altitudes, as depicted in Figure 1. Different space missions use different orbits to optimise the performance of their mission system. An imbalance exists in the space orbit economy between assured availability of some of the more popularly used orbits and the orbital spaces needed for new missions, compounded by the problems of a growing number of space debris and risk of on-orbit collisions.

Imagine a simple analogy where the orbital economy is considered as a closed system. Space launches deliver new objects to access different orbits, as a controllable event. In this system, orbits can be regarded as being a finite and consumable resource. User demands for the more popularly desired orbits have reached the point where congestion is an operational risk to the choice of orbit and this introduces compromises to the designs for the mission and satellite, increasing cost and mission risk. Furthermore, the uncontrollable generation of natural and artificial debris is also threatening valuable orbital positions and trajectories.

A common problem regarding the orbital space environment is the imbalance between objects being inserted into the orbit system compared to the numbers of objects being removed. Satellites are designed to function on orbit for periods ranging from several months up to about seven to 15 years. New classes of very used small sized satellites are commonly used for their low cost and lesser design complexity compared to the very large satellites. One way that small satellites reduce their cost and complexity is to exclude a propulsion system with fuel reserve to perform a de-orbiting manoeuvre when the mission expires. Non-operational satellites deployed above and beyond the reaches of the expanding atmosphere can potentially remain stable in orbit for an unknown time, affecting future space users seeking to re-use the orbit.

More useable orbits have been made available through better technology, and cooperation by industries and nations, to increase satellite stacking, allow narrower spacing between adjacent space missions, better regulation of the frequency spectrum usage and satellite transmission techniques to reduce mutual interference. However, the user demands for access to space continue to increase consuming a finite number of popularly orbits at such a rate they can become a scarce resource. A review of some examples of the different ways that the choices of orbits can affect a space mission can illustrate how the choice of orbit is dependent on the choices of available orbits, mission designs, space systems, spacelift services, and the level of performance expected of a new operational space mission.[5]

The space debris entropy influence on user preferences for orbits

The space orbit economy is being put at risk by an entropic and growing variable of space debris. Spent rocket boosters, expired satellites, space flotsam, and both artificial and natural debris are also adding to the resident debris problem. Space debris has twofold effects: orbital debris poses a collision hazard to space missions and the numbers of debris objects is increasing uncontrollably due to their long life on orbit and the on-orbit collisions that create more debris fragments. This uncontrollable cascading effect where debris collisions to generate more debris fragments is known as the 'Kessler Syndrome'.[6]

Atmospheric drag can retard low altitude satellites to bleed their kinetic energy and, if not configured with a propulsive manoeuvring system, will cause their descent into the atmosphere and burnup on re-entry. However, the density decreases with increasing altitude and above 600 km, space objects can "remain in orbit for tens, thousands or even millions of years".[7] Predictions for the uncontrolled descent and re-entry of expired satellites are based only a short history of space operations spanning a limited number of decades since Sputnik was the first satellite launched in 1957. The US Vanguard 1 satellite was the fifth space object launched into orbit in 1958. Although Vanguard 1 expired in 1964, it continues in its stable low-Earth orbit as the longest orbiting artificial object. NASA estimates it can continue orbiting for another 240 years.[8]

Space launch vehicles need safe passage to cross through different orbital planes, including through the orbital space debris, in order to access the target orbit. Space mission designers are facing increasing risks of on-orbit collisions with the shared presence of uncontrollable orbital space debris. Mission designers now have to consider options for an orbit based on the risk of on-orbit collisions rather than access the recommended optimal orbital altitude that maximise the satellite system's performance and effectiveness, if that orbit presents an unacceptable risk to the satellite's survivability.

The influences of space mission needs on user preferences for orbits

Accessing the orbit poses two key problems for mission designers: lifting the satellite to the objective orbit and optimising the satellite systems for a best performance at the orbit altitude. Additionally, the satellite survivability depends on the orbital altitude since the damaging effects of cosmic radiation and space weather are worse with increasing altitude. The economic cost of a space mission has many interdependent variables that depend on the orbit.

The orbit altitude determines the energy needed to lift the satellite into orbit and the physical distance between it and the Earth over which its mission systems must function. The Low-Earth orbital region is the nearest and quickest accessed region of orbits and requires the least effort for a launch using the smallest, least energetic, and typically lowest cost rockets. Earth observation sensors have physical design limits to deliver the best performance over a pre-calculated distance between the sensor and the Earth's surface. The typical sensor will perform at its best only over a specific limited range of orbital altitudes corresponding to the operating limits of the sensor that produce the best observations.

The orientation of the orbit determines the geographic locations that can access, or be accessed by, the orbiting satellite. Satellites following the north-south oriented polar orbit cross over the poles on a fixed trajectory while the Earth rotates beneath it. This orbit is popular to enable space missions that need to access any point on Earth's surface over a number of orbits. Sun-synchronised orbits are popular because the Earth's surface directly below the satellite's ground pointing sensors, and the satellite's solar panels, will always be illuminated by the sun.

Raising the orbit altitude increases the coverage area of the satellite field-of-view and communications across the Earth's surface. Geosynchronous orbital slots are situated over the Earth's equator at particular longitudes. The country that is situated at the sub-point directly below a geostationary satellite, gains the maximum benefit from the coverage area to maximise its range of communication and broadcasting. Since many countries can exist on the same line of longitude, the International Telecommunications Union is established as the authority to regulate the fair and equitable allocation of geostationary orbits and frequency spectrum usage for the popularly used geostationary belt[9]. However, the availability and accessibility to the other popular orbital regions are less controlled.

The orbit altitude also determines the limits of the Earth horizon for two or more cooperating satellites to be visible on each other in order to directly communicate, as part of a networked constellation. The Earth horizon determines the minimum orbit altitude needed to directly link two separated satellites. Only three satellites, evenly spaced along the geostationary belt, are needed to provide communications services to the majority of the world's population.[10] The greater the number of satellites used in a constellation, the lower the orbit altitude can be to establish a network, and smaller are the mass and power needed to communicate with terrestrial customers.

New customers wanting to access space will, in many cases, seek space missions for the same purposes as successfully used by other space users, for their own unique commercial or sovereign needs. This drives competition and contest for the commonly used orbits as a finite resource.

The influence of satellite design standards on user preferences for orbits

The acceptable choices for orbits needed for a space mission are derived from trade-off analysis[11] to analyse acceptable alternative options and compromises. For example, a communications mission might be fulfilled by a single large geostationary satellite, launched from an expensive heavylift launcher, or alternatively, a constellation of networked small satellites that can be deployed as ride-sharing payloads into low-Earth orbits for less cost than dedicated space launches. The mission payload design to deliver the communications service will determine an optimum effective distance between the satellite and the terrestrial user, driving the user's choice of orbit.

Manufacturers of satellites and mission systems have sought to maximise their trade in supplies and the ease of construction of satellites by standardising the designs and components. Thus, components can be manufactured by different companies but remain compatible for uses in different satellite projects to deliver a satellite is assured of being compatible with the space launch vehicle and terrestrial infrastructure, regardless of the choice of manufacturer. One commonly adopted standard for small satellites is the Cubesat design specification.[12] The orbit choice is influenced by the system design standards adopted for guiding the mission payload design; choosing the wrong orbit will be detrimental to the performance of the payload.

The influences of available space launch services on user preferences for orbits

Space 2.0[13] has driven industry to provide more affordable and accessible technology options for space launch vehicles and space missions that have 'democratised space'[14] and increased the numbers of space missions that are complementing the continuing programs of Space 1.0[15] projects by traditional government and industry actors. Space 2.0 provides new and affordable opportunities as low-cost alternatives to the big satellites and also to encourage space users from smaller and developing countries, small business, universities, and schools.

Individual designs for many spacelift vehicles are standardised and optimally designed to reach a specific limited range of orbital altitudes. However, space launch vehicles are designed with different payload configurations to life one or many individual satellites to different discrete orbital altitudes. The geographic location of the launch site can physically limit the access needed to reach some orbits (ie sites at low latitudes cannot reach orbits with high declination angles without an add-on booster or kick-motor to provide the extra energy needed to change orbits to the new orbital plane).

Hosted payloads provide users with a low-cost option for launching small mission payloads that piggy-back onto a spacecraft[16]. Some large satellites may have surplus capacity onboard the satellite bus to host an extra small payload that is funded and deployed to conduct a discrete mission that is different to the primary mission of the large satellite. An example of a hosted payload is the nuclear detonation detection system[17] hosted onboard the US Global Positioning System satellites. The small hosted payload may also have the opportunity option to access the onboard mission support subsystems for the main payload, such as electrical power and communications. However, the primary mission determines the choice of orbit, which is a trade-off accepted for the hosted payload to be a low-costing piggyback design as an alternative to the cost of a full mission.

Each time a spacelift vehicle launches one or two of the very large class of satellites as a primary payload, it typically does so with room to spare in the payload section. Space 2.0 provides options, both for generating smaller satellites that can rideshare[18] with the larger satellites for a space launch, as a hosted payload that piggy-backs onto a spacelift vehicle, for a much lower cost than arranging a dedicated space launch. Additionally, for smaller non-traditional space-farers, Space 2.0 has motivated space launch services providers to dedicate launchers for carrying clusters of small satellites constructed to common design standard to be compatible with the launch vehicle. In 2017, India set a world record by launching 104 small satellites into a sun-synchronous orbit from the same spacelift vehicle.[19] The choice of space launch vehicle determines the destination orbit for non-manoeuvring and ridesharing satellites.

The mega-constellation disruption of user preferences for orbits

The rates of change in the traditional variables influencing the space orbit economy will soon be disrupted by a step-change in the total number of orbital space objects with the introduction of megaconstellations. At the start of 2019, the UN Office for Outer Space Affairs reported that 4987 satellites were in orbit; an increase of 2.7 % over the previous year.[20] The benefits of Space 2.0 technologies that reduced the costs of satellite acquisitions and space launches, made it possible for space entrepreneurs to develop their separate proprietary designs for the high-volume production and deployment of small satellites into megaconstellations. Whereas previously, thousands of actors each demanded orbits for their handful of satellites, soon a handful of space entrepreneurs will be demanding orbits for hundreds or even thousands of their satellites.

The benchmarks for satellite constellations have previously been the Iridium (77 satellites), and US Global Positioning System (32 satellites), each designed to operate on a spherical surface of different orbits at the same altitude. OneWeb is a mega-constellation designed for 1980 satellites and Elon Musk's Starlink is designed to deploy 12,000 satellites[21], more than the total number of satellites currently in orbit. The orbital space environment will see a merger of the current satellite situation with new megaconstellations designed as satellites distributed throughout a spherical volume of different orbits at different altitudes.

Megaconstellations will unbalance the space orbit economy in two different domains: by consuming many more orbits and inserting more space objects at an unprecedented rate, and increase the volume of radio frequency activities needed for their own exclusive use across a global sphere, at the risk of interfering with other space missions. Furthermore, the ease of deploying a mega-constellation into the orbital commons to provide a global service cannot assume a unified and global user system on Earth. Already, Russia has disagreed with the OneWeb proposed frequencies for user access which do not match the frequency spectrum usage approved by Russia within its sovereign terrestrial boundaries.[22]

Conclusions - Towards a sustainable space orbit economy

The macro-space economy is influenced by a complex and unbalanced mix of both controllable and uncontrollable economic forces from micro-space effects that are affecting space accessibility and availability. The currency of the orbital space economy are space orbits characterised by their circular trajectory, a position on that trajectory, and the orientation of the orbit over the Earth.

Space sustainability is achieved when the 'supply' of orbital trajectories supports the users' demands for current and future space missions. A space consumer's decision to select a particular orbit is influenced by:

1. the designs of space launch services to reach certain orbital regions, complemented by extra add-on boosters and kick-motors, and access through gaps in orbital debris fields;
2. space mission designs where that performance is dependent on the orbital altitude;
3. designs for commonly used space systems being standardised and shared, that have been optimised for specific orbital altitudes; and
4. the unwanted risks of on-orbit collisions or interference with space debris that varies over different orbital altitudes.

Orbits are a finite resource that, in a sense, are being consumed more rapidly than expired missions are vacating their orbits, resulting in a continually growing number of space objects that is an aggregation of long running missions, new missions, expired missions, stable space debris, and debris fragments resulting from on-orbit collisions and breakups.

Space 2.0, technology miniaturisation, and cheaper spacelift have democratised space access, increasing orbital congestion, competition, and contest. Compounded by the entropic debris growth problem in the unregulated orbital space commons, space will continue to head towards an unsustainable space system without more international recognition, cooperation, and shared control measures. Additionally, the space orbit economy will be disrupted by the expansion of consumer demands, previously from the many thousands of space actors each needing many single orbits, with the addition of a new handful of individual entrepreneurial actors each needing many thousands of orbits to fulfil their megaconstellations in the global space commons.

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Australian Capabilities for Space Situational Awareness: Common Proposals of, and Australia's Contribution to, Space Sustainability and Security

Scott Schneider

Introduction

Australia has developed and will continue developing space-related capabilities and space assets. The growth in its qualified interests in space and the resulting development of space assets are vital to Australia's critical infrastructure. Space assets (and their applications on Earth) are at risk to the global commons of outer space, an unavoidable core feature of international space law; no government or private entity may take a claim to secure any aspect of outer space. In other words, space is free for all to use and its resources are to be shared. To minimise the adversity of a tragedy of commons and threats to national security, space situational awareness (SSA) systems are deployed to identify, monitor space objects and provide space data that may be used to manage the space situation while remaining compliant with international law. Accordingly, SSA is an integral component in maintaining the sustainability of the uses of outer space, especially in respect of protecting a country's national economic and security interests.

The key aspects needed to realise long-term sustainability of the Earth orbital space environment are broad enough to require the combined capabilities and cooperation of multiple nations. Australia is one such State partnered in global efforts through its international cooperation with regulators, business, research and Defence. Through an outline of some of the activities supporting space traffic management and debris mitigation initiatives around the world, Australia's activities and prospects are placed in context to show its capabilities in contributing to a global effort in SSA.

SSA Today

The Australian Defence Force (ADF) defines SSA as the "requisite current and predictive knowledge … to enable commanders, decision-makers, planners and operators to gain and maintain freedom of action in space, throughout the spectrum on conflict". Such knowledge is gained through making observations and gathering information of the following space-related criteria:[1]

1. events;
2. activities;
3. conditions and status of space systems;
4. capabilities;
5. constraints; and
6. employment.

However, SSA outputs are not only applicable to defence needs. The significance of SSA is also relevant to debris monitoring, the national monitoring of space activities and for civil engagement of non-state actors in space. The above six criteria feed into these three aspects. Moreover, the topic of SSA employs several academic and practical fields. In order to address only the examples of SSA activities, this report presumes or bypasses several important elements related to SSA. Obligations under international law, fair use of outer space, economic benefit, protection of the space environment, and management of liability each warrant far more discussion than this piece can offer. For the purposes of outlining Australia's SSA capabilities, three metrics are identified here which provide basis for context against Australia's SSA activity: a summary of global efforts in space traffic management, debris mitigation endeavours and the significance of including SSA into a national strategy.

Space Traffic Management Initiatives around the World

The concept of space traffic management is made up by a combination of provisions, including those which use techniques employed in space situational awareness. The long-established Space Surveillance Network of the United States Strategic Command (SSN) is the first recognised space object detection and tracking capability to be established and share its space data to the public. The United States Strategic Command SSA Sharing

Program allows some information gathered through the SSN to be shared with non-US defence actors.

Many space agencies in the west, at least, have been less inclined to commit to SSA initiatives,[2] and with the growth and diversity in space activities today, there is a drive by non-governmental-dependant space efforts to establish new and improved SSA capabilities. The World Economic Forum is currently undergoing the Space Sustainability Rating (SSR) which offers a means to keep the global commons of Earth orbit viable in advancing human welfare. By collecting the available analytical tools for categorising space sustainability, the SSR intends to develop means to comprehensively assess the sustainability of space activities.[3] The Space Data Association takes a different approach, aiming to bring satellite operators together to maintain the integrity of the space environment. From the research side, the University of Texas at Austin's ASTRIAGraph[4] pulls data from several sources including governmental (eg SSN), private (eg Planet Labs Inc), and non-governmental (eg Union of Concerned Scientists) organisations to raise awareness through visualisations. The intention of ASTRIAGraph (ie Advanced Sciences and Technology Research in Astronautics) is for all its sources to link data and reduce discrepancies in space traffic detection.

Collaborative efforts amongst different countries are also being pursued to find new viable initiatives that contribute to space traffic management. The governmental consortium of the Group of Latin American and Caribbean States was formed give a common voice to non-major space-faring nations in international fora.[5] A means to achieve this is one voice is the coordination of space objects and activities between the member states.[6] This form of international cooperation ultimately facilitates SSA and, in turn, offers greater effect to space traffic management initiatives.

Debris Mitigation Initiatives from Around the World

In 2002 the Inter-Agency Space Debris Coordination Committee (IADC) drafted the non-binding Space Debris Mitigation Guidelines. Upon working with the IADC, the United Nations Committee on the Peaceful Uses of Outer Space (UNOOSA) introduced the *Space Debris Mitigation Guidelines*, which were adopted by the United Nations General Assembly in 2007.[7] In 2010, a Working Group on the Long-term Sustainability of Outer Space Activities was created within UNOOSA.

A more direct means to slow the growth of space debris is active debris removal. The Surrey Space Centre's RemoveDEBRIS, for instance, is a project attempting to capture some 40,000 pieces of debris.[8] As an alternative to active debris removal, on-orbit servicing is employed as a means to repair defunct satellites or manoeuvre them into other orbits to avoid congestion. Here ESA has taken initiative in its E.DEORBIT mission; one intended to refuel, refurbish or reboosting satellites already in orbit.[9] The world's leading defence firms are investing in on-orbit servicing, such as Airbus with its O.CUBED Services platform.[10] Though smaller enterprises are also engaging in SSA. In 2017, US company Space Systems Loral partnered with the US Defense Advanced Research Project Agency (DARPA) to develop an on-orbit robotic servicer as a means to lower the risk of space missions.[11] Such activities naturally also lower the risk of adverse space traffic.

SSA in Defence

Outside of active debris removal, the complex and risky nature of SSA is something worthy of consideration by federal defence and national security divisions. The U.S.' global SSN demonstrates the strategic nature of SSA's genesis, that being SSA was primarily pursued under a defence agenda and the capabilities arose through defence infrastructure.[12] Although less of the world's SSA capabilities are today supported by the SSN (compared to the last decades), military SSA data and infrastructure nevertheless remain an integral part of civil SSA endeavours.[13]

Australian Efforts in Space Situational Awareness

Australia recognises the importance of a nation needing to be aware of the status of its own activities in space, from the initial stage of mission planning to beyond the conclusion of the mission.[14] Leading up to the establishment of the Australian Space Agency ("Agency"), the Australian government-commissioned an Expert Reference Group review of Australia's space capability. The group's final report demonstrates how Australia may, and recommends Australia does, increase its strength in SSA.[15]

Space Traffic Management

Notwithstanding the research into the Integrated Air and space Traffic Management System,[16] Australia has no official space traffic management plan or body. However, Australia's activities in SSA and the data available to its authorities are capable in supporting any formal space situational awareness protocol. The University of New South Wales Canberra notes

Australia's main contribution to the awareness of space traffic is through space surveillance sensors hosted by ground stations.[17] However, the industry landscape is changing, with both private enterprise and research initiatives looking to utilise above-ground solutions in permitting space traffic management.

Business

Electro Optic Systems (EOS) is an Australian company which recently secured a collaboration with Northrop Grumman. EOS specialises in developing laser technology and software to track space debris. Newer commercial players include smaller companies with national recognition and international application. Adelaide-based Inovor Technologies is developing an SSA mission titled 'Hyperion.' By positioning a constellation of nanosatellites in low earth orbit, Hyperion's sensors look outwards (away from the earth) in order to capture data for a range of SSA applications. This mission builds upon Australia's sovereign SSA capabilities and contributes to the SSN.[18]

High Earth Orbit Robotics is another emerging company from Australia. "HEO Robotics" applies sensing solutions to cube satellites in swarms. This enables high resolution observations of space debris and other space objects. HEO Robotics' Argus mission is in principle similar to Inovor's Hyperion; use of low-cost satellites which look to outer orbits and thus providing high value solutions to SSA.[19]

Private players also help form the cohort advancing the signal aspects of SSA; that is the monitoring of frequencies rather than orbiting objects. In 2018 Sydney-based Sabre Astronautics was awarded a more than one million dollar contract to develop its system for monitoring and defining electronic threats.[20] Such is an illustration of the breadth Australia offers to the global SSA network.

