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The Security Dilemma in Earth Orbit:

A New Space Arms Race

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ABSTRACT

This thesis investigates the deep security dilemma in Earth orbit, taking the space arms race that has been ongoing since 2007 as the point of departure. Building upon Robert Jervis's conceptualisation, three indicators from the offence-defence theory were derived to investigate the intensity of the dilemma. These were based on the space domain itself, on states' posturing in space, and on the nature of space weapons. My analysis showed that the dilemma is driven by a combination of offence-dominant factors, strongly advantageous to would-be attackers. This combination is deepening the security dilemma, incentivising aggressive state posturing, and increasing the likelihood of spiralling escalation. In addition, I proposed an effects-based typology of space weapons in an effort to find a new definition for this currently ambiguous concept, and explored the potentially catastrophic consequences of the use of such weapons with regards to the international security situation and the space environment. Finally, a possible avenue for arms control is given which could contribute to preventing the most harmful consequences and may alleviate the security dilemma.

Preface

You are reading my thesis "*The Security Dilemma in Earth Orbit: A New Space Arms Race*", which I started writing in January 2022. Building upon a couple of seminar papers I wrote in 2021, I already knew I wanted to write my thesis on the space domain from an international security perspective since at least 2017. Over these last couple of years, various people at Radboud University, NGOs, and the Dutch public sector inspired me to explore what I believe to be a very exciting – if rather worrisome – research topic that frankly deserves more attention from scholars, decision-makers, and general audiences alike. My hope is that I can make a small but useful contribution to that end, both as a student and in my future adventures,

I would like to express my deepest gratitude to my supervisor, Dr Gustav Meibauer, for his constructive and thorough feedback. His very helpful guidance has greatly contributed to the further refinement of my thoughts in this thesis, and I hope that this is reflected well in this final iteration.

I am also very thankful for the moral support provided by Jan-Gert and Jochem, with whom I have had the pleasure of regularly working and having (lots of) coffee together. While our three topics could not have been more different, I am glad we shared our writing process, and I wish them all the best with their future endeavours.

Finally, thanks should also go to my significant other and my family, for I could not have done this without their invaluable patience and support. I started writing this thesis during the most recent lockdown in the ongoing COVID-19 pandemic, and if I have learned anything in these unprecedented times, it is that I ought to spend more time with them now my thesis is complete.

I hope you find this thesis an interesting and pleasant read.

Bastiaan Smit
Nijmegen, 15 August 2022

*Disclaimer**:** I wish to emphasise that although writing this thesis partially coincided with my internship at the Security Policy Department of the Netherlands Ministry of Foreign Affairs, the contents of this thesis are entirely my own. While both my work in this thesis and at the ministry concerns issues of outer space security policy, I have not used any information from or received any assistance through my internship in any shape or form.*

*Title page image**:*** "The U.S. Gulf Coast at night" [Astronaut photograph ISS040-E-090540], by the International Space Station Expedition 40 crew, 2014, NASA Johnson Space Center (https://www.nasa.gov/content/the-us-gulf-coast-at-night). In the public domain.

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LIST OF ABBREVIATIONS

ABM	Anti-ballistic missile
ASAT	Anti-satellite (weapon)
ICBM	Intercontinental Ballistic Missile
SDI	Strategic Defense Initiative
WMD	Weapon of mass destruction

Glossary

Dual-use	Assets or technologies that can be used for civilian/peaceful purposes and military/hostile purposes alike.
Orbit (Earth)	The region of outer space in which objects revolve around Earth, as opposed to either in-atmosphere objects or space objects revolving around other celestial bodies such as the Sun and Moon. Four orbital regions exist at different altitudes relative to Earth: low, medium, geosynchronous, and high.
Space asset	Any artificial space object that fulfils a certain purpose to the controller, as opposed to natural space objects or non-functional debris. This also includes crewed vehicles and space weapons. Partially synonymous with 'satellite', though the latter may be confused with natural satellites (e.g., the Moon).
Space weapon	Those assets that are intended by the user to inflict one of three hostile effects: irreversible destruction, permanent disablement, or temporary disruption. A space weapon achieves such an effect by targeting objects in space, inflicting it from space, or both (see Chapter 5).
Terrestrial	Earth-based, located inside the planet's atmosphere; as opposed to space-based, outside the atmosphere. The Kármán line international norm sets this boundary at 100 kilometres above Earth's mean sea level.
Co-orbital	Synonymous with 'Orbit-to-Orbit'. A trajectory or direct fire path towards a space-based target that entirely takes place within Earth orbit, either because the space weapon was permanently stationed in orbit or because it has completed one or several orbital revolutions since its launch from Earth.
Direct fire	A direct path towards a target that does not involve a trajectory, requiring a line-of-sight between the weapon and the target. This is generally the case for non-kinetic weapons, which unlike projectile-based weapons would require mirrors or signal repeaters to hit targets beyond their line-of-sight.
Trajectory, sub-orbital	Any trajectory that leaves Earth's atmosphere and thereby enters orbital space, but does not include the circularisation manoeuvre that would establish an orbital trajectory and make an object revolve around Earth.
Trajectory, ballistic	A launch trajectory from the surface towards a surface-based target. Long-range ballistic missiles travel through outer space at the trajectory's peak, thereby conducting a sub-orbital spaceflight. As such weapons can be described as inflicting an 'Earth-to-Earth' effect, they are excluded from the effects-based typology of space weapons proposed in this thesis.
Trajectory, direct-ascent	For projectile-based space weapons, synonymous with 'Earth-to-Orbit'. A direct launch trajectory towards a space-based target, intercepting the target before completing its first revolution around Earth. This means no circularisation manoeuvre to first establish an orbit is conducted.
Orbital manoeuvre	In-orbit use of a space asset's propulsion (usually chemical or electric thrusters) to change its position relative to Earth, such as raising its orbital altitude or intercepting a target asset.
Global Navigation Satellite System	Satellite constellations offering worldwide positioning, navigation, and timing services. As prominent examples of dual-use space assets, these are

	commonly known as the American *GPS*, European *Galileo*, Russian *GLONASS*, and Chinese *BeiDou* constellations used by consumers and militaries alike.
Warfare, domain	The physical environment in which military operations are conducted, regardless of the means or media used for such operations, whose characteristics require a unique perspective and approach from the armed forces.

1. Introduction

The collapse of the Soviet Union saw a declining interest in military activities in outer space throughout the 1990's. As public discourse on the final frontier became increasingly de-securitised, spaceflight became a platform for newfound inter-bloc diplomacy, milestone scientific collaboration, and pioneering commercial enterprises. The Cold War space race and its related strategic arms projects, which included various types of space weapons, became a distant memory as Americans, Russians, and international partners joined forces to build the International Space Station in Earth's orbit.

However, even this golden era for the peaceful use of outer space never saw military space actors leaving the stage entirely. Since the end of the Cold War, three major events have gradually increased global insecurity in the space domain. First, the 1990-1991 Gulf War pioneered the large-scale military use of space assets to significantly contribute to combat operations on land, at sea, and in the air. Second, the 2002 US withdrawal from the 1972 Anti-Ballistic Missile Treaty revived the discussion on space-based ballistic missile defences, a topic that had laid dormant since the end of the controversial and ill-fated Strategic Defense Initiative launched by the Reagan administration in 1983. Third, a series of three anti-satellite missile tests conducted by the People's Republic of China between 2005 and 2007 challenged the US hegemony in the space domain, cementing the fact that space security had now become a multipolar affair. In response to the destructive 2007 Chinese space weapon test, the US destroyed one of its satellites in 2008, followed by India in 2019 and Russia in 2021. In addition, in rapid succession, states around the world have adopted national space policies that explicitly address questions of defence and national security. Indeed, space is now widely and publicly recognised as a new warfare domain (see Bodner, 2015; NATO, 2019; State Council PRC, 2015, chap. 4).

These phenomena are the observable manifestations of the security dilemma in Earth orbit: Perceiving the space domain as a source of security threats to their vital interests, states seek to obtain space weapons to defend from these threats. Yet in doing so, they increase the perception of threat among their counterparts, increasing mutual insecurity and becoming a self-defeating exercise. Previously dormant throughout the 1990's and early 2000's during which the United States enjoyed uncontested military superiority in space, the dilemma has been activated now this status quo is being challenged. Between the United States seeking to preserve its military dominance, Russia reviving its old space ambitions, China and India obtaining space weapons, and other advanced space actors such as France, Japan, and Israel openly exploring related capabilities, a new form of space weaponisation is unfolding well beyond the scope of the Cold War's nuclear triads.

In this thesis, I will argue that this weaponisation can now be characterised as a true space arms race; and that present conditions are unfavourable to such an extent that it is likely that the security dilemma will intensify even further. Should the space security situation spiral beyond our control and escalate into violence, then the consequences will be exceptionally grave. To avoid this outcome, the international community needs to prevent further escalation of the arms race by addressing the underlying security dilemma. Therefore, improving our understanding of the mechanisms of the outer space security dilemma, including the nature of the domain, states' posturing, and space weapons, is key. This leads me to the structure of my argument, which will be based around the following research question and five sub-questions:

> *What are the main drivers of the security dilemma in outer space, and how have these deepened the dilemma resulting in a space arms race?*

> a. *What is a security dilemma, and how does its spiralling mechanism operate?*
> b. *What constitutes the space domain, and what does its recognition as a military domain entail?*
> c. *How has states' posturing contributed to the perception of threat in and weaponisation of space?*
> d. *What constitutes a space weapon, and how have they become involved in this new arms race?*
> e. *What could be the consequences of further escalation of the arms race, and how can we prevent these?*

By answering these questions, I aim to contribute to the emerging field of international security in outer space, a topic that has received an increasing amount of scholarly interest over the last 15 years (see Klimburg-Witjes, 2021, pp. 529–530). As Peperkamp (2020) also noted, it is now important to determine to what extent space weaponisation has already progressed; if we have reached the threshold of a space arms race, then scholarly discourse should focus on the causal origins and vicious cycle mechanics of this arms race rather than proposing instruments that could prevent it. As is often the case with research on cutting-edge military technologies, state actor confidentiality and limited verifiable information in the public domain may have to some extent blindsided our discussions thus far, which would require us to 'catch up' with the military reality in outer space. This would be of particular academic concern as the scholarly and policy debate on space weaponisation has historically been prone to political polarisation, confusion of concepts, lack of neutral information, and lack of research interest (Johnson-Freese, 2007, pp. 2–4). It is my hope to contribute to the ongoing debate by taking an argued position that the space arms race is already taking place and, more importantly, why and how it is taking place. Improving our understanding of this mechanism will allow future studies to either challenge my findings and propose different frameworks, or to further develop these insights into the most suitable courses of action to alleviate the space security dilemma.

In a similar vein, the conclusions of this thesis have practical implications for states' defence and space policies as well as closely related efforts within the international community. One of the most active policy discussions is that of the European Union member states. Space security has become one of the main priorities of the Union's Common Foreign and Security Policy as defined by the 2022 Strategic Compass (European Union, 2022, pp. 35–36). The non-EU European Space Agency has similarly changed its view on the subject, only recently starting to criticise its international partner organisations for what it perceives to be security threats to its activities (Aschbacher, 2021). Indeed, the security-focused space policies implemented by the European Union and the European Space Agency in the last two years are perhaps most remarkable for the fact that they were recognised to be the exceptions to the rule that states' space and military policies have historically been strongly intertwined (Klimburg-Witjes, 2021, p. 537; see also Pasco, 2007, pp. 55–57; Payer, 2022). Given the European project's historical uneasiness with overt military affairs, this thesis' exploration of collective security instruments could be useful for European policy-makers seeking to secure Europe's interests in outer space but wishing to avoid participation in the space arms race.

A second interesting case is that of the United States, one of the space powers that has historically been the most proliferate pursuer of space weaponisation (as discussed in the forthcoming chapters). Under the Biden administration, the government has to some extent recognised the negative consequences of such activities. This was reason for Vice President Kamala Harris to announce a United States moratorium on destructive direct-ascent anti-satellite missile tests in an address to US Space Force personnel (The White House, 2022, 24:55-28:40). If more space powers implement such a moratorium, then this may serve as one of various possible instruments towards disincentivising the space arms race and preventing the harmful consequences that continued weaponisation could inflict on humankind.

To expand our understanding of the origins, mechanisms, and further development of the space security dilemma and the ongoing arms race, a literature review of primary and secondary source information was conducted. The rest of this thesis is structured in thematic chapters as follows. In the next chapter, I will explore the security dilemma as it was originally proposed by Butterfield and Herz, how it was further elaborated upon and popularised by Jervis including his offence-defence theory, followed by its refinement by Tang's that differentiates the dilemma from the broader spiral model. These concepts will form the theoretical foundations for the rest of the thesis as I translate the security dilemma . Subsequently, I will discuss in detail the three key aspects for the intensity of the space security dilemma: The nature of the space domain itself in Chapter 3, states' security-related behaviour in space in Chapter 4, and the specifics of space weapons in Chapter 5. Next, in Chapter 6, I will reflect on the implications of these aspects by examining the potential hazardous consequences of the different categories of space weapons. Finally, I make my concluding remarks in Chapter 7, where I will provide an overview of the main drivers of the space security dilemma discussed in this thesis, and why the intensity of the dilemma is a matter of significant international concern.

2. THE SECURITY DILEMMA

The security dilemma is a core concept in international relations theory, and the analytical point of departure for numerous debates on both historical and contemporary international security. It provides a useful analytical tool to explore the anarchy-based process of how uncertainty and fear about the other's intentions can gradually turn benign cooperation and peace into malign acts and violent conflict. First proposed independently by John Herz and (under a slightly different term) by Herbert Butterfield, both authors mainly used the security dilemma to warn their audiences of the uneasy balance and fragile peace between the post-war United States and Soviet Union. While the work of Herz (1950) was predominantly a revisitation of and response to the pre-war realism/liberalism 'Great Debate' for which he proposed a synthetical 'realist liberalism' (p. 178), Butterfield (1951) placed the international security situation of the early Cold War in the classical realist tradition of Thucydides and Hobbes to emphasise the mutual fear, misunderstanding, and the resulting unintentional violent conflict inherent to the security dilemma (pp. 19-21). Both authors used the concept to reflect on the failure of the League of Nations and the lessons learned for its successor organisation, rejecting the Interbellum ideals of collective security and grand conferences while warning against the precarious balancing act of extended deterrence, proposing a middle-ground option instead (Butterfield, 1950, p. 161; Herz, 1950, p. 180). However, unlike later scholars, both focussed on the decision-making of the individual actors rather than their relations and relative positions within the anarchic international system. More importantly, neither explored the mechanisms through which both states' actions can intensify the security dilemma or escalate it towards warfare (P. Roe, 1999, p. 2). The security dilemma concept thus remained a largely descriptive one, predominantly applied to historical cases and to reflect on the new bipolar balance of power of the 1950's.

The concept of the security dilemma was further developed by the late Robert Jervis in the 1970's, and it is his version that has shaped and popularised the modern understanding of the concept (P. Roe, 1999, p. 186; Tang, 2009, p. 591). Combining the work of Butterfield and Herz with neorealist theory and expanding the mechanisms underneath the concept, Jervis' security dilemma became the core assumption of the school of defensive realism. According to defensive realists, states seek to maximise their own security, yet by doing so irresponsibly they may unintentionally upset the status quo, pose a (perceived) threat to other states, and in turn solicit a response from others that will decrease their own security (Jervis, 2016, p. 11). Here there is room for misinterpretation and misjudgement, either by accident and ignorance or on purpose through threat inflation and deterrence-by-bluffing. How a state's perception of the threat posed by another relates to the other's actual intentions and capabilities is not particularly important to the logic of the dilemma itself; as the 1950's bomber gap and especially missile gap reflected in the defence policy of the United States, a strong sense of insecurity and the resulting measures can be entirely based on exaggerated assumptions and fabrications. It seems likely that the risk of such a situation does increase as the misunderstandings inherent to the security dilemma aggravate. One prominent example of how to address the mismatch between perception and reality are the confidence-building measures on which the Russian-American strategic arms agreements rely, which not only prevent a repetition of the 1950's nuclear hysteria but also form the foundation for careful nuclear reduction and disarmament. Perhaps the most successful cases are the armed neutrality policies of Switzerland and, until May 2022, Sweden: both states have maintained sophisticated armed forces, though only using these as a deterrent. Recognised as such throughout the 19th and 20th centuries, these countries closely mimic the ideal type of the defensive realist state, and have successfully prevented a regional security dilemma by convincing others of their benign intentions. In Jervis's interpretation, the security dilemma can thus be alleviated through restraint in both one's actions and reactions, in turn making cooperation between states possible.

Different interpretations of the concept can be found in other schools of international relations as well. Offensive realists argue that the security dilemma instead rationalises conflict and renders war inevitable; (neo)liberals believe international or democratic institutions have the unique capability and legitimacy to alleviate the dilemma; and constructivists have posited that the dilemma is one of the processes through which identities can reduce or exacerbate the issues associated with international relations in an anarchic world (Tang, 2009, pp. 587–588). Since the security dilemma concept is recognised by (or at least compatible with) every widespread theory of international relations, I will not specifically address the great debates between them in this thesis. Instead, I heed the warning of Olav Knudsen (2001) not to get bogged down in 'camps' but rather integrate what could be perceived as cross-school and interdisciplinary insights into an encompassing argument based on the topic at hand, as I believe will be the case in the later Chapters. Nevertheless, I recognise that the security dilemma remains most commonly associated with defensive realist thought, as it follows the five core assumptions of neorealism and has its origins in Herz's critique of what would later come to encompass the school of offensive realism (Mearsheimer, 1994, p. 7; cf. Jervis, 1978, pp. 199–200; Herz, 1950, pp. 177–179).

This difference in interpretation is perhaps best illustrated by Jervis's use of game theory to illustrate the general overview of his version of the security dilemma. Both Rousseau's Stag Hunt and the Prisoner's Dilemma involve two parties who each have two options: cooperate with the other party or defect. Subsequently, there are four possible outcomes: mutual cooperation *CC*, being betrayed as the other party defects from cooperation *CD*, defecting and betraying the other *DC*, or mutual defection *DD*. Jervis (1978) affirms that, as widely found in literature, the Prisoner's Dilemma create a logic in which the party achieves the highest relative gains in the *DC* outcome, but since the same is true for the other party who may thus attempt to achieve *CD*, this has the risk of resulting in *DD,* which unlike *CC* incurs costs rather than gains for both parties. Yet since this costs are equal, the *DD* outcome constitutes a Nash equilibrium, thus making defection the only rational option and the *DD* outcome the 'solution' of the game (ibid., pp. 170-171). Jervis argues that this logic is not representative of interstate relations however, as diplomacy does not follow a one-time logic but one that is perpetually repeated. Instead, he points to the Stag Hunt problem, in which unlike the Prisoner's Dilemma measures are taken to make *CC* the most preferable, rational, and thus likely outcome (originally explained by Rousseau as the need for hunters to cooperate so they can catch a stag rather than the easier but less valuable hares). This is done by 1) increasing the gains of *CC* while decreasing the costs of *CD*; 2) decreasing the gains of *DC* while increasing the costs of *DD*; and 3) reinforcing both parties' expectation that the other will cooperate (ibid., p 171). If successful, then mutual cooperation is now in the best interests of both parties, making it the rational outcome that it is not under the Prisoner's Dilemma; thus making the Stag Hunt representative of the defensive realist position while the Prisoner's Dilemma follows the logic of its offensive counterpart.

In terms of international security, Jervis equates the games' outcomes to interstate cooperation versus conflict (ibid., pp. 167, 176). These outcomes can relate to a great diversity state behaviours, including non-military acts, but all have implications for the bilateral security relationship (though I will focus on the development and deployment of space weapons). The security dilemma, then, is the situation where the state fears the *CD* scenario in which it is betrayed by the other state despite both states' benign or at least non-malignant intentions – and it will take measures to alleviate that fear such as reducing its vulnerability by refusing cooperation, seeking third states' protection, and/or building up its military power (ibid., p. 172). Such measures carry the risk of being not just self-defeating but rather disastrous:

> Statesmen who do not understand the security dilemma . . . do not understand that trying to increase one's security can actually decrease it, [and will therefore] overestimate the amount of security that is attainable; they will think that when in doubt they can 'play it safe' by increasing their arms. Thus it is very likely that two states which support the status quo . . . will end up, if not in a war, then at least in a relationship of higher conflict [such as an arms race] than is required by the objective situation. (Jervis, 1978, p. 182)

This is the tragedy of the dilemma; if only states could be convinced to trust each other's willingness to cooperate, then at least some violent conflicts between security-maximisers may be avoided.

2.1. The broader spiral model

It is important to stress here that when the breakdown of cooperation under the security dilemma results in conflict, this conflict is neither desired nor inevitable. Both states involved are defensive realist states, i.e., benign security-maximisers. The equation changes drastically when this is not (or no longer) the case: when one or both states involved are offensive realist states with the malign intent on expanding their power. Conflict would now not be a tragic outcome but an intentional one, serving outwards-oriented aims such as expansionism, imperialism, and belligerent manifestations of ideology, ethnicity, and religion. While Jervis (1978) does briefly acknowledge the existence of and behaviour from such states using the case of Nazi Germany (pp. 192-194), he still includes them within his version of the security dilemma[1]. Yet there is no dilemma here: a security-maximiser that is confronted not with a like-minded counterpart but with the power-maximiser opposite would not be wrong in interpreting the other's intentions as malignant, may rightfully suspect its adversary is not genuinely committed to cooperation, and would not act in a self-defeating manner by taking defensive (or even pre-emptive offensive) measures.

[1] Jervis (1978) uses the term "status-quo states", differentiating these from states that challenge said status quo (p. 193).

Indeed, Jervis explicitly mentions that the British and to a lesser extent the French military leaders were utterly misguided in their response in the face of the 1939 German aggression (ibid., p. 193). He blames this on Allied overconfidence in the defensive advantage established by trench warfare two decades earlier, resulting in defensive stances in which the British Isles were protected by the Royal Navy's unrivalled Home Fleet while France hid behind the state-of-the-art fortifications of the Maginot Line. For Germany, neither of these boundaries created the grave sense of insecurity on which the security dilemma relies. Jervis thus argues the Allied posturing made the security dilemma "less powerful", and would therefore not have led to conflict even with high levels of military investments as long as the German leadership had consisted of security-maximisers as well (ibid., p. 193). Evidentially, few of the events that transpired between 1933 and 1939 – such as the clear rejection and large-scale subversion of the Treaty of Versailles; the annexation of the Sudetenland and Austria; and the collapse of both the Interbellum's patchwork of European alliances and the global League of Nations – pointed towards a German security-maximising intent. The retributive rhetoric used by fascists throughout Europe at the time certainly did not befit a defensive posture either. In the end, Jervis seems to imply that the security dilemma was weak given the non-threatening security-maximising postures of Britain and France; while I do not believe the concept was at all applicable given the threatening power-maximising postures of Germany and Italy.

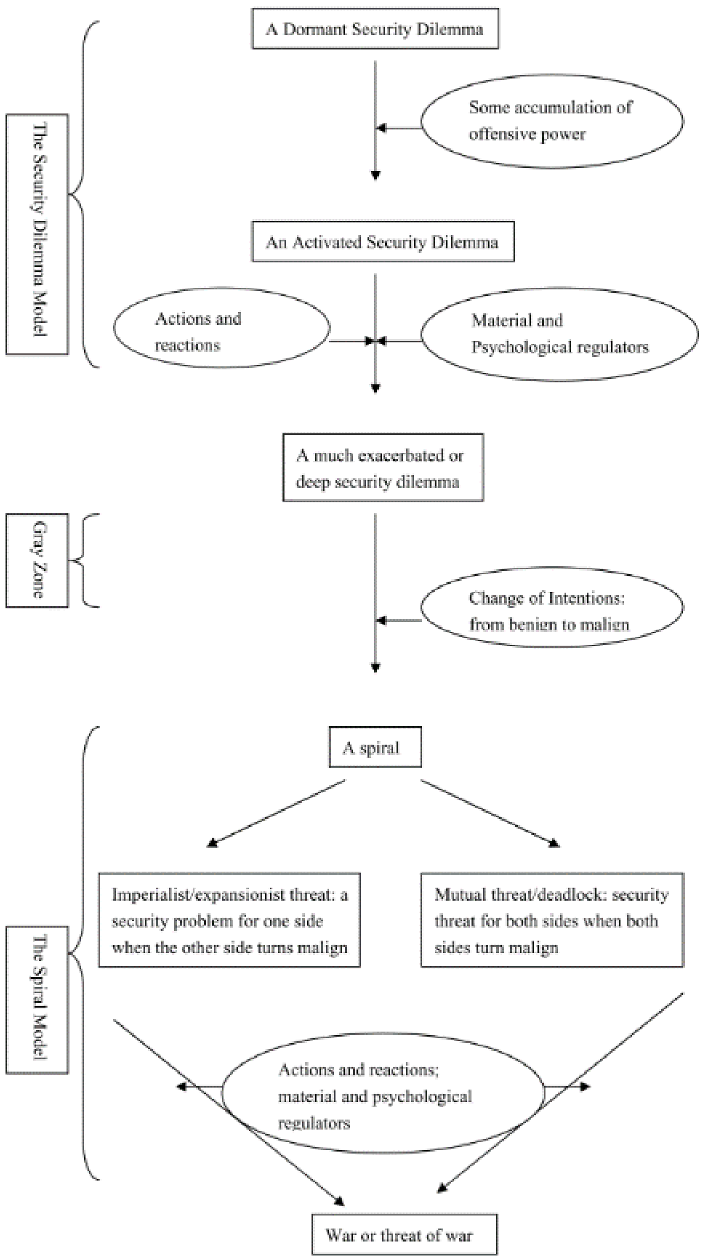
In hindsight, a spiral in the relations between what would eventually become the Allied and Axis powers – increasing tensions, competitive rearmament, the outbreak of violence – can be clearly discerned. But where this spiral deviates from the security dilemma's spiral is that it was not driven by a tragic, self-defeating logic. In game theory terms, the prelude to the Second World War is instead represented in the logic of the Prisoner's Dilemma: through various means and channels, the power-maximisers sought to exploit others while the security-maximisers sought to prevent being exploited. While the observations of non-cooperation, an increasing sense of insecurity, and eventually conflict may be identical, the theoretical logic behind this process changes when offensive realist states are in play. In other words, a certain spiral model involving offensive realist states exists that may be confused in practice for the spiral of a genuine security dilemma. As Shiping Tang (2009) states in his analysis of the concept in the three decades following Jervis's foundational contributions, "many extensions of the security dilemma were attempts to accommodate spirals rather than genuine security dilemmas", diluting the valuable insights that can be gained from a broader understanding of spiral models (p. 617). If we are to determine the current state and consequences of the *security dilemma* in outer space, it is thus important to clearly distinguish said dilemma from other forms of spirals beforehand.

One alternative provided by Jervis himself is one based on deterrence theory. Once again, the author uses game theory to illustrate his point, proposing that the logic of deterrence is akin to the game of Chicken: "if you think the other side is going to defect, you have to cooperate because, although being exploited (CD) is bad, it is not as bad as a total breakdown (DD)" (Jervis, 1978, p. 178). The most infamous example of this logic is that of the Cold War concept of mutual assured destruction through an exchange of nuclear weapon strikes, as Jervis recognises as well (ibid., p. 198). However, this model is – at least in theory – the very antithesis to a spiral model: it is the status quo in which “offensive weapons are those that provide defence”, depending on a fragile balance under which no side can be allowed to gain a decisive offensive or defensive advantage over the other (ibid., p. 206). If such an advantage is achieved by either side, then the balance would cease to exist, resulting in a grave destabilisation of the security relationship. This is exemplified by historical discussions on the self-defeating consequences of either deploying effective defences in the form of anti-ballistic missile (ABM) systems on the one hand, or further developing offensive first-strike capabilities through innovations such as warheads with multiple independently targetable re-entry vehicles, space-based launch platforms, or the use of hypersonic missiles. However, in the case such a destabilising capability would be introduced, we would once again return to the aforementioned logics of security-maximisers trapped in the security dilemma or power-maximisers inducing the still-unidentified spiral model. Jervis (1978) similarly concludes that, especially in the détente of the 1970’s when the author wrote this work, the nuclear arms race mostly followed the logic of a security dilemma in which both the United States and Soviet Union understood very well that tipping the precarious balance in one’s favour could be catastrophically self-defeating (pp. 212-213). While the feasibility of deterrence strategies in outer space is certainly a relevant notion worthy of further consideration, both unidirectional or mutual deterrence do not make for spiral models. Rather, deterrence tends to precede or succeed such a situation: Its ideal outcome is to prevent or halt further escalation, not induce it – the latter outcome would be a clear security dilemma.

Building upon Jervis’s work, Tang (2009) therefore proposes a clear distinction between any spiral model in international security and the specific spiral model that forms the core mechanism of the security dilemma *theory*. Aside from solving the aforementioned issue of erroneously including offensive realist states in a firmly defensive realist theoretical concept, the author argues that this distinction is useful in gaining additional insight into what have historically been ‘best practices’ for defensive realist states’ security policies in the face of both malign and benign neighbours (Tang, 2009, p. 617). Furthermore, it makes the security dilemma a dynamic process: Rather than being a tragic fact of life between security-maximisers, the dilemma can now be the prelude to the broader, ‘malign’ spiral model. Should the mechanism of the dilemma instil such grave fear into a state that it believes a pre-emptive strike to be necessary, then it flips from a defensive to an offensive posturing, thereby becoming a malign actor that transforms the security dilemma’s spiral into a general spiral model (ibid., pp. 617-618). Tang argues that this transformation between the two models is a gradual and especially reversible process, which I will refer to as the *spiral continuum*, displayed in ***Figure 1****.*

Figure 1

The spiral continuum between the security dilemma and the broader spiral model



Note. From "The Security Dilemma: A Conceptual Analysis", by S. Tang, 2009, *Security* Studies, *18*(3), p. 619. https://doi.org/10.1080/09636410903133050. Copyright 2009 by Taylor & Francis Group.

This more dynamic notion of the security dilemma is very useful for analytical purposes: it not only allows us to more precisely determine whether a dilemma exists, but also how intense (or deep) this dilemma has become thus far, how it could develop further in the coming years and decades, and how to freeze or reverse the current intensity. Importantly, further deterioration relies on 'actions and reactions', which are directly observable phenomena in such forms as weapons tests and state behaviour in international fora, but also on the 'material and psychological regulators' that can only be deduced (Tang, 2009, pp. 620–621). It is the latter that this thesis will focus on by taking the 'activated security dilemma' as the status quo and the spiralling 'grey zone' as a possible outcome should the space arms race escalate further. To understand the underlying regulators (or drivers) that could result in such escalation, I will make a selection of the numerous conceivable factors by using Jervis's final component of the security dilemma.

2.2. The offence-defence theory

If the spiral model is the 'what', the security dilemma is the 'how', and seeking to increase one's own security is the 'why', one question remains unanswered: *when* does increasing one's own security become a self-defeating spiral under the dilemma? Surely, it should be possible to do so without decreasing the security of the other; but there should simultaneously exist some indicators of the likelihood that such an attempt will devolve into the security dilemma. The answer to this question is perhaps the greatest contribution of Robert Jervis to the security dilemma theory: the offence-defence theory. The author envisions this theory as a causal framework for understanding, alleviating, or even nullifying a security dilemma (and its harmful consequences):

> The differentiation between offensive and defensive systems permits a way out of the security dilemma. . . . Indeed, if the advantage of the defense is great enough, there are no security problems. The loss of the ultimate form of the power to alter the status quo would allow greater scope for the exercise of nonmilitary means and probably would tend to freeze the distribution of values. This world would have existed in the first decade of the 20th century if the decision makers had understood the available technology. . . . When crises arose, no one would have had incentives to strike first.
> (Jervis, 1978, p. 214)

Of course, this differentiation itself was not a novel concept: as briefly discussed earlier, states have explicitly formulated offensive or defensive intents throughout the modern era. But what is original is that Jervis (1978) uses a more interpretative and a more military-technological perspective, proposing two variables as the primary conditions for a security dilemma: "whether defensive weapons and policies can be distinguished from offensive ones, and whether the defence or the offence has the advantage" (pp. 186-187).

Taken together, I translate these two variables into three indicators of the (likely) intensity of the space security dilemma. First, we can determine whether the space domain has an inherent offensive advantage or a defensive advantage by exploring the peculiarities of this exoatmospheric environment and human activities therein. Second, it can be derived from recent space security discussions and decisions (military doctrine, policy white-papers, funding allocations, etc.) to what degree states take a reserved and defensive or aggressive and offensive stance in space as a military domain. Such posturing is quite similar to the defensive realist / offensive realist distinction mentioned earlier, though this would be based on readily-observable state policies rather than the theoretical behaviour of ideal types. Third, we can explore what the term 'space weapon' actually includes and excludes and, if possible, differentiate between defensive and offensive space weapons. These three indicators should make for a plausible extrapolation for the further development of the outer space security dilemma's spiral over the coming decade.

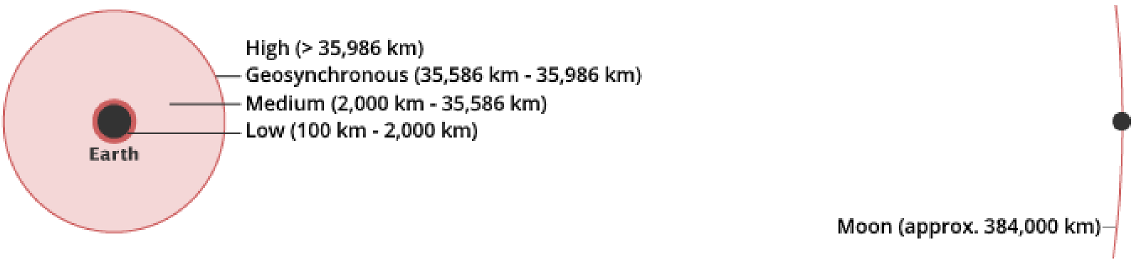
The refinement of the security dilemma theory by Jervis and Tang will form the foundations of my discussion of the outer space security dilemma in this thesis. Using Tang's spiral continuum, I argue that the security dilemma in space has been activated since the destructive 2007 Chinese space weapon test. What differentiates the Cold War space security dilemma from the current one is that it has the potential to become significantly deeper, which would risk approaching the grey zone at which point the security dilemma ceases to exist and the broader spiral model would take over. To illustrate the depth of the dilemma, I will cover each of the proposed indicators for the offence-defence theory in-depth in the following three chapters. Subsequently, the worst-case consequences of escalation into the broader spiral model are explored in Chapter 6, after which I will return to the application of the offence-defence theory to the current space security dilemma for my concluding remarks.

3. THE SPACE DOMAIN

In this thesis, 'outer space' will be used interchangeably with 'orbital space' or simply 'space'. While strictly speaking these are not synonymous as outer space consists of all space beyond Earth's atmosphere, current debates on the weaponisation of space are limited to the transitional volume of orbital space only. Military activities in interplanetary space or on other celestial bodies such as the Moon are rarely the topic of discussion in academic or policy-making circles and is therefore beyond the scope of this thesis[2]. While various altitudes have been proposed as the border between our atmosphere and orbital space, the Kármán line of 100 kilometres above Earth's mean sea level has seen the most widespread adoption as an international standard[3]. Subsequently, orbital regions exist which are divided according to their altitude relative to Earth's mean sea level, with the high orbital region extending to the point where objects no longer orbit the Earth but revolve around other celestial bodies such as the Moon or the Sun. The relatively narrow region of geosynchronous orbits has special value for space actors as at these altitudes space assets revolve around the planet at velocities that coincide with the Earth's rotation period. This enables assets to maintain their relative position in the skies permanently, or return to their original position every 24 hours. An illustration of the four orbital regions that comprise Earth's orbital space can be seen in ***Figure 2***.

Figure 2

Illustration of Earth's four orbital regions



Note. Altitudes and diameters to approximate scale. Orbital region altitudes as defined in intergovernmental regulatory practice, sourced from the Inter-Agency Space Debris Coordination Committee (2007, p. 7). Original illustration adapted from *Catalog of Earth Satellite Orbits*, by H. Riebeek and R. Simmon, 2009, NASA Earth Observatory (https://earthobservatory.nasa.gov/features/OrbitsCatalog/). In the public domain.

Each of the four orbital regions has different implications for the military space activities. High orbits have been commonly used for atmospheric and low-orbit monitoring satellites, including the specific purpose of detecting nuclear detonations and ballistic missile launches. One well-known example would be the American *Vela 5B* satellite known for detecting the 1979 Vela Incident, a possible nuclear detonation in

[2] Though with the notable exception of space law discussions, such as those regarding the modern-day interpretation of the 1967 Outer Space Treaty and the ongoing United Nations efforts towards an international regime for exploiting space resources (see for example Luxembourg & the Netherlands, 2020).

[3] The only alternative definition in common usage is the 80 kilometres boundary traditionally used in the United States. This minority view has been a recurring point of contestation in the United Nations Committee on the Peaceful Uses of Outer Space for decades (see Legal Subcommittee, 2021). However, since the establishment of its separate Space Force, the US seems to be adopting the 100 kilometres boundary as well (United States Department of Defense, 2021, p. 198).

violation of the Partial Test Ban Treaty. Other prominent examples include the Soviet *US-K* and Russian *Tundra* early warning satellites, which maximise the time spent at their intended position 'above' the Arctic while minimising the time spent crossing the Earth's southern hemisphere. These orbits are represented by the more dispersed assets to the north and south in ***Figure 3***. Far removed from Earth, early warning and monitoring satellites are less vulnerable to damage and interference and can cover more of the planet's surface within their broader field of view.

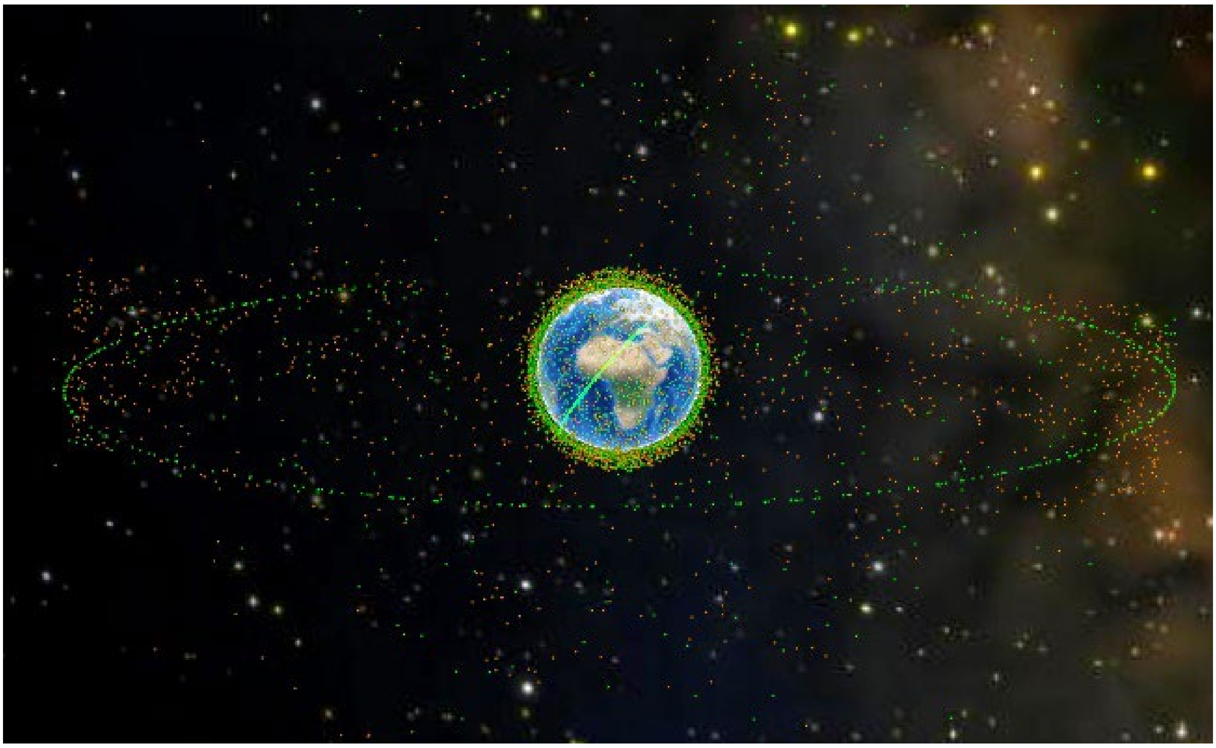
Of special value to military and civilian uses of outer space alike, geosynchronous orbits are used when it is desirable that an asset returns to the same position in Earth's sky every 24 hours. This is made possible due to the asset revolve around the Earth within the exact same period the Earth rotates arounds its own axis (a single sidereal day). In addition, the sub-type of *geostationary* orbits allow assets to remain in the same position in the sky permanently. Both types are useful for communications satellites as ground-based receivers are not required to physically move their antennae for optimal signal strength. In addition, geostationary satellite constellations can cover large regions or even the entire Earth, requiring only four satellites at minimum placed over Earth's equator (Draim, 1985). This is visible as the 'geosynchronous ring' in ***Figure 3***. Such global coverage at geosynchronous altitudes is commonly known from meteorological satellites, satellite TV, and a portion of satellite-based telephony and Internet services. These now-omnipresent civilian technologies have seen parallel military use, dating back to the 1960's and first being used by military actors in the Vietnam War for satellite telephony in the field.

A similar orbit is found in the medium orbital region, where assets in semi-synchronous orbits revolve around the Earth in approximately 12 hours – returning to the same position in the sky twice a day. Such orbits are well-known as the main altitude for global navigation satellite systems widely used by military forces and consumers alike, such as the American *GPS*, European *Galileo*, Russian *GLONASS*, and Chinese *BeiDou*. Of these, the GPS constellation was the first to see significant use in combat operations during the 1990 Gulf War (Bruger, 1995). Being closer to Earth, communications satellites placed at medium altitudes require less signal power and rocket fuel compared to their counterparts in geosynchronous orbits; reason for the first communications satellite *Telstar 1* to be placed in this orbital region.

Finally, the low orbital region is home to the majority of humanity's space assets, with 5,963 of the 7,849 of all assets (both derelict and operational) being located in this region (European Space Agency, 2022, p. 25). This relative density encompassing our planet can be clearly seen in ***Figure 3***. Of these assets, 3,483 satellites are part of the new mega-constellations of satellite-based broadband internet services providers *Starlink* and its rival *OneWeb* (McDowell, 2022). The number of commercial satellites within and without such constellations is set to grow exponentially towards the 2030's, and more and more governments operate their own satellites for myriad purposes as well. However, since this region therefore contains the most and arguably the highest-value space assets, the primary targets of any space weapon are likely found among these as well. Compared to their higher-orbit counterparts, these space assets are also less difficult to track as well as less costly to harm[4], further increasing the likelihood that any use of force will occur in this region. Indeed, all known anti-satellite weapon tests have been conducted in low Earth orbit; with the 1994 Russian *Nayrad-V* test being the highest-altitude case at the outer edge of the low Earth orbit, resulting in a portion of its resulting debris fragments still orbiting on the 2,000 km border with the medium orbital region (Weeden et al., 2022).

Figure 3

Visualization of space asset positions in Earth orbit



Note. Seen from high Earth orbit at a slight inclination northward. Green dots represent active space assets, whereas orange dots represent derelict assets. The diagonal green line crossing North Africa represents the orbit of the International Space Station, which is located in low orbit at an average altitude of 418 km. All positions are based on the *CelesTrak* real-time calculations for 25 May 2022 at 14:00 UTC. See Section 7.2. for notes on data limitations. Superimposed composition of screenshots of the *CelesTrak Orbit Visualization* (Kelso, 2022).

Whereas the ground, naval, and aerial domains of warfare are mostly self-explanatory within discussions on military affairs, I believe this not to be the case for the rather intangible, relatively new, and less understood domain of orbital space; a trait the space weaponisation debate shares with the other new warfare domain of cyberspace. With all major military powers now recognising the importance of both outer space and cyberspace for modern warfare, what does their recognition of these spaces as a *domain of warfare* actually entail? Sadly, it is difficult to find clarity on this matter from the military space actors themselves. The online database of the NATO Terminology Office does not provide a definition of the term nor any related term for

[4] Requiring less energy: missiles require less fuel for shorter orbital manoeuvres, and both directed-energy (e.g., lasers) and electromagnetic weapons (e.g., jammers) require less energy input to deliver their intended energy output at closer relative distances.

outer space (NATO, 2022). Official Chinese publications on military strategy do refer to both spaces as 'security domains', but do not elaborate what this means (State Council PRC, 2015). Meanwhile, the most recent public version of the United States' *Dictionary of Military and Associated Terms* does provide a definition of 'space domain' but only to differentiate it from the air domain; predominantly reflecting which branch of the armed services is responsible (United States Department of Defense, 2021, pp. 11, 198). Clearly, the global recognition of orbital space as a warfare domain is a notable development for space weaponisation; or at the very least, the recent explicitness of this consensus is. Yet what this actually means in practice remains unspoken.

As an alternative, we can extrapolate what 'domain' means by comparing the traditional and the new domains. An in-depth comparison can be found in the typology of warfare domains recently proposed by Michael Kreuzer (2021) of the United States Air University. In his article, Kreuzer struggles with the classification of the novel warfare domains and other technological developments in warfare. Although his main argument is that cyberspace should not be one, he also argues outer space *is* a domain for the very same reason cyber is not: a physical boundary. While the cyberspace debate is sadly beyond the scope of this thesis, I believe his article provides a very useful point of departure for the outer space one. Subsequently, "a *domain of warfare* is defined as a sphere of the operating environment that has physical characteristics requiring unique doctrines, organizations, and equipment for military forces to effectively control and exploit in the conduct of military operations" (Kreuzer, 2021, par. 13). In the case of our soil, seas, skies, and space, these physical characteristics are quite self-explanatory; domains are thus defined by their main geographical feature. In this case, the aforementioned Kármán line (which is based on considerations from aerophysics) can be then used as the boundary between the air and space domains. Kreuzer distinguishes such domains from what he calls 'layers of warfare', which are "mediums of the operating environment through which military operations can be conducted and operational effects [can be] achieved that span all domains of warfare. . . . [Forming these operations'] physical and social contexts" (ibid., par. 13-14). The author proposes four such layers: the physical (visible and kinetic), electromagnetic (physical but non-kinetic), information (data and communications), and cognitive (sociological and psychological) layers (ibid., par. 14). The first three of these layers will return in my typology of space weapons in Chapter 5. In conclusion, for the purposes of this thesis, a domain of warfare is the physical environment in which military operations are conducted, regardless of the means or media used for such operations, whose characteristics require a unique perspective and approach from the armed forces.

So when over the last decade all relevant space-capable states declared outer space to be a new domain of warfare, what intent did these actors convey to each other? Why is the 'domain' classification important to the interests of these states? And why should academics and policy-makers alike pay attention to these developments? I believe looking at the space domain itself only provides half the answers to these questions. To truly understand the space domain, we must compare it with more familiar territory by returning to Earth; and more specifically, its seas.

3.1. Analogies between the space and traditional domains

Outer space is widely regarded among contemporary scholars and militarists as analogous to the oceanic domain to varying extent (Bowen, 2020, p. 2). With the particular legacy of the high seas in military theory and history, this comparison seems to be a rather favourable one. States have acquired sea power by controlling the oceans with their navies, and at times fought battles between those navies to protect or contest that control. Yet unlike the brutish and hellish warfare on the ground and in the air, naval warfare is traditionally seen as a gentlemanly, brave, and almost romantic affair. Since naval warfare usually occurs far away from civilian populations, any engagement is seen by some authors as occurring in a pure battlespace where two sides exchange fire until one side is sunk or disengages (Walzer, 2015, p. 147). Furthermore, this exchange is to regulated by some of the oldest forms of laws of war still adhered to today (ibid., p. 148). With this oceanic analogy in mind, one could be led to assume that the testing and actual use of space weapons is not as problematic as similar weapons on Earth. Indeed, to a far greater extent than is true the oceans, orbital space is undeniably vast and only visited by a dozen humans at a time at most. Unlike terrestrial domains, there are no apparent chokepoints to fortify, no resources to seize, no ecology to damage, no populations to protect. Any use of force would seemingly involve nothing more than combatant forces and their legitimate counterforce targets, as space weapons are used to attack adversaries' weapons, supporting assets, and other orbital infrastructure only. Even more, since most spacecraft are uncrewed, the destruction of orbital forces would not necessarily involve the loss of even a single human life. Clearly the loss of dual-use assets would affect their civilian terrestrial applications, but surely outer space would still be the most pure warfare environment imaginable?

I argue that this oceanic comparison and its subsequent assumptions is a mistaken one, and that scholars and practitioners alike should take care in applying traditional military wisdoms and hypothetical scenarios to a novel domain to which these assumptions may not be at all applicable. When Alfred Thayer Mahan famously argued that a great power cannot exert control over geopolitics, economic trade, and land warfare without being able to project power at sea, he could not have addressed the major or even decisive role that aerial warfare would play throughout the wars of the 20th century, let alone the possibility of space warfare in the 21st. Yet such military lessons still feature prominently in the American space security debate, having been dubiously translated to apply to the space domain as well (Bowen, 2020, p. 2; e.g., L. A. Roe & Wise, 1986, p. 2). In a similar vein, the contemporary Chinese debate on military operations in outer space appears to be centred around how control of the orbital environment could replace air power and the earlier sea power as the main support element for land-based strategies, apparently in agreement with both Mahan's 19th century theory as well as their American competitors (State Council PRC, 2015, par. 'Force development in critical security domains'; Weeden & Samson, 2021, p. 1:30). Furthermore, the Chinese space policy consistently refers to outer space as the 'high ground' or the 'commanding height' (ibid.), both referring to how the classical Chinese work *The Art of War* prescribes military tactics on seizing the literal high ground; though I believe it safe to assume that Sun Tzu was referring to China's hills and mountains rather than the space operations in support of terrestrial combat forces that are being discussed in military academies. Clearly, by drawing on history's great theorists, these militarists wish to convey the importance of obtaining space capabilities. But making connections to the important strategies and tactics of the past alone does not equate an actual explanation of *why it is important* to obtain these capabilities specifically. In the end, while certainly colourful, these comparisons remain too superficial to be helpful in understanding the specifics of orbital space as a domain.

Perhaps the reality of space weaponisation is, as Johnson-Freese (2007) put it, "too distant, too technical, or too unimaginable to deal with" for outsider audiences (p. 4). But as the author rightfully points out to her audience of national policy-makers, conceding that a subject is inaccessible and prone to false assumptions is unacceptable. Similarly, Bowen (2020) notes that in the late 90's and early 00's "authors may have had to aggressively 'sell' the importance of spacepower for otherwise excessively geocentric audiences who did not grasp the importance of the development of Earth orbit as essential military and critical infrastructure" (p. 5). This in turn led to misguided, uninformative comparisons such as the oceanic analogy. Yet it is important to note that this is not the first time in modern warfare that a novel technological concept is translated to a theoretical military capability and in turn translated to broader (elite) audiences; the 20th century saw many such developments. Some of these, such as aerial, submarine, and nuclear warfare, had significant implications for the international balance of power, military ethics, and subsequent political sentiments and regulation efforts – so much so that Jervis (1989) suggests we may freely describe these developments as revolutions of international security (p. 10-11, 15). Not merely in hindsight either; these severe implications have often been discussed on both the domestic and international levels prior to their actual use on the battlefield[5]. There is no reason to assume that orbital warfare is any different from the 20th century revolutions in this regard.

To the contrary, the space weaponisation debate is most remarkable for the fact that it discusses a group of controversial and potentially destabilising weapons first tested more than half a century ago but never used in conflict. Even if orbital warfare becomes a reality, we may not necessarily face a military-technological shock like those of 1914, 1939, and 1945. We already have the weapons, we know how to use them, and at the surface level this information is freely available not just between adversary elites but to the public at large. The puzzle identified by other authors – and the most misunderstood aspect of this as-of-yet not quite mainstream topic in international security – is the context in which they are used and the consequences of that use. The scholarly and policy debates are thus in need of more accessible, more accurate, and more useful explanations to help solve this puzzle. As Shachtman and Singer (2011) noted in their discussion of policy-makers' equally misguided comparisons between the cyberspace domain and the Cold War's nuclear arms race, historical analogies can be quite useful insofar they "open new horizons and perspectives [instead of creating] new barriers" by drawing incorrect parallels that invoke the wrong lessons (par. 26). We should thus find better a better analogy that allow us to intuitively explain the outer space domain by showing familiar points of similarity and important points of divergence, which will then allow us to continue with the specifics of space security.

[5] For example, the 1907 Second Hague Conference extensively considered aerial bombardment of cities before its first occurrence in 1914. The Conference did not specifically address the use of bomber airships and airplanes (which at the time did not yet exist in military practice) though it did predict, and fail to prevent, the concept of strategic bombing.

Fortunately, this military analogy can be found in Earth's coastal waters. In Bowen's (2020) work on constructing a new strategic theory of space power in the Mahan tradition of sea power (and the later air power), he considers the orbital domain to be "a secondary, littoral and contestable realm like coastal waters . . . have [historically] been for continental powers" (pp. 3). This is in contrast to the popular comparison with the high seas, as that analogy would imply that contemporary space security would be equivalent to historical "island sea powers projecting power over oceans with the sea seen as a primary theatre and geographic medium" (ibid., pp. 3-4). Bowen warns not to oversimplify or caricaturise the military value of orbital space (as occurs with the aforementioned comparisons) because the space domain is not in any way isolated from Earth-based interests, conflicts, and harmful consequences (ibid., p. 6). The key difference with military contestations on the open oceans is that space is not a largely self-contained domain; nor is it akin to the electromagnetic spectrum in that space is far more than merely an operational environment in which operations occur that are inseparable from, and exclusively meant to provide support in the actual domains of warfare (which includes electronic warfare in space, as discussed in Chapter 5). It is this in-between or multi-domain nature that Bowen compares to coastal waters, and I believe this to be a key notion both to illustrate the military importance of orbital space but also how traditional theories on land, sea, and air are unable to capture this new frontier.

One sidenote that should be made on the coastal comparison is that the United States Department of Defense (2014) agrees that coastal waters are a special case, but unlike Bowen it regards such waters as a combination of two operational environments instead of a single entity (p. 156). This theoretical separation does not appear to be shared by other armed forces however, which generally treat it as a single operational environment within the maritime domain. I suspect this aberration may be in large part due to a legacy of American inter-service rivalry; within the same coastal waters, the US Marine Corps is usually responsible for landward operations while the Navy is responsible for seaward operations. In addition, until the 1970's, the Army was responsible for coastal defence with its shore-based *Nike* missile emplacements[6]. I wish not imply here that the multi-domain nature of orbital space will lead to similar rivalries affecting contemporary space forces, whether referring to the separate United States Space Force or elsewhere where space forces are generally subordinated to an air force or merged into an aerospace or special operations branch. Instead, it is the mutual dependency and necessary cross-branch integration historically found in coastal waters that will shape contemporary relations between space forces on the one hand and land, sea, air, cyber, and electronic forces on the other.

Following this line of reasoning, Bowen's work combines well with Kreuzer's (2021) typology of warfare domains, in which he attempts to combine the new multi-domain reality of warfare on the one hand with the more traditional domains (e.g., land and sea) and operational environments (e.g., electronic and information warfare) on the other. He proposes a third category of 'trans-domain regions', which are formed

[6] One of the nuclear warhead variants of these US Army missiles, the *Nike Zeus*, was intended in the 1950's to intercept Soviet ICBMs but perhaps became more notorious for their successful testing as nuclear anti-satellite weapons throughout the 1960's (Weeden & Samson, 2021, p. 3:12). As we will see in Chapter 5, a single weapon design fulfilling various different functions – including that of a space weapon – is one of the key peculiarities of space weaponisation.

by the overlap between the physical domains. The author proposes two such regions currently exist: the littoral (i.e., coastal) region between land and sea, and the close air region between land and air or sea and air (Kreuzer, 2021, par. 15). Kreuzer argues that while outer space as a warfare domain is currently indistinguishable from Earth's orbit space, it may become its full and independent domain in the future as humanity spreads beyond Earth, morphing into "a trans-domain region of orbital space, and the space domain as interplanetary . . . space" (ibid.). Aside from significant human settlement of outer space and other celestial bodies, such a shift might already gradually occur in the near future as various public and private actors have announced initiatives to exploit space resources on the Moon and in the asteroid belt in the 2030's. However, as long as such a shift in perspective is absent as I believe it to be today, I suggest combining Kreuzer's multi-domain concept with that of Bowen's space power theory. It follows, then, that space is a true warfare domain, yet it is quite unlike the traditional domains. Instead, while it is geographically located outside Earth's atmosphere, it remains inseparably dependent on Earth-based interests and events in today's geocentric security context; indeed, analogous to Earth's coastal waters viz-a-viz the land and sea. Until such time in the (far) future when a distinction between the trans-domain region of orbital space and the separate domain of outer space will become meaningful, these spaces are effectively synonymous. Subsequently, there exists a singular space domain which derives its value as an extension of the traditional terrestrial domains.

Indeed, this extended-value nature is reflected in the practice of multiple armed forces. In the military doctrine of the independent United States Space Force, it is stressed that "strength and security in space enables freedom of action in other warfighting domains" (United States Space Force, 2020, p. vii), and that in turn space operations are inherently multi-domain as they depend on terrestrial components, space-based components, as well as the electromagnetic communications between them (ibid.). Therefore, the 2019 separation of the space components of the United States Air Force and establishment of the joint United States Space Command do not necessarily represent a doctrinal shift in how the space domain is envisioned, but rather that the domain has become of such significant value to all service branches that a more wholistic, independent, yet fully-interwoven approach was necessary. Such an approach was previously often called for in discussions on potential 'force enhancers' or 'force multipliers', where space capabilities support ongoing combat operations and improve the effectiveness of other military forces (United States Department of Defense, 2014, p. 237; see for example Aberle, 2003). Similarly, other countries that do not have a separate space force branch also follow this multi-domain approach. In 2015, Russia merged its space, air, and missile defence forces into the new Russian Aerospace Forces, breaking with a decades-long legacy in which the Soviet and later Russian space forces were either an independent branch or subordinated to its Strategic Rocket Forces branch. In the same year, China consolidated its space, cyber, and electronic warfare forces into its Strategic Support Force branch. It now combines these high-technological, information-rich, non-kinetic domains within one organisation that supports, but is independent from, its traditional and missile forces. Most recently, in 2019, the French government expanded and elevated its Space Command within the French Air Force to a major command, with the latter being renamed to the Air and Space Force in the following year. While each of these countries have placed different emphases on what their space forces' tasks and how these relate to their other service branches, they share in common that military space capabilities are seen as both a necessary investment in itself but particularly as a valuable force enhancement for capabilities in the more traditional domains.

In conclusion, until a fundamental shift occur as humanity establishes a significant presence beyond Earth orbit, the space domain is a firmly geocentric phenomenon in which orbital space and outer space are militarily synonymous. For now, it predominantly derives its value as an extension of the traditional domains of warfare, where space power may very well be as vital to the armed forces of the 21st century great powers as sea power and air power respectively were in the 19th and 20th century. This space power is thus firmly rooted in and inseparable from our terrestrial concerns of international security. In this regard, it is analogous to Earth's coastal waters, which resembles the cross-branch importance and multi-domain nature of military space capabilities (including space weaponisation) better than the flawed oceanic comparison or those from fiction.

4. POSTURING IN SPACE: THE SHIFT TOWARDS WEAPONISATION

Peperkamp (2020) argues that "today, it is assumed (based on accepted state practice) that military activities in space are permitted, as long as they are non-aggressive (i.e., passive or defensive)" (p. 48). By now, the military use of outer space is widely accepted as the *status quo* in space practice, and all space-capable states have adopted security policies for outer space[7]. Furthermore, there exists consensus among scholars that space militarisation is hardly a new phenomenon; which is why, by itself, it is not the underlying cause of the space security dilemma discussed in this thesis. In the broadest sense, military space actors predate the establishment of civilian and private space actors and have held – and still hold – responsibility over a sizeable share of the global space industry. Most space programmes were dual-use in nature carrying both military and civilian payloads, most famously the American Space Shuttle programme between 1982 and 2011. And traditionally, the overwhelming majority of spacefarers around the world are either recruited from or simultaneously enlisted in the armed forces; in fact, the first spaceflight without military personnel on board was the *Inspiration 4* flight which flew as late as September 2021. But for this discussion, militarisation is an ongoing process that influences how outer space is envisioned as a subject of international security *in addition to* the presence of military actors in space affairs – and especially, what implications this has for the domain. In this case, the normative implication is that military space actors are here to stay despite increasingly sharing the stage with their civilian and commercial colleagues, with the political consequence being that defence personnel remains closely involved in the evolution of the space sector. By itself, this does not mean that their presence creates insecurity for other actors nor does it directly incentivise the competitive development of space weapons.

Various authors have sought to delineate militarisation with the intent to distinguish it from weaponisation. Johnson-Freese (2007) defines militarisation as "the military recognising the value of and using space assets . . . [in order to gain] security advantages", which occurred well before the first human spaceflight (ibid., p. 2). A more military practice-oriented definition is offered by Harrison et al. (2021), who suggest the term denotes "the passive use of space systems to support military planning and operations on Earth" (pp. 2-3). They concur that "space has been used for military purposes since the beginning of the space age, and it remains one of the main uses of space today. . . . Space is already militarised and will remain militarised for the foreseeable future" (ibid., p. 3).

The militarisation of outer space is nevertheless important to consider as the historical context in which space was securitised and weaponised during the Cold War. When an American *Bold Orion* missile became the first space weapon by successfully simulating a satellite interception on 19 October 1959 (Hays, 2011, p. 113), this did not occur in a military-strategic vacuum; there was an intent to develop this capability, a military purpose for doing so, and the necessary technologies and resources were already available. Yet simultaneously, the

[7] Remarkably, this now even includes the member states of the supranational European Union and the intergovernmental European Space Agency, with both organisations being the last major space powers to in some manner militarise their space activities (Klimburg-Witjes, 2021, p. 537; see also European Space Agency Council, 2021, p. 3; European Union, 2022, pp. 35–36)

non-weapons space race had only just begun: the *Bold Orion* anti-satellite test was conducted only two years after the Soviet Union's 1957 launch of the *Sputnik I* satellite signalled the start of the race between the Soviets and Americans. Moreso, the missile test predates the first operational intelligence satellites by nearly a year; the proven ability to destroy adversaries' military space assets was thus achieved prior to this ability becoming relevant for military practice. Part of the reason for this time discrepancy between technological ability and military use is rather mundane: strategic arms are theorised, conceptualised, and developed years before they are introduced, and space weapons are no exception. But the more important reason is that both the space race and the space arms race of the Cold War share not just the same technologies and actors but also a single origin: the state-of-the-art missile development projects during and in the aftermath of the Second World War.

The German A-4 ballistic missile is widely regarded as the grandfather of all modern space launch rockets and ballistic missiles (Becklake, 1995, p. 109; Burrows, 1999, p. 94; L. A. Roe & Wise, 1986, pp. 5–8). Chief engineer Wernher on Braun and his colleagues already recognised the dual-use nature of missile technology years before the war, seeing the potential and advocating for both peaceful space exploration and novel strategic weapons (Harbaugh & Dunbar, 2017). With the world's first ballistic missile becoming operational in the final years of the Nazi German regime, its primary purpose was to terrorise Allied populations including those in Belgium, the United Kingdom, France, and the Netherlands, made clear by its 1944 rebranding as the *Vergeltungswaffe 2*. Thousands died due to the forced and slave labour used to produce the missiles or in the Western European cities at which the missiles were launched. Besides the death and destruction it caused, the missile also set the stage for the space age. One of the A-4 missiles became the first human-made object to make a sub-orbital spaceflight on 20 June 1944, reaching a maximum altitude of 176 kilometres (Milazzo et al., 2017). At the end of the war, both the Western Allies and the Soviet Union seized as many assets and personnel of the German missile programme as they could. The missile and its derivates would see service on American, Soviet, and British military proving grounds for some years, setting another historical record on 24 October 1946 when a American A-4 became the first spacecraft to take images of Earth from outside the atmosphere. Subsequently, the gained knowledge and recruited German engineers were used to develop new missiles that truly illustrated the dual-use nature of spacefaring technology. For every peaceful achievement such as the first satellite (1957), animal (1957), and human (1961) in space, there was a parallel military development including the first nuclear-armed intercontinental ballistic missile (1957), anti-ballistic missile (1958), anti-satellite missile (1959), and first intelligence satellite (1960). Some of these involved the exact same rockets; the Soviet Union used the R-7 rocket was for both its peaceful and military 1957 achievements, and the American initially developed the *Bold Orion* as an anti-ballistic missile with only the final test being used to prove its secondary ability to destroy satellites; which has remained true for most American ABMs to this day. What this brief history of the 1940's and 1950's clearly shows is that the dual-use nature has always been an inherent characteristic of spaceflight, and that to some extent the technologies used for civilian spaceflight, ballistic missiles, and space weapons have been one and the same. Rather than the incorrect notion of spaceflight having become militarised over the decades, it would be more accurate to say that spaceflight has seen peaceful, civilian, and increasingly commercial developments both owing to and despite its origin as a predominantly military affair centred around ballistic missiles and military space assets.

This historical dual-use nature of outer space remains true today, though suffice it to say the usage of outer space has both expanded and diversified throughout the decades. Contemporary militarised purposes typically fall within one of three categories: "Intelligence, Surveillance, and Reconnaissance (ISR); Communications; [or] Position, Navigation, and Timing (PNT)" (Harrison et al., 2021, p. 3). In this sense, 'Communications' includes theatre-wide and worldwide command and control capabilities as used on Earth and in orbit alike, often collectively referred to as 'C3'. The 'ISR' umbrella also includes weather/climate satellites and space-based ballistic missile warning systems (Bruger, 1995, pp. 77–79). Taken together, space assets serving any of these purposes are known as "force multipliers" when they are used to support military operations on Earth (United States Department of Defense, 2014, p. 237). To a large extent, the perception of space militarisation is as either an issue or new phenomenon stresses the expansive but perhaps misunderstood dual-use nature of outer space compared to other domains. For instance, the commonplace repurposing of nuclear-tipped ICBMs into (civilian) space launch systems seems dramatic at first glance; but it is not too dissimilar from the historically common practices of turning naval combat ships into merchant ships or strategic bombers into passenger airplanes. The use of such dual-use space assets does not pose a significant development either.

In her influential book *Space as a Strategic Asset* on American space security policy debates, Joan Johnson-Freese (2007) therefore criticises the assumption held by some United States militarists that there has been an overall increase in global space militarisation. As discussed above, this increase did not exist: rather, the author argues, the militarists were framing the development of space capabilities by foreign states as a national security threat. Lobbying policy-makers for increased funding, administrative independence, and new missions for the military space actors of the United States – which would eventually appear successful due to the establishment of the independent United States Space Force in 2019. Indeed, it is in the United States where we can first find the transition from 'old' militarisation to the 'new' weaponisation that drives and is being driven by the space security dilemma since the 2007 Chinese anti-satellite missile test at the latest. First its Air Force, and then its Space Force, were no longer content with the traditional missions of "space support" and "space force enhancement", which respectively are the maintenance and management of military satellites and the aforementioned space-based supportive services (Lambeth, 2003, p. 97). Instead, the new military buzzword became "space control", defensive and offensive operations to ensure "friendly access and denying enemy access" to space (Lambeth, 2003, p. 105). Furthermore, the United States military should be prepared to use force to, in, through, and from space itself, including the use of destructive weapons and lethal force (Aberle, 2003; Joint Air Power Competence Centre, 2021; Lambeth, 2003). It is here that we see a clear shift in, as Peperkamp called it, from the passive military use of outer space to a more active posturing in which aggression against other states is justified in the defence of one's own security.

5. DEFINING SPACE WEAPONS

The discussion of space weaponisation is currently complicated by the fact that no widely agreed upon definition of 'space weapons' exists. The lack of consensus on what does – and especially, what does *not* – constitute a space weapon has had significant and long-standing implications for both theoretical discussions and policy and military practice. Across different authors, two fundamental points of contestation can be discerned: what domains are involved in the use of a space weapon, and what is the nature of the weapon's delivery method or intended effects?

Discussions in the relevant United Nations fora, the Conference on Disarmament, and related intergovernmental bodies have thus far remained inconclusive. Among the several draft treaties currently being considered within the United Nations General Assembly's First Committee (for Disarmament and International Security), no definitions on what constitutes a 'space weapon' is provided, and this lack of agreement on what space weaponisation thus entails is one of the main unresolved points of contestations preventing further regulation (General Assembly, 2019, par. 46–48, 2021; First Committee, 2020, 2021). Insofar as space weapons are concerned, consensus has only been achieved regarding the undesirability of orbital weapons of mass destruction, which resulted in Article IV of the 1967 Outer Space Treaty comprehensively prohibiting "nuclear weapons or any other kinds of weapons of mass destruction" from being placed in orbit or anywhere else in outer space.

In the decades since, most state space actors seem to agree that space-based anti-satellite weapons as well as space-based weapons striking terrestrial targets could be characterised as space weapons; though there remains significant opposition towards the notion that Earth-based anti-satellite weapons should also fall under this definition (Harrison, 2020, p. 4). This exception seems to be based on three different motivations. First, since 1959 the United States had developed and tested Earth-based, direct-ascent anti-satellite missiles whereas the Soviet Union had focussed on space-based, co-orbital missiles instead (Weeden & Samson, 2021, pp. 10:2-10:3). If any international agreement on regulating space weapons was to be reached, it had to impact both sides of the Iron Curtain equally by either prohibiting both types of anti-satellite weapons or by prohibiting neither. The latter option was the result, as seen in the Outer Space Treaty. Second, both historical and contemporary direct-ascent anti-satellite missiles are closely related to, and in fact often derivative of, anti-ballistic missiles; a notion I will further explore Section 5.2.3. Suffice to say, the regulation of anti-satellite missiles could have implications for missile defence systems as well, especially since such systems partially rely on space-based assets – with the 1980's American Strategic Defense Initiative even aspiring to place all components in orbit, including the weapons that would intercept the missiles. Third, the Outer Space Treaty's Article I provision on the applicability of international law is commonly interpreted as a prohibition of all military space activities that would violate Article 2(4) of the United Nations Charter, the prohibition on the use of force. In combination with Article 51 of the Charter, the unimpaired right to individual or collective self-defence, this interpretation is then used to justify military space activities that fall below the threshold of a use of force or because they are intended to be used for self-defence (Peperkamp, 2020, p. 4). Following this line of reasoning, it is argued by some member states that anti-satellite weapons are defensive weapons whereas space-based weapons are not (Harrison, 2020, p. 4), thereby implying the first category falls outside the purview of ongoing UN discussions whereas the latter should be subjected to an arms control regime.

As for military and scholarly discourse, a categorisation of weapons according to the underlying principles of physics appears to be the most commonly used: kinetic-energy weapons in the form of explosives, projectiles, and intentional collisions; directed-energy weapons in the form of lasers or particle beams; and electromagnetic weapons such as jammers, electromagnetic pulse devices, and unfocused radiation. In Western military jargon, the latter two categories both fall under the umbrella of electronic warfare as they similarly weaponise the physics of the electromagnetic spectrum. The difference between the two is that directed-energy weapons use concentrated energy to damage or destroy a target, whereas the latter describes forms of relatively dispersed energy which may produce any effect ranging from destruction to limited degradation (United States Department of Defense, 2007, pp. 169, 185; see also Bloembergen et al., 1987, p. 9; Weeden & Samson, 2021, p. xxxi). Notably, none of these three categories include the contemporary military phenomenon of cyber operations, which do not directly involve kinetic energy nor the electromagnetic spectrum[8].

To the contrary, Harrison et al. (2021) only discern between "kinetic" and "non-kinetic" weapons, but do include cyber operations in the latter category (p. 3). This dichotomy between kinetic-energy weapons on the one hand and the various other types of weapons on the other does not provide us with any expectations regarding what effects such weapons would produce, what the consequences would be for the target, nor what implications this may have for international security. The authors do note that some non-kinetic weapons may produce physical damage whereas others do not, and that these two sub-types require different defensive measures; these are substantially the same as the aforementioned directed-energy and electromagnetic weapons, respectively (ibid., pp. 25-26). In an earlier report, Harrison acknowledged that for these reasons a further sub-division of this dichotomy is warranted to differentiate the use of nuclear weapons from other kinetic-energy attacks, as well as permanent from temporary effects (Harrison, 2020, p. 5). This sidenote does not adequately address the issue of a lack of clarity of the proposed kinetic/non-kinetic division, however. The resulting framework describes a great number of possible effects, outcomes, and implications for each category (ibid., p. 6). In the end, Harrison does not elaborate on why he chose to differentiate between kinetic and non-kinetic means of delivering weapon-like effects, nor in what way this dichotomy is useful in the broader discussion of space weaponisation. However, I agree with Harrison that cyber operations should indeed be considered in discussions on defining space weapons. Like outer space, cyberspace has similarly been widely recognised as a new domain of warfare aside from the traditional land, sea, and air (North Atlantic Council, 2016, par. 70–71). The interplay between these two new and unique domains may present us with additional challenges for defining space weapons.

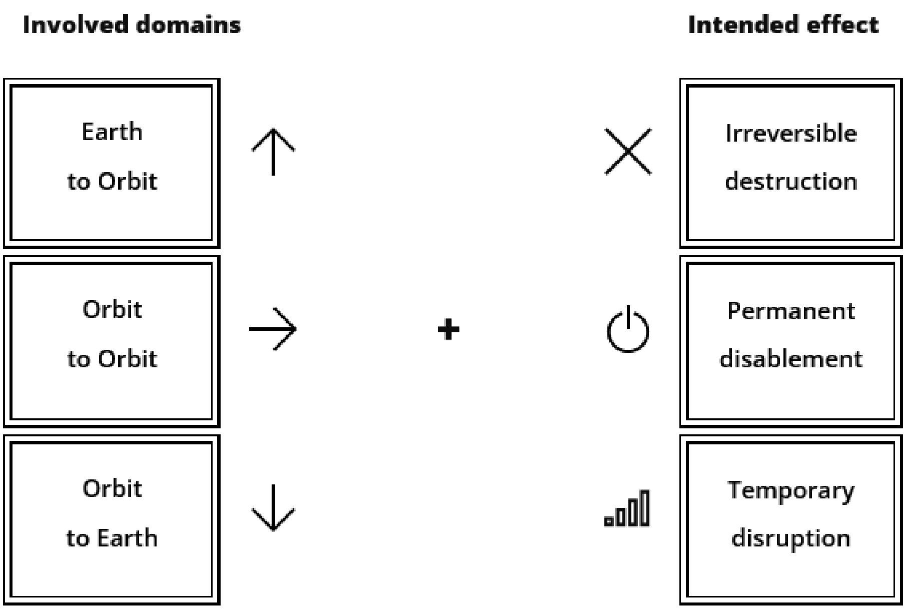
[8] The electromagnetic spectrum would only be indirectly involved when a cyber attack is transmitted within a wireless network. This generally involves radiofrequency or infrared radiation; including Wi-Fi, Bluetooth, cellular networks, etc.

5.1. The effects-based typology of space weapons

Recognising the insightful work of the aforementioned authors and taking note of the difficulties encountered, I instead propose a new definition of 'space weapons' solely based on the effects they intend to inflict[9]. From this point of departure, I propose that space weapons must meet two criteria. First, space weapons are those assets that are intended by the user to inflict one of three hostile effects upon its target: *irreversible destruction*, *permanent disablement*, or *temporary disruption*. I call this the **dimension of intended effect**, which differentiates weapons from non-weapons. Second, a space weapon is used to either inflict its effect in space, inflict its effect from space, or both. In other words, what differentiates any weapon from being a space weapon is its characterisation as an *Earth-to-Orbit*, Orbit-*to-Earth*, or *Orbit-to-Orbit* weapon. I call this the **dimension of involved domains**. Taken together, these two dimensions form the effects-based typology of space weapons as illustrated in ***Figure 4***. Subsequently, for an asset to be considered as a space weapon, its characteristics must combine at least one category from each dimension; again, this is the key difference with other types of weapons and non-weaponised (space) assets.

Figure 4

The effects-based typology of space weapons



[9] I first proposed this typology in an unpublished seminar paper in April 2022. The version discussed here has been revised with clearer terminology and additional emphasis on assets that do not fulfil the criteria of both dimensions. Coincidentally, I later discovered that the United Nations General Assembly's 2018-2019 *Group of Governmental Experts on the prevention of a space arms race* seems to have taken a similar approach in its discussions, though it was unable to find consensus on definitions as well as the technological capabilities related to but distinct from space weapons (General Assembly, 2019, pp. 11–12). The typology proposed in this Chapter is my original answer to the same questions.

5.1.1. The dimension of involved domains

These domains and effects warrant further discussion. As for involved domains, I propose a categorisation of space weapons along 1) the warfare domain in which the weapon is positioned, launched, or transmitted from and 2) the warfare domain in which its subsequent effect is intended to affect a target. In the case of a space weapon, one of these domains would of course be Earth's orbital space, which I will simply refer to as the **Orbit** domain. Again, space weapons positioned beyond Earth's orbit or on other celestial bodies are outside the scope of this thesis and I do not consider them to be relevant to the geocentric discussion on the current weaponisation of orbital space. The other domain would be the three terrestrial domains of land, sea, and air, which I will collectively refer to as the **Earth** domain. The reason for aggregating these domains is because there is no fundamental difference between ground-based, maritime, and airborne counterspace systems, nor between orbital weapons targeting ground, naval, and aerial assets. While there are advantages and disadvantages to choosing any particular delivery vehicle, this is a case-specific trade-off that does not affect the nature of a space weapon as a whole.

For instance, the United States is the sole state publicly known to have tested air- and sea-launched space weapons during the Cold War (Weeden & Samson, 2021, p. 10:5). This did not necessarily provide the US armed forces with more counterspace capabilities than its then-Soviet adversaries however; it merely had a greater variety of delivery options at its disposal. Indeed, of the four countries to have recently demonstrated their direct-ascent anti-satellite (DA-ASAT) missile capability, China, the United States, and Russia are likely to be able to use this capability through different delivery methods. China conducted its weapons test in 2007 from a launch pad, though with the assumed ability to do so from existing mobile missile trucks built for the ballistic missile its DA-ASAT missile was derived from as well (ibid., p. 1:17). The United States conducted its 2008 test from a Ticonderoga-class missile cruiser using an SM-3 anti-ballistic missile, which may also used by the naval and land components of the modular American/Japanese/European Aegis Ballistic Missile Defense System (Gubrud, 2011, pp. 622–624; Weeden & Samson, 2021, p. 10:5). And most recently in November 2021, Russia launched its DA-ASAT missile from the near-Arctic Plesetsk missile launch complex, which uses both mobile launchers and immobile launch pads; both Russian state media and US defence sources claim that the missile has already been successfully tested from a missile truck (Weeden et al., 2022, sec. 'Cosmos 1408'; Weeden & Samson, 2021, pp. 2:16, 11:9). What these historical capabilities and recent weapon tests show is that the delivery method of a space weapon is not a defining characteristic: ground-launched weapons may also be stationed on mobile launchers, airborne platforms may be used as well, and vehicles could be used interchangeably due to the use of modular systems. It is thus not particularly relevant whether a space weapon is launched, fired, or positioned on land, at sea, or in the air. Therefore, for the purpose of an effects-based typology of space weapons, I propose a binary distinction between the Orbit and Earth domains.

Subsequently, four combinations of the two domains can be made: a weapon can be described as inflicting its effect **Earth-to-Orbit**, **Orbit-to-Earth**, **Orbit-to-Orbit**, or Earth-to-Earth. I argue the latter combination does not represent a space weapon even if such a weapon, its projectile, or its effect passes through orbital space before reaching its intended target, as I will explore in more detail in Section 5.2.3.

5.1.2. The dimension of intended effects

Continuing with the dimension of intended effects, **irreversible destruction** means bringing a comprehensive end to the target's continued existence. The target is beyond repair; it must be replaced. If the target was situated in outer space, the risk of generating substantial amounts of orbital debris is high and recovery of the assets' remains is either unfeasible or impossible. Historically, most space weapons relied on kinetic energy and were intended to deliver such destruction, either in the form of nuclear-tipped anti-satellite missiles, their chemical explosives-tipped counterparts, and the more recent kinetic kill vehicles which rely on high-velocity collisions instead. The four most recent examples would be the 2007 Chinese kinetic, 2008 American kinetic, 2019 Indian kinetic, and 2020 Russian conventional explosive weapons tests; all of which struck derelict satellites resulting in the generation of thousands of debris fragments each (Weeden et al., 2022). Indeed, tests like these are responsible for the majority of Earth's orbital debris, as we will see in Chapter 6. A more recent development would be the possibility of directed-energy, electromagnetic, and cyber weapons being used to achieve a similar effect. This can be accomplished by either 'pushing' or manoeuvring an asset to send it on a de-orbiting trajectory so that it burns up during re-entry into Earth's atmosphere, by intentionally detonating an asset's hazardous components such as fuel tanks or batteries, or by activating the self-destruct mechanism carried by some satellites (see also IADC, 2007, par. 5.2.1.). Meanwhile, the use of orbital weapons against terrestrial targets may in some cases involve or be characterised as being equivalent to weapons of mass destruction (WMDs). Concerns over in-orbit nuclear missile platforms were highly salient in the top political and military circles of both sides of the Cold War (Gotlieb, 1965, pp. 3–5, 20–21). After six years of negotiations, orbital WMDs were regulated under 1963 Partial Test Ban Treaty – which also brought an end to the aforementioned nuclear weapon tests in outer space – and have been comprehensively prohibited since the landmark Article IV of the 1967 Outer Space Treaty. All major space-capable states are party to this treaty, and to date this is the only category of space weapons prohibited by hard international law. However, the international community has yet to address the placement of anti-ballistic missiles nor any other type of missile, projectile, or other weapon in orbit in so far as the use of such weapons does not meet the non-defined threshold of WMDs. In practice, this lack of a clear boundary may be problematic as instead of nuclear missiles, orbital bombardment weapons could also use small projectiles, Earth's gravity, and the sheer kinetic force of 'falling back' to Earth instead to provide a silent, global, resilient, and destructive strike capability (Harrison et al., 2021, p. 3). Such orbital bombardment systems have been seriously contemplated within American military circles at the beginning of the millennium (e.g., Sillis, 2001).

Permanent disablement differs from destruction in that an asset fully ceases to function due to inflicted damage, but can still be recovered and/or repaired. The most likely scenario for this effect occur in orbit is the physical damaging of an asset's vital components without which the asset cannot perform its intended tasks, ranging from the perforation of solar panels and irradiation of its on-board electronics to seizing control of its operating systems and impairment of its sensors. Such an effect can be achieved by kinetic energy, electromagnetic, cyber, and especially directed-energy weapons alike. While rendering an asset (largely) unusable by its owner, permanent disablement does not necessarily result in the fragmentation of the asset and thus carries a significantly lower risk of generating orbital debris. This advantage has made the development of this category of space weapon preferable to authors wishing to limit the unwanted consequences of future operational use, most notably the Chinese Strategic Support Force which focusses on these weapons by virtue of its assigned responsibility for China's electronic, cyber, and space warfare (Mackey, 2009, p. 84; Weeden & Samson, 2021, p. xv). After the cessation of hostilities, robotic spacecraft or crewed vehicles may restore the derelict asset to operational status or retrieve it for disposal (placing it in a graveyard orbit or de-orbiting it). Similar in-situ capabilities have been successfully demonstrated in the last three decades, most prominently by the Space Shuttle programme and the International Space Station. As for terrestrial targets, permanent disablement could be accomplished through limited orbital strikes that damage support infrastructure rather than directly destroying weapon systems and killing human combatants. Non-kinetic weapons are especially suitable for such objectives, as directed energy weapons have the ability to inflict high-precision damage against critical assets such as power plants and logistical hubs, whereas electromagnetic weapons may saturate an area with non-lethal radiation to overload the vulnerable electronics found in electrical grids, radar systems, and telecommunications equipment. Similarly, cyber-attacks routed via orbital infrastructure may hijack command-and-control systems to cause physical damage or injury, similar to the not-space-related 2010 Stuxnet attack against the Iranian Natanz nuclear facility's industrial control systems which silently destroyed its uranium enrichment centrifuges (Bulletin of the Atomic Scientists, 2011, p. 5; Kushner, 2013).

Finally, **temporary disruption** is the most limited effect in the sense that it is not intended to inflict lasting damage. Unlike destruction or disablement, its effect ends when its user halts the attack or the target's controller succeeds in denying the effect with counter-measures. In addition, the effect may range from full denial of control over the asset, to disrupting the transmitted and receiving signals, to only degrading the quality of the asset's services. Such effects are most likely achieved through either electronic warfare or cyber warfare capabilities. From a technological perspective, the use of electronic or cyber warfare to disrupt assets in orbital space closely resembles similar uses in the land, sea, and air warfare domains. For cyber warfare, the specific media through which data is transmitted and received is not of particular relevance when considering the ultimate effect; between the attacker and the intended target, this may involve numerous distinct means resulting in an untraceable 'pathway' (Schmitt & Vihul, 2017, pp. 452–453); ultimately, it is the inflicted effect that determines how such a cyber operation should be perceived (Brown & Tullos, 2012). As for orbital electronic warfare weapons inflicting such effects in terrestrial domains, the key difference between a truck-based area denial energy weapon, a ship-based sensor-blinding laser, a jetfighter's electronic warfare suite, and a satellite-based communications jammer would be the context-specific advantages and disadvantages to the chosen delivery method and electromagnetic wavelength and frequency. Historically, satellite-based electronic warfare has been considered the most suitable for missile defence and counterspace missions, as was first developed in the 1980's under the American Strategic Defense Initiative (SDI) (Bloembergen et al., 1987, pp. 9–10; Reagan, 1987, p. 8), and has been the focus of some of its successor projects since the 1990's (Mackey, 2009, p. 84). As a former Director of Operations of the United States Air Force Space Command noted, "you don't need to take out a satellite to deny its use. . . . Technology is not the problem and I don't think it ever has been" (Jones, 1993, as cited in Bruger, 1995, p. 81). Indeed, Vice Commander Daniel P. Leaf of the same command later noted that "temporary and reversible means" are the priority when it comes to offensive, counterspace operations (Koplow, 2009, p. 169). As far as the United States is concerned, such means likely include the SDI-funded *MIRACL* high-powered laser and the more recent *Counter Communications System* electromagnetic jammer that have been tested by the United States between the 1980's and 2000's (Koplow, 2009, p. 170; Plante, 1997; Strout, 2020). More recently, the French government announced its intention to equip its military satellites with self-defence weapons capable of disrupting other space assets (Poncet, 2019). Russian investments in widespread ground-based satellite signal jammers to disrupt adversaries' communications and GNSS navigation capabilities have been one of the priorities of its armed forces modernisation programme, and like the United States it has developed blinding lasers for use against satellite sensors (Weeden & Samson, 2021, pp. xvii–xviii). Furthermore, since early 2022, the Russian armed forces have been accused of using a combination of electronic warfare and cyber warfare capabilities against commercial satellite constellations as part of their operations in the War in Ukraine (Borrell, 2022; Musk, 2022a, 2022b, 2022c; Santamarta, 2022; Viasat, 2022). It seems likely, then, that the intended effect of temporary disruption may become the most likely use of space weapons within future armed conflicts.

5.2. Sidenotes to the typology

It is important to consider closely related capabilities and definitional issues in the space weaponisation debate for two reasons. First, space weapons may prove difficult to identify in practice until they are overtly revealed as such during a weapons test or a use of force. It stands within reason that we should expect the revelation of such cases as the space arms race continues and these capabilities are developed; the 'inspection satellites' employed by Russia make for credible candidates of such weapons (Pfrang & Dickinson, 2022). After all, we have little reason to assume that all major space powers are unwilling to develop Orbit-to-Orbit or Orbit-to-Earth weapon capabilities to at least some extent – after all, both the Soviet Union and United States extensively developed such capabilities throughout the Cold War (Weeden & Samson, 2021, pp. 10:2-10:5). Assumedly the overt testing or deployment of these weapons would draw quite some ire from the international community – more so than the recent and overt development of Earth-to-Orbit weapons since 2007 – thus making the current covert development of such capabilities a possibility that should not be readily dismissed.

Second, the blurred lines between space weapon technology and related capabilities have noteworthy implications for the future proliferation of such weapons. Even though only four states are known to have demonstrated a space weapon capability thus far (the United States, Russia, China, and India), a greater number of states possess related space capabilities for military use or civilian purposes. It stands within reason to expect that these states, already possessing key missile and spaceflight technologies, would have a considerable head start in developing space weapons should they wish to do so. The 2007 Chinese use of a modified mobile launcher-based ballistic missile and the 2008 American use of a ship-launched anti-ballistic missile as direct-ascent anti-satellite weapons clearly exemplify how intertwined space weapons are with more conventional weapons. Aside from the 38 partners and adherents to the Missile Technology Control

Regime, the armed forces of North Korea, Pakistan, Iran, Israel, Saudi Arabia and Qatar are also known to possess advanced missile capabilities (see also Brockmann, 2021). With this list virtually including all major and regional military powers, the risk of the proliferation of space weapons seems to be particularly high; with all of its consequences for our societies and economies, which increasingly rely on peaceful space technologies. To be able to discuss such proliferation within an ongoing space arms race, it is thus necessary to identify which technologies have some degree of capability overlap with actual space weapons, and more importantly, to discern when exactly an actor can be said to be actively pursuing technological developments towards acquiring space weapons.

These frameworks are important for our theoretical understanding of space weaponisation, but are also key to the development of national, multinational, and international space security policies. Perhaps the best example of this can be found in the very insightful discussions of the United Nations General Assembly's 2018-2019 *Group of Governmental Experts on the prevention of a space arms race*. The Group was unable to find consensus on two important questions: whether a distinction should be made between threats posed by weapons and threats posed by dual-use assets capable of producing the same effects, and whether harmful behaviour and acts should be comprehensively regulated and understood as threats rather than only the deployment and use of tangible harm-inflicting assets and capabilities (General Assembly, 2019, p. 12). In addition, concerns were raised by some experts on the prospects of the covert development of space weapon capabilities, weaponisation by non-state space actors, and the circumvention of a future regulation or prohibition by investing in "weaponizable capabilities" rather than overt space weapons (ibid., p. 12). I recognise the complexity of these questions, which are exemplary of the difficulty of translating the paper reality of any space weapon typology to the complex and unintuitive nature of space warfare. Finding answers therefore requires clear conceptual choices. Unhindered by the constraints the Group faced during its diligent work, I will attempt to do so by placing a number of sidenotes to my proposed typology.

First, I have made the explicit choice to exclude both dual-use assets and any harmful behaviour from non-weapons from the proposed typology due to the issues of attribution and verification regarding, and the omnipresence of, weaponizable assets. In addition, I have previously argued that cyber operations further complicates arms regulation discussions due to its unique, intangible, and covert nature (which also affects attribution and verification) as well as its inherent asymmetry in being more advantageous to offensive than defensive capabilities (see Smit, 2021). And as mentioned before, I argue that Earth-to-Earth weapons should not be considered as space weapons even if they follow a ballistic trajectory that crosses into space. This excludes ballistic missiles with an exoatmospheric midcourse phase (in which the missile reaches its maximum altitude) and some space-related anti-ballistic missile systems, even if the use of these weapons may have negative consequences for the orbital space domain. Together, these issues pose significant challenges towards any effort towards regulation and compliance – and as we will see in the next Chapter, for military strategy as well. Before moving on, I will elaborate why weaponizable assets are problematic for the definition of space weapons, how cyber operations fit in the typology, and why I do not consider ballistic missiles to be space weapons.

5.2.1. Weaponizable space assets are not space weapons

First, I would like to point out that the issue of weaponizable assets itself is not novel or particular to outer space; but it is a more pressing concern than it is on Earth. The use of non-weapons to kill persons or damage objects has been recorded throughout history, and such violence is not limited to the use of force within armed conflicts. Likewise, if a military actor were to commandeer and misuse a space asset that has not been designed or intended by its rightful owner to be a dual-use asset in potential support of military/hostile missions, then this would be the *weaponisation of a space asset* rather than a true space weapon. After all, I believe we would not consider kitchen equipment, fireworks, and vehicles to be actual weapons in their ordinary usage either; yet it is clear that these objects have been used as improvised weapons in recent terrorist attacks. However, the potential of improvised weapons is arguably even greater with space assets, where the combination of orbital velocities of kilometres per second, gravity-assisted kinetic energy, contemporary assets' possession of manoeuvring thrusters, and the widespread presence of highly-explosive, toxic, and radioactive fuels and batteries makes for numerous and potentially very destructive weaponizable objects. Quite ironically, these characteristics facilitate the use of relatively low-tech, ballistic-trajectory munitions relying on brute force to inflict severe harm; one does not necessarily require the sophisticated capabilities and extensive resources commonly associated with spaceflight to weaponise space assets. Bluntly put, successfully launching assets to orbit and ensuring a safe and sustainable space environment (collectively referred to as 'space traffic management') is the difficult part; intentionally doing the opposite is not.

What is of especial concern in the context of outer space is that the weaponizable assets in this domain would be civilian, peaceful, and predominantly privately-owned assets unrelated to any armed forces, where their use as improvised weapons could have far-reaching consequences in orbit and on Earth alike. While Article VI through VIII of the 1967 Outer Space Treaty's established that states retain responsibility and jurisdiction over the space assets of its nationals and registered corporations at all times, and any commandeering of such assets would thus be subject to national sovereignty, such actions are likely to have international consequences. Examples could include the harmful generation of orbital debris; a total disruption of academic, governmental, and commercial satellite services; resulting hazards for space-reliant sectors such as passenger aviation, maritime safety, and emergency services; and by setting a precedent for further commandeering of space assets. It is reasonable to assume that the international community would not consider the weaponisation of space assets a domestic affair. Even more, in principle peaceful assets do not present any hostile threat, which raises questions on the legitimacy of pre-emptively targeting such assets to prevent their commandeering and weaponisation by military actors.

I have attempted to address this through the typology's criterium that any effect must be as intended by the actor responsible. In other words, truly unintended effects would not be considered as (uses of) space weapons even though the end result may equate the destruction, disablement, or disruption we would expect from such weapons. One example of this would be the aforementioned destructive *Iridium 33 / Cosmos 2251* collision in 2009, which was an accident. Similarly, the hypothetical commandeering and use of a peaceful space asset for hostile purposes – for example, intentionally manoeuvring a commercial weather satellite towards a collision course with an adversary's early warning satellite – would clearly be a hostile act, but is not a space weapon as understood within this typology. The only exception would be if such a hostile act is an intended secondary purpose of a space asset that fulfils a peaceful purpose; such a dual-use asset would in fact be a space weapon, albeit a latent one. In effect, if dual-use assets have an intentional but covert secondary purpose as self-destructive munitions, then in this 'weaponised' mode they would be similar in effect to the terrestrial phenomenon of aerial loitering munitions or 'kamikaze drones'. Such a capability was the topic of discussion in United States military circles at the turn of the millennium, where the idea of a "Civil Reserve Space Fleet" of dual-use assets was proposed to be used for peaceful NASA missions, non-hostile military missions, and use as Orbit-to-Earth weapons alike (Sillis, 2001, pp. 8-9. 20-21). Needless to say, as long as a space asset's covert nature as a space weapon is unknown, we would be unable to classify it as such; an issue I return to in Section 6.1. In conclusion, a clear distinction between the *weaponisation of space* by introducing new weapons on the one hand, and the *weaponisation of non-weapon space assets* on the other should be made; the latter are not space weapons for the purposes of the proposed typology.

5.2.2. Fitting cyber operations in the typology

Second, cyber operations are a somewhat difficult fit in any typology of space weapons as due to that particular domain's similar definitional issues. While cyber weapons are widely understood as having the same destructive potential as more conventional types of weapons (Schmitt & Vihul, 2017, pp. 330, 340, 415), cyberspace is also a unique domain that is ill-defined beyond the simple recognition that it is closely connected to but distinct from the traditional ones (North Atlantic Council, 2016, par. 70; Schmitt & Vihul, 2017, p. 328; United States Department of Defense, 2014, p. 63). In this sense, cyber weapons are unlike the aforementioned electromagnetic space weapons; electronic warfare is not seen as a self-contained domain but as one of multiple components of any land, sea, air, space, or indeed cyber operation (United States Department of Defense, 2007, pp. 177–180, 2014, pp. 82–84). But whereas the interaction between the three traditional domains and the orbital domain can be illustrated in a rather straightforward manner (as I have attempted with the *involved domains* dimension), how cyberspace relates to outer space is far less intuitive. This raises the question when exactly the use of a cyber weapon is said to have been an Earth-to-Orbit, Orbit-to-Orbit, or Orbit-to-Earth attack.

I propose to take the physical infrastructure used during a cyber operation as the point of departure for determining the domain from which (the use of) the space weapon originates and the domain that is intended to be affected. In practice, this basic assumption means that cyber-enabled space weapons would generally be Earth-to-Orbit weapons as state actors' cyber weapons are compiled and executed by human personnel, relying on carefully assembled packages of data that are tailored to their specific targets. In other words, within the context of contemporary space weaponisation, I would expect cyber weapons to be used by ground-based operators stationed in cyber warfare centres to affect orbital targets by destroying, disabling, or disrupting the asset. This could be achieved by targeting one of the various digital components of a satellite or spacecraft, as the various on-board functionalities are controlled by computer systems (whether simple algorithms or complex operating systems; see for example European Space Agency, n.d.-b, 2019; Wind River Systems, n.d.). While it is certainly plausible that cyber warfare operators could also operate from orbital habitats (crewed spacecraft, space stations) to affect orbital or terrestrial targets with cyber weapons, I believe it safe to assume that this is not a serious possibility for space weaponisation simply due to the fact that there is no apparent advantage in doing so. In addition, I would label cyber attacks against terrestrial targets that are transmitted via satellite-based communications as Earth-to-Earth weapons rather than space weapons; even if such a terrestrial target may indirectly affect space systems by virtue of being a space launch centre or satellite control system. Therefore, it seems likely that cyberspace will only play a minor role in the space arms race, though the possible use of Earth-to-Orbit cyber weapons to directly affect space assets should be considered.

5.2.3. The role of ballistic missiles and missile defence systems

Finally, I must admit that various forms and derivatives of ballistic missiles and missile defence systems have historically often been included in the space weaponisation debate. As mentioned earlier, they share a common origin in the missile programmes of the 1940's and 1950's, though more substantive debates include the proposed supplementing of nuclear triad forces with Orbit-to-Earth weapons of mass destruction (Gotlieb, 1965, pp. 20–21), the use of nuclear weapons discourse as the *raison d'être* for space weaponisation programmes (Reagan, 1987, pp. 2–4; Russett, 1983, pp. 182–183), and the conversion of ICBMs and ABMs into missile-based space weapon systems (e.g., Mackey, 2009, p. 85; Sillis, 2001, pp. 8–9; United States Department of State, 2010, pt. 2). More recently, the United States Department of Defense (2014) did consider combat operations against terrestrial targets through space to be "space force applications"; which explicitly included ballistic missiles but did not define what a 'space weapon' is (p. 237). However, since the establishment of the separate United States Space Force in 2019, all references to ballistic missiles have been removed from the space-related definitions (United States Department of Defense, 2021, p. 198). Subsequently, it is notable that its military doctrine describes its mission is to "protect, defend, and project spacepower. . . . in, from, and to the space domain" (United States Space Force, 2020, p. vi). This mission statement quite clearly relates to the typology's Orbit-to-Orbit, Orbit-to-Earth, and Earth-to-Orbit types, but not the Earth-to-Earth type that would describe ballistic missiles.

I argue that the issue of ballistic missiles and the related nuclear arms race is a different discussion from the space weapon and space arms race debates, and have been separate even during the Cold War when these debates were undeniably strongly related. The subsequent similarities between and confusion of these two debates is to some extent intentional: the threat of nuclear weapons has served to legitimise space weaponisation under the guise of space-based missile defence systems, and space weapons have previously been regulated as extension or 'by-catch' of regulation efforts primarily oriented towards limiting the nuclear arms race (as was the case in the 1967 Outer Space Treaty and the 1979 SALT II Treaty.

The clearest example of both these legitimation and regulation processes were the policies and programmes of US president Ronald Reagan. His administration was the first to publicly announce its defence-oriented space policy and the establishment of new military space organisations in 1982, a controversial break from the extreme secrecy that had steadily encompassed more and more American military space activities since the Second World War until the 1962 *US Department of Defense Directive S-5200.13* prohibited even the most mundane information on such efforts from becoming public knowledge (Hays, 2011, pp. 115, 119–120). With the US national space policy now being revealed to the public, it became clear that the American space efforts were intended to address the strategic arms balance viz-a-viz the Soviet Union, to enhance and expand the capabilities of the respective armed forces, and to support new space-related weapon development projects. From 1983 onwards, the new Strategic Defense Initiative turned these dispersed and previously-classified projects into a unified and overt space weaponisation agenda, announced by Reagan on live television in his famous address to the nation:

> What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack, that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies? . . . I call upon the scientific community in our country, those who gave us nuclear weapons, to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete. (Reagan, 1983)

These means were to be researched, developed, and tested under the new SDI Organization, which contracted various American laboratories, universities, and defence contractors. Whereas ground-based anti-ballistic missiles relied on fundamental technologies that had been theorised in the 1940's and well-developed by the 1960's, the alternative technologies explored under the auspices of the SDI had never been tested as potentially viable weapons or were little more than the subject of theoretical discussions between physicists by the 1980's (Bloembergen et al., 1987, p. 9). Even in the scholarly discourse prior to Reagan's announcement there were significant doubts whether such exotic weapons would prove useful if they were successfully developed and deployed to the service branches for operational use. International security scholar Bruce Russett (1983) questioned whether they would be more effective than traditional ABM missiles, and feared that the operational use of such a missile defence system would be significantly more costly than an adversary's costs for building, deploying, and firing a single ICBM (pp. 183-184). Despite such widely-held doubts, the Reagan administration carried on with the Initiative, hoping to gradually construct an impenetrable and future-proof Strategic Defense System that would indeed make (adversaries') nuclear arsenals obsolete. However, this may have been in part due to the futuristic space-based missile defence systems' equal value for offensive space missions. This notion was even mentioned by Reagan in the same address in which he announced the SDI:

> I clearly recognize that defensive systems have limitations and raise certain problems and ambiguities. If paired with offensive systems, they can be viewed as fostering an aggressive policy,

> and no one wants that. . . . We seek neither military superiority nor political advantage. Our only purpose — one all people share — is to search for ways to reduce the danger of nuclear war. (Reagan, 1983)

In hindsight, this promise of defensive military posturing in outer space only did not coincide with the truth. From its inception, the SDI was inseparable from the ongoing efforts of the Reagan administration to develop an operational ASAT capability, which had been publicly announced a year prior in the 1982 US National Space Policy. These two capabilities of space-based missile defence and both Earth-to-Orbit and Orbit-to-Orbit counterspace systems were two sides of the same military-technological coin, as well as part of the same budgetary allocation for improving America's position in the nuclear arms race and strategic arms balancing with the Soviet Union (Reagan, 1987, pp. 8–9; L. A. Roe & Wise, 1986, pp. 8, 16; Russett, 1983, pp. 182–184; Williams, 1989, p. 29). By 1986 in Ronald Reagan's second term, the administration celebrated the US Air Force's successful testing of ASAT missiles launched from F-15 fighter aircraft despite growing Congressional resistance against the further development of these weapons (Reagan, 1987, pp. 6–7). However, political support collapsed shortly afterwards with the publication of an extensive report from two dozen leading American physicists on the technological state of affairs of the SDI projects. Bloembergen et al. (1987) concluded that multiple decades of further research and development were required before any of the projects' value in operational use could be properly evaluated (p. 9). In addition, there were serious doubts about the cost-effectiveness of all the projects proposed, especially in comparison to the Soviet Union's hypothetical development of new weapons that could plausibly circumvent or defeat the American systems at much lower cost (ibid., p. 10). SDI's most promising projects based on various types of laser systems received the most criticism, as the physicists concluded that their current energy output was orders of magnitude removed from military usefulness at best, and the core theoretical foundations of the technologies being put into question at worst (ibid., pp. 64-65).

With the focus of both Congress and the Pentagon having turned against the administration's expensive and exotic programmes, calls for strategic arms budget cuts and termination of further development efforts started to dominate the political discourse surrounding space weaponisation (Williams, 1989, pp. 27–28, 32–34). The aircraft-launched ASAT missile project was finally cancelled in 1988 despite having entered operational status (Parsch, 2004; Weeden & Samson, 2021, 3:13), and the Strategic Defense Initiative faced multiple cycles of defunding under the new George H. W. Bush administration until all development on space weapon and missile defence projects were put on hold in 1990 during the dissolution of the Soviet Union. The subsequent Clinton administration put an end to the SDI altogether in 1993, with the organization being absorbed in the less ambitious Ballistic Missile Defense Organization (now the Missile Defence Agency) and all space-based projects being cancelled or transferred to other defence organisations.

The SDI's stellar rise and demise over the course of a decade shows how the two separate debates of ballistic missiles and space weapons have been intentionally confused to be one and the same. Space weapons were developed under the guise of exorbitantly expensive and exotic concepts for space-based ballistic missile defences, legitimised by the promise of putting an end to the Cold War fears over nuclear annihilation. In reality, doubts over and political resistance against the SDI grew by the year, and the issue of mutually assured destruction remained unsolved despite the advanced weapons projects on the one hand and successful bilateral strategic arms reductions in the 1980's and 1990's on the other. Yet it would be unfair to say that the SDI produced no results. In hindsight, it made significant contributions to the weaponisation of space, with some of its projects surviving the Initiative's end either through retained knowledge or further development. The experience gained with the aforementioned air-launched ASAT missile project was used to some extent in the 2008 sea-launched ASAT missile test, which used an SM-3 anti-ballistic missile developed from earlier ABM projects under the SDI (Mackey, 2009, pp. 87–88; Weeden & Samson, 2021, 3:15). Furthermore, the MIRACL ground-based anti-satellite blinding and dazzling laser first developed under the SDI was successfully tested in the 1990's (Plante, 1997), despite the earlier report from Bloembergen et al. (1987) that the ground-based chemical laser was unable to produce sufficient power and that it was highly uncertain whether it could be scaled up any further (pp. 10-11, 39).

Therefore, Reagan's Strategic Defense Initiative promised to end the nuclear arms race but instead intensified the Cold War space arms race. The respective anti-satellite weapons developed under the SDI are clear examples of destructive and disabling/disrupting Earth-to-Orbit space weapons, intended to affect space assets. To the contrary, as Tom Harrison (2020) quite simply noted, typical ICBMs and ABMs neither originate from space nor are intended to have any effect in space (p. 5). While it is undeniable that they share a common technological, military, and political history with space weapons, ballistic missiles and space weapons should be regarded as two separate concepts.

5.3. Applying the typology to historical space weapons

Returning to the effects-based typology, and despite the exclusion of the aforementioned related technologies, we can conclude that outer space has been weaponised to a large extent, with seven of the nine categories already having been developed and tested by various states. Two categories reached operational status during the Cold War. Both the Americans and Soviets have operationally deployed direct-ascent anti-satellite missiles systems for decades, initially with nuclear warheads until these were replaced by more accurate conventional explosive and kinetic-kill successors. In addition, the Soviet Union deployed a fractional orbital bombardment system which could be described as ICBM derivates that, rather than following a ballistic trajectory, establish an orbital trajectory and then conduct a de-orbiting manoeuvre towards their target.

Today, four categories of space weapons are known to exist either as prototypes undergoing active testing or as operationally ready but not necessarily deployed capabilities. These can be seen in ***Table 1***.

Table 1

Types and examples of space weapons per the effects-based typology

	Earth-to-Orbit	Orbit-to-Orbit	Orbit-to-Earth
Irreversible destruction	Direct-ascent anti-satellite missiles	Co-orbital anti-satellite missiles, orbital projectile cannons, space-based kinetic interceptors	Global strike munitions, fractional orbital bombardment systems, orbital WMDs.
	1960's-1990's fully operational missile systems (US, SU), Recent missile tests (US, RU, CN, IN) *	1974 Almaz 2 space station (SU) †, Strategic Defense Initiative (US) †	1965-1984 R-36O fractional orbital bombardment system (SU) †
Permanent disablement	Electromagnetic pulse devices, blinding lasers, cyber weapons	Space-based electronic warfare and directed energy weapons	Anti-terrestrial electronic warfare and directed energy weapons
	1958-1962 high-altitude nuclear weapon tests (SU, US) †, MIRACL ground-based laser (US) *	1987 Skif-DM laser prototype (RU) †, Strategic Defense Initiative (US) †	No known example
Temporary disruption	Electromagnetic jammers, dazzling lasers	Low-energy space-based non-kinetic weapons, close-approach satellites	Low-energy anti-terrestrial non-kinetic weapons.
	Counter-Communications Systems jammer (US) *	Recent 'inspector satellite' tests (RU) *	No known example

Note. This includes all credible examples of space weapons developed by the United States, Russia (including the former Soviet Union), China, and India. Examples were derived from the open source assessment and database of the Secure World Foundation (Weeden et al., 2022; Weeden & Samson, 2021).
* Recent weapons publicly known to have entered active development, testing, or limited deployment.
† Weapon projects dating back to the Cold War with no known contemporary restart or successor system.

6. LOSING THE PROVINCE OF ALL HUMANKIND

Clearly, outer space is not merely a security domain, but also one that is vital to our societies and the international system. Losing free and safe access to what Article 1 of the 1967 Outer Space Treaty describes as "the province of all [hu]mankind" would be a rather disastrous event down on Earth. Clearly, our dependence on space system services has significantly increased over the last decades, with such crucial services as long-distance communications, financial transactions and exchanges, emergency and disaster response, energy production, and international aviation and shipping now relying on the unique capabilities of satellite constellations. The hypothetical mass disruption of civilian satellite operations, and the loss of our most expansive commons, is a matter of international concern equal in severity to the space arms race itself.

Indeed, it is not merely conceivable that space weapons can cause significant harm to the peaceful use of outer space; it has already occurred before. At the start of the Cold War space arms race in 1962, a series of both US and USSR nuclear weapon tests damaged or crippled up to one-third of all orbiting satellites at the time (CTBTO, n.d.). While this year also saw the highest number of nuclear weapon tests in general, it was the testing of nuclear weapons in outer space especially that showed the potential of their use as radiation-based rather than explosion-based space weapons. The first civilian communications satellite, the American *Telstar 1*, was among those crippled by the these tests, with its premature failure ironically being caused by the also American *Starfish Prime* test conducted at an altitude of 400 km (Hays, 2011, p. 115; CTBTO, n.d.). Although these tests are therefore commonly referred to as 'high-altitude tests', this is quite the euphemism since such altitudes are placed well into Earth's lower orbital region where both space stations and the majority of space assets can be found. Were such weapons tests to be reintroduced in the future – though explicitly prohibited by the Outer Space Treaty to which all recognised and unrecognised nuclear-weapons states are parties – similar effects would be far more impactful in today's congested and vital space than it was in the early 1960's.

Yet more worrying is the most destructive, most difficult to monitor, and most difficult to avoid scenario even if the November 2021 Russian test will prove to be the final use of a destructive space weapon: the Kessler syndrome. Using a predictive model for space debris collisions, the astrophysicist Donald Kessler first proposed such collisions would lead to a significant self-reinforcing growth of debris by the year 2000, and without intervention would exponentially increase throughout the 21st century (Kessler & Cour-Palais, 1978). This prediction caught the attention of his colleague John Gabbard, who had had maintained a personal record of orbital debris created by accidents and early space weapon tests while working for NORAD in the 1960's and 1970's. Gabbard would coin the term 'Kessler syndrome' to describe how debris (whole objects or fragments) would impact with both other debris and operational space assets alike, creating more and more debris which would in turn cause more collisions (Kessler, 2009). In the long term, the worst-case scenario would be the destruction of most human-made objects in low Earth orbit, posing a severe collision hazard to all forms of spaceflight. The province of humankind would become virtually inaccessible until such time when future generations succeed in actively removing this debris in some manner; or at astronomical timescales, until the amalgamation of the orbital debris into an equatorial planetary ring not unlike the *natural* ring systems of the Solar System's gas giants (Kessler & Cour-Palais, 1978, p. 2645). Given this grim scenario, the Kessler syndrome was popularised in 1982, inspiring many works of science-fiction, the establishment of orbital debris as an sub-discipline, as well as various international military and civilian policy initiatives such as the Inter-Agency Space Debris Coordination Committee (Kessler, 2009; see for example IADC, 2007). Further research concluded that the cascading effect had indeed begun by the early 1990's as originally predicted, but that the rate of growth was limited and could still be reversed – in large part thanks to the debris mitigation and prevention measures that were adopted worldwide (Kessler, 1991).

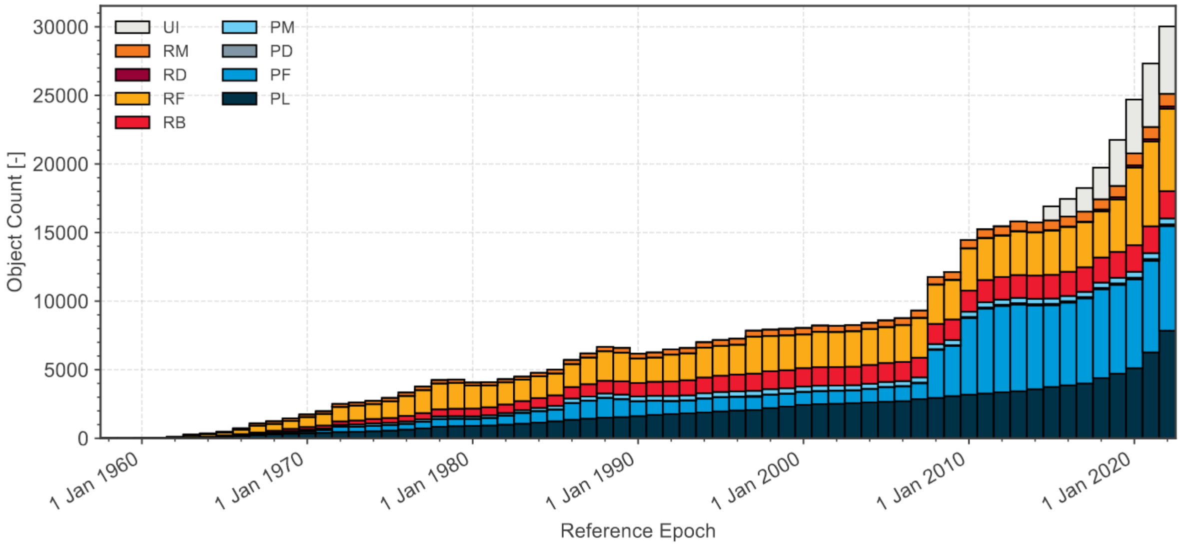
However, the relatively hopeful findings of the 1990's did not survive the following decade. Since the 1990's, the fatal damage to several satellites as well as multiple cases of minor impact damage to crewed spacecraft have been attributed to collisions with human-made debris. Similarly, in recent years, the debris issue has turned the International Space Station's rare collision avoidance manoeuvres into a situation that occurs multiple times a year, with crew emergency evacuation procedures ('abandonment of ship') becoming more frequent as well (Bartels, 2021; Breton, 2021; NASA, 2012). These events support the original 1978 model, which predicted the first debris collision to occur between 1989 and 1997, after which the frequency would increase over the following decades (Kessler & Cour-Palais, 1978, p. 2639). Indeed, the first confirmed case became the French military CERISE reconnaissance satellite in 1996, which collided with a tracked and catalogued fragment of a spent French Ariane rocket that had exploded one decade earlier (Sweeting et al., 2004). Although the satellite was damaged and lost a component, it remained operational and did not fragment. Instead, the first *catastrophic collision* occurred in 2009; in which both involved objects are completely destroyed resulting in far greater numbers of debris fragments (European Space Agency, 2022, p. 114; Kessler & Cour-Palais, 1978, p. 2640). Even worse, this first case involved two previously-intact space assets: the commercial *Iridium 33* and the derelict Russian military *Cosmos 2251* communications satellites, creating at least 2,200 pieces of trackable debris fragments (Kelso, 2012b).

Yet none of these incidents quite compare to the harm caused by the new arms race described in this thesis. As shown in ***Figure 5***, while fragmented debris objects have always been the most numerous type of space objects[10], multiple recent increases can be discerned. These coincide with the aforementioned collision in 2009, but more importantly, the 2007 Chinese (3,432 tracked fragments), 2008 American (175), 2019 Indian (129), and the 2021 Russian (1,402) weapons tests (Weeden et al., 2022). The Chinese weapons test alone dramatically increased the total space object population by 25% (European Space Agency, n.d.-a).

[10] In quantity, not necessarily in total mass or surface area. Current estimates for the mass and area of fragmented debris have such a high degree of uncertainty that they tend to be excluded from current models (European Space Agency, 2022, pp. 12–13).

Figure 5

Number of artificial space objects in Earth orbit on 1 January, by year



Note. This graph shows all human-made objects known to be orbiting Earth in each year. The payloads category (PL; **dark blue**) represents active and intact but derelict space assets. All other categories represent debris objects of various origin. Of these categories, two consist of the smaller, fragmented debris that would typically result from explosions and (catastrophic) collisions, including those caused by space weapons: fragmented payload debris (PF; **light blue**), fragmented rocket body debris (RF; **yellow**). The smaller unidentified objects (UI; **grey**) are also assumed to be debris fragments, but their origin and nature have not yet been determined. From *ESA's Space Environment Report*, by the European Space Agency, 2022, p. 4. CC BY-NC-ND.

Even if from this moment forward no destructive space weapons are used in whatever capacity, the harm already caused by the space arms race is reflected in the latest calculations for the Kessler syndrome models. By the first centennial of the Space Age on 4 October 2057, when extrapolated for future space launches and without significant changes in current debris mitigation measures, catastrophic collisions are likely to occur every year (European Space Agency, 2022, pp. 114–117). Similarly, the number of debris objects larger than 10 cm is expected to nearly double by then (ibid.). And the more debris objects orbit the Earth, the higher the probability of more collisions to occur, further intensifying the Kessler syndrome's cascade and increasing the costs of reversing its effect (Kessler & Cour-Palais, 1978, p. 2639). While the Kessler syndrome already forces us to consider the sustainability of space utilisation and the safety of human spaceflight in general, the four weapons tests that signalled the new space arms race especially have severely increased its momentum. The next use of a destructive space weapon, even for testing purposes only, could be the catalyst for an unintentional but practically irreversible cascade of collisions that transforms humankind's constellation of space assets into a shroud of hazardous debris.

6.1. The space weapons typology and the hazardous impact index

Taking this potential catastrophe in mind, let us return for a brief moment to the space weapons typology proposed in this thesis. Can we deduce what hazard the use of each category of space weapons will pose for deepening the space security dilemma and harming the space environment? After all, it would be oversimplistic to simply assume that all uses of space weapons would be equally harmful. While I do not wish to legitimise any use of force in the space domain – all space weapons deepen the security dilemma and risk destabilising the international security situation – it seems reasonable to differentiate between how each category relates to specific issues. After all, a security dilemma relies in part on genuine security concerns; no matter how self-defeating this behaviour is, we cannot disregard the desire of a growing number of states to obtain space weapons. Instead, we must seek to channel these desires, both by alleviating the sense of insecurity at the root of the dilemma and by better explaining why the perceived remedy of possession of space weapons is undesirable. Rather than advocating the ideal of a complete halt to space weaponisation, the enforcement of which would be difficult given the identification and attribution issues stipulated in the previous chapter, I suggest identifying the most problematic aspects of space weaponisation and attempting to limit these first.

After all, "if wars are to be kept limited, not only the weapons used but also the objectives sought must be limited. If the latter are not restrained, neither will the former be, and the results will be disastrous" (Jervis, 1989, p. 227). Indeed, in this context, the objective of self-defence from space-based threats would be justifiable; this inherent right of states per Article 51 of the UN Charter cannot be impaired. Yet I find only two out of nine categories of space weapons can be said to respect this limited objective by inflicting the least possible unintentional harm while achieving their intended effect: Earth-to-Orbit weapons that either disable or disrupt a space-based threat. This is not to say these could be described as defensive weapons – I have argued in the previous chapter that the defensive/offensive differentiation is inapplicable to space weapons – but the combination of these *intended effects* and *involved domains* are fitting for the objective of self-defence whereas the other combinations are not.

To this end, I propose an index of space weapons' relative hazardous impact based on the effects-based typology. This index exists of six characteristics based on the discussions throughout this thesis: 1) The space weapon's effect could be characterised as a traditional weapon of mass destruction on Earth, or cause equivalent destruction in orbital space; 2) The use of a space weapon is likely to aggravate the Kessler syndrome's cascade; 3) The space weapon presents such a military threat to Earth-based assets that an attack against it, despite the severe risk of incidental harm to the space environment, could be justifiable under the principle of proportionality; 4) The space weapon enables the first-strike ability of the attacker; 5) The space weapon's nature can be concealed as a non-weapon space asset, complicating attribution of attacks; and 6) The space weapon relies on readily-available military technology not specific to space capabilities, increasing the risk of proliferation. The characteristics applicable to each of the nine categories in the typology are shown in ***Table 2***. The categories to which only one characteristic applies can be said to have a 'Limited' hazardous impact, whereas categories with two and categories with three or more applicable characteristics could be described as having a 'Significant' and 'Excessive' impact, respectively.

Table 2

Index of the relative hazardous impