Earth, Solar and Lunar Lagrangian Point Management in the Mitigation of Anti-Competitive Conduct and Management of Natural Monopolies in Commercial and Military Space Activities

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Abstract

Lagrangian Points constitute a stable gravitational point between two or more celestial bodies. Previously used for scientific endeavours, such as the SOHO mission, in the future, Lagrangian Points may also serve to be both commercially and strategically advantageous given the nominal amount of resources required to keep a satellite or similar orbital asset in station-keeping on a Lagrangian Point.
To that extent, Lagrangian Points may be viewed as having a commercial 'value ' because of the competitive advantage afforded to the owner/operator of a spacecraft occupying such a position. This 'value 'proposition has certain similarities with geostationary orbital positions in Earth orbit.
Although propertisation of space and celestial bodies is prohibited under the *Outer Space Treaty 1967* (UN), orbits within space still remain rivalrous and commercially lucrative (Green, et al. 2018). By operating in a Lagrangian Point, satellites could effectively exclude competing services from also operating within those Lagrangian Points. For example, where one satellite — or a satellite constellation — operates within a Lagrangian Point, another satellite or satellite

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constellation might be precluded from operating within the same space of that Lagrangian Point, or its proximity.
This paper builds on previous work regarding the regulation of natural monopolies to mitigate anti-competitive behaviour risks (Green, et al. 2018) and proposes recommendations on how the risk of natural monopolies forming amongst Lagrangian Point missions may be mitigated under a variety of instruments available to both UNOOSA and the ITU.
In addition to this, this paper considers the military use of Lagrangian Points to mitigate the risk of transforming space into a warfare domain.

1. Introduction

On 2 December 1995, the ESA in partnership with NASA were prepping the Solar and Heliospheric Observatory (SOHO) for launch on board an Atlas II from Cape Canaveral Air Force Station.[1] Writing for *Solar Physics* journal in anticipation of SOHOs launch, Domingo, Fleck & Poland would note that not only would SOHO be tracked through various ground stations including Canberra, Australia, but that it would provide greater solar telemetry than had been achieved by SkyLab's Apollo Telescope Mount twenty years earlier.[2]
SOHO, however, would safely avoid the fate suffered by SkyLab — and its telescopic mount — of an uncontrolled de-orbit and impact with the township of Esperance in Western Australia on 12 July 1979.[3]

SOHO not only avoided SkyLab's fate of an uncontrolled de-orbit and impact with a populated area, but has continued on to have a significantly extended mission lifespan. As opposed to SkyLab's operational lifespan of nine months between May 1973 and February 1974, SOHO has been in continuous service for 24 years since its original launch in 1995, going well beyond its originally planned three-year operational window.[4]
Part of SOHOs successful longevity is due to its orbital choice of environments. Unlike Skylab which was located in Low Earth Orbit (LEO) at an altitude of 440 km, SOHO is orbiting in a Halo Orbit at a gravity-neutral position at Earth-Solar Lagrangian Point 1 (ESL1), located approximately 1.5 million km distance from the Earth.

1 National Aeronautics and Space Administration, 'SOHO Mission Overview', 3 August 2017, <https://www.nasa.gov/mission_pages/soho/overview/index.html> (accessed 27 October 2019).
2 Domingo, V., Fleck, B., & Poland, A. I., 'The SOHO Mission: an Overview 'Solar Physics, Volume 162, Issue 1-2 (1995). <http://articles.adsabs.harvard.edu//full/1995SoPh..162....1D/0000007.000.html> (accessed 27 October 2019), pp 2, 4 & 18.
3 Wynne, Emma 'When Skylab fell to the earth 'ABC Goldfields, ABC News (online), 9 July 2009, http://www.abc.net.au/local/photos/2009/07/09/2621733.htm> (accessed 27 October 2019).
4 Ibid, n 1.

ESL1 is one such Lagrangian Point that moves in sync with the orbit of the Earth and the Sun; allowing for satellites and other orbital assets to extend their mission lifespan and duration through remaining tidally locked in gravity-wells between the Earth-Sun celestial bodies. This distance provides SOHO, and other spacecraft several advantages in reduced fuel costs and improved efficiency for orbital mechanics.[5]

The advantages of Lagrangian Points are not reserved to SOHO. Lagrangian Points offer reduced fuel costs for satellites undertaking station-keeping for both attitude and altitude control; as their orbits would not require constant readjustment of their relative position to see the Earth's surface. They also offer the potential for hitherto untapped orbital environments, as Earth's orbital regions become more congested with the rise of NewSpace and the continued delay of effective active debris removal initiatives being implemented.[6]

Given the nominal amount of resources required to keep a satellite or similar orbital asset in station-keeping on a Lagrangian Point, these points may also prove to be commercially advantageous as they represent a potentially low-cost means of providing on-orbit station keeping and servicing of satellites, telecommunication services or similar telemetry services. To that extent, Lagrangian Points may be viewed as having a commercial 'value 'because of the competitive advantage afforded to the owner; or, operator of a spacecraft occupying such a position. This 'value 'proposition has certain similarities with geostationary orbital positions in Earth orbit. Finally, their locations may be unique for purposes of asteroid mining, and for government and military purposes.[7]

2. What are Lagrangian Points

2.1. History

Lagrangian Points, also referred to as Lagrange Points, "L-points"; or, "Libration Points" are gravity points that are formed in relation to two celestial bodies with independent gravity-wells. Leonhard Euler and Joseph-Louis Lagrange independently derived and published work showing the

5 European Space Agency Sharing Earth Observation Resources, 'Lagrange Points '2 November 2017, <http://www.esa.int/ESA_Multimedia/Images/2017/11/Lagrange_points> (accessed 27 October 2019).

6 Erwin, Sandra, 'At Small Satellite Conference, Frustration About Lagging Efforts to Deal With Space Junk '18 November 2018, space.com <https://www.space.com/42365-space-junk-cleanup-efforts-frustration.html> (accessed 27 October 2019).

7 Cohen, Marc, 'Phase I Final Report to NASA Innovative and Advanced Concepts (NIAC) Robotic Asteroid Prospector (RAP), 12 December 2013, National Aeronautics and Space Administration <https://www.nasa.gov/sites/default/files/atoms/files/niac_2012_phasei_cohen_rap_tagged.pdf> (accessed 27 October 2019), pp. 47-48.

existence of equilibrium orbits in a special case of the three-body problem in the late 1700s.[8] In this problem, where all three bodies are constrained in the same orbital plane, and there is a large difference of mass between the central object, the secondary orbiting object and a third satellite or tertiary object, gravitational and centrifugal forces can become stable or semi-stable.
There are five orbits where the gravitational and centrifugal forces placed on the satellite, when described in a rotating reference frame, combine to keep the satellite in equilibrium. The first three points are L1, L2 and L3, and were first described by Euler and are unstable equilibrium points colinear with the centres of mass of the primary and secondary bodies.[9] However, the fourth and fifth points — referred to as L4 and L5 – were described by Lagrange and represent stable equilibria in the same orbit as the secondary around the system barycentre, but 60 degrees either side of the secondary.[10]

2.2. Orbital Mechanics

It is not necessary to place objects precisely at the equilibrium points to take advantage of the stability of Lagrangian Points, as small perturbations to objects placed at L4 and L5 will result in “halo” orbits about the stable points such as that experienced by SOHO. Similarly, halo orbits exist for the other three Lagrangian points, though they are less stable.
For example, the stability of these orbits is demonstrated by the natural objects in these orbits, such as the Trojan asteroids that correspond to the Jupiter-Sun L4 and L5 points and the Hilda family of asteroids which orbit near the Jupiter-Sun L3 point.[11]
In addition to this, satellites in halo orbit may not require constant tracking of the Earth for their attitude control as such adjustments would not be so necessary with each body so relatively far apart, thereby providing a greater advantage in reducing overheads for ground station facilities. One such example of this is the SOHO satellite which requires orbital maintenance only once every eight weeks, or the NASA spacecraft WIND which was sent

8 Lagrange, Oeuvres de, Le Probleme Des Trois Corps 1772, <"Tome 6, Chapitre II: Essai sur le problème des trois corps"> (accessed 27 October 2019). See also; Euler, Leonhard, De Motiv Rectilineo Trivm Corporvm Se Mvtvo Attrahentivm, 1765, <http://eulerarchive.maa.org//docs/originals/E327.pdf> (accessed 27 October 2019).

9 Euler, Leonhard, De Motu Rectilineo Trium Corporum Se Mutuo Attrahentium, 1765, <http://eulerarchive.maa.org//docs/originals/E327.pdf> (accessed 27 October 2019).

10 Lagrange, Oeuvres de, Le Probleme Des Trois Corps 1772, <"Tome 6, Chapitre II: Essai sur le problème des trois corps"> (accessed 27 October 2019).

11 Broz, M.; Vokrouhlický, D. "Asteroid families in the first-order resonances with Jupiter". Monthly Notices of the Royal Astronomical Society (October 2008) 390 (2): 715–732. <arXiv:1104.4004. Bibcode:2008MNRAS.390..715B. doi:10.1111/j.1365-2966.2008.13764.x> (accessed 27 October 2019).

to L1 in 1994 on a five-year mission for radio detection of the sun.[12] Despite a planned operational life of only five years, WIND has remained operational for 24 years, with enough on-board fuel to remain effective at ESL1 until 2074.[13]

2.3. Practical Applications and further consideration

Presently, the focus of commercial and non-government actors undertaking space activities — commonly referred to as "NewSpace" — are limited to Low Earth Orbit (LEO) with some planned activity in Medium Earth Orbit (MEO) into the future.[14]

There are numerous missions that benefit from the orbital stability offered by Earth-Solar (ESL) and Earth-Moon (EML) Lagrangian Points, including solar monitoring such as demonstrated by SOHO; [15] communications as demonstrated by Queqiao,[16] and future settlement activities.[17]

Lagrangian Points also promise the same — or better — commercial and national advantages found in Earth's orbital environments of LEO, MEO and GEO. For example, the Earth-Moon L4 and L5 Points meet the criteria for telecommunication and telemetry services admirably, with a communications delay of approximately 2.5 seconds, thereby enabling shorter telepresence decision loops.

In addition to this, Lagrangian Points - specifically Earth-Moon Lagrangian Points - may permit crew-change and material transfer using vehicles

12 Worrall, W, Muhronen, D, Menrad, R, Berner, C, 'The SOHO Ground Segment and Operations', November 1995, European Space Agency Bulletin Nr. 84 <http://www.esa.int/esapub/bulletin/bullet84/worral84.htm> (accessed 27 October 2019). See also; European Space Agency Sharing Earth Observation Resources, 'WIND '<https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/wind> (accessed 27 October 2019).

13 European Space Agency Sharing Earth Observation Resources, 'WIND ' <https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/wind> (accessed 27 October 2019).

14 Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, IBFS File No. SAT-LOA-20161115-00118 (filed Nov. 15, 2016) (SpaceX Application) <https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0329/FCC-18-38A1.pdf> (accessed 27 October 2019). See also; Henry, Caleb, 'Dankberg teases ViaSat-4 specs, still mulling MEO constellation '16 October 2019, Space News <https://spacenews.com/dankberg-teases-viasat-4-specs-still-mulling-meo-constellation/> (accessed 27 October 2019).

15 European Space Agency Sharing Earth Observation Resources, 'SOHO '<https://directory.eoportal.org/web/eoportal/satellite-missions/s/soho> (accessed 27 October 2019).

16 Wall, Mike, 'China Launching Relay Satellite Toward Moon's Far Side Sunday' 18 May 2018, space.com <https://www.space.com/40626-china-launching-moon-mission-sunday-change-4.html> (accessed 27 October 2019).

17 O'Neill, Gerald. "The Colonization of Space." Physics Today, (1974) 27:32-40.

currently under design,[18] as well as requiring less station-keeping and acceleration propellant. For example, the additional delta-v required to shape the orbit of a vehicle returning from a near Earth object so that it reaches LEO is significantly larger than that required for transit from a heliocentric orbit to either Earth-Moon L4 (EML) or EML5. EML4 to LEO is approximately 7km/s for low thrust systems or 4km/s for high thrust systems, while many near Earth objects resource targets are 2 to 6km/s from EML4.

Operational considerations encourage the use of transfer stations to enable transfer of cargo or passengers between vehicles optimised for lunar descent and landing operations and vehicles optimised for orbital transfer; placing these stations in halo orbits about EML1 simplifies orbital transfer and station-keeping problems,[19] and could serve a logistics purpose similar to today's intermodal freight transfer stations. Further, communications with surface outposts that do not have line-of-sight to terrestrial ground stations will require relay satellites. This is a market that would be available for entrance by small satellites placed at EML2, enabling links to the lunar far-side. Government actors have already demonstrated the potential for this model.[20]

Additional communications relays for deep space operations could conceivably include vehicles at Earth-Sun L3 (ESL), ESL4 and ESL5, to serve as relays for those times when the Sun comes between the Earth and a distant spacecraft. Planetary protection missions, whether undertaken by government or by insurance firms, to track solar activity or near-Earth objects would benefit by being placed at ESL3, 4, and 5; the former by permitting more coverage of the solar surface as the Sun rotates beneath the spacecraft, and the latter by enabling better detection of small asteroids orbiting inside the orbit of the Earth.

3. Commercial use within the scope of the *Outer Space Treaty 1967* (UN) and Domestic Legislation

3.1. Outer Space Treaty 1967 (UN)

Like these Earth orbital regions, although Lagrangian Points also remain non-proprietary due to Article II of the *Outer Space Treaty 1967* (UN), they still remain rivalrous. As noted by Green, Neumann & Grey while discussing the rise of constellation satellites:

18 Ibid, n 5.
19 National Aeronautics and Space Administration, 'Lunar Gateway '21 June 2019, <https://www.nasa.gov/topics/moon-to-mars/lunar-gateway> (accessed 27 October 2019).
20 Ibid, n 16.

> Some orbital planes are more favourable for communications than others. The entities that commence operations first may have the unintended consequence of preventing their competitors from also providing similar services by monopolising the orbits of interest.[21]

Furthermore, as the orbital planes of Earth become more congested, costs for launches and space-rated equipment reduces, and improved telemetry and instrumentation begin to overcome the problems of distance for deep-space, it is reasonably foreseeable that the same issues faced in the regulation of orbital altitudes or planes for Earth may also begin for Lagrangian Points that connect with Earth, specifically the Earth-Sun and Earth-Moon Lagrangian Points.

Managing access to Lagrangian Points is critical for the continued development of near-Earth space. Implementing traffic control measures now, while utilisation is still nascent, may be a more effective jurisprudential strategy than waiting until there are complications due to historical use-cases.

Writing on the topic of commercial use for outer space, and the application of the *Outer Space Treaty 1967* (UN) Green, Neumann and Grey noted that:

> The *Outer Space Treaty 1967* (UN) also remains silent on the use of space by commercial entities, as well as the use of space for non-scientific and non-military purposes, such as for providing telecommunication services to the general public from space.[22]

To that end, it is not immediately apparent that commercial activities in Lagrangian Points are restricted by the application of the *Outer Space Treaty* 1967 (UN).

3.2. Domestic legislative hurdles to be overcome

Presently, foreign jurisdictions are making a move to commercialise space resources for the private sector, such as 51 U.S.C.A. *Space Resource Exploration and Utilization Act 2015* (USA).

§ 51301(1) of the *Space Resource Exploration* and *Utilization Act 2015* (USA) defines an asteroid as being a space resource, and § 51301(2) allows a private entity to commercialise a space resource for commercial gain. Similar legislative powers will need to be considered underneath the *Space Activities Act 1998* (Cth) or an additional legislative instrument, to enable Australia and other foreign jurisdictions to effectively exploit asteroids for resources.

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21 Green, Thomas, et al, 'Mitigation of anti-competitive behaviour in telecommunication satellites and management of natural monopolies', IAC-18-E7.2.9, 69th International Astronautical Congress, Bremen, Germany, 1-5 October 2018, p. 3.

22 Ibid, p. 4.

4. Regulatory framework to prevent congestion through active satellites and orbital debris forming in Lagrangian Points

The International Telecommunications Union's Radio-communication Sector (ITU-R) acts as a UN specialist agency that administers and regulates terrestrial, surface-to-orbit and inter-spacecraft radio-frequency communications. The ITU-R is also responsible for allocation of radio spectrum bandwidth for communications for satellites and other orbital objects, as well as the allocation of physical 'slots 'within GEO orbit. As has been previously noted, the ITU has 'achieved decades of peaceful and productive operations in the GEO communications market, while disallowing any monopolisation of communications spectrum by any operator or class of spacecraft'.[23] Through its previous decisions, the ITU-R has also established a precedent of decision-making with nation states, and has become a guiding authority on space traffic management within specific regions of space.

Part of the effectiveness of the ITU-R's management of the GEO region includes conditions for operating a satellite or other orbital asset in GEO to ensure that part of a spacecraft's propellant is held in reserve so that a spacecraft can be ejected out of GEO and into a 'Graveyard Orbit'. This disposal requirement, better known as Recommendation ITU-R S.1003,[24] forms part of a satellite operator's application to their national bodies for approval for launch; and is subject to the ITU treaty.

The application of the disposal requirement by the ITU-R to the GEO environment has kept the GEO environment relatively free of debris as opposed to its MEO and LEO counterparts, which the ITU-R do not regulate. Indeed, the effectiveness of ITU-R regulation of orbital slots in GEO, has led some members of the legal and scientific community to propose that the ITU-R also regulate the LEO and MEO environments.[25]

Introducing a scheme for the regulation of slots and positions within — and orbiting – Lagrangian Points, may also be advantageous in ensuring that these regions of space also remain relatively free of debris and the licensing requirements and management of these 'slots 'by the ITU-R may prevent monopolisation and anti-competitive conduct from forming within these regions of space.

23 Ibid, p. 6.

24 International Telecommunication Union, 'Recommendation ITU-R S.1003-2', *Environmental protection of the geostationary-satellite orbit,* (2010) <https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1003-2-201012-I!!PDF-E.pdf>.

25 Ibid, n 21, pp. 5-6.

5. State priority for disaster and military Applications

5.1. Lagrangian Points may compel the peaceful use of outer space through the formation of 'Neutral Bays' for government priority and emergency satellites

Beyond their potential commercial use, Lagrangian Points may also have immediate and practical advantages for government emergency and military purposes. The LEO environment commences at the Karman line at 100 km and terminates at 2 000 km altitude; Medium Earth Orbit (MEO) commences at 2 000 km and terminates at 35 000 km and GEO is located at approximately 35 000 km.

Although these altitudes are relatively distant for the purposes of manned flight and aeronautical engineering, they are still within the scope of most conventional weapons and anti-satellite technology.[26]

Government and military organisations adopting the use of Lagrangian Points over LEO, MEO and GEO may effectively de-militarise space entirely and in so doing, maintain the core focus of keeping the use of space peaceful for all nations.

This is in part due to the inability for conventional terrestrial-based weapons systems from targeting these areas. For example, ESL1 and ESL2 are 1.5 million km distant from Earth. A conventional ballistic missile does not possess the accelerant required to escape Earth's gravity well and reach either ESL1 or ESL2. Further, the distance required to reach a target in ESL1 may provide enough advanced warning to allow an intended target to alter course to avoid damage, or for the anti-satellite weapon itself to be intercepted by ground-based systems. These challenges may be significant enough mediating factors as to dissuade state actors from investing and innovating in the field of space-capable weaponry.

Under such a framework where state and military actors commence new missions to Lagrangian Points instead of LEO, MEO and GEO environments, the risk of transforming the space environment into a warfare domain may be significantly reduced.

5.2. Current Strategies for Government and Military responses to space warfare

The present intention of military and government to overcome the risks afforded by anti-satellite weaponry is to create constellations of satellites to absorb losses through numerical superiority. As noted by Captain Nayak in 2017:

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26 'US shoots down toxic satellite' 21 February 2008 The Daily Telegraph (online) <https://web.archive.org/web/20081222024953/http://www.news.com.au/dailytelegraph/story/0%2C22049%2C23251796-5001028%2C00.html> (accessed 27 October 2019).

> One immediate deterrent to hostile space action is therefore to distribute the US concentration of space power, lessening the reward for hostile action. Fielding duplicate, redundant systems to those in existence is unrealistic in a fiscally constrained environment. Distributed or disaggregated systems, on the other hand, are intrinsically less vulnerable. Since the capability is exerted through a larger number of redundant component parts, multiple component satellites can be lost before total system failure. The exploding growth of CubeSats, which have a reputation for being low-cost and easily reproducible, has a natural place in this discussion. …
>
> The forte of CubeSats appears to be in the "numbers game." Even in the absence of direct conflict, a disaggregated system allows for cost and efficiency benefits in acquisition and operations. Such systems are resilient by nature.[27]

However, whereas the strategy of replacing military satellites with satellite constellations may be effective against non-state actors, or actors with limited ballistic resources, such a strategy may only serve to inspire conventional enemy actors to produce more anti-satellite weapons thereby increasing the scope of warfare in the space domain.

Even worse perhaps, military satellite constellations may have the unintended effect of compelling state actors to design satellite weapons that disrupt large areas of orbital planes or environments, such as was achieved with the high-altitude nuclear bombing tests of the Soviet Union and the United States of America throughout the 1950s and 1960s. These high-altitude bombing tests effectively demonstrated that nuclear discharge in a space environment would effectively disrupt satellites over large areas through electromagnetic interference such as in *Operation Starfish Prime*.[28]

5.3. Movement towards non-orbital based communications

Countries and their leaders have realised the over-reliance and frailness of LEO, MEO and GEO satellites.[29] GPS for example represents a dual-use technology that civilians use in their day-to-day life, right down to the cellphone applications and in-car navigational aids that transport work forces

27 Nayak, Michael, 'Deterring Aggressive Space Actions with Cube Satellite Proximity Operations: A New Frontier in Defensive Space Control 'Air & Space Power Journal , Winter 2017 pp 92-102 <https://www.afspc.af.mil/Portals/3/documents/Schreiver%20Essay%202019/2017_SEW-Nayak.pdf> (accessed 27 October 2019), p. 94.

28 Plait, Phil, 'The 50th anniversary of Starfish Prime: the nuke that shook the world' 9 July 2012 Discover (online) <http://blogs.discovermagazine.com/badastronomy/2012/07/09/the-50th-anniversary-of-starfish-prime-the-nuke-that-shook-the-world/#.XbUYmy8ZNPM> (accessed 27 October 2019).

29 Ibid, n 27, p. 92.

all across the world. GPS are also used for military activities including for gathering intelligence, defence, and forward operations.

Military forces have found ways to destroy GPS satellites or 'spoof 'GPS receivers 'positions.[30] Events of "GPS-Spoofing" are already in-play as a means to throw off a vessel or an aircraft's assumed position.[31]

GPS may prove a lucrative target for enemy action in the event of conflict with a state actor. In addition to spoofing, the frailness of LEO, MEO and GEO satellites means that industrial-use laser operators need to refer to a gridded chart showing satellite locations before they use any laser systems in order to not damage satellites in LEO, MEO and GEO orbital planes. Even the slightest discharge can damage or destroy a vital satellite. In an effort to mitigate risks if GPS is lost, leaders have called for the revival of Celestial Navigation (C-Nav) and Long Range Navigation (LORAN).[32]

However, C-NAV has limitations of time, visibility, and education of personnel. Time to wait between obtaining running-fixes of the sun, user time to calculate lines of position from celestial bodies, and even certain times of night are unfavourable. If the sky or horizon is unclear, accurate navigation cannot be made. In addition to this, Celestial Navigation is prone to human-error. For these reason, it is foreseeable that Celestial Navigation cannot take the place of GPS if GEO and MEO systems were down.

Furthermore, LORAN, was a hyperbolic radio navigation system developed in WWII. LORAN was the primary land-based means for navigation to assets before GPS.[33] Much like Celestial Navigation, LORAN training has ceased and the programs for maintaining and manning LORAN towers have been cut.[34] LORAN also needs to be forward operated, and since it is a land-based system, it can be compromised. A system in Lagrangian points may be safe from compromise from conventional warfare.

5.4. Lagrangian Points favourable over alternative systems

Satellite placement in Lagrangian points can be a superior means of navigation over C-Nav and LORAN. A single line of position given from a

30 Cimpanu, Catalin, 'Report deems Russia a pioneer in GPS spoofing attacks' 28 March 2019, ZDNet <https://www.zdnet.com/article/report-deems-russia-a-pioneer-in-gps-spoofing-attacks/> (accessed 27 October 2019). See also, Goff, Stan, 'Russia Jammed GPS Signals During NATO Military Exercise Involving US Troops' 14 November 2018, Inside GNSS <https://insidegnss.com/russia-jammed-gps-signals-during-nato-military-exercise-involving-us-troops/> (accessed 27 October 2019).

31 Ibid.

32 Gallagher, Sean, 'Radio navigation set to make global return as GPS backup, because cyber '8 July 2017, *Ars Technia* <https://arstechnica.com/gadgets/2017/08/radio-navigation-set-to-make-global-return-as-gps-backup-because-cyber/> (accessed 27 October 2019).

33 Ibid.

34 Ibid.

Lagrangian reference could quickly expose GPS / LORAN failure or sabotage. Pursuing to have a satellite source so far away from danger, to cross-check government devices in time of need, should be taken into serious consideration.

In addition to this, due to their relative distance from Earth, satellites in Lagrangian Points may also be at lesser risks of photo optic-based weaponry such as lasers, given the lux effect and diffusion of light over such large distances. Similarly, and for those government and military organisations concerned about latency across such distances, EML1 is 61350 km, and EML3, EML4 and EML5 are all approximately 380 000 km distance from Earth. Whereas this distance may pose latency issues for real time radio frequency communication, it may allow for asset tracking of vessels, sub-sonic and non-hypersonic aircraft and other government and military assets.

5.5. Application of the Outer Space Treaty 1967 (UN)

It is foreseeable that without the capability to launch anti-satellite weaponry from Earth effectively, some State actors may instead 'embed 'anti-satellite weaponry into craft that could be stationed around Lagrangian Points. However, such a course of action may be prevented from occurring pursuant to Article IV of the *Outer Space Treaty 1967* (UN) which prevents state actors from stationing weapons within Earth's orbit, on celestial bodies, or in outer space.

Furthermore, although Article IV of the *Outer Space Treaty 1967* (UN) has not been interpreted to prohibit or regulate the placement of military satellites, it is proposed that Article IV may be further reviewed to expressly require military satellites to be placed in Lagrangian Points or alternatively fielded outside of LEO, MEO and GEO, to reduce the risk of space being transformed into a warfare domain.

6. Conclusions

Space is infinite, however, the areas that are of commercial use are limited. This poses the risk of natural monopolies forming from State or Commercial actors who have a first-mover advantage in placing their satellites in commercially or nationally advantageous orbits or positions within Lagrangian Points, thereby denying future State and Commercial actors use of those orbits or positions within Lagrange Points.

Currently, the use of Lagrangian Points is limited to scientific purposes. However, the opportunity for regulatory intervention through the ITU or a similar organisation to prevent congestion of these areas is a promising solution to a looming problem.

Such an organisation, however, would need to balance public and private interests in the allocation of orbits within Lagrangian Points to ensure that State actors are also provided emergency and disaster priority.

Finally, Lagrangain Points may also assist in mitigating risk of warfare in space given their relative distance from conventional weaponry, and scope is afforded currently to amend the *Outer Space Treaty 1967* (UN) further to require military actors to place satellites in this area to avoid transforming space into a warfare domain.