Other approaches to meet the SSA challenge include the 2019 Nova Systems announcement of its upcoming Australian space industry course.[21] The suite is designed to support Australia's growing capabilities in the space domain. With a Joint Statement of Strategic Intent between Nova Systems and the Australian Space Agency mentioning SSA, it is plausible the course will include training in SSA specific fields.[22]

Research

In April 2019 UNSW Canberra hosted a space traffic management panel addressing the commons of space being used for hostilities. In its press release of this event the university outlined its plan for an SSA research program which proposes to investigate the link between physics and available data. This research would consist of simulations, ground-based experiments and orbital flight experiments to reduce the risk of orbital collisions.[23] UNSW Sydney, on the other hand, provides an undergraduate study unit on SSA. Elsewhere in Australia, Curtin University, RMIT University and Latrobe University both have debris tracking research foci.[24]

Defence

The Royal Australian Air Force (RAAF) has SSA capabilities primarily comprised of ground station infrastructure which detect and track space objects. This is not surprising considering Australia's natural advantage of access to land in the southern hemisphere with undisturbed skies allows enhances the SSN's global coverage of space objects. Several functions are performed by RAAF SSAF capabilities, enabling Australia to contribute to the monitoring and detection of orbital space objects, including space debris:[25]

1. SST: the Space Surveillance Telescope, though owned by the United States, is to be stationed at the Harold E Holt Naval Communication Station in Western Australia with the primary purpose to provide SSA data. The SST is to be operational in 2021;
2. 1RSU: Number 1 Remote Sensor Unit is planned to operate the Space Surveillance Telescope to address SSA;
3. C-band space surveillance radar: a radar system hosted at Harold E Holt Naval Communication Station to track orbiting space objects; and
4. SBIRS-AMP: the Space-Based Infra-Red System – Australian Mission Processor is a constellation of satellites operated by the United States for specific military awareness of space activity.

In 2017, through the ADF's prime research body, Defence Science and Technology Group, a joint project was undertaken with Western Sydney University using neuromorphic imaging to map space traffic.[26] Such technology offers terrestrial-based and space-based SSA capabilities.[27]

Debris Mitigation

Australia's ventures into debris mitigation are less obvious than its evident capabilities in traffic management. However, there are recent and significant sovereign developments which offer benefit to the global SSA community.

Business

Beyond its traffic management capabilities, EOS' debris management model uses the data it collects to avoid collisions and execute debris removal programs. Moreover, EOS is developing a laser for use to directly influence certain objects and move them into other orbits.[28]

Research

The Cooperative Research Centre for Space Environment Research was announced in March 2014. It was thereafter known as the Space Environment Research Centre (SERC). This $60 million program was to last five years covering four main programs:[29]

1. identification of space objects and preservations of the space environment;
2. orbit determination and predicting behaviours of space objects;
3. space asset management; and
4. space segment (ie payload testing and adaptation of optics).

SERC's primary industry partner is EOS, with which it has undergone research into debris manoeuvring using ground-based lasers. The ground network facilitating this research is Mt Stromlo Observatory, operated by the Australian National University's Advanced Instrumentation and Technology Centre.

In May 2019 another space-related cooperative research centre was announced, the Cooperative Research Centre for Smart Satellite Technologies and Analytics (SmartSat CRC). Though the SmartSat CRC's main objectives are enhanced connectivity, navigation and monitoring of Australia, one of its core research themes deals with debris mitigation and remediation.[30]

Defence

The Australian Defence Force acknowledges the importance of its future access to space and the significance of increasing risks of space debris.[31] The Australian Space Operations Centre (AUSSpOC) is a support body for space resources and guidance. Its activities include reporting on debris re-entry, space weather monitoring and sharing information with the United States through the Combined Space Operations Centre.[32] In April 2018 Lockheed Martin announced its provision to Australia of its iSpace (intelligent space) SSA system. The AUSSpOC will deploy the iSpace platform and input data from Australian infrastructure to assess and manage space manoeuvres, break-ups, re-entry and co-orbital threats.[33] Also to address SSA, Defence is engaging with the commercial sector in Plan Jericho, a strategy intended to harness intelligence and surveillance capabilities to increase situational awareness.[34] In March 2019, for instance, Inovor, HEO Robotics and EOS gave a demonstration or trial of their respective missions to the RAAF.[35]

Implementation of Relevant Regulations and Strategy

Australia has a limited range of SSA policies and regulatory conditions. *Australia's Satellite Utilisation Policy* of 2013 (Policy) seeks to promote cooperation between civilian and defence research in work domains contributing to space weather, SSA, and work that prioritises the strengthening of SSA capabilities.[36] Although the Policy does not outline directions for to guided stakeholders to reach these goals, Australian endeavours in these domains seem to be progressing towards these goals. Stakeholders in the space and defence communities have realised the significance of SSA for understanding the risks to accessing and using space, and the potential risks from re-entering space debris.[37]

The Agency was established in July 2018 as an office under the Department of Industry, Innovation and Science. Although one of the Agency's seven priority areas include SSA and debris monitoring,[38] it has yet to demonstrate any ongoing commitment to this domain, notwithstanding recognising it as a common priority through a statement of strategic intent with Australian defence solutions company Nova Systems.[39] This might be seen in contrast with the United States of America's *Space Policy Direction 3*, announced in June 2018. This direction designates the department of commerce to take an active lead in civil SSA, including formulating analyses and disseminations of government and private SSA data, capabilities and services.[40]

From a regulatory point of view, however, the Agency has included in its revision of the space activities legislation the requirement for satellite operators and launch vehicle operators to provide a debris mitigation strategy when applying for the relevant authorisation.[41] The exact standard is not yet defined but the Agency has so far proposed it must be an internationally recognised guideline or standard which is identifiable. Such a debris mitigation strategy is likely to also include an orbital debris assessment based on an internationally recognised model.[42] Such regulations are to be confirmed by and enforced on 31 August 2019. This means the enforcement will likely occur before the Australian industry analyses and agrees on the debris models to be used. This presents a risk to operators who may wish to devise a space debris mitigation strategy in line with practice and knowledge of Australian activities and discoveries, as opposed to a non-binding and little-demonstrated international standard.

Conclusion

As the space domain is used as a shared global commons, the long-term sustainability of space, and operations within, face a growing risk from the continuation of little coordinated and uncontrolled space access and usage. Fortunately, Australia is among the nations with key capabilities in SSA. Accordingly, it is in a prime position to contribute space tracking data and be global player with interests in better space traffic management and space sustainability. Although Australia is not yet managing any sovereign space traffic management system, its sovereign SSA-related activities are capable of contributing to such an initiative. The several examples of Australian initiatives and contributions to SSA compris of business, research and Defence activities in space traffic management and space debris removal.

Australia's existing approaches towards developing policy for the space domain will almost surely see it become a more significant actor in the global response to the increasing stresses in the utilisation of outer space. Some of these capabilities are well established, such as its ground infrastructure and collaborative efforts in SSA between Defence and the United States. Australia is also continuing to realise its potential in this field through addressing the gaps in its SSA-related capabilities. Civil actors are contributing to SSA with capabilities offering the country strong avenues to building a space traffic management plan. Many of these, research centres and those in the private sector are developing expertise in debris mitigation methods which can themselves play a major role in effecting space traffic management. Space traffic management itself is perhaps Australia's next step after Defence's Plan Jericho has increased Australia's proficiencies in the SSA domain and helped the country realise and appreciate its capabilities.

With the ripe business environment in Australia and the opportunities available through new civil projects such as the SmartSat CRC and the rise of private launch operators, the country is likely to see more companies, research centres and defence applications defining Australia as a global example in SSA domains.[43] As such, SSA is going to continue to gain traction among the discussions and projects in the Australian space and defence communities. These discussions and projects should be welcomed, as they are necessary to ensure Australia best secures its own space assets and national interests.

Appendix I

List of organisations involved in Australian space situational awareness.

Organisation name	Organisation type	SSA activities	Relevant webpage
Australian National University	Research	Adaptive optics	https://rsaa.anu.edu.au/aitc/capabilities
Australian Space Operations Centre	Defence	Monitoring and reporting	-
CSIRO	Research	Australian SKA Pathfinder	https://www.atnf.csiro.au/projects/askap/index.html
Curtin University	Research	Tracking	https://astronomy.curtin.edu.au/
Defence Science and Technology Group	Defence	Facilities for research	https://www.dst.defence.gov.au/research-area/surveillance-and-space
Electro Optic Systems	Commercial	Laser tracking	https://www.eos-aus.com/space/
High Earth Orbit Robotics	Commercial	Cubesat components	https://www.heo-robotics.com/
Inovor Technologies	Commercial	Satellite manufacturing	https://www.inovor.com.au/space-technology/hyperion-mission/
La Trobe University	Research	Radar development (for space weather)	https://www.latrobe.edu.au/engineering/research/tiger
Lockheed Martin Space Systems	Commercial	Facilitating Australian industry and research	https://www.lockheedmartin.com/en-au/products/space-systems.html
Nova Systems	Commercial	Strategic intent with Australian Space Agency	https://novasystems.com/news/media-release-nova-systems-makes-commitment-enhancing-capability-australian-space-sector/
Optus	Commercial	Operator for research	http://www.serc.org.au/research/program-3/

Organisation name	Organisation type	SSA activities	Relevant webpage
RMIT University	Research	Software and algorithms	https://www.rmit.edu.au/research/research-institutes-centres-and-groups/research-centres/space-research-centre/research-areas/space-debris-and-tracking
Sabre Astronautics	Commercial	Software and analytics	https://saberastro.com/analytics
Silentium Defence	Commercial	Radar	https://www.silentiumdefence.com.au/
Space Environment Research Centre	Research	Laser development	http://www.serc.org.au/
UNSW Canberra	Research	Space traffic management and astrodynamics	https://www.unsw.adfa.edu.au/research/research-areas/integrated-air-and-space-traffic-management-system ; https://www.unsw.adfa.edu.au/space-research/research-themes/space-situational-awareness
UNSW Sydney	Research	Education	https://www.handbook.unsw.edu.au/undergraduate/courses/2019/ZEIT4507/
Western Sydney University	Research	Tracking	https://www.westernsydney.edu.au/icns/astrosite

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43 A list of currently evident endeavors is provided in Appendix I below.

Part 2

Rules for Space Activities

The Law of Rules:
The Use of Rules for the Advancement
of Debris Mitigation Strategies in Space Activities

Enforcement of Commercial Regulation in Outer Space

The Woomera Manual: Clarifying the
Law of Military Space Operations to
Promote Sustainable Uses of Outer Space

Developing Effective Space Traffic
Management to Promote Sustainable Uses of Outer Space

Earth Observation Data - Climate Change Monitoring

The Law of Rules: The use of Rules for the Advancement of Debris Mitigation Strategies in Space Activities

A. Griffin, P. Mackenzie, A. Sherborne, H. Sit and L. Jackson[1]

> *'[Debris management and mitigation is] the one area where we can step up as a responsible citizen ... that is why it is highlighted as one of [the Australian Space Agency's] key priorities.'*[2]

Introduction

As many as 95% of the man-made objects tracked in space can be considered 'space debris'.[3] Indeed, the saturation of orbital debris has caused some in the space user community to comment that the situation is at 'tipping point'.[4] Despite the vastness of space, functional orbits have become increasingly dangerous and expensive,[5] and potentially unusable if the issue of space debris is not adequately addressed.[6]

Outer space has traditionally been the domain of government entities. However, as the costs of access to space decrease, governments are increasingly focused on the regulation of new commercial space participants. This is especially true for those States obliged to supervise the domestic activities of its citizens under the *Outer Space Treaty*.[7] Pressure to develop robust international space debris regulation is also mounting in response to a number of recent trends – the number of launches is increasing year-on-year as commercial enterprises have greater access to conduct space activities given the reduction in barriers to entry, states are increasingly interested (and becoming dependent on) activities and infrastructure in outer space (notably for telecommunications and military purposes), and the Kessler Syndrome effects continue to loom large.[8]

Given the relative infancy of Australia's space industry, and the increasing levels of investment and research and development, Australia is in a prime position to emerge as an industry leader in global efforts for space debris mitigation.[9] As there is a general reluctance in adopting new multilateral treaties as a means of tackling global pollution issues,[10] developing domestic regulation appears to be an effective and proven means for motivating international norms around space debris mitigation.[11] Furthermore, the supra-national constraints on European countries, such as those imposed by the European Space Agency (ESA) and the European Union (EU), and the self-interest of sovereign nations, makes any cohesive approach to developing internationally adopted standards difficult.[12]

In August 2019, the *Space Activities (Launches and Returns) Act 2018* (Cth) will come into effect,[13] amending the *Space Activities Act 1998* (Cth) ('*Act*'), after extensive consultations with the public community, including the Australia New Zealand Space Law Interest Group. For the first time in Australia, there will be an express requirement for space permit applicants to consider the impact of debris consequent upon their proposed activities. Under the *Act*, applicants for the grant, variation or transfer of an Australian launch permit,[14] or overseas payload permit will be required to submit a strategy for debris mitigation.[15] With the content of a debris mitigation plan left fairly unprescribed in the rules,[16] this requirement represents an opportunity for Australia to position itself as a pioneer in effective debris mitigation strategies.

This paper discusses international standards that can be used as a benchmark for Australian debris mitigation plans and how they can be improved. It also demonstrates why the enforcement of debris mitigation standards is important in shifting global norms to a point where debris mitigation is a positive legal obligation.

Existing approaches to debris mitigation standards

International standards

In 1995, the United States, through the National Research Council published the first comprehensive review of the problem of space debris, and included recommendations for future debris mitigation.[17] Eventually, other space agencies published their own debris mitigation guidelines. For example, in 2002, the Inter-Agency Space Debris Coordination Committee (IADC) published a consensus set of guidelines in order to ensure consistent approaches were being taken by the various spacefaring nations (‘*IADC Guidelines*’).[18] In arriving at these guidelines, the IADC identified three common fundamental principles of debris mitigation strategies.[19] They are:

1. prevention of on-orbit break-ups;
2. removal of spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbital regions; and
3. limiting the objects released during normal operations.[20]

In 2007, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) largely adopted the *IADC Guidelines* in the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, albeit in more aspirational, less technical language than their IADC equivalents (‘*COPUOS Guidelines*’).[21]

In 2007, the United Nations (UN) officially endorsed the *COPUOS Guidelines*.[22] Critically, the UN invited Member States to implement national and international guidelines through relevant national mechanisms.[23]

State implementation

A variety of different approaches have been taken to incorporate international standards into domestic legislation. In the United Kingdom, compliance with the *IADC Guidelines* is ‘one of the factors to be considered in granting a licence’.[24] There is, however, little guidance on what constitutes sufficient compliance in order for a licence application to be successful.[25] Similar approaches can be seen in legislative regimes of France and Canada.[26]

The *United States Government Orbital Debris Mitigation Standard Practices* was approved by all United States (US) Government agencies in 2001, and has been shared with the US aerospace industry in an attempt to encourage voluntary compliance.[27] NASA has also developed the *Procedural Requirements for Limiting Orbital Debris*, which came into effect in August 2007, and reflect NASA's policy to limit future orbital debris generation.[28] Furthermore, for certain satellites in a geostationary orbit, the US mandates the performance of a specific end of life disposal manoeuvre.[29] This is the most developed series of guidelines imposed on space object operators.[30]

China adopts a 'semi-regulated' model under which space activity participants are required to submit a 'memorandum' that outlines how the problems of pollution and space debris are addressed.[31] An 'administrative sanction' can be imposed for misstatements made during the application stage.[32] This is similar to the legislative requirements in Australia that an applicant for a space launch licence must provide a debris mitigation plan.[33]

In 2009, Russia introduced the *General Requirements to Spacecraft and Orbital Stages on Space Debris Mitigation*[34] which are consistent with the *COPUOS Guidelines*, and require compliance during all stages of a space project.[35]

The Australian approach

1. The framework

Under the rules to accompany the Act that came into force on 26 August 2019 ('*Rules*'),[36] the strategy for debris mitigation in an application for the granting of an Australian launch permit[37] or overseas payload permit,[38] must:

1. be based on an *internationally recognised guideline* or standard for debris mitigation (ie in both the terrestrial and orbital space environments), and identify the guideline or standard used;
2. describe any mitigation measure planned for orbital debris arising from the proposed launch or launches (including from payloads); and
3. include an orbital debris assessment based on an internationally recognised model.[39]

The *Rules* also provide examples of mitigation measures – for instance, how debris may be limited during normal operations, how the potential for break-ups during normal operational phases will be minimised, how the probability of accidental collision in orbit will be limited, how the potential for post-mission break-ups as a result of stored energy will be minimised, and how the long-term presence of payloads and launch vehicle orbital stages in the low-earth orbit region or in geosynchronous earth orbit will be limited after the end of the mission.[40]

One criticism of the language used in the *Rules* is the loose reference to 'internationally recognised guidelines' as a benchmark. The *COPUOS Guidelines*, for example, are internationally recognised as debris mitigation guidelines, however, they are aspirational statements, rather than technical and quantifiable standards.

2. Direct enforcement

The only requirement under the current *Rules* is that the application for a permit is accompanied by an applicant's debris mitigation strategy. The *Rules* and the *Act* are silent on the consequences of failure of a permit-holder to comply with the content of the debris mitigation strategy.[41] Furthermore, under the *Rules*, the standard conditions imposed on launch permits and overseas payload permits do not make any reference to consequences for non-compliance with the proponent's strategy for debris mitigation,[42] despite breaches of other conditions imposed by the *Act* attracting civil penalties and even criminal sanctions. Although additional conditions may be specified in the permit,[43] and therefore could provide means for the enforcement of space debris mitigation, this leaves considerable discretion in the hands of Government decision makers.

The omission of any reference to compliance with debris mitigation strategies is glaring. Currently, the Australian regulations do not contain any clear enforcement mechanism to ensure compliance with space participants' strategies for debris mitigation.

3. Indirect enforcement

The only apparent mechanism by which compliance for debris mitigation strategies may be enforced appears to be through the general competence assessment that forms part of the assessment of an application for a launch permit.[44] The Minister may exercise their discretion and refuse to issue a permit to a person if they find the person who is to carry out the launch is not competent to do so.[45] Further, under s 28(3)(e), the Minister may consider reasons relevant to the international relations of Australia in not granting a permit.[46] Given Australia's obligations under the *Outer Space Treaty* to supervise its nationals,[47] to remain liable for damage caused by

Australian space objects,[48] to retain jurisdiction over Australian space objects,[49] and to not cause harmful contamination of the outer space environment,[50] applicants that will not be able to adequately implement debris mitigation plans could be refused a permit on the basis that they will damage Australia's international relations.

In terms of sanctioning non-compliance with a debris mitigation strategy once a space object has reached orbit, the only mechanism appears to be a suspension of the permit by the Minister under s 36 of the Act. However, it remains unclear what the consequences of suspension of the launch permit at this stage would be.

Improving Australia's approach

Australia's aspiration is to become a world leader in debris management and mitigation.[51] However, the *Rules* reflect a reality where Australia is merely playing catch-up with the rest of the global space industry, rather than setting itself as a benchmark jurisdiction.

In the absence of enforceable laws against space participants, there is no means to capture the negative externality caused by space debris, rendering outer space a 'classic example of the tragedy of the commons'.[52] This leaves functional orbits prone to destruction through participants choosing low cost options rather than more expensive options that are likely to generate less debris.[53] The challenge for Australia is to balance implementing a new regulatory regime that encourages space participation and protects national interests, but does not stifle growth of the domestic industry or disincentivises foreign space participants from using Australia as the launch state due to its stricter regulatory regime.[54]

Australia could improve the *Rules* in three ways;

1. introducing clearer and higher technical standards;
2. introducing clearer enforcement mechanisms; and
3. introducing compliance incentives.

The adoption of clearer enforcement mechanisms will also be significant for the recognition of space debris mitigation as a more concrete international legal obligation and its acknowledgement as an issue already contemplated in international law.[55] This discussion regarding the impact of Australia's domestic approach on the international legal landscape is discussed below in Chapter III.

1. Implementing clearer and higher technical standards

Li asserts that the space debris issue is a technical issue, not a legal issue, and as such the most effective solutions will be found through a technical solution, not legal frameworks.[56] Therefore, a light touch approach should be provided, rather than heavy handed regulation. Despite this, given Australia's ambitions to be a global leader in this area, a possible way forward would be implementing technical standards to be adhered to by permit holders.

Using the *IADC Guidelines* as a starting point, a number of simple modifications can be made that are within existing technical capabilities. These changes include:

1. introducing mandatory international standards imposed on states by UN-affiliated organisations;
2. introducing operational standards in outer space;
3. introducing construction standards;
4. introducing launch standards;
5. imposing legal obligations on the operator and the authorising country to remove debris caused by new launches;
6. lowering the maximum years to deorbit from 25;
7. registration of space debris and imposing a duty to catalogue and register as much space debris as possible;
8. more efficient transfer of satellites in GEO into graveyard orbits at the end of their useful existence;
9. greater restrictions on launches into certain orbits;
10. imposing design requirements to ensure that satellites and launch vehicles cannot break up; and
11. introducing passive protection techniques (as are currently used to protect the International Space Station).[57]

Other aspects of the *IADC Guidelines* appear at odds with other policy objectives – for example, increasing restrictions on the number of launches. Given the significance of the technical developments not only in relation to space but also debris management techniques since the *IADC Guidelines* were developed, the authors consider that it an opportune time to review the appropriateness of the measures identified in the *IADC Guidelines*.

It is critical that in developing these standards that Australia finds an appropriate balance between the desire to be a world-leader in debris mitigation, and the possible negative consequences of implementing higher standards—in particular, the risk that applicants may choose to launch from a nation with lower standards, in an effort to decrease costs.

For example, the push towards reducing the lifespan of space objects is increasingly relevant as manufacturers shift towards swarm and micro-sats in low-Earth orbit to provide terrestrial services, and the market moves away from constellations with fewer objects. This is also a function of the reduction in the costs of accessing space. SpaceX can now for instance launch and deploy its own swarm of Starlink Satellites, although the height of operation of the Satellites was lowered to reduce latency and so that they would naturally deorbit within 5 years without propulsion, in acknowledgement of the growing issue of space debris. Although the market may trend towards shorter lifespans, Australia has the opportunity to get ahead of the game by imposing a shorter lifespan than 25 years on the deorbit of non-functional space objects.

2. Introducing clearer enforcement mechanisms

Although non-binding policies do play a substantial role in space debris mitigation efforts,[58] introducing clear enforcement mechanisms is a necessary step to ensure recipients of an Australian launch or overseas payload permit comply with their proposed debris mitigation plan. The ESA has acknowledged that even if States were fully compliant with the *IADC Guidelines*, long-term proliferation of space debris is still expected.[59] As the *Act* and the *Rules* currently stand, they do not contain any consequence or penalty for an applicant's failure to comply with their proposed debris mitigation strategy. This, if not addressed, will inevitably reduce the likelihood of compliance. Enforcement should be three-fold, through:

1. the introduction of a standard condition under r 36 of the *Spaces (Launches and Returns) (General) Rules*,[60] requiring compliance with a proponent's strategy for debris mitigation;
2. the introduction of a penalty provision for a failure to comply; and
3. by considering any previous non-compliance when assessing any future applications for a launch or overseas payload permit.

3. Introducing compliance incentives

It is also necessary to balance the possible negative consequences of introducing enforcement mechanisms with Australia's desire to increase space investment, including by attracting prospective launch participants. If enforcement measures are too restrictive and burdensome, space participants are likely to be discouraged from selecting Australia as their preferred location for launches and other space activities.

As the space industry matures, the imposition of, and compliance with, higher standards will result in benefits through a reduction in insurance premiums. Eventually it would be hoped that a space participant who decides to launch in Australia under Australian oversight and with the authority of an Australian launch permit would be rewarded with lower premiums than if they were to choose a different, less stringent jurisdiction. This is particularly relevant in the context of the Space Sustainability Rating mechanism propounded by the World Economic Forum,[61] where the choice of jurisdiction will be reflected in the overall rating of a particular space mission with consequent benefits in the pricing of the appropriate level of insurance coverage.

The role of rules in international law

While it is accepted there is currently no explicit international legal obligation to mitigate risks associated with space debris,[62] nations causing space debris may already likely be in violation of the *Outer Space Treaty* and also at least one treaty relating to a specific use of space due to the effect of space debris preventing nations from accessing space.[63] Australia, through strong State practice, can leverage off this and help establish debris mitigation as an international legal obligation in light of the space treaty regime currently in place. Indeed, Li argues that space debris mitigation may yet form part of customary international law.[64]

Customary international law

The absence of explicit treaty obligations does not preclude the development of customary international legal obligations. Analogously, international environmental obligations seem to be one area in which customary law is considered to be an important source of law.[65] For instance, the duty to prevent transboundary pollution is 'generally observed as one of the most firmly established norms of customary international law'[66] and this principle has been confirmed by the *Trail Smelter Arbitration*[67] which held that a state was liable for pollution damaged caused to another state.

The International Court of Justice summarised the formation of customary international law in *Northwest Sea Continental Shelf*:

> Not only must the acts concerned amount to a settled practice, but they must also be such, or be carried out in such a way, as to be evidence of a belief that this practice is rendered obligatory by the existence of a rule of law requiring it.[68]

Therefore, for debris mitigation to be recognised as part of customary international law, there must be (1) sufficient settled state practice, and (2) evidence of the belief that the practice is rendered obligatory by the existence of a rule of law requiring it (*opinio juris*).

Settled state practice

Based on the domestic regimes already discussed, there appears to be a body of state practice in considering the impact of space debris when supervising and regulating space operations. Further, although a short passage of time is not a barrier to state practice becoming customary international law,[69] state practice in recognising the importance of mitigating space debris can be traced back to the early 1990's and the *Debris Mitigation Standard Practices* developed by NASA in 1997,[70] which supports the position that debris mitigation is a customary international legal obligation.

What is important in establishing customary norms however, is that that the State practice is both 'extensive and virtually uniform.'[71] We can see from the domestic regimes of most major space participants, such as the US, Russia, (the ESA and the various agencies under it),[72] China and Australia, that there is extensive implementation of debris mitigation guidelines. It is arguable that although countries such as the United States and Russia have implemented higher standards than most, domestic regimes are 'virtually' uniform in that the *IADC Guidelines* and *COPUOS Guidelines* seem to be common minimum standards. Several authors assert that these domestic regimes demonstrate the first limb in establishing debris mitigation as part of customary international law has probably been realised.[73]

Opinio juris

Where debris mitigation being part of customary international law falls down is the apparent lack of *opinio juris*. Although widespread and uniform, state practices must be underpinned by a sense of legal obligation for adopting those practices. Wessel argues that despite the widespread State practice, there have been consistent assertions by States that they do not believe the practices they are adopting are a legal obligation.[74] Indeed the *IADC Guidelines* themselves are non-binding.[75]

An important step along the way is recognising debris mitigation as a formal legal obligation incumbent upon all space participants. First, through the form of customary international law, where domestic legal frameworks regarding debris mitigation impose binding obligations on states on the basis of some international legal obligation to do so.[76] Second, through interpretations of the existing treaty framework, in particular the way in which debris mitigation guidelines provide evidence of the standard required in order to comply with the international treaty obligations.[77]

However, through the implementation of consequences for a failure to comply with strategies for debris mitigation, the mitigation of debris by a State's nationals in space would appear to be reflective of an international legal obligation to not contaminate outer space with debris, rather than being just a nice thing to do.

Conclusion

In conclusion, Australia has used the opportunity to update the Act to catch up to, rather than get ahead of, global best practice on space debris mitigation. Australia can still improve its domestic regime by introducing clearer technical standards that are required of space participants when applying for launch and overseas payload permits. Further, by introducing clear consequences for a failure to adhere to strategies for debris mitigation, Australia can help shift debris mitigation from a series of ad hoc domestic regimes and into the realm of customary international law. This will, in the long run, benefit all space participants and preserve space as the 'province of all mankind'[78] and promote Australia's intent and commitment to space debris mitigation to the local space industry and the global space user community.

Endnotes

1 The authors are writing in their personal capacities. The views in this paper do not reflect the views of their employer, King & Wood Mallesons.

2 Moderated Discussion with Megan Clark (Space Economy: the Future for WA, Committee for Economic Development of Australia, held on 26 March 2019).

3 Li, L (2015). Space Debris Mitigation as an International Law Obligation. 17(3) International Community Law Review. *p* 297, 298. Online at https://heinonline.org/HOL/P?h=hein.journals/intlfddb17&i=297. Accessed 12 September 2019; Bressack, L (2011). Addressing the Problem of Orbital Pollution: Defining a Standard of Care to Hold Polluters Accountable. 43(4) *George Washington International Law Review* p741, 747. Online at http://connection.ebscohost.com/c/articles/77480582/addressing-problem-orbital-pollution-defining-standard-care-hold-polluters-accountable. Accessed 12 September 2019; St John, D (2012). *The Trouble with Westphalia in Space.* 40(4) Denver Journal of International Law and Policy. p 686, 688. Online at www.questia.com/library/journal/1G1-304466308/the-trouble-with-westphalia-in-space-the-state-centric. Accessed 12 September 2019; Space debris is defined by the Inter-Agency Space Debris Coordination Committee (IADC) as 'all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional': see Inter-Agency Space Debris Coordination Committee (2007) *IADC Space Debris Mitigation Guidelines* (IADC-02-01, Revision 1, September 2007) *('IADC Guidelines*'). Online at Online at www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf. Accessed 12 September 2019*;* see also Li (n 2) p311.

4 National Research Council of the National Academies (2011). *Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs.* National Academies Press. P 1. Online at www.nap.edu/catalog/13244/limiting-future-collision-risk-to-spacecraft-an-assessment-of-nasas. Accessed 12 September 2019.

5 Bressack (n 2) 742; Merges, R; Reynolds, G (2010). *Rules of the Road for Space?: Satellite Collisions and the Inadequacy of Current Space Law.* 40(1) Environmental Law Reporter 10,009, 10,010. Online at www.law.berkeley.edu/files/article-2011-10-40.10009-1.pdf. Accessed 12 September 2019.

6 St John (n 2) 688.

7 UNOOSA (1967). *Treaty on Principles Governing the Activities of State in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, opened for signature 27 January 1967, 610 UNTS 8843 (entered into force 10 October 1967), art VI ('*Outer Space Treaty*'). Online at www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html. Accessed 12 September 2019.

8 Larsen, P (2018). Solving the Space Debris Crisis. 83(3) *Journal of Air. p* 475, 481. Online at https://heinonline.org/HOL/P?h=hein.journals/jalc83&i=498. Accessed 12 September 2019. The Kessler Syndrome, loosely defined, is the resulting destruction of lower-earth orbit by organic multiplication of existing debris caused by collisions.

9 Debris mitigation is defined by the Inter-Agency Space Debris Coordination Committee as 'all efforts to reduce the generation of space debris through measures associated with the design, manufacture, operation, and disposal phases of a space mission': see *IADC Guidelines* (n 2).

10 Li (n 2) p310; Roe, M (2009). *Multi-Level and Polycentric Governance: Effective Policymaking for Shipping.* 36(1) Maritime Policy and Management. pp39, 50, 53. Online at www.tandfonline.com/doi/abs/10.1080/03088830802652296. Accessed 12 September 2019; Vorbach, J (2001). *The Vital Role of Non-Flag State Actors in Pursuit of Safer Shipping.* 32(1) Ocean Development and International Law, pp 27, 31. Online at www.tandfonline.com/doi/abs/10.1080/00908320150502186. Accessed 12 September 2019; Lampertius, J (1992). *The Need for an Effective Liability Regime for Damage Caused by Debris in Outer Space.* 13(2) Michigan Journal of International Law *pp* 446, 454. Online at https://repository.law.umich.edu/cgi/viewcontent.cgi?article=1619&context=mjil. Accessed 12 September 2019; St John (n 2) p712; Morgera, E (2009). *Corporate Accountability in International Environmental Law.* Oxford University Press. p 41. Online at http://dl4a.org/uploads/pdf/9780199558018.pdf?bcsi_scan_f3c628fb27335eb8=1. Accessed 12 September 2019; Goedhuis, D (1989). *Reflections on Some of the Main Problems Arising in the Future Development of Space Law*. 36(3) Netherlands International Law Review, pp 247,267. Online at https://doi.org/10.1017/S0165070X00009013. Accessed 12 September 2019; von der Dunk, F (2015). International Space law, *The Handbook of Space Law.* Edward Elgar Publishing. pp 29, 43; Goh, G (2008). *Softly, Softly Catchee Monkey: Informalism and the Quiet Development of International Space Law*. 87 Nebraska Law Review. pp 725, 744. Online at https://digitalcommons.unl.edu/nlr/vol87/iss3/5/. Accessed 12 September 2019.

[11] von der Dunk, F (2015). *International Space Law*. The Handbook of Space Law. Edward Elgar Publishing. pp 29, 43; Goh, G (2008). *Softly, Softly Catchee Monkey: Informalism and the Quiet Development of International Space Law.* 87(3) Nebraska Law Review. pp 725, 743–4. Online at https://digitalcommons.unl.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1033&context=nlr. Accessed 13 September 2019.

[12] Wouters, J; De Man, P; Hansen, R (2016). *Space Debris Remediation, Its Regulation and the Role of Europe. Working Paper No. 153 – March 2015.* Institute for International Law. Online at https://ghum.kuleuven.be/ggs/publications/working_papers/2015/153woutersdemanhansen. Accessed 13 September 2019.

[13] The *Space Activities (Launches and Retrievals) Act 2018* (Cth) received royal assent on 31 August 2018.

[14] Australian Government (2018). *Space Activities Act 1998* (Cth), s 34(2) (as amended by *Space Activities (Launches and Returns) Act 2018* (Cth)) ('*Space Activities Act*'). Department of Industry, Innovation, and Science. Online at www.industry.gov.au/regulations-and-standards/space-regulation. Accessed 13 September 2019.

[15] ibid s 46G(2).

[16] ibid ss 34(2) and 46G(2). See *Space (Launches and Returns) (General) Rules 2019* rr 49 and 74 ('*Rules*') which respectively require debris mitigation strategies for Australian launch permits and overseas payload permits to be based on an 'internationally recognised guideline or standard' and 'describe any mitigation measures planned'. The Rules provide examples of appropriate mitigation measures, but do not prescribe those measures.

[17] National Research Council (1995). *Orbital Debris: A Technical Assessment.* National Academies Press. Online at www.nap.edu/catalog/4765/orbital-debris-a-technical-assessment. Accessed 13 September 2019.

[18] *IADC Guidelines* (n 2).

[19] ibid 4.

[20] ibid. It is worth noting that since the last revision of the IADC Guidelines in 2007, there has been a marked increase in the number and type of activities conducted in, or connected to, outer space. This can be linked to the significant advancement of technological capability combined with a reduction in costs. To reflect these developments, the Inter-Agency Space Debris Coordination Committee is planning to consider several possible amendments in the next revision of the IADC Guidelines.

21 Li (n 2) 305. Paragraph 24 of the *COPUOS Guidelines* provides that the Committee may periodically review and revise the guidelines to ensure their effectiveness at promoting the long-term sustainability of outer space activities. This should be done to ensure the guidelines are effective and current, taking into consideration advancements in technology and the increased use of outer space.

22 UNOOSA (2007). *International Cooperation in the Peaceful Uses of Outer Space.* GA Res 62/217, UN Doc A/RES/62/217 (22 December 2007). United Nations Office for Outer Space Affairs. Online at www.unoosa.org/oosa/oosadoc/data/resolutions/2007/general_assembly_62nd_session/ares62217.html. Accessed 13 September 2019.

23 ibid.

24 Li (n 2) 318.

25 UK Space Agency (2018). Guidance for Licence Applicants—Outer Space Act 1986. United Kingdom Space Agency Report, August 2018. Online at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/744428/GUIDANCE_FOR_APPLICANTS_Revised_08-08-2018_sw1.pdf. Accessed 13 September 2019.

26 Li (n 2) 319.

27 NASA (2017). *NASA Procedural Requirements for Limiting Orbital Debris*. Astromaterials Research & Exploration Science Orbital Debris Program Office. August 2017. Online at https://orbitaldebris.jsc.nasa.gov/mitigation/. Accessed 13 September 2019.

28 ibid.

29 Li (n 2) p319.

30 Tronchetti, F (2015). *The Problem of Space Debris: What Can Lawyers Do About It?* 64(2) German Journal of Air and Space Law. pp 332, 339. Online at https://heinonline.org/HOL/Page?handle=hein.journals/zlw64&div=27&g_sent=1&casa_token=&collection=journals. Accessed 13 September 2019.

31 Li (n 2) p319.

32 ibid.

33 Australian Government (2018). *Space Activities Act 1998* (Cth), s 34(2) and 46G(2) (as amended by *Space Activities (Launches and Returns) Act 2018* (Cth)) (‘*Space Activities Act*’). Department of Industry, Innovation, and Science. Online at www.industry.gov.au/regulations-and-standards/space-regulation. Accessed 13 September 2019.

[34] ROSCOSMOS (2019). *Inter-Agency Space Debris Coordination Committee*. Russian Federal Space Agency Online at www.iadc-home.org/agencies_roscosmos. Accessed 13 September 2019.

[35] Li (n 2) p315.

[36] *Rules* (n 15).

[37] *Space Activities Act* (n 13) s 34(2).

[38] ibid s 46G(2).

[39] *Rules* (n 15) rr 49 and 74 (emphasis added).

[40] ibid rr 49(2) and 74(2).

[41] Li (n 2) p319.

[42] *Rules* (n 15) r p36.

[43] *Space Activities Act* (n 13) ss 29(1)(b) and 46C(b).

[44] ibid s 28(3)(a).

[45] ibid s 28(3)(a).

[46] ibid s 28(3)(a).

[47] *Outer Space Treaty* (n 6) art VI.

[48] ibid art VII.

[49] ibid art VIII.

[50] ibid art IX.

[51] Clark (n 2); Clark, M (2018). *Australian Space Agency Launches Operations: A Message from Head, Dr Megan Clark AC.* Department of Industry, Innovation and Science. Online at www.industry.gov.au/news-media/australian-space-agency-news/australian-space-agency-launches-operations-a-message-from-head-dr-megan-clark-ac. Accessed 13 September 2019; Driver, S (2018*). The Big Global Space Agencies Rely on Australia—Let's Turn that to our Advantage.* The Conversation. Online at https://theconversation.com/the-big-global-space-agencies-rely-on-australia-lets-turn-that-to-our-advantage-97939. Accessed 13 September 2019; The Space Environment Research Council, located in Canberra, Australia, has significant capacity and expertise in the measurement, monitoring, analysis and management of space debris, and is involved in development of new technologies and strategies to preserve the space environment.

[52] Merges and Reynolds (n 4) pp10,011.

[53] See for instance the collision between Iridium 33 and Kosmos-2251, which was arguably contributed by the failure to de-orbit the Kosmos-2251

satellite once it reached the end of its functional life. Instead, the Russians left it in orbit, without enough fuel to de-orbit it. The cost of storing fuel on board to deorbit space craft is very expensive in terms of payload.

54 The same methodology can be seen in the use of flags of convenience in oil shipping contexts.

55 Although issues of liability in outer space are beyond the scope of this paper, it is worth noting that there appears to be growing consensus that liability rules ought to be updated in light of recent developments in space technology. As commercial actors become more prevalent than nation states in outer space, the rules under the *Convention on International Liability for Damage Caused by Space Objects* appear to have less significance.

56 Li (n 2).

57 Larsen (n 7), p481.

58 Popova, R; Shaus, V (2018). *The Legal Framework for Space Debris Remediation as a Tool for Sustainability in Outer Space.* 5(2) Aerospace. pp 55, 11. Online at www.mdpi.com/2226-4310/5/2/55/pdf-vor. Accessed 13 September 2019.

59 ESA (2017). *Active Debris Removal.* Space Debris. European Space Agency. Online at www.esa.int/Our_Activities/Space_Safety/Space_Debris/Active_debris_removal. Accessed 13September 2019.

60 *Rules* (n 15) r 36.

61 Foust, J (2019). *Consortium to Develop "Space Sustainability" Rating System.* Space News. *Online at* https://spacenews.com/consortium-to-develop-space-sustainability-rating-system/. Accessed 13 September 2019.

62 UNOOSA (2011). *Towards Long-Term Sustainability of Space Activities: Overcoming the Challenge of Space Debris—A report of the International Interdisciplinary Congress on Space Debris*, 48th session, Draft Provisional Agenda Item 7, UN Doc A/AC.105/C.1/2011/CRP.14 (3 February 2011). Online at www.unoosa.org/pdf/limited/AC105_C1_2011_CRP14E.pdf. Accessed 13 September 2019.

63 Munoz-Patchen, C (2018). *Regulating the Space Commons: Treating Space Debris as Abandoned Property in Violation of the Outer Space Treaty*. 19(1) Chicago Journal of International Law. *pp* 233, 252. Online at https://chicagounbound.uchicago.edu/cgi/viewcontent.cgi?article=1741&context=cjil. Accessed 13 September 2019.

64 Li (n 2) 317.

[65] Bodansky, D (1995). *Customary (And Not So Customary) International Environmental Law.* 3(1) Indiana Journal of Global Legal Studies. pp 105, 106. Online at www.repository.law.indiana.edu/cgi/viewcontent.cgi?article=1060&context=ijgls. Accessed 13 September 2019.

[66] ibid 110.

[67] United Nations (2006). *Trail Smelter Arbitral Tribunal (1941).* Reports of International Arbitral Awards. Vol III. pp 1905-1982. Online at http://legal.un.org/riaa/cases/vol_III/1905-1982.pdf. Accessed 13 September 2019.

[68] International Court of Justice (1969). *North Sea Continental Shelf (Federal Republic of Germany v Denmark). (Judgment)* [1969] ICJ Rep 3, 44 [77]. Reports of Judgments, Advisory Opinions and Orders. Online at www.icj-cij.org/files/case-related/51/051-19690220-JUD-01-00-EN.pdf. Accessed 13 September 2019.

[69] ibid 43 [74].

[70] Tronchetti (n 29) 339.

[71] *North Sea Continental Shelf* (n 67) 43 [74].

[72] The member states of the European Space Agency are Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Canada also sits on the ESA Council, Slovenia is an Associate Member, while Bulgaria, Croatia, Cyprus, Latvia, Lithuania, Malta and Slovakia have Cooperation Agreements with the ESA. Refer ESA (2019). *New Member States.* European Space Agency: Online at www.esa.int/About_Us/Welcome_to_ESA/New_Member_States. Accessed 13 September 2019.

[73] Wessel, B (2012). *The Rule of Law in Outer Space: The Effects of Treaties and Nonbinding Agreements on International Space Law.* 35(1) Hastings International and Comparative Law Review. pp 289, 298. Online at https://repository.uchastings.edu/hastings_international_comparative_law_review/vol35/iss2/. Accessed 13 September 2019; Li (n 2), p320.

[74] Wessel (n 72) p299.

[75] ibid p300.

[76] Li (n 2) p317.

[77] ibid p317.

[78] *Outer Space Treaty* (n 6) art I.

Enforcement of Commercial Regulation in Outer Space

Joel Lisk

Outer space is a popular domain for a broad variety of commercial, civil and military activities. With the increased usage of outer space comes an increased risk of misuse, abuse and activities by some operators that may have significant detrimental effects on others. Nations are regulated by international law and are bound by the treaties, conventions and customary norms that have been established over decades of state practice. Comparatively, commercial activities are regulated by domestic laws; laws that require entities to be licensed, to seek permission for certain classes of activities, and that impose continuing obligations on operators to ensure that their activities do not detrimentally impact others who also seek to explore and exploit space. This paper will explore the legal mechanisms that have been introduced in domestic statutory regimes to protect against commercial misuse of outer space and enforce the regulatory regimes that attempt to regulate the commercial activities in a domain devoid of traditional conceptualisations of jurisdiction and control. Enforcement of regulatory regimes, especially in respect of emerging commercial operations, is an important aspect in the long-term sustainability and protection of the space domain and ensuring that space can be accessed and available to future users of space.

Introduction

In January 2018, four satellites - smaller than $10cm^3$ (known as 'SpaceBEEs') - were launched by American start-up Swarm Technologies Inc ('Swarm').[1] The satellites, launched on an Indian Polar Satellite Launch Vehicle, were not licenced or authorised by American authorities.[2] United States law requires that all satellites operated by American companies that use spectrum are to be licenced by the Federal Communications Commission ('FCC') prior to launch.[3] Swarm had previously applied for an experimental licence to operate their SpaceBEE satellites, but the FCC rejected the application on grounds that the satellites were too small to be effectively tracked by the US global Space Surveillance Network ('SSN').[4] On 20 December 2018, following an investigation into Swarm's activities, the FCC publicly issued a consent order, imposing a USD900,000 fine and binding Swarm to a range of compliance activities – all after the SpaceBEEs had been launched and were in operation in orbit.[5]

The Swarm Technologies incident appears to be the first publicly known example of an unauthorised private space activity; one that breached US domestic laws put in place to regulate the possible risks and hazards to the national and foreign policy interests of the United States.

The Earth orbital environment is becoming a popular focus for the corporate sector, buoyed by continued and rapid reductions of the cost barriers to satellite technologies, space operations, and access to orbit. Space activities are not risk-free: high input costs (eg. space launch), a complicated international legal regime, and high levels of interest in orbit make regulation of the space environment essential. With increased traffic in outer space, it is likely that without States enforcing their domestic laws related to space activities or implementing mechanisms that act as a deterrent for unlawful activities, there will be an increase in unauthorised and unlawful commercial activities carried out in orbit. This paper reviews a range of national legislative enactments to consider the primary enforcement mechanisms currently in place, to conclude that the approaches across numerous nations are similar. There are prohibitions on unauthorised activities in orbit and terrestrial activities connected to space operations, and with a range of powers at the disposal of regulators to address any potentially unlawful activities. The primary limitation in most instances is that if unlawful private activities are not being detected in outer space, we are unlikely to know how effective the full suite of enforcement mechanisms are until they are most needed.

International Law

International law plays an essential role in the regulation of *outer space* activities.[6] At present, five treaties regulate outer space activities at the international level: the *Outer Space Treaty,*[7] *Rescue Agreement,*[8] *Liability Convention,*[9] *Liability Convention,*[10] and the *Moon Agreement*[11] (collectively, the 'Space Treaties'). The *Outer Space Treaty* creates an overarching framework of international obligations that apply to all adopting parties. There are also suggestions from many academic quarters[12] that obligations in the *Outer Space Treaty* are also customary international law, although this is debatable.[13] A number of the articles of the *Outer Space Treaty* are relevant to the activities that nations and private individuals undertake in orbit today. Throughout the late 20th century, there was little need to contemplate the breadth and significance of many obligations contained in the Space Treaties as only a small number of States had the resources and capabilities to act in orbit and beyond, using government-controlled capabilities.

States are required to authorise and continually supervise the activities of their nations to ensure they comply with the provisions of the Space Treaties.[14] This obligation has generally been regarded as obliging States to formulate a supervisory regime whereby they review the activities of their nationals in outer space.[15] This is in addition to provisions of the *Outer Space Treaty* and the *Liability Convention* that make a State financially liable for the actions of private actors - a fundamentally different regime than exists on earth.[16] These provisions, in addition to the provisions that impose jurisdiction and control requirements over space objects on national registers,[17] create a legal system as unique as space itself.

Domestic Legislation

The right of a State to legislate in respect of its citizens and territory is a long-respected principle of international law tied to a State's inherent sovereignty over its internal affairs.[18] Regulation of outer space is no different. A State is encouraged to implement national legislative regimes to regulate its citizens' private activities in outer space in accordance with article VI of the Outer Space Treaty and documents produced by the United Nations Committee on the Peaceful Uses of Outer Space.[19]

Many States have embraced their obligations to authorise and supervise the activities of non-governmental actors through the introduction of licensing and permit-based regimes - an approach recommended by the UN General Assembly.[20] In most instances, the trigger to introduce a domestic legal regime is not a State's obligations under the Space Treaty regime, but an assessment of the commercial space industry and a desire to foster the development of localised space capabilities.

National legislative regimes adopt a common approach: activities undertaken by private actors in outer space are prohibited unless authorised by a national compliance authority. Alternative processes have existed (such as the use of individual authorisation contracts that provide for all the conditions and limitations on actions that legislation does), but are much rarer and generally employed in the time between a company or individual expressing the desire to conduct space activities from a certain jurisdiction and the implementation of relevant laws.[21]

The full scope of activities covered by national legal regimes varies between States. Australia only maintains space-related legislation connected to the launch and return of space objects.[22] Comparatively, United Kingdom has recently legislated in respect of not only launching activities, but also human spaceflight.[23] These variations arise as a consequence of national political motivations and the nature of the relevant domestic space industry.

One of the most significant components of a national legal regime is the enforcement mechanism – a legal regime with no enforcement mechanism is unlikely to be successful in regulating a specific population and, conversely, a regulatory regime that is too heavy-handed is likely to suppress the development of space economy. In the immediate circumstances, there is a need to effectively enforce the prohibitions on conducting activities without a licence and to enforce the terms and conditions attached to a particular authorisation. This presents two primary aspects of domestic space law: pre-authorisation and post-authorisation enforcement. Within these two categories, we see a convergence of mechanisms, with highly developed prohibitions, direction and direct action capabilities in place across different jurisdictions.

While the mechanisms are relatively similar, the execution varies from state-to-state, with content influenced by a range of social, political and contextual factors. The vast majority of the domestic legal enforcement mechanisms remain untested and there are extremely limited examples of where domestic law has been declared to be a breach by a private actor.

The following analysis is based on a review of legislation from Australia,[24] New Zealand,[25] the United Kingdom,[26] the United States,[27] Belgium,[28] Luxembourg,[29] and Canada,[30] arguably a large selection of legislation that encapsulates much of the existing commercial space activities.[31]

Pre-authorisation

National supervision and authorisation regimes are unlikely to be effective where there are no, or inadequate, consequences for failing to comply. While the spectrum of activities regulated by national legislation varies between States, the pre-authorisation enforcement and deterrent mechanisms are relatively consistent internationally.

As foreshadowed above, States use national laws to define a series of activities that are to be regulated by the State. The *Space Industry Act 2018* provides that 'spaceflight activities' and operation of a 'spaceport' require a licence.[32] 'Spaceflight activities' is comprised of two components, encompassing both 'space activities' and 'sub-orbital activities'.[33] These terms are further defined to specify a range of activities.[34] Failing to acquire a permit or licence, from the State, for a spaceflight activity results in the party responsible for conducting the operation becoming liable for prosecution by the State.[35]

This approach has been near-universally adopted. Luxembourg, in implementing its 2017 legislation to allow companies to exploit space resources, included provisions that make it unlawful to engage in resource exploitation activities without authorisation, opening the responsible party to fines and potential imprisonment.[36] In Australia, the *Space (Launches and Returns) Act 2018* and its predecessor take a more thorough and detailed approach to pre-authorisation offence provisions.[37] Each Act provides separate provisions and the required elements for each type of offence, be it launching or operating a launch facility without a permit – in contrast to select regimes that possess more generalised prohibitions on acting in breach of the legislation.[38] This approach was also adopted by New Zealand in their *Outer Space and High-altitude Activities Act 2018*.[39]

Both approaches reach the same end - it is unlawful for a non-governmental entity to engage in space activities without the State approving or authorising the space activity, including the launch event, and irrespective of whether it is launched from within sovereign territory or abroad. The full extent of these prohibitions varies between States, although in most instances this is due to the scope and design of the legislation.

Post-Authorisation

Once an authorisation has been granted, a private actor will immediately proceed to action that authorisation and commence orbital operations. This does not extinguish the potential for enforcement action. Domestic laws require authorised entities to be subject to various conditions that limit or direct how they may conduct themselves in orbit. Licence terms may be included in statutes, subsidiary legislation or licences as a result of discretionary powers held by relevant regulators to impose additional obligations. These conditions are structured around themes; restrictions on activities, permitted operations, end of operational life requirements, debris mitigation plans, public safety, international obligations and additional matters that vary between individual States.

As with pre-authorisation, enforcement mechanisms play an essential role in ensuring that licence terms and conditions are complied with and the regulatory regime remains viable and effective. While there is a degree of variability across post-authorisation enforcement mechanisms, three clear categories of action have formed; prohibitive provisions, directions and direct action. While this may not describe all post-authorisation enforcement mechanisms employed by all States, the vast majority of actions fall into one of these categories.

Prohibitive Provisions

The prohibitive provisions operate in the same way that the pre-authorisation prohibitions operate – legislation deems it to be an offence to contravene licence terms or legislation relevant to the operation of regulated activity. This will be heavily dependent on what an individual statutory enactment regulates and what the legislatures intended on regulating. Generalist prohibitions, such as that in Chapter 509 of the United States Code prohibit a person from violating the chapter, on the whole, and subsidiary regulation, or any term of a license issued under the chapter.[40] Comparatively, the New Zealand legislation makes it an offence to 'knowingly or without reasonable excuse' fail to comply with a licence or permit condition.[41]

Directions

Due to the nature of space activities and the ability for an operator to continue to breach their legal obligations even after a contravention of legislation or licence conditions has been identified, many domestic regimes allow for a regulator or appropriately empowered individual to 'direct' an operator to act in a certain way. Directions are limited by the legislation that empowers them - with directions generally restricted to narrow compliance or safety-related matters.

The United Kingdom was one of the first nations to implement domestic space legislation, following the United States and Sweden, in 1986.[42] The *Outer Space Act 1986* remained largely unamended in its substance until the introduction of the *Space Industry Act 2018*.[43] The *Outer Space Act 1986* confers broad-based directions and direct action powers on the United Kingdom Secretary of State where it appears 'necessary' to secure compliance with the conditions of an operator's licence terms or the international obligations of the United Kingdom.[44] This includes directions for securing the cessation of space activities and the disposal of a space object (irrespective of where it is).[45] These directions are enforceable through the use of injunctions and offence provisions.[46] Directions can also be supplemented by direct action and this is discussed below.

The scope of the United Kingdom's power to give directions to regulated entities was expanded and clarified in the *Space Industry Act 2018*.[47] Directions under that statute must be related to breaches of licence conditions, safety and security, or international obligations. Similar provisions with the same or comparable scope in other legislative regimes are difficult to identify. The Australian *Space (Launches & Returns) Act 2018* grants a 'launch safety officer' powers related to the safety and security of launch operations.[48] A launch safety officer is charged with monitoring the activities of a licensee for compliance with the regulatory regime and their licence conditions.[49]

Launch safety officers are appointed by Minister responsible for the *Space (Launches & Returns) Act 2018* in connection with an authorised launch or return of a space object.[50] The Act empowers a launch safety officer to do 'all things that are reasonably necessary or convenient' to ensure licence conditions are complied with,[51] and of importance is the power of the launch safety officer to give directions to an operator in respect of how a launch or return is carried out to ensure that danger to the general public and property is avoided.[52] This includes a power to direct that a launch is halted or a space object is destroyed.[53]

Similar provisions are again used in New Zealand. Enforcement officers are not expressly granted the ability to issue directions, but they are empowered to 'promote compliance' with the relevant statutory regime and licences by providing information, education and advice on the relevant statutory regimes.[54] Enforcement officers in New Zealand hold more of an investigative role supported by a range of offence provisions. It is an offence to refuse an enforcement officer access to launch facilities, refuse to present equipment, data and documents for examination, refuse to submit to questioning, and refuse to test launch vehicles and other space objects on request.[55]

Direct Action

Direct action is where statute empowers a regulator or designated individual to act in a certain way to force the cessation of activities that conflict with a statutory regime. In the context of domestic space law regimes, direct action is primarily related to a regulator either intervening in the operations of the licensee, or seizing the operator's assets or data connected with the licensed operations.

Belgium, in its *2005 Law on the Activities of Launching, Flight Operations or Guidance of Space Objects*, included a provision that requires the responsible Minister to 'take all necessary measures in order to guarantee the safety' of operations and to protect property.[56] Necessary measures are explicitly stated to include the transfer of activities to another operator to 'ensure the continuity of flight and guidance operations'. Furthermore, the legislation also references that, if required, the appropriate actions may include the de-orbiting or destruction of a space object.[57] In a subsequent guidance document, the regulator expressly recognises its ability to intervene in the operations of a licensee and transfer operations to third parties where necessary.[58] This particular mechanism appears to quite formidable on its face, especially in respect of a transfer of operations to a third party.

The *Outer Space Act 1986* empowers the Secretary of State to seek out a warrant authorising direct actions.[59] These warrants authorise the Secretary to do 'anything necessary to secure compliance with the international obligations of the United Kingdom or with the conditions of the licence.'[60] To seek out this warrant, there must be reasonable grounds for believing that an activity is being conducted in a manner that contravenes the Act or terms of the licence that has been granted. A warrant may give an individual power to enter premises and use reasonable force if necessary.[61] The *Space Industry Act 2018* retains these powers, but in a more targeted manner, linking to the more specific and defined directions powers within that Act. This limits direct action to matters involving health and safety, international obligations, licence conditions and compliance with the *Space Industry Act 2018* itself.[62] The powers granted in the United Kingdom legislation are limited by statutory processes – there must have been a direction given before direct action can be taken.[63]

In the United States, the Secretary of Transport and the Federal Aviation Administration are the primary regulators of launch activities. Activities related to orbital earth observation and satellite communications are regulated by other government bodies.[64] Chapter 509 of the United States Code empowers the regulators to act in several ways.[65] It is the responsibility of the Secretary of Transport (or their delegate) to ensure that all licences, authorisations and permits have been obtained prior to a launch taking place.[66] If the requisite permissions have not been obtained, the Secretary is empowered to 'prevent the launch' where there is a risk to public health and safety, safety of property, or there is a risk to the national security or foreign policy interests of the United States.[67] This is supplemented by the ability, where an appropriate authorisation has been granted, to enter a launch site, production facility or other prescribed facility to inspect and record information about regulated objects (i.e. launch vehicles) and, if necessary, seize such objects and any records or reports related to them where there is probable cause to believe those items are being used or likely to be used in contravention of the United States' domestic commercial space legislation.[68]

Seizure of objects or launch vehicles, intended for uses in space operations, on these grounds is quite common. The *Outer Space and High-altitude Activities Act 2017* permits an enforcement officer to seize and detain any 'launch vehicle, payload, … related equipment, or technical data' in exercising their duty to investigate compliance with that Act.[69] Australian launch safety officers are also empowered to seize 'a thing' where there is reasonable grounds to suspect that the 'thing' is relevant to an offence against the *Space (Launches & Returns) Act 2018* and the circumstances are 'so serious and urgent' that a search of a launch facility and seizure of 'a thing' is necessary to prevent that 'thing' being concealed, lost or destroyed.[70] This power is restricted and may only be used in 'emergency situations' – there is no general power to seize objects where a breach of licence conditions or the statute is occurring and there is no risk that the object involved in the contravention will not be destroyed.

Conclusion

While the method of designing legislation varies greatly dependent on the State implementing the legal regime, there is a convergence of methodologies in respect of enforcement. While the common enforcement mechanisms are not implemented in an identical manner across different States, there is a generally predictable pattern among the majority of private-enterprise promoting spacefaring nations. The increased popularity of commercial space activities and the rapidly increasing demand for space-based services is likely to stretch these regimes. Questions regarding the coercive powers and capabilities of regulators are sure to be asked in the coming years, especially as operators seek to venture further from the earth and reach of regulators. As orbit becomes more congested, there is the ever-increasing chance that licence terms and regulations will become stricter, imposing greater 'good citizen' and on-orbit regulatory obligations. This will increase pressure on regulators and national governments to use their powers more liberally, but without unlawful activities occurring presently it is difficult to assess whether the coercive powers of States will be effective in regulating orbital space activities.

Endnotes

1 Harris, M (2009). *FCC Accuses Stealthy Startup of Launching Rogue Satellites.* IEEE Spectrum. Online at https://spectrum.ieee.org/tech-talk/aerospace/satellites/fcc-accuses-stealthy-startup-of-launching-rogue-satellites. Accessed 13 September 2019.

2 ibid; FCC (2018). *In the Matter of Swarm Technologies, Inc*. US Federal Communications Commission. *pp* 18-184. Online at https://docs.fcc.gov/public/attachments/FCC-18-184A1_Rcd.pdf. Accessed 13 September 2019.

3 See, eg. 47 USC 6.

4 Letter from Anthony Serafini (Experimental Licencing Branch, Federal Trade Commission) to Sara Spangelo (Swarm Technologies, Inc.) – refer FCC (2017). *Dismissed-Without Prejudice.* US Federal Communications Commission. Online at https://apps.fcc.gov/els/GetAtt.html?id=203152&x=. Accessed 13 September 2019.

5 FCC (2018). *In the Matter of Swarm Technologies, Inc* [December 20, 2018]. FCC 18-184. US Federal Communications Commission. Online at https://docs.fcc.gov/public/attachments/FCC-18-184A1_Rcd.pdf. Accessed 13 September 2019.

6 While there is no legally accepted definition of *where* outer space *is,* for the purposes of this paper 'outer space; is taken to include Earth orbit and all 'space' beyond that, including the Moon and other celestial bodies.

7 UNOOSA (2002). *Treaty on Principles Governing the Activities of the States in the Exploration and use of Outer Space, including the Moon and Other Celestial Bodies,* opened for signature 27 January 1967, 610 UNTS 205, (entered into force 10 October 1967) ('*Outer Space Treaty*'). Online at www.unoosa.org/pdf/publications/STSPACE11E.pdf. Accessed 13 September 2019.

8 UNOOSA (2002). *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space,* opened for signature 22 April 2968, 672 UNTS 119 (entered into force 3 December 1968) ('Rescue Agreement'). Online at www.unoosa.org/pdf/publications/STSPACE11E.pdf. Accessed 13 September 2019.

9 UNOOSA (1971). *Convention on International Liability for Damage Caused by Space Objects*, opened for signature 29 March 1972, 961 UNTS 187, (entered into force 1 September 1972) ('Liability Convention'). Online

at www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html. Accessed 13 September 2019.

[10] UNOOSA (1974). *Convention on Registration of Objects Launched into Outer Space,* opened for signature 14 January 1975, 1023 UNTS 15 (entered into force 15 September 1976) (‘*Registration Convention*’). Online at www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introregistration-convention.html. Accessed 13 September 2019.

[11] UNOOSA (1979). *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies,* opened for signature 18 December 1979, 1363 UNTS 3 (entered into force 11 July 1984) (‘Moon Agreement’). Online at www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/intromoon-agreement.html. Accessed 13 September 2019.

[12] Although academics may not be primary actors in the international law-making process, their opinions may be considered by the International Court of Justice when determining what the law is. See, Statute of the International Court of Justice art 38(1)(d).

[13] Lyall, F; Larsen, P (2018). *Space Law: A Treatise* (Routledge, 2nd ed, 2018) 176; For a brief discussion of the Outer Space Treaty and customary international law, see Lisk, J (2018). *Space Law: A Treatise*. 32(2) Adelaide Law Review. pp 453, 460 – 462. Online at http://classic.austlii.edu.au/au/journals/AdelLawRw/2018/17.pdf. Accessed 13 September 2019.

[14] *Outer Space Treaty* art VI.

[15] Minister for Industry, Science and Tourism, Submission No JH97/0546 to Cabinet, *Commercial Space Launch Activities – Australian Regulatory Framework,* 25 November 1997, 3 [3]; Testimony to the Committee on Science, Space, and Technology (Subcommittee on Space), United States Congress: House of Representatives, Washington D.C., 8 March 2017 (Laura Montgomery).

[16] Outer Space Treaty art VII.

[17] ibid art VIII.

[18] International Court of Justice (1986). *Case Concerning the Military and Paramilitary Activities In and Against Nicaragua (Nicaragua v United States of America)* (Judgment) [1986] ICJ Rep 14, 133 [263]. Online at www.icj-cij.org/en/case/70/judgments. Accessed 13 September 2019.

[19] UNOOSA (2013). *Outer Space Treaty* art VI; *Recommendations on national legislation relevant to the peaceful exploration and use of outer space,* GA Res 68/74 UN Doc A/RES/68/74 (11 December 2013). Online at https://undocs.org/en/A/RES/68/74. Accessed 13 September 2019;

UNOOSA (). Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee, *Guidelines for the Long-term Sustainability of Outer Space Activities*, UN GAOR, 56th sess, UN Doc A/AC.105/C.1/L.366 (17 July 2018). pp 5 – 8. Online at http://www.unoosa.org/oosa/oosadoc/data/documents/2019/aac.105c.1l/aac.105c.1l.366_0.html. Accessed 13 September 2019.

20 UNOOSA (2013). *Recommendations on national legislation relevant to the peaceful exploration and use of outer space,* GA Res 68/74 UN Doc A/RES/68/74 (11 December 2013) [2] – [3]. Online at http://www.unoosa.org/oosa/oosadoc/data/resolutions/2013/general_assembly_68th_session/ares6874.html. Accessed 13 September 2019.

21 See, eg, New Zealand Government (2016). Contract between the Government of New Zealand and Rocket Lab Limited (NZ) and Rocket Lab USA Inc dated 16 September 2016. Office of the Minister for Economic Development. Online at www.mbie.govt.nz/assets/85a65881f2/agreement-nz-government-rocket-lab-nz-usa.pdf. Accessed 19 September 2019; and Minister for Industry, Science and Tourism, Submission No JH97/0546 to Cabinet, *Commercial Space Launch Activities – Australian Regulatory Framework*, 25 November 1997, Attachment F [9] – [10].

22 *Space Activities Act 1998* (Cth).

23 *Space Industry Act 2018* (UK) s 1(1).

24 *Space Activities Act 1998* (Cth) as amended by the *Space Activities Amendment (Launches and Returns) Act 2018* (Cth). As at 31 August 2019, the *Space Activities Act 1998* is to be renamed the *Space (Launches and Returns) Act 2018* (Cth). Subsequent references to the *Space (Launches and Returns) Act 2018* are to the amended *Space Activities Act 1998* following commencement of that amendment on 31 August 2019.

25 *Outer Space and High-altitude Activities Act 2018* (Cth)

26 *Outer Space Act 1986* (UK); *Space Industry Act 2018* (UK)

27 US Congress (2010). *Commercial Space Launch Activities* 51 USC 509 (USA). Online at https://uscode.house.gov/view.xhtml?path=/prelim@title51/subtitle5/chapter509&edition=prelim. Accessed 13 September 2019.

28 Government of Canada (2005). *Remote Sensing Space Systems Act*, RSC 2005, c 45 (Canada). Online at https://laws-lois.justice.gc.ca/eng/acts/R-5.4/. Accessed 13 September 2019.

29 Government of Belgium (2013). *Law of 17 September 2005 on Activities of Launching, Flight Operations or Guidance of Space Objects* (Belgium).

Online at www.belspo.be/belspo/space/doc/beLaw/Loi_en.pdf. Accessed 13 September 2019.

30 Government of Luxembourg (2017). *Loi du 20 juilet 2017 sur l'exploration et l'utilisation de ressources de l'espace* (20 July 2017) (Luxembourg) (translate provided by Government of Luxembourg of Draft Law on the Exploration and Use of Outer Space (13 July 2017)). Online at http://legilux.public.lu/eli/etat/leg/loi/2017/07/20/a674/jo. Accessed 13 September 2019.

31 These nations were selected due to their availability for this project, the context for their introduction, the differing States policy contexts and recent reforms. It must be acknowledged that there is a vast number of other States with domestic space legislation that contemplate enforcement activities in a similar manner to those sampled for this paper.

32 *Space Industry Act 2018* (UK) s 3(1).

33 ibid s 1(6).

34 ibid s 1(4) – (5): 'space activity' includes launching or the procuring the launch or the return to earth of a space object or of an aircraft carrying a space object, operation of a space object, or any activity in outer space. 'Sub-orbital activity' mean launching or the procuring the launching of, or operating or procuring the return of a craft that is capable of operating above the stratosphere or a balloon capable of reaching the stratosphere while carrying crew or passengers that is not a space activity.

35 ibid s 3(6) - (7).

36 Government of Luxembourg (2017). *Loi du 20 juilet 2017 sur l'exploration et l'utilisation de ressources de l'espace* (20 July 2017) (Luxembourg) (translate provided by Government of Luxembourg of Draft Law on the Exploration and Use of Outer Space (13 July 2017)) art 18. Online at http://legilux.public.lu/eli/etat/leg/loi/2017/07/20/a674/jo. Accessed 13 September 2019.

37 *Space (Launches and Returns) Act 2018* (Cth); *Space Activities Act 1998* (Cth).

38 *Space Activities Act 1998* (Cth) ss 11 – 15; *Space (Launches and Returns) Act 2018* ss 11 – 15A.

39 *Outer Space and High-altitude Activities Act 2018* (NZ) ss 65 - 68

40 51 USC §50917.

41 NZ Parliamentary Counsel Officer (2017). *Outer Space and High-altitude Activities Act 2017* (NZ) s 70. New Zealand Legislation. Online at www.

legislation.govt.nz/act/public/2017/0029/45.0/DLM6966275.html. Accessed 13 September 2019.

[42] The United Kingdom was preceded by the United States (1970) and Sweden (1982).

[43] The *Space Industry Act 2018* (UK), which received assent on 15 March 2018 amends the *Outer Space Act 1986* (UK) to only apply to activities of United Kingdom individuals and entities *outside* of the United Kingdom. These amendments have not yet come into force at the time of writing. Refer UK Government (2018). Space Industry Act 2018 (UK). Online at www.legislation.gov.uk/ukpga/2018/5/contents/enacted. Accessed 13 September 2019.

[44] UK Government (1986). *Outer Space Act 1986* (UK) s 8. Online at www.legislation.gov.uk/ukpga/1986/38/contents. Accessed 13 September 2019.

[45] ibid s 8(2).

[46] ibid ss 8(3), 12(1)(d).

[47] UK Government (2018). *Space Industry Act 2018* (UK) ss 27 – 29. Online at www.legislation.gov.uk/ukpga/2018/5/contents/enacted. Accessed 13 September 2019.

[48] See *Space (Launches & Returns) Act 2018* (Cth) pt 3 div 8.

[49] *Space (Launches & Returns) Act 2018* (Cth) s 51.

[50] ibid s 50(1).

[51] ibid s 52(1).

[52] ibid s 52(2)(c)-(d).

[53] ibid s 52(2)(d).

[54] *Outer Space and High-altitude Activities Act 2017* (NZ) s 59.

[55] ibid s 60.

[56] *Law of 17 September 2005 on Activities of Launching, Flight Operations or Guidance of Space Objects* (Belgium) art 11§4.

[57] ibid.

[58] Federal Office for Science Policy (Space Research and Applications Department), *12 questions and 40 points to present the law on activities relating to the launching, flight operations and guidance of space objects,* [14] https://www.belspo.be/belspo/space/doc/beLaw/PresentLoi_en.pdf.

[59] *Outer Space Act 1986* (UK) s 9

[60] ibid s 9(1).

[61] ibid s 9(3) – (4).

[62] *Space Industry Act 2018* (UK) s 32.

[63] ibid.

[64] Payloads that utilise spectrum are regulated by the Federal Communication Commission while earth observation activities (i.e. satellite imagery and sensing) is regulated by the National Oceanic and Atmospheric Administration.

[65] 51 USC 509.

[66] 51 USC §50903.

[67] 51 USC §50904(c).

[68] 51 USC §50917(b)(D).

[69] *Outer Space and High-altitude Activities Act 2017* (NZ) ss 59(a) – (b), 60(1)(c).

[70] *Space (Launches & Returns) Act 2018* (Cth) s 56(1).

The Woomera Manual: Clarifying the Law of Military Space Operations to Promote Sustainable Uses of Outer Space

Dale Stephens and Matthew Stubbs

Introduction

Space sustainability is a key topic for our time.[1] However, in an era of both extraordinary dependence on outer space and increasing divergence of strategic interests in outer space, key questions about the applicability of the law of armed conflict to outer space remain unresolved.[2] Given that 'countries face an increasing danger of aggression or even open conflict in outer space',[3] how will international space law meet the challenge of preserving space sustainability from the risks of great power competition and potential armed conflict?

The *Outer Space Treaty* of 1967 confirms in Art III that the 'the exploration and use of outer space' shall be carried out 'in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding'. While this confirms the application of the law of armed conflict to outer space, it does not assist in determining how it should be interpreted and applied in the unique context of outer space. In particular, it is unclear how the fundamental principles of space law – enshrined in the *Outer Space Treaty* of 1967 – interact with the law of armed conflict to regulate military activities in outer space.

The United Nations General Assembly has stressed 'the need to ensure the long-term sustainability of outer space activities and, in particular, the need to address the significant challenge posed by space debris' while expressing its serious concern 'about the possibility of an arms race in outer space'.[4] Concern about the risks from potential armed conflict in outer space have been expressed annually by the General Assembly in its International

Cooperation in the Peaceful Uses of Outer Space resolutions, where it has urged States:

> to contribute actively to the goal of preventing an arms race in outer space as an essential condition for the promotion of international cooperation in the exploration and use of outer space for peaceful purposes.[5]

In its annual Prevention of an Arms Race in Outer Space resolutions, the General Assembly has gone further and acknowledged that:

> the legal regime applicable to outer space by itself does not guarantee the prevention of an arms race in outer space … [and] that there is a need to consolidate and reinforce that regime and enhance its effectiveness.[6]

However, recognition of the need to clarify how the law of armed conflict applies in outer space has not led to binding treaty action. Two drafts of a *Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects*[7] proposed by China and Russia have been rejected by key space-faring States,[8] and a *Draft International Code of Conduct for Outer Space Activities* (2014)[9] has also failed to garner sufficient support.[10] Indeed, the prospects for binding treaty action in respect of arms and armed conflict in outer space appear bleak,[11] and are a good example of the treaty stasis that Brian Israel has identified in respect of outer space.[12] Israel's point, though, is that much can happen in the absence of treaty action: 'layering of bilateral and non-binding mechanisms atop multilateral treaties is common across issue areas and has proven to be an effective approach to adapting a legal framework to evolving circumstances over time.'[13] The lack of treaty action therefore leads us to look to non-binding (though potentially norm generating) mechanisms that might clarify how the law of armed conflict applies in outer space.

To date, the issue is addressed only tangentially in key soft law instruments. The *Space Debris Mitigation Guidelines of the UN Committee on the Peaceful Uses of Outer Space*[14] provide that 'the intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided',[15] and the Inter-Agency *Space Debris Coordination Committee Space Debris Mitigation Guidelines*[16] indicate that 'Intentional destruction of a spacecraft or orbital stage, (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other spacecraft and orbital stages should be avoided.'[17] These principles, however, offer no definitive guidance as to what should be done if such actions cannot be avoided (as is likely to occur in armed conflict).

The challenge has been clearly articulated by Saadia Pekkanen:

> New actors and geopolitical rivalries are extending to outer space, making it critical to develop a common legal understanding that can provide predictability, clarity, and consistency for military operators worldwide.[18]

There are lacunae in our understanding of the law applicable to armed conflict in outer space. In this chapter, we examine the project to draft the *Woomera Manual on the International Law of Military Space Operations*, which will clarify and articulate how the law applies to military space operations.[19] We first examine the tradition of international operational law manuals and their role in stimulating the evolution of the law of armed conflict, before addressing the *Woomera Manual* project itself.

Manuals and the Evolution of International Law

There is a long tradition of manuals addressing the law of armed conflict, including:

- (Oxford) *Manual on the Laws of War on Land*,[20]
- *Oxford Manual on the Laws of Naval Warfare*,[21]
- *San Remo Manual on International Law Applicable to Armed Conflicts at Sea*,[22]
- (San Remo) *Manual on the Law of Non-International Armed Conflict*,[23]
- (Harvard) *Manual on International Law Applicable to Air and Missile Warfare*,[24]
- *Tallinn Manual 2.0 on the International Law Applicable to Cyber Operations*,[25]
- a forthcoming *Oslo Manual on Select Problems of the Law of Armed Conflict*.

As the increasing number of such publications reveal, we are in the age of the manual. [26]

While each of these manuals is different, the general principles underlying their writing and adoption are similar. These common principles regarding manuals include:

- the manual is the work of experts acting in their individual capacity, and not of State representatives,[27]
- the manual aims to articulate the existing law (*lex lata*), rather than advocate for the progressive development of the law in some desired direction (*lex ferenda*),[28]
- while States will often have opportunities to make comments on the manual before its adoption,[29] they have no control over its content.

Two key questions arising from these principles warrant further examination. First, what is the purpose of these manuals? Second, given they are the creation of groups of experts rather than of States, are these manuals any more influential than an academic journal article or book?

The purpose of these manuals, in very broad terms, is to clarify the law relating to a particular domain of armed conflict. This need arises because 'traditional legal sources, such as treaties or customary international law, have been too slow to keep up.'[30] There are two potential reasons for this. First, in some cases it is in the strategic interests of some States to maintain ambiguity. Michael Schmitt has explored the phenomenon of grey zones: areas in which 'international law principles and rules … are poorly demarcated or are subject to competing interpretations.'[31] He argues that, in the context of cyberspace, States exploit such grey zones because they make it 'difficult for other States to definitively name and shame the country as having committed an internationally wrongful act' and notes that '[l]egal ambiguity … hobbles responses.'[32] Second, in the face of rapid technological change, the machinery to change international law lacks 'the granularity necessary to shrink grey zones … given the typically slow pace of progress in multinational fora dealing with international law.'[33] As Matthew King and Laurie Blank have put it, 'the technology, geophysics, and geopolitics of outer space make tackling the contours and the sometimes domain specific intricacies of general principles and customary international law a challenge.'[34] Manuals offer a means to clarify the application of the law, and thus reduce the scope of grey zones. As Kubo Mačák has memorably described it, the authors of manuals are working in '"norm-making laboratories" for states.'[35] As Schmitt notes, there is considerable value in such work to bring normative clarity to legal grey zones: 'legal clarity breeds international stability. The brighter the red-lines of international law … the less opportunity States will have to exploit grey zones in ways that create instability'.[36]

This purpose, of course, aspires to the manual having some legal significance. This is somewhat of a paradox, given the genesis of manuals. As the *Tallinn Manual* explains in its introduction:

> It is essential to understand that *Tallinn Manual 2.0* is not an official document, but rather the product of two separate endeavours undertaken by groups of independent experts acting solely in their personal capacity. … Ultimately, *Tallinn Manual 2.0* must be understood only as an expression of the opinions of the two International Groups of Experts as to the state of the law.[37]

Methodologically, for a manual to assume legal significance, its interpretations of the law would need to either be accepted as correct interpretations of a treaty in the subsequent practice of States parties to that treaty,[38] or be the subject of sufficient State practice and *opinio juris* as to form customary international law.[39] This is precisely what manuals aim to do. As Stephens has observed, manuals aim to 'influence the practice of the law, and through that means, the law itself.'[40] Significantly, the assembled experts may themselves qualify as publicists of requisite standing for the purposes of Art 38(1)(d) of the *Statue of the International Court of Justice*, as a subsidiary means for the determination of international law, but no manual has ever overtly made that claim.

Our intention here is not to traverse whether particular rules of particular manuals have acquired the status of law,[41] but to generally reflect on the influence of manuals. As Sandesh Sivakumaran has observed: '[w]hen states are unable or unwilling to make and shape the law … and where there is a need for the law to be developed, expert groups can play a particularly influential role.'[42] As an illustration, consider the following statement regarding the San Remo Manual which is found in Denmark's *Military Manual on International Law Relevant to Danish Armed Forces in International Operations*:

> The SRM as such has not been adopted by Denmark or incorporated into Danish law, but it has gained great significance as the only modern comprehensive work on the rules of naval warfare, and the individual SRM rules are widely

> considered to reflect customary international law, which is binding on Denmark.[43]

This is a remarkable status for non-State manual to have assumed, and there are many similar expressions of the legal status of manuals to be found.[44] For example, Wolff Heintschel von Heinegg has recently argued that

> The San Remo Manual stands in the tradition of the 1913 Oxford Manual. Undoubtedly, both manuals have had a considerable impact on how the law of naval warfare applies in times of armed conflict at sea. Therefore, their value and significance cannot be overestimated.[45]

One point of interest is Heintschel von Heinegg's acceptance that, in some respects, that San Remo Manual contained progressive interpretations of the law which have subsequently been accepted by States, thus evidencing the ability of manuals to reflect evolving norms of customary international law:

> Despite of the innovative elements introduced into the San Remo Manual it may be held that, twenty-five years after its adoption, those elements are no longer considered as progressive development of the international law applicable to armed conflicts at sea because many States seem to have accepted them.[46]

Accordingly, manuals are capable not only of clarifying but also of reflecting nascent developments in the relevant law.[47] Generally, however, manuals act through clarification and not progressive development, aiming to be 'a conduit through which pre-existing norms are synthesized and clarified. They already exist as a matter of treaty or customary international law, but are given a specific articulation and application.'[48] As Dan Efrony and Yuval Shany have recently put it, the authors of manuals are 'part of a longstanding tradition of legal scholars and practitioners labouring to adapt existing law to new circumstances, opting to extend the law by way of interpretation and analogy rather than by developing a brand-new legal paradigm.'[49]

Manuals, therefore, can serve an important role in clarifying the application of international law to particular domains of armed conflict. While not enjoying any legal status of their own, the capacity of manuals to influence States in their approach to the interpretation and application of their treaty commitments, and their obligations under customary international law, has been repeatedly demonstrated.[50] As King and Blank have observed:

> As the military space environment leans towards one of realistic threat of action … [o]ne way to address competition in this congested, contested environment may be through shared understandings of the law governing state behavior in space.[51]

In the final section of this chapter, we examine the development of a new manual articulating how the law of armed conflict applies to outer space – the *Woomera Manual on the International Law of Military Space Operations.*

The Woomera Manual on the International Law of Military Space Operations

The *Woomera Manual* joins this rich tradition of manuals in pursuing its aim:

> To articulate and clarify extant law applicable to military activities associated with the space domain, especially that which is relevant in periods of tension (when States and non-State actors may consider using force) or outright hostilities. The Manual will examine the circumstances in which operations associated with space infrastructure would be considered unlawful as a violation of the law on the use of force. It will also consider the responses available to States in reacting to such operations. Further, the Manual will discuss how the law of armed conflict governs operations that are conducted from, to or through outer space, should armed conflict break out. Ultimately, the Manual is meant to support a stable, rules-based global order, even in periods of tension and armed conflict.[52]

The *Woomera Manual* is a collaborative project led by four academic institutions, namely the University of Adelaide, University of Exeter, University of Nebraska, and University of New South Wales – Canberra. In common with other recent manuals, the *Woomera Manual* is being written by experts, from both academia and government legal practice, acting in their personal capacities. It is led by management and editorial teams jointly comprising Professors Melissa de Zwart and Dale Stephens (University of Adelaide), Professor Hitoshi Nasu (University of Exeter), Professor Jack Beard (University of Nebraska), Professor Rob McLaughlin (UNSW Canberra), Colonel Robin Holman (Canadian Armed Forces) as an Observer and Mr Duncan Blake as a Managing Editor.

The *Woomera Manual* drafting process has been in train since 2018, with the key drafting work being undertaken at workshops in Exeter, United Kingdom (August 2018), Lincoln, Nebraska (February 2019), The Hague, Netherlands (August 2019) and plans for workshops in Canberra, Australia (February 2020) and Japan (2020). The Core Experts of the *Woomera Manual* geographically cover Australia, Canada, China, Estonia, France, Israel, Netherlands, Sweden, United Kingdom and United States. The Associate Experts expand that coverage further to include Germany, India and Singapore. Observers and technical experts contributing to the *Woomera Manual* are drawn from the International Committee of the Red Cross, Union of Concerned Scientists, Secure World Foundation and NATO.

The methodology of the *Woomera Manual* is firmly planted in locating State practice, both in terms of customary international law and also in terms of Article 31(3)(b) of the *Vienna Convention on the Law of Treaties*,[53] to identify positions adopted regarding the legal regime applicable to military space operations. The approach to the reconciliation of regimes, especially of international space law with the use of force (*jus ad bellum*) and law of armed conflict (*jus in bello*), adopts the methodological approach favoured by the International Law Commission (ILC) in the Fragmentation study,[54] namely acting under a 'presumption against normative conflict'.[55] Methodological tools of induction, deduction and analogy are drawn upon to situate how disparate areas of law may be accommodated successfully. Ultimately, however, when it comes to the law of armed conflict the methodological approach has been to adopt the conclusions of the ILC in its 2011 *Draft Articles on the Effects of Armed Conflicts on Treaties*,[56] namely allowing for normative priority of such rules, as consistently as possible with the applicable space law regime.

The draft text of the *Woomera Manual* will be subject to extensive peer review. The *Woomera Manual* will be further informed by a process of State engagement and consultation, known as the 'Soesterberg Process' that will be facilitated by the Netherlands. Through this process, which will be undertaken in 2020, States will have the opportunity to provide comments in writing and also through attendance at a State engagement workshop.

Such an approach tests the veracity of positions taken in the manual and allows for a level of qualitative integrity as to the conclusions reached and methodological approaches undertaken in the drafting process. The *Woomera Manual* itself will be published in 2021.

Conclusion

The *Woomera Manual* is being readied to take its place in the canon of manuals on operational international law, providing much needed articulation and clarification of the international law applicable to military space operations. While only time will tell if it finds the same acceptance as other manuals, we have demonstrated the great significance that manuals can ultimately have in influencing States in the interpretation of treaties and the clarification of customary international law. Given the threat to space sustainability posed by the potential for armed conflict in outer space, and the inability of States to agree on binding treaty action to address the issues, the *Woomera Manual* will serve as an important means of providing clarity as to States' legal obligations which will contribute to enhancing geopolitical stability and reducing (as far as possible) threats to humankind's continuing exploration and use of outer space.

Endnotes

1 We note the adoption in 2019 of a definition of space sustainability by the UN Committee on the Peaceful Uses of Outer Space: 'long-term sustainability of outer space activities is defined as the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations': UNOOSA (2018). *Guidelines for the Long-term Sustainability of Outer Space Activities*. United Nations Office for Outer Space Affairs. UN Doc A/AC.105/C.1/L.366 (17 July 2018). Online at www.unoosa.org/oosa/oosadoc/data/documents/2019/aac.105c.1l/aac.105c.1l.366_0.html. Accessed 14 September 2019.

2 Schmitt, M (2006). International Law and Military Operations in Space. *10 Max Planck Yearbook of United Nations Law.* Online at www.mpil.de/files/pdf3/04_schmittii1.pdf. Accessed 14 September 2019; Stephens, D (2018). *The International Legal Implications of Military Space Operations: Examining the Interplay between International Humanitarian Law and the Outer Space Legal Regime.* 94 *International Law Studies* 75. Online at https://digital-commons.usnwc.edu/ils/vol94/iss1/3/. Accessed 14 September 2019; Mačák, K (2018). Silent War: Applicability of the *Jus in Bello* to Military Space Operations. 94 *International Law Studies* 1. Online at www.law.upenn.edu/live/files/7807-macak---silent-war-2018-94-ils-1pdf. Accessed 14 September 2019; Stephens, D; Steer, C (2015). *Conflicts in Space: International Humanitarian Law and Its Application to Space Warfare.* 40 *Annals of Air and Space Law* 71. Online at www.law.upenn.edu/live/files/7859-conflicts-in-space-stephens-steerjan-2016pdf. Accessed 14 September 2019.

3 Pekkanen, S (2019). Governing the New Space Race. 113 *American Journal of International Law Unbound* 92, 95. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/governing-the-new-space-race/14BD9B37A7A15A8E225A5355BB29E51B/core-reader. Accessed 14 September 2019.

4 GA Res 73/6 (26 October 2018).

5 GA Res 73/91 (7 December 2018) [13].

6 GA Res 73/30 (5 December 2018) [2].

[7] *Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, and of the Threat or Use of Force against Outer Space Objects*, proposed by Russia and China, 29 February 2008, UN Doc CD/1839; *Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects*, proposed by Russia and China, 12 June 2014, UN Doc CD/1985.

[8] See, eg, *Analysis of a Draft 'Treaty on Prevention of the Placement of Weapons in Outer Space, or the Threat or Use of Force Against Outer Space Objects'*, submitted by the United States, 26 August 2008, UN Doc CD/1847.

[9] EEAS (2014). *DRAFT International Code of Conduct for Outer Space Activities.* Version 31 March 2014. European External Action Service. Online at https://eeas.europa.eu/sites/eeas/files/space_code_conduct_draft_vers_31-march-2014_en.pdf. Accessed 14 September 2019.

[10] Beard, J (2016). *Soft Law's Failure on the Horizon: The International Code of Conduct for Outer Space Activities.* 38(2) University of Pennsylvania Journal of International Law 335. Online at https://digitalcommons.unl.edu/spacelaw/87/. Accessed 14 September 2019.

[11] King, M ; Blank, L (2019). *International Law and Security in Outer Space: Now and Tomorrow.* 113 American Journal of International Law Unbound. pp 125, 129. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/international-law-and-security-in-outer-space-now-and-tomorrow/2591D90C09C4A9375DE81F750DA98DDE, Accessed 14 September 2019: 'The likelihood of new treaties being developed and coming into force is slim, however, given the steadily growing cast of characters with an equally expansive set of competing interests in outer space'.

[12] Israel, B (2014). *Treaty Stasis.* 108 American Journal of International Law Unbound 63. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/treaty-stasis/EC004CDD39BDF638E02435E9CDFA049C. Accessed 14 September 2019.

[13] ibid 67.

[14] Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, *Space Debris Mitigation Guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space*, 50th sess, UN Doc A/AC/105/890 (6 March 2007) annex IV, endorsed by the General Assembly in *International Cooperation in the*

Peaceful Uses of Outer Space, GA Res 62/217 (UN Doc A/RES/62/217, 1 February 2008) [26].

15 ibid guideline 4.

16 IADC (2007). *IADC Space Debris Mitigation Guidelines*. IADC-02-01 Revision 1. Inter-Agency Space Debris Coordination Committee. Online at www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf. Accessed 14 September 2019.

17 ibid [5.2.3].

18 Pekkanen, n 3 above, 96.

19 University of Adelaide (2019). *The Woomera Manual.* Adelaide Law School. University of Adelaide. Online at https://law.adelaide.edu.au/woomera/. Accessed 14 September 2019.

20 Institut de Droit international (1880). *Manual on the Laws of War on Land*. Oxford. Online at https://ihl-databases.icrc.org/ihl/INTRO/140?OpenDocument. Accessed 14 September 2019.

21 Institute of International Law (1913). *Manual on the Laws of Naval Warfare. Oxford*. Online at https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/INTRO/265?OpenDocument. Accessed 14 September 2019.

22 Doswald-Beck, L (1994). *San Remo Manual on International Law Applicable to Armed Conflicts at Sea*, Cambridge University Press, Cambridge. Online at https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/INTRO/560?OpenDocument. Accessed 14 September 2019.

23 Schmitt, M; Garraway, C; Dinstein, Y (2006). *The Manual on the Law of Non-International Armed Conflict.* International Institute of Humanitarian Law. Online at www.fd.unl.pt/docentes_docs/ma/jc_MA_26125.pdf. Accessed 14 September 2019.

24 Program on Humanitarian Policy and Conflict Research at Harvard University (2013). *Manual on International Law Applicable to Air and Missile Warfare*, Cambridge University Press, Cambridge, 2013. Online at www.cambridge.org/core/books/hpcr-manual-on-international-law-applicable-to-air-and-missile-warfare/EB28F7A1701637CA2390B25FB4840629. Accessed 14 September 2019.

25 Schmitt, M (2017) *Tallinn Manual 2.0 on the International Law Applicable to Cyber Operations,* Cambridge University Press, 2nd edition (Tallinn Manual).

26 Stephens, D (2015). *The Age of the Manual - The Impact of the Manual on International Law Applicable to Air and Missile Warfare.* 45 Israel

Yearbook on Human Rights 19. Online at https://drmc.library.adelaide.edu.au/dspace/handle/2440/97930. Accessed 15 September 2019.

[27] See below text accompanying n 37.

[28] See, eg, Tallinn Manual, n 25 above, 2-3: 'This Manual is meant to be a reflection of the law as it existed at the point of the Manual's adoption … It is not a 'best practices' guide, does not represent 'progressive development of the law', and is policy and politics-neutral. … [It] is intended as an objective restatement of the *lex lata*.' But cf Lianne JM Boer, 'Lex Lata Comes With a Date; Or, What Follows from Referring to the "Tallinn Rules"' (2019) 113 *American Journal of International Law Unbound* 76, 77–8.

[29] Stephens, n 26 above, 23-5; Efrony, D; Shany, Y (2018). *A Rule Book on the Shelf? Tallinn Manual 2.0 on Cyberoperations and Subsequent State Practice.* 112(4) American Journal of International Law. *pp* 583, 588. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/rule-book-on-the-shelf-tallinn-manual-20-on-cyberoperations-and-subsequent-state-practice/54FBA2B30081B53353B5D2F06F778C14. Accessed 15 September 2019.

[30] Stephens, n 26 above, 21.

[31] Schmitt, M (2017). *Grey Zones in the International Law of Cyberspace.* 42 *Yale Journal of International Law Online* 1, 1. Online at https://cpb-us-w2.wpmucdn.com/campuspress.yale.edu/dist/8/1581/files/2017/08/Schmitt_Grey-Areas-in-the-International-Law-of-Cyberspace-1cab8kj.pdf. Accessed 15 September 2019.

[32] ibid 2.

[33] ibid 20.

[34] King and Blank, n 11 above, 128.

[35] Mačák, K (2019). *On the Shelf, But Close at Hand: The Contribution of Non-State Initiatives to International Cyber Law.* 113 American Journal of International Law Unbound, pp 81, 85. Online at https://www.cambridge.org/core/journals/american-journal-of-international-law/article/on-the-shelf-but-close-at-hand-the-contribution-of-nonstate-initiatives-to-international-cyber-law/B2B45B05750572E78FBD835D104E7EAD. Accessed 15 September 2019.

[36] Schmitt, n 31 above, 21.

[37] Tallinn Manual, n 25 above, 2

[38] *Vienna Convention on the Law of Treaties*, 23 May 1969, 1155 UNTS 331 (entered into force 27 January 1980) (VCLT) art 31(3)(b) 'any subsequent practice in the application of the treaty which establishes the agreement of the parties regarding its interpretation'. Online at https://treaties.un.org/doc/Publication/UNTS/Volume%201155/volume-1155-I-18232-English.pdf. Accessed 15 September 2019.

[39] *Statute of the International Court of Justice* art 38(1)(b) 'international custom, as evidence of a general practice accepted as law'. See, eg, *Military and Paramilitary Activities In and Against Nicaragua* (*Nicaragua v United States*) (Merits) [1986] ICJ Reps 14, 97-8 [183]-[186].

[40] Stephens, n 26 above, 33.

[41] On that topic, see, eg, Efrony and Shany, n 29 above; Stephens, n 26 above, 25-33.

[42] Sivakumaran, S (2018). *Making and Shaping the Law of Armed Conflict*. 71(1) Current Legal Problems 119, 142. Online at https://academic.oup.com/clp/article-abstract/71/1/119/5095708, Accessed 15 September 2019.

[43] Defence Command Denmark (2016). *Military Manual on International Law Relevant to Danish Armed Forces in International Operations.* (Denmark Manual) [4.2.2]. Online at https://fmn.dk/eng/allabout/Documents/Danish-Military-Manual-MoD-defence-2016.pdf. Accessed 15 September 2019.

[44] Türkel, J; et al (2011). *The Public Commission to Examine the Maritime Incident of 31 May 2010. p* 43. Onlien at www.legal-tools.org/doc/f2aae4/pdf/. Accessed 15 September 2019; Palmer, G; et al (2011). *Report of the Secretary-General's Panel of Inquiry on the 31 May 2010 Flotilla Incident*, United Nations [157]. Online at https://graphics8.nytimes.com/packages/pdf/world/Palmer-Committee-Final-report.pdf. Accessed 15 September 2019; Garraway, G (2004). The Use and Abuse of Military Manuals. 7 *Yearbook of International Humanitarian Law* 425, 429; McLaughlin, R; Letts, D (2016). *Routledge Handbook of the Law of Armed Conflict*, Taylor & Francis, London. p276; Mačák, n 35 above, 85; von Heinegg, W.H (2006). The Current State of The Law of Naval Warfare: A Fresh Look at the San Remo Manual. 82 *International Law Studies.* pp269, 269. Online at https://digital-commons.usnwc.edu/ils/vol82/iss1/16/. Accessed 15 September 2019; Sivakumaran, n 42 above, 127-8; Henderson, I (2010). *Manual on International Law Applicable to Air and Missile Warfare: A Review.* 49(1-2) Military Law and the Law of War Review. *pp*169, 180. Online at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2200060. Accessed 15 September 2019.

45 von Heinegg, W.H. (2019). *The San Remo Manual – History, Methodology and Future Application* in Stephens, D; Stubbs, M (2019). *The Law of Naval Warfare*, LexisNexis, [2.44].

46 ibid [2.36].

47 See, eg, Stephens, n 26 above, 23.

48 ibid 35.

49 Efrony and Shany, n 29 above, 583.

50 We agree that this process will not necessarily be instant – see Tsagourias, N (2019). The Slow Process of Normativizing Cyberspace. 113 *American Journal of International Law Unbound. pp* 71, 74. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/slow-process-of-normativizing-cyberspace/61AA5CC087FC50963B2A15C86DBF49D1. Accessed 15 September 2019: 'This process of norm translation, which will eventually lead to the crystallization and consolidation of rules … can nonetheless be quite slow. States must weigh interests and options, consider how existing international rules can be applied … and evaluate the practical implications of any normative commitment. … In the process of norm translation, international lawyers—including those who do not work for governments—can play an important role. The experts who promulgated the Tallinn Manuals offer an inventory of rules that apply to cyberspace, explaining their content and how they apply to this new environment. But experts do not produce international law. … as the primary normative engines of international law, [states] refuse to delegate this function fully to others, even if those other actors may influence states' thinking and actions. … states have an institutional as well as a vested interest in controlling the process of norm-building, rule specification, and rule application. Whereas the Manuals can be part of the normativizing process, they are not themselves the normativizing process.'

51 King and Blank, n 11 above, 127.

52 Schmitt, M; DeZwart, M; McLaughlin, R (2018). *The Woomera Manual on the International Law of Military Space Operations.* Online http://law.adelaide.edu.au/woomera/system/files/docs/Woomera%20Manual.pdf. Accessed 15 September 2019.

53 VCLT, n 38 above.

54 Koskenniemi, M (2006). *Fragmentation of International Law: Difficulties Arising from the Diversification and Expansion of International Law*, Report of the Study Group of the International Law Commission, Finalized

by Marttii, A/CN.4/L.682. United Nations. Online at http://legal.un.org/ilc/documentation/english/a_cn4_l682.pdf. Accessed 15 Septembere 2019.

55 ibid 25 [37].

56 Adopted by the International Law Commission at its sixty-third session, in 2011, and submitted to the General Assembly as a part of the Commission's report covering the work of that session (UN Doc A/66/10).

Developing Effective Space Traffic Management to Promote Sustainable Uses of Outer Space

Matthew Stubbs and Melissa de Zwart

Introduction

In 2019, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) adopted a definition of space sustainability:

> the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations.[1]

One of the key threats to the long-term sustainability of outer space comes from the risk of collisions affecting space objects,[2] whether with active satellites or debris, and consequent increases in the amount of long-lived debris in outer space (which in turn further increases the risk of collisions, potentially exponentially).[3] This challenge is particularly exacerbated in the context of New Space – the rapidly increasing commercial use of outer space.[4]

Concern about these issues has been expressed by the United Nations General Assembly, which in 2018 stressed 'the need to ensure the long-term sustainability of outer space activities' by:

> ensuring that outer space remains an operationally stable and safe environment suitable for use by current and future generations … at a time when more participants, representing both governmental agencies and non-governmental entities, including industry and the private sector, are increasingly

> becoming involved in ventures to explore and use space and carry out space activities.[5]

The solution, which is the focus of this chapter, is space traffic management (STM). The International Academy of Astronautics (IAA) has defined STM as 'the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference.'[6] The aims of a system of STM would be: 'to achieve safe access to outer space, safe operations of space activities, collision avoidance as well as the prevention of pollution.'[7] Paul Larsen has recently pointed out the scope of the problem requiring action to develop an STM regime:

> Traffic in outer space is increasing drastically in the New Space age. There are currently more than 1,200 functional satellites in orbit. Estimates of satellites to be launched into orbit in the immediate future range up to 27,000 … The amount of space debris in orbit is also increasing rapidly. … For new launches to be safely orbited, new international STM is urgently needed.[8]

In this chapter, we first examine the existing legal framework and identify the areas in which it is insufficient to meet humankind's present and future needs. We then examine proposals for the development of an effective legal regime of STM which may be capable of overcoming the inevitable challenges. While perhaps the most important aspect of implementing an effective STM regime in practice will be its technical content,[9] our focus is on how a regulatory regime can be constructed which enables STM to be effective.

Insufficiency of the Existing Situation

An instructive comparison can be made between STM and airspace traffic management.[10] The basic principles of traffic management in airspace are perhaps often taken for granted, but they reflect an effective system of pre-flight information provision, inflight identification of aircraft following established routings, and active air traffic control which serves to reduce the possibility of collision even in congested airspace.[11] In contrast, there is no real equivalent of any of these traffic management concepts in existing space law – the present system in outer space is one of track and avoid: it generally relies upon conjunction warnings being issued on the basis of unilateral space object tracking,[12] with the decision as to whether to respond to such warnings to avoid potential collisions resting with individual operators.[13] In this context, James Rendleman notably described satellites in low earth orbit as being like 'cars driving blindly through a corn field, at top speeds, in all directions at once.'[14]

The following foundational principles of international space law, articulated in the Outer Space Treaty, are of particular relevance to the development of an effective STM regime:

> Art I. Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law.
>
> Art II. Outer space … is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.
>
> Art VI. States Parties to the Treaty shall bear international responsibility for national activities in outer space…whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty.
>
> Art IX. States Parties … shall conduct all their activities in outer space … with due regard to the corresponding interests of all other States Parties … If a State Party … has reason to believe that an activity or experiment planned by it or its nationals in outer space … would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space … it shall undertake appropriate international consultations before proceeding with any such activity or experiment.[15]

The first two of these principles – freedom of exploration and use, and non-appropriation – will serve as limits on the imposition of an STM regime. Conversely, the latter three obligations of States – that of international responsibility and the corresponding duties to conduct space activities with due regard for the interests of other States and to avoid harmful interference – offer justifications for an STM regime.

This means that some STM will require some accommodation with the Outer Space Treaty, given that it 'will limit the freedom of use of outer space. Therefore an international consensus on internationally binding regulations will only be achieved, if States identify certain urgency and expect a specific as well as collective benefit – including an economic benefit – from this.'[16] However, STM is well suited to give effect to the obligations of due regard and harmful interference, and indeed it actually 'supports the universal freedom to use outer space as laid down in the Outer Space Treaty.'[17] In this latter sense, STM can be seen as an implementation of the Outer Space Treaty, and the limitations on the freedom of exploration and use of outer space which STM would require can even be seen as consistent with ensuring non-discrimination and equality of access. From that perspective, STM will involve an acceptable set of 'rules of the road – limiting complete freedom but assuring the basic freedom of use and the safe execution of this right.'[18]

While the IAA study of 2006 indicated that 'the existing legal framework provides the foundation for the establishment of a space traffic management regime',[19] this is perhaps too optimistic a conclusion. Certainly, these principles of international space law offer guidance, but as the IAA study concludes, they 'seem to call for a more precise regulation to ensure safety and proper implementation.'[20] This is the challenge now in the development of an effective STM regime.

One step in the right direction can be found in the COPUOS *Space Debris Mitigation Guidelines*, which call upon States to '[l]imit the probability of accidental collision in orbit',[21] explaining that 'accidental collisions have already been identified. Numerous studies indicate that, as the number and mass of space debris increase, the primary source of new space debris is likely to be from collisions.'[22] There is no doubt that STM is the classic mechanism for limiting the probability of accidental collisions on orbit.[23]

It is illustrative, however, to consider the limited progress made in this area to date. In 2006, a set of 'possible first steps' were identified in the IAA study.[24] Only one – endorsement of the debris mitigation guidelines – has occurred. The remaining three – improvement and coordination of space surveillance for collision avoidance, enhanced inspection and enforcement mechanisms for existing rules such as those of the ITU, and developing a legal distinction between active space objects and debris to facilitate active debris removal – all remain unachieved. This perhaps reflects a strategic as well as a coordination challenge, as PJ Blount has explained: 'space is a strategic domain with deep military implications, which means that there is conflict between the ambiguity prized by military actors and the predictability needed by commercial investors.'[25]

Notable challenges also include the sequence of 'tests' undertaken by various nations involving the intentional destruction of their own space objects,[26] several of which have created large debris fields.[27] Most recently, the Indian Government announced that, through the successful targeting of its own Microsat-R satellite in Low Earth Orbit, it had become a member of an 'exclusive group of space faring nations consisting of USA, Russia and China.'[28] Despite claims that the Mission Shakti test 'was done in the lower atmosphere to ensure that there is no space debris', debris from the test is still being tracked as of August 2019 and continues to pose a threat to the International Space Station.[29] Following this test, the German Delegation to COPUOS noted that 'the growing number of space debris unquestionably poses one of the biggest threats to the safe conduct of outer space activities.' They observed that despite the increasing number of actors in space, there appear to be worryingly 'low compliance rates with the space debris mitigation guidelines.'[30]

Further, some space operators are pushing the boundaries of existing regulation of the space environment, through challenges to domestic licensing of launches and payloads (as required under Art VI of the Outer Space Treaty). In 2018, Swarm Technologies agreed to pay US$900,000 to settle an investigation by the US Federal Communications Commission into the unlicensed launch of experimental picosatellites from India, having previously been refused a licence from the FCC.[31] In August 2019, it was revealed that the *Beresheet* mission, which crash landed on the Moon in April 2019, was carrying a secret cargo of tardigrades, a microscopic lifeform with the ability to survive the vacuum of space.[32] Since that time, Nova Spivak, the founder and director of the mission responsible for including the tardigrades, has challenged the regulation of planetary protection under existing space laws.[33]

Realistic Proposals for Change

The General Assembly has, in the *Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries*, exhorted States in the context of outer space to 'contribute to promoting and fostering international cooperation on an equitable and mutually acceptable basis'.[34] This has not resulted in effective agreement on treaty action. In this section, we therefore examine proposals for a way forward to identify the most promising avenues through which an effective STM regime could be introduced.

Some of the key threats that an STM regime needs to address have been identified by Larsen:

> Earth and our space-related infrastructure are threatened by traffic congestion, collisions with satellites and space debris, and NEOs [near earth objects]. Technical norms must be developed so that commercial opportunities in outer space can be realized and enlightening scientific exploration can continue.[35]

To this list of issues – congestion, debris and NEOs – may be added the avoidance of pollution, improvements in the enforcement of existing rules (for example, those of the ITU), the registration of space debris (not merely functioning space objects),[36] the acknowledgement of a distinction between space objects and debris to facilitate active debris removal,[37] and enhancing and sharing space weather forecasting. This is not meant to be an exhaustive list, but to highlight the range of issues that will need to be considered in developing an effective STM regime.[38]

The most likely avenues to develop an STM regime do not include that which may have appealed to an earlier generation of international lawyers – a comprehensive, multilateral treaty. It is not our intention here to canvass all of the reasons for this, but we note the treaty stasis which Brian Israel has observed in outer space.[39] This does not entirely rule out treaty action, but even more importantly it does not rule out the possibility of effective action – instead, it draws our attention to alternative means of introducing an effective STM regime. The point Brian Israel is making regarding treaty stasis is that there are alternatives, as he explains: 'layering of bilateral and non-binding mechanisms atop multilateral treaties is common across issue areas and has proven to be an effective approach to adapting a legal framework to evolving circumstances over time'.[40] In a more recent piece, he has identified generations of international space law: Space Law 1.0 (treaties and customary international law), Space Law 2.0 (national space laws whose broad adoption can create an effective international regime) and Space Law 3.0 (private agreements which structure the actions of commercial parties with a degree of overall consistency).[41] The point of relevance of those concepts for this chapter is that a comprehensive treaty is not the only way to implement an effective STM regime. Indeed, in many ways, international space law is already a mixture of legal forms, as Saadia Pekkanen has noted: 'today the multitype design of space governance interweaves hard and soft law, formal and informal organizational structures, and intrastate and transnational interactions.'[42]

A key recent contribution to the debate on STM has been made by Larsen. He has argued for the adoption of an approach to STM which parallels the approach to airspace issues – recommending the establishment of a body similar to ICAO which could develop STM standards for commercial space activities, without attempting to regulate military space activities.[43] The recommendation to limit STM development to civil space activities is a pragmatic one – States are unlikely to agree to the regulation of their military activities.[44] However, this pragmatic approach could also be highly effective. As Larsen has argued:

> Separating military from civil uses is now common practice … The International Maritime Organization (IMO) does not regulate maritime military activities. The International Telecommunication Union (ITU) also does not regulate military radiofrequencies or their related orbital slots. … ITU's civil regulations apply in outer space and are acceptable to military authorities. … Experience shows that military users appreciate the greater safety that results from using the uniform international air navigation standards. In fact, the military is also threatened by unregulated space activities that lead to military traffic collisions with other space objects and space debris. Any improvement in civilian traffic rules and space debris avoidances would diminish interferences with military operations. Order in outer space would also leave military operations free to follow civilian traffic rules, as has actually happened in military aviation, maritime traffic, and space telecommunication.[45]

Based on the airspace example, Larsen therefore argues that much can be achieved by focussing on regulating only civil uses of outer space, and notes that there may be considerable voluntary compliance in respect of military uses as well.[46] After all, 'with growing space traffic, the military will also have a growing interest in reliable regulations.'[47] Thus, an effective STM regime may be supported and used by military operators, even if it does not formally apply to them.

In addition to narrowing the scope of regulatory action by not attempting to cover military activities, Larsen would also constrain the scope of the STM regime to address 'safety and not apply to economic exploitation'.[48] Again, this is a pragmatic position which will reduce the scope of potential conflicts amongst States in establishing an STM regime.

Having identified a civil safety-focussed STM regime as the most achievable goal, Larsen has also examined potential models for a coordinating institution: ICAO, the ITU and COPUOS. He rejects the COPUOS model as too weak (lacking the power to make binding decisions) and too slow and cumbersome to be effective.[49] He rejects the ITU model as being too rigid and too slow because the regulations are treaty obligations that must be accepted by a political assembly of States parties.[50] Larsen's recommendation is to establish an STM body modelled on ICAO.[51] The advantages of this approach are that whilst the body would be established by treaty, the norms it establishes would be set by expert bodies rather than political ones,[52] which can lead to faster norm creation which draws on expertise and eschews politics. States would have the ability to make a formal deviation from the resulting norms if they think it necessary.[53] Larsen argues that:

> The ICAO model has proven effective and successful in establishing norms for aviation. ICAO has managed to preserve its technical nature and not be contaminated by international politics. The standing expert ICAO International Air Navigation Commission has formulated and updated norms as necessary. The urgent and continuing need for studying existing norms and updating them as the technology and environment change is particularly important for space debris.[54]

There is considerable force in these observations as to the advantages of the ICAO model. However, in order to pursue this model, Larsen envisages the negotiation of a new protocol to the Outer Space Treaty.[55] In many ways, this appears to us to be overly optimistic, although the intent is admirable. We therefore now look to whether there may be alternative means of pursuing a similar aim. The most likely alternative means involves unilateral action through national regulation which has the possibility of being adopted with sufficient consistency to form an effective international regime (what Brian Israel would call Space Law 2.0).[56] One important example of how this might work is that STM is now on the policy agenda of the United States, with its 2018 US Space Policy Directive 3 stating that it would 'Develop STM standards and best practices. As the leader in space, the United States supports the development of operational standards and best practices to promote safe and responsible behavior in space.'[57]

We note Larsen's point that, while this is an important step, 'the growth of international space activity clearly points to the need for international uniformity. Outer space activities are inherently international, and only international norms and standards can reduce space debris and possible collisions.'[58] However, we share PJ Blount's view that:

> While the most effective way to establish uniform STM rules with global coverage would be through a treaty that establishes an intergovernmental organization for such purposes, such a solution is very unlikely to materialize, as currently states seem to be unwilling to move forward on a variety of proposals for increasing collective security in space. … an international framework for STM will likely emerge bottom up … it will bubble up from the domestic level through state legislation, judicially made liability rules, and best practices among operators.[59]

Indeed, Blount has suggested the United States could establish an STM system, implementing it in domestic law, which 'as a global public good could have a huge influence on the rules that operators from different states establish.'[60] Blount's argument is that

> As the rules that emerge solidify into best practices, it will become easier for states to come to consensus on the norms, rules, and protocols that will govern STM at the international level. A gradual emergence of the law, especially in a highly technical and militarily strategic domain, will be more palatable to states.[61]

Of course, this is far from a utopian vision, but unilateral progress by a major space player certainly has the potential to inspire similar commitments from other States and build up – through national regulation – the foundation for an effective international STM regime. There is, however, a leap of faith that will be required. STM will require space situational awareness (SSA) data,[62] there is 'no comprehensive data pool for SSA data, and much of the data is still considered sensitive and restricted'.[63] Blount is optimistic that this challenge can be met:

> The biggest obstacle to STM is not data, or algorithms, or even law. The main obstacle is trust. … any STM system, whether national or international, must be built upon strong, open data and modelling. … While states may be wary of full openness for national security reasons, there is no need to compel states to share sensitive data or algorithms. A multinational data pool could help to fill gaps, and algorithms could be developed outside the national security context.[64]

In our view, the challenges posed by the need for pooling of SSA data and collative development of algorithms are significant. However, there is already evidence of effective private SSA data-gathering by the Space Data Association.[65] Further, it may be that key States conclude on balance that their interests are better served by engaging in an STM regime than by hoping for the best in the absence of effective STM. Certainly, those States wishing to encourage entrepreneurship in outer space have a commercial imperative to secure an effective STM regime:

> Loss of satellites from collisions can be financially ruinous. Operators need to know where other satellites and space debris are located in outer space. Operators need to have exclusive radio frequencies and orbital slots for safe navigation and control of their satellites. Space traffic management and rules of the road for outer space are now necessary for safe operations in outer space.[66]

States also have interests of their own. Even if military users of outer space remain outside the STM regime, it is true that:

> military operators have long seen the value in standardized interactions that provide operators with reduced risk to their capabilities, reduced risk of inadvertent conflict, and a metric with which to judge whether certain behavior may be hostile based on nonconformity with accepted norms.[67]

Moreover, 'governments have a direct interest in outer space norms through their own use of outer space and are guardians of space-related public interests, such as the availability of national and international communication lines.'[68] An example of this broader perspective is given by Blount, who notes that in an STM regime:

> having legal standards and rules for when a spacecraft must maneuver to avoid another object becomes critical … because maneuvering on-orbit is costly in terms of fuel, meaning that the life of the spacecraft is shortened. Some operators may choose to take the risk of collision rather than expend available fuel … In such cases, while the loss to the operator may make economic sense, the damage will increase risk for all operators.[69]

Accordingly, accepting the pragmatic limitations on an STM regime that dictate it focus on civil safety-based norms and leave aside military uses of the regulation of economic exploitation of outer space, it is possible to see the enlightened self-interest of States coalescing around a set of STM norms. Whether this occurs as a matter of treaty development, or initially through the acceptance at national level of standards which eventually gain broader acceptance, time will tell. The increasing international acceptance of the need for an effective STM regime, and recent US policy actions suggesting an intention to act in that respect, may be creating an environment in which progress on STM can be made.

Conclusion

As Brian Weeden has noted, STM is a challenge more important than sometimes realised:

> The problem we should be trying to solve is not how to keep a co-orbital anti-satellite weapon from destroying a US military satellite in Earth orbit. Rather, it's how to prevent an Iranian satellite from colliding from German satellite, which maneuvered to avoid a piece of Chinese debris, thus creating a piece of debris which collides with a US military satellite. The latter is a far more likely scenario, and has much more significant consequences for all actors in space.[70]

Improved STM is going to be necessary in the future if we are to preserve outer space as 'free for exploration and use by all States' as art I of the Outer

Space Treaty proclaims. STM alone will not be enough – debris mitigation will need to continue and be supplemented by active debris removal,[71] and the threat from intentional destruction of space objects in armed conflict will need to be addressed[72] – but enhanced STM will be necessary to productively manage increasing volumes of space traffic and avoid the growing risk of collisions.[73]

There is no obvious clear path to agreement on an STM regime. There is much to commend Larsen's suggestion that a suitable regime of civil safety-focussed STM (which does not regulate military activity or address economic exploitation issues) offers a promising way forward. As he notes, the Chicago Convention regulates only civil uses of airspace, and the ITU similarly has no power over military radio installations. In both cases, the regimes function effectively to coordinate civil users, and have some level of voluntary compliance from military and government users in any event. There are also clear advantages of an STM institutional model based on the ICAO model. While we find ourselves unable to share Larsen's optimism as to the prospects of treaty action to establish an STM regime, we are somewhat more optimistic about the prospects for more organic development commencing at the national level.

While the specific content of an acceptable STM regime is a technical matter rather than a legal one, the task of constructing an effective legal framework for an STM regime is one of the most pressing confronting international space lawyers today. While the challenges are considerable, it may be that the time is finally arriving for concrete action to start being taken, with leadership at the national level starting a process which ultimately leads to the emergence of an effective international STM regime.

Endnotes

1 UNOOSA (2019). *Guidelines for the Long-term Sustainability of Outer Space Activities.* UN Doc A/AC.105/C.1/L.366 (17 July 2018). Online at www.unoosa.org/oosa/oosadoc/data/documents/2019/aac.105c.1l/aac.105c.1l.366_0.html. Accessed 15 September 2019; There is also increasing academic attention to space sustainability. In addition to the contributions in this volume, see, for example, Ailor, W (2015). *Space Traffic Management* in Schrogl, K; et al (2015). *Handbook of Space Security.* Springer, New York. p231; Blount, P (2019*). Space Traffic Management: Standardizing On-Orbit Behavior*. 113 American Journal of International Law Unbound. *p*120. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/space-traffic-management-standardizing-onorbit-behavior/336B7F6141E7F2174013FAE508B9AACD/core-reader. Accessed 15 September 2019; Contant-Jorgenson, C; Lála, P; Schrogl, K (2016). *Cosmic Study on Space Traffic Management.* International Academy of Astronautics. Online at https://iaaweb.org/iaa/Studies/spacetraffic.pdf. Accessed 15 September 2019; Hobe, S (2016). *Space Traffic Management: Some Conceptual Ideas.* 65 Zeitschrift fuer Luft- und Weltraumrecht. p3; Larsen, P (2018). Minimum International Norms for Managing Space Traffic, Space Debris, and Near Earth Object Impacts. 83 *Journal of Air Law and Commerce.* p739; Miller, D (2017). Calling Space Traffic Control: An Argument for Careful Consideration before Granting Space Traffic Management Authorities. 23(2) *ILSA Journal of International and Comparative Law. p*279; Rendleman, J (2014). Space Traffic Management Options. 57 *Proceedings of the International Institute of Space Law. p*109; Takeuchi, Y (2011). Space Traffic Management as a Guiding Principle of the International Regime of Sustainable Space Activities. 4(2) *Journal of East Asia and International Law. p*319; Yan, Y (2019). Maintaining Long-Term Sustainability of Outer Space Activities: Creation of Regulatory Framework to Guide the Asia-Pacific Space Cooperation Organization and Selected Legal Issues. 47 *Space Policy. p*51; See also: Secure World Foundation (2018). *Space Sustainability: A Practical Guide.* Secure World Foundation (2018). Online at https://swfound.org/media/206289/swf_space_sustainability-a_practical_guide_2018__1.pdf. Accessed 15 September 2019.

2 See, eg, Ailor, n 1 above, [12.2.1], [12.2.3]-[12.2.4]; Secure World Foundation (2010). *2009 Iridium-Cosmos Collision Fact Sheet.* Secure World Foundation. Online at https://swfound.org/media/6575/swf_

iridium_cosmos_collision_fact_sheet_updated_2012.pdf. Accessed 15 September 2019.

[3] Larsen, P (2018). *Solving the Space Debris Crisis.* 83 Journal of Air Law and Commerce. pp 475, 475-481, 492-4. Online at https://pdfs.semanticscholar.org/a8c7/25ea846a68cab9d0d13d98351958d731e420.pdf. Accessed 15 September 2019.

[4] Larsen, P (2018). *Space Traffic Management Standards.* 83 Journal of Air Law and Commerce. pp 359, 362. Online at https://scholar.smu.edu/jalc/vol83/iss2/5/. Accessed 15 September 2019: 'Outer space traffic is expected to increase four-fold in the near term. The explosive growth of small satellites during the next few years plus the increase in space debris without any immediate prospect of significant debris removal will intensify the dangers.'

[5] UN General Assembly (2018). *Fiftieth anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space: space as a driver of sustainable development.* GA Res 73/6 (26 October 2018). Online at https://undocs.org/en/A/RES/73/6. Accessed 15 September 2019.

[6] Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 10.

[7] ibid 40. Similarly: 'The goal of STM is to use technical and legal mechanisms to reduce the likelihood of incidents such as collisions in Earth orbit': Blount, n 1 above, 120.

[8] Larsen, 'Minimum International Norms,' n 1 above, 751. Similarly: 'As the number and intensity of space activities increase, so will the need for rules on … STM. Emerging technologies such as mega-constellations … may stretch the limits of the current informal coordination system': Blount, n 1 above, 120.

[9] See, eg, Larsen, 'Minimum International Norms,' n 1 above, 752-3; Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 13, 59-89, 91-92.

[10] 'Outer space traffic could safely be managed much more intensely so as to allow more traffic in outer space similar to the way air traffic is managed in air space': Larsen, 'STM Standards,' n 4 above, 364. See also: Hobe, n 1 above, 15-17.

[11] On the legal system for the regulation of airspace, see, eg, Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 46-52, 55.

[12] See, eg, Larsen, 'Space Debris Crisis,' n 3 above, 481-2; Miller, n 1 above, 283-4.

[13] Weeden, B (2009). *Billiards in Space.* The Space Review (23 February 2009) Online at www.thespacereview.com/article/1314/1. Accessed 15 September 2019 ; Blount, n 1 above, 121-3. Of course, individual aviators seek to avoid collisions, and have technology such as TCAS (a traffic collision avoidance system) to assist them. These are, however, the last line of defence, not the first. Weeden includes a memorable quote from the Vice-President of Iridium about its approach to collision avoidance in outer space: 'grit our teeth and hold our breath'.

[14] Rendleman, n 1 above, 111.

[15] UN Treaty Collection (1967). *Treaty on principles governing the activities of States in the exploration and use of outer space, including the moon and other celestial bodies*, 610 UNTS 8843 (entered into force 10 October 1967). Online at https://treaties.un.org/Pages/showDetails.aspx?objid=0800000280128cbd. Accessed 15 September 2019.

[16] Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 10.

[17] ibid.

[18] ibid 39.

[19] ibid.

[20] ibid. Indeed, a useful list of important legal issues not addressed by present international space law relevant to STM is provided at 39-40.

[21] UNOOSA (2006). *Report of the Committee on the Peaceful Uses of Outer Space.* UN Doc A/62/20 Annex, Guideline 3. UN Office of Outer Space Affairs. Online at www.unoosa.org/pdf/gadocs/A_62_20E.pdf. Accessed 15 September 2019.

[22] ibid.

[23] Similarly, the proposed EEAS (2014). *Draft International Code of Conduct for Outer Space Activities.* European External Action Service. Online at https://eeas.europa.eu/sites/eeas/files/space_code_conduct_draft_vers_31-march-2014_en.pdf. Accessed 15 September 2019 would require States to 'minimise the risk of accidents in space'.

[24] Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 15.

[25] Blount, n 1 above, 121.

[26] Weeden, B (2014). *Through a glass, darkly: Chinese, American, and Russian anti-satellite testing in space. The Space Review* (17 March 2014) Online at www.thespacereview.com/article/2473/1. Accessed 15 September 2019.

27 For example, the Chinese destruction of its FengYun-1C weather satellite in 2008, creating at least 3,000 trackable pieces of debris in January 2007 (see Secure World Foundation (2010). *2007 Chinese Anti-Satellite Test Fact Sheet.* Online at https://swfound.org/media/205391/chinese_asat_fact_sheet_updated_2012.pdf. Accessed 15 September 2019).

28 Ministry of External Affairs (2019). *Frequently Asked Questions on Mission Shakti, India's Anti-Satellite Missile Test conducted on 27 March 2019.* Press Releases. Government of India. Online at www.mea.gov.in/press-releases.htm?dtl/31179/Frequently_Asked_Questions_on_Mission_Shakti_Indias_AntiSatellite_Missile_test_conducted_on_27_March_2019. Accessed 15 September 2019; Weeden, B; Samson, V (2019). *India's ASAT test is wake-up call for norms of behavior in space*. Space News (8 April 2019). Online at https://spacenews.com/op-ed-indias-asat-test-is-wake-up-call-for-norms-of-behavior-in-space/. Accessed 15 September 2019.

29 D'Mello, G (2019). Space Debris Left By India's Mission Shakti Continues To Threaten The ISS After 4 Months. Technology. India Times, 13 August 2019. Online at www.indiatimes.com/technology/science-and-future/space-debris-left-by-india-s-mission-shakti-continues-to-threaten-the-iss-after-4-months-373465.html. Accessed 15 September 2019.

30 Germany UN Vienna (2019). *Statement on Space Debris at the 58th session of the UN Space Legal Subcommittee, Vienna, 1-12 April 2019.* Speech. German UN Mission Vienna. Online at https://wien-io.diplo.de/iow-en/news/statement-debris/2208724. Accessed 15 September 2019.

31 Henry, C (2018). *FCC fines Swarm $900,000 for unauthorised smallsat launch.* SpaceNews (20 December 2018) Online at https://spacenews.com/fcc-fines-swarm-900000-for-unauthorized-smallsat-launch/. Accessed 15 September 2019.

32 Johnson, C; et al (2019). The curious case of the transgressing tardigrades (part 1). The Space Review. Space News (26 August 2019). Online at www.thespacereview.com/article/3783/1. Accessed 15 September 2019.

33 See @novaspivack <https://twitter.com/novaspivack/status/1165679997580759040>.

34 UNOOSA (). Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries. A/RES/51/122 (13 December 1996) [3]. UN General Assembly. Online at www.unoosa.org/oosa/oosadoc/data/resolutions/1996/general_assembly_51st_session/ares51122.html. Accessed 15 September 2019.

[35] Larsen, 'Minimum International Norms', n 1 above, pp 741-2. On NEOs, see: Larsen, P (2018). *International Regulation of Near Earth Objects (NEOs).* 67 Zeitschrift fuer Luft- und Weltraumrecht. p 104. Online at www.zlw.heymanns.com/fileadmin/landingpages/zlw/pdf/inhalt_2018.pdf. Accessed 15 September 2019.

[36] Larsen, 'Minimum International Norms', n 1 above, 773-4; Larsen, 'Space Debris Crisis', n 3 above, 518-19.

[37] Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 15; Larsen, 'Space Debris Crisis', n 3 above, 483-4.

[38] See also: Rendelman, n 1 above, 117-18.

[39] Israel, B (2014). *Treaty Stasis.* 108 American Journal of International Law Unbound. p 63. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/treaty-stasis/EC004CDD39BDF638E02435E9CDFA049C. Accessed 15 September 2019.

[40] ibid 67.

[41] Israel, B (2019). Space Resources in the Evolutionary Course of Space Lawmaking. 113 *American Journal of International Law Unbound. p* 114. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/space-resources-in-the-evolutionary-course-of-space-lawmaking/C139472F946BC6C48304C268062F419A. Accessed 15 September 2019. Indeed, Rendelman, n 1 above, states that 'It is a mistake to assume that space traffic management necessarily involves any government, or international governmental system. … In establishing any space traffic management regime, incorporating privately performed regulation, instead of a more traditional and onerous domestic or international governmental scheme, could provide a significant opportunity to select a more flexible, responsive, and evolutionary system': at 133.

[42] Pekkanen, S (2019). *Governing the New Space Race.* 113 American Journal of International Law Unbound. pp 92, 97. Online at www.cambridge.org/core/journals/american-journal-of-international-law/article/governing-the-new-space-race/14BD9B37A7A15A8E225A5355BB29E51B. Accessed 15 September 2019.

[43] Larsen, 'Minimum International Norms', n 1 above, pp 744-746.

[44] 'The establishment of a comprehensive space traffic management regime will have to cope with the reluctance of the military sector around the world to coordinate in an open manner': Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 53.

[45] Larsen, 'Minimum International Norms,' n 1 above, 746. But cf: 'Traffic management only works well when all users of the orbits abide by it. The transparency requirement of such a regime does not allow for secretive operations and manoeuvres that endanger the safe operations of others': Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 53-54.

[46] Larsen, 'Minimum International Norms,' n 1 above, 764.

[47] Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 54. Similarly: 'The establishment of legal rules of behavior will make all satellites, including military satellites, safer': Blount, n 1 above, 124.

[48] Larsen, 'Minimum International Norms,' n 1 above, 783.

[49] ibid 778.

[50] ibid 779.

[51] ibid 775-7.

[52] ibid 776.

[53] ibid 775-7. UN Treaties Collection (1948). *Convention on International Civil Aviation*, 15 UNTS 102 (entered into force 4 April 1947) (*Chicago Convention*) art 38. Online at https://treaties.un.org/doc/Publication/UNTS/Volume%2015/volume-15-II-102-English.pdf. Accessed 15 September 2019. It is for this reason ICAO's standards and recommended practices (SARPS) have been described as 'quasi-legislative': Contant-Jorgenson, Lála and Schrogl (eds), n 1 above, 48.

[54] Larsen, 'Minimum International Norms,' n 1 above, 776.

[55] ibid 750.

[56] Israel, n 41 above.

[57] US Government (2018). *Space Policy Directive-3, National Space Traffic Management Policy*. US Presidential Memoranda. Infrastructure and Technology. Online at www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/. Accessed 15 September; Weeden, B (2019). *Time for a compromise on space traffic management.* The Space Review (11 March 2019). Online at www.thespacereview.com/article/3673/1. Accessed 15 September

[58] Larsen, 'Minimum International Norms,' n 1 above, 784.

[59] Blount, n 1 above, 123-4. Similarly, Hobe, n 1 above, 19: 'In view of the more recent past, any kind of "hard" space legislation beyond the quality of a UNGA Resolution seems to be hard to achieve.'

[60] Blount, n 1 above, 124.

[61] ibid.

[62] ibid 121-2.

[63] ibid 122.

[64] ibid 123. See also: Hobe, n 1 above, 12-14.

[65] Larsen, 'STM Standards', n 4 above, 379-81; Rendelman, n 1 above, 121.

[66] Larsen, 'Minimum International Norms', n 1 above, 747.

[67] Blount, n 1 above, 121.

[68] Larsen, 'Minimum International Norms', n 1 above, 763.

[69] Blount, n 1 above, 123. But as to possible liability consequences of ordering manoeuvres, see: Miller, n 1 above.

[70] Weeden, n 13 above.

[71] See chapter X of this book; Larsen, 'Minimum International Norms', n 1 above, 753-6; Larsen, 'Space Debris Crisis', n 3 above; Larsen, 'STM Standards', n 4 above.

[72] See chapter X of this book; <https://law.adelaide.edu.au/woomera/>.

[73] We note that Larsen, 'Minimum International Norms', n 1 above, 759 proposes to address these challenges and a range of others through one comprehensive mechanism.

Earth Observation Data: Climate Change Monitoring

Mark Meegan

Introduction

Earth Observation (EO) data plays a crucial role in determining and mitigating the effects of climate change. The United Nations Sustainable Development Goals supports free and open data for the benefit of all citizens. Numerous stakeholders have a duty to ensure that the Paris Agreement targets are being met. To best address these legal issues, the legal profession must become more scientifically literate. Reform is needed with collaboration between national and international intergovernmental organisations.

Increased Carbon dioxide emissions lead to an increase in average global temperature, resulting in the phenomenon of climate change. The Intergovernmental Panel on Climate Change ('IPCC') has estimated that 21st-century global temperatures will increase from between 1.8°C and 4.0° C. Official policy reviews of climate change position is to maintain Greenhouse Gases (GHG) at 2-3° C; however, these levels are too low to prevent climate change.[1] EO data from orbital space missions are vital to monitoring the effects contributing to climate change and timely data on changes in the climate change. Doctor K. Kasturirangan, the former Head of the Indian Space Research Organisation (ISRO) identified that the great challenge facing the space community is understanding the interrelationship between this data and the international legal framework so to mitigate climate change.[2]

Earth Observation (EO) data can expand the local, national and regional monitoring capabilities of climate change.[3] The problem with the application of international treaties (eg the Paris Agreement[4]) has not been the content of the treaties but rather effectively recognising the relationship between legal compliance and technical complexities.[5] Satellite remote sensing applications are vital to ensuring states meet their international obligations. Satellite data provides technical information that can assist in the development of other areas of law (including human rights and climate change).[6]

The Foundations of United Nations Principles

After much discussion, The United Nations (UN) developed Principles that were not explicit on the full and open use of data or with respect to its use to monitor climate change.[7] In 1986, The UN General Assembly formulated the 'Principles relating to remote sensing of the Earth from space'.[8] These principles define 'primary data' as being raw data acquired and 'processed data' as processes that made the primary data. The principles define 'remote sensing activities' as being the primary data collection and storage stations for which the processing, interpreting, and disseminating of the process data occurs. Principle 10 expresses the need for remote sensing to advocate and disclose information on climate change. Principle 12 specifies that both primary data and processed data that has been gathered under the jurisdiction of the state that has produced it, the Sensed State can have access to this data on a non-discriminatory basis or a reasonable cost terms.

The principles were not formally binding agreement for states to follow, but they opened discussions between the advanced Space faring nations and the developing Space nations on the appropriate restrictions were in line with the Outer Space treaty. Principles 4 and 11 acknowledged the benefits of all countries based on equality without any form of discrimination to restrict the Sensed state from accessing the data.[9]

In 1996, the United Nations General Assembly was convinced from the Committee on the Peaceful uses of Outer Space the Declaration on the mutual benefits for all States, in particular, developing states.[10] The declaration elaborates on Principle 10 of remote sensing. The Declaration considers the various stakeholders' interests (including private, public, and universities) and the space capabilities of states. The main emphasis of the Declaration is on international cooperation that aims to assist developing nations to access space technology and finances to use space applications to improve their national capabilities via training and funding.[11]

Earth Observation and the 2030 Agenda

In 2015, the United Nations Members adopted the 2030 Agenda for Sustainable Development[12] ; World leaders formulated an international reporting measure known as the 17 Sustainable Development Goals (SDGs) to track the progress of 169 Indicators. UN members recognised that EO data could be exploited and data needed to be accountable.[13]

To effectively report the progress of meetings the SDGs, requires traditional data sourced from both domestic household surveys and modern data derived from Earth Observations (EO). EO data is essential to SDG monitoring efforts due to its continuous availability of information gathered with spatial and temporal resolutions that use modern data processing via satellites.[14] The SDG uses EO to monitors at least 40 of its 169 Targets.[15]

EO data provides conclusive evidence on reporting the progress of the Indicators. The world's agencies are currently or planning more than 300 different satellite missions with multiple applications but not limited to the atmosphere.[16]

Air pollution monitoring for Sustainable Human Habitat

In 2012, the World Health Organisation (WHO) identified that 3.2 million deaths were linked to uncontrolled air pollution. Over 2.6 million were these deaths Asian residents. Uncontrolled air pollution results in more droughts, bush fires and smoke haze. The following SDGs monitor air pollution 11.6 (reduce the impacts of air pollution in cities) and 3.9 (reduce the number of deaths from air pollution).[17] The integrity of data reporting against these targets is crucial. The geostationary satellite Himawari-8 is used to provide data on Aerosols in the atmosphere to support monitoring of the interrelationship between SDG 11 and SDG 3.[18]

On the 26th of June 2019, the European Court of Justice (ECJ) decided that different areas cannot be averaged to assess air quality standards.[19] The effect of the judgment requires strict compliance with air pollution standards by European local and national organisations.

Brussels residents and a Hoofdstedelijk Gewest Belgian environmental group sued the local authorities on the current air quality policy. The Brussels court referred the case to the ECJ to decide how EU laws were to apply in this region. The ECJ deliberation on two main issues: 1) do national courts have the authority to review the air quality measurements and 2) distinguishing how sampling stations measure toxicity in the air, be averaged to determine the quality of air.[20]

ECJ judges reasoned that the location sampling stations are crucial to determine the air quality levels exceed the EU pollution law threshold. Also, they agreed that national courts have jurisdiction to review these decisions.[21] With respect to the Court's case law, in the absence of EU rules, the domestic tribunals must follow the detailed rules of the EU law in particular Directive 2008/50. These detailed rules provided that the air pollution regime must not be less favourable than those in the practice of the domestic tribunal when a plaintiff is exercising their rights conferred by EU law.[22]

The averaging of the air quality the data samples from individual sampling stations shows that there are higher levels of toxicity in the particular region, which is deemed a violation of EU air quality standards.[23] The measurements obtained determined the levels of pollutants but cannot exceed the limit values under Article 13(1) of Directive 2008/50.[24] Article 1 of the Directive aims to protect human health to ensure that the appropriate measures are in place to combat the sources of air pollution.[25]

Human Right Considerations

Laura Horn and Steven Freeland recognised that a majority of states focus is on economic factors relating to climate change, but pay little attention to social and human right implications. In 2009, the United Nations Commissioner for Human Rights report focused on 'The Relationship between Climate Change and Human Rights'. Many fundamental human rights will be affected by climate change. Numerous intergovernmental bodies monitor and report on human right implications, whether directly or indirectly impact on the social needs climate change.[26]

The IPCC predictions indicate that climate change will intensify heatwaves, floods, bush fires, droughts and lead to an increase in human deaths.[27] These weather changes will impact on the right to life for all humanity.[28]

UNFCCC Reporting requirements

All Annex I parties[29] must submit an annual national greenhouse gas inventory with data sources to the United Nations Framework Convention on Climate Change (UNFCCC). Non-Annex I Parties are required to submit a less sophisticated report every four years. However, they must provide biennial update reports on their emissions.[30]

The inventory compilation consists of multiple activities. The collection of "activity data" includes but is not limited to estimated GHG emission sources and verifying of national data that is submitted to the UNFCCC expert review panel. For Non-Annex I Parties "consideration" requires a less extensive expert review. All parties must submit policy-related information on mitigation, adaption and funding every four years.[31]

The Paris Agreement

On the 12 December 2015, the Paris Agreement was adopted to provide a policy guideline to all levels of government and intergovernmental organisations to work together to support the SDGs.[32] The importance of accessible space-based data is vital to addressing climate change.[33] Both Articles 7(a) and (c) of the Paris Agreement recognise the need to improve scientific knowledge on climate change gathered from earth observations and improve sharing the information.[34] To address the Paris Agreement and 2030 Agenda, access to data is required.[35]

In 2019, the G20 members Theresa May, Emmanuel Macron and Angela Merkel have stated they are fully committed to the Paris Agreement.[36] However, unlike other members the United States withdraw from the Paris Agreement.[37] SDG 13 assists in the enforcement of the Paris Agreement.[38]

France makes a national commitment through CNES

France and its National Centre for Space Studies (CNES) were committed by President Macron to ensure that France meets its obligations Paris Targets and the SDGs indicators relating to climate change. CNES subsequently lead the initiative to help establish the Mexico Declaration.[39] In 2015, the Mexico Declaration was agreed in order to seek to ensure that all states are committed to achieving the SDGs in all areas to improve the quality and access of data for all. The Declaration required strong leadership with proactive action to achieve the SDGS.[40]

At the 2017, One Planet Summit in Paris, CNES submitted the Paris Declaration to the heads of the space agencies to coordinate their space specialists to reduce climate change leading to the creation of the Space Climate Observatory (SCO).[41] The SCO provides adequate, timely and reliable data on climate change with the utilisation of space technologies to address the Paris Agreement and SDG 13.[42]

International Data Sharing

The space community plays a vital role in meeting the Paris Agreement. Fifty GCOS (Global Climate Observing System) and 26 essential climate variables by the IPCC (International Panel on Climate Change) require all space stakeholders to improve the accuracy of the data[43] .

The Group on Earth Observations (GEO) was established in February 2005[44] as a global network consisting of over 100 national governments and 100 Participating Organisations which aims to promote human welfare with a better understanding via the Global Earth Observation Systems of Systems (GEOSS) Common Infrastructure (GCI).[45] The 2005 GEOSS 10-Year Implementation Plan recognises that to better understand climate change we must share data. The GEOSS Data Sharing Principles are as follows:

1. Full and open exchange of data within GEOSS, recognising international and national legal instruments.
2. All shared data made to be available without delay and at the lowest cost possible.

3. In relation to '2') data is made available free of charge or no more cost to reproduce for research and education.[46]

The principle of full and open access through the GEOSS initiatives grants the re-use of data for the intended purpose. GEO participants can impose restrictions on these activities with respect to international legal frameworks, national policies or legal mechanisms requires minimum legal intervention. This applies to private, government and mixed entity (eg private and public ownership in the corporation). All stakeholders can gain open access, if they satisfy the aims of the GEO. The drafters considered that sharing data are for the public good. Thus, the distribution of data can be inclusive to fully benefit humanity.[47]

The fundamental issue preventing the global space community to achieving effective and efficient open access to EO data is non-harmonisation of their different approaches. The terminology varies greatly across different national or, regional organisations and jurisdictions vary on the interpretation of access to data. Costs and deadlines in jurisdictions are inconsistent. Also the term "full and open" has been approached differently. A majority of the frameworks do not provide deadlines or provide a framework making data openly available. A key problem is the lack of harmonisation of definitions concerning stakeholders having full data.[48]

World Meteorological Organisation (WMO) Resolution 40 (Cg-XII) acknowledged the exchange of meteorological and related data which included commercial activities should provide free and unrestricted basic meteorological data on a non-discriminatory basis or to limit charges in relations to cost. The Resolution provides a comprehensive framework for commercial activities.[49] Also, the WMO Resolution 60 all data is free for implementing the GCOS.[50]

The adoption of the Open Data Charter emphasised the need for open data to combat climate change. The Chapter aims to build upon the climate data policies from the WMO Resolution 60.[51] Open data experts developed these six principles for data:

- Open by Default;
- Timely and Comprehensive;
- Accessible and Useable;
- Comparable and Interoperable;
- For Improved Governance and Citizen Engagement; and
- For Inclusive Development and Innovation.[52]

The Open Data Charter empowers stakeholders to deliver better outcomes for human rights and climate change. The Open by default principle allows free access for all citizens. Government data is defined to be not limited to, data held by all forms of government and by non-government organisations. The accessible and usable principle reduces the burden of releasing data to citizens. It allows for the data to be available across multiple formats that are free without any limitations.[53] The Charter has been adopted by 71 nations (including Australia) and endorsed by 52 organisations.[54] A desired outcome for the Charter will 1) improve the harmonisation of data terminologies and framework for all stakeholders and 2) enhance the accountability and transparency of climate change monitoring.

Copernicus data Policy

The EU Regulation No 9.11/2010 authorised the European Commission to adopt a dedicated data policy, known as the Global Monitoring for Environment and Security (GMES). This data policy later developed the Copernicus Data Policy from the Delegation Regulation No.1159/2013.[55]

The Copernicus data requires to be shared with stakeholders on the basis of free, full and open access to Copernicus data subject to conditions and restrictions. Article 7 provides access to the data within respects to the lawful uses.[56]

Article 11 to 16 of the policy set comprehensive restrictions on the access of the data. Article 11 provides appropriate restrictions where a stakeholder may be conflict of international agreement; or intellectual property rights; or affect the rights and principles of the EU Charter of Fundamental Rights. Furthermore, Article 12 recognises that some of Copernicus data may be affected by highly sensitive data or place the stakeholder at risk of accessing data that impair the security interests of the EU.[57] Article 16 acknowledges sensitivity of this data with considering the environmental, societal and economic benefits to obtain access to the data required. Article 16 sub-section 2, the security assessment made by the Commission will consider whether restrictions are required if similar data is available from other sources.[58]

The urgent need for Scientific understanding in law

A fundamental problem within international legal systems is resolving climate change violations. Under treaties, difficulties arise in determining how best to apply the technical legal complexities concerning the law. A revised legal approach may be required to resolve the cause and effects of climate change. Existing legal structures appear to be counterproductive that require a more sophisticated judicial system.[59]

The International Tribunal for the Law of the Sea is composed of 21 independent members, elected by the people who enjoy 'the highest reputation for fairness and integrity and of in field of law of the sea'.[60] The leadership of this court provides a useful example to potentially model courts to employ legal professional specializing in climate change. The International Court of Justice has a special chamber for resolving disputes subject to the authority of the court. A permanent chamber is required for dealing with particular categories of cases which deal specifically with cases relating to transit and communications. Judges with technical knowledge will far better at applying the law in these matters. Article 26 (2) of the Statute of the International Court of Justice empowers the court to form a chamber for dealing with a particular case.[61]

The public will greatly benefit from having such specialised courts. A litigant having technical knowledge will 1) better understand the concerns of their clients 2) have an enhanced ability to apply technical aspects to the law and 3) improve the public confidence in the profession. An expert panel consisting of the legal profession and the space community to establish a legal structure in addressing climate change would greatly benefit the broader community. A hybrid specialised legal structure; could develop legal precedent with scientific literacy so as to address the monitoring of climate change.

In the later part of the 20th century, there have been over 200 multilateral environment agreements that address broad environment issues, but few recognise the technicalities derived from space data.[62] These agreements have further created a pressing need for climate change data.[63] Nicolas Peter stated 'the existing Earth observation satellites were not designed to meet the information requirements of international environmental treaties. These satellites can be used to generate key information necessary for developing and implementing such treaties'.[64]

The International Convention for the Prevention of Pollution (MARPOL) articles refers to the uses of remote sensing in monitoring and regulating marine oil pollution.[65] In 1997, MARPOL Resolution 8 allowed the Marine Environmental Protection Committee (MEPC) to implement CO_2 reductions strategies for the Marine Industry.[66] Before the Paris Agreement, the International Maritime Organisation (IMO) had taken important steps to reduce the sectors of greenhouse gas (GHG) emissions. In 2000, the IMO estimated that ships in international trade contributed in 1996 contributed to approximately 1.8 % of the world total CO2 emissions. The second IMO GHG Study 2009 found that international shipping contributed to approximately 2.7 % of the total CO_2 emissions in 2007. The third IMO GHG Study 2014 estimated that 2.2 % of total global CO_2 emissions for that year. This study showed that total GHG emissions for shipping had substantially fallen from about 10-15 % than 2007-08 levels.[67]

At a national level, the Supreme Court of India has established a Central Empowered Committee to deal with the technical considerations of 'the 1980 Forest Conservation Act in terms of admissible evidence' of particular satellite data in court.'[68] Similarly, the Queensland government has legislation that acknowledges EO data in monitoring vegetation clearances.

EO data used as evidence in a court of law - an Australian case study

Since 2001, the Department of Environment and Resource Management (DERM) Remote Sensing Team (RST) has used EO data to determine Queensland vegetation clearing cases. The RST has assisted over 600 hundred investigations into unlawful vegetation clearing. EO data evidence has assisted in mapping to determine a suitable clearing for ninety cases.[69] RST officers have provided their Expert opinion on twelve cases, resulting in three of these cases being found not guilty. Only two cases that were heard by Queensland courts, judges in viewing EO evidence accepted that tree clearing occurred.[70]

During the 1990s, Queensland was divided by the debate on annual clearing rates. In 1994, the Queensland government introduced the *Land Act 1994* (Qld) to better promote the balance between economic, environmental and social opportunities. To address the aims of the new legislation, EO data was required. The Minister for Lands asked remote sensing scientists to determine the level of statewide tree clearing monitoring system.[71] In 1995, with the support of the Minister, the scientists used Landsat satellite images effectively monitor the tree clearing creating the Statewide Landcover and Trees Study (SLATS) Team.[72]

Between 1998 and 2010, SLATS annual monitoring was vital to notify the government of any potential non-compliance with legislation. Key geographic information (GIS) data layers determine legislative exemptions. The process will remove all known exempt clearing, while the remaining potential unlawful clearing will prioritise using another assessment of environmental metrics. The SLATS then provide the analysed data to the regional compliance and investigation (C&I) teams for further investigation.[73] EO data plays an integral role in leading evidence used in the investigations of vegetation clearing cases.[74]

Conclusion

Users of EO data have come to rely on it to play vital role in the monitoring the conditions of the Earth environment and measure stakeholders' behaviours against regulations for climate change. EO provides accurate data over large global geographic areas.[75] Stakeholders and stakeholders organisations have been established to play an authoritative role in monitoring the effects of climate change. The UNFCCC and related organisations (including space agencies) play a crucial role in collecting data that is crucial for decision-makers.[76]

French President Macron said at the latest G20 summit "scientists remind us of our duty every day. Young people remind us of our duty, too".[77] For stakeholders to meet the numerous targets of the SDGs accurate data is required. For the general public to understand the effects of climate change, a meeting of the minds is required to take place immediately. An expert panel consisting of scientists, policy-makers and lawyers must determine how to reform the legal system to address climate change issues.

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[69] Goulevitch, B (2013). '*Ten Years of Using Earth Observation Data in Support of Queensland's Vegetation Mangement Framework'* in Ray Purdy and Denise Leung (eds) *Evidence from Earth Observation Satellites* (Martinus Nijhoff Publishers, 2013). p113.

[70] *Elliot v Knights* (unreported, QMC, Cornack SL, MCJ, Dalby MC, 31 October 2006), *Witheyman v Simpson* (unreported, QMC, Cornack SL, MCJ, Dalby MC, 24 October 2006) citied in Bruce Goulevitch, 'Ten Years of Using Earth Observation Data in Support of Queensland's Vegetation

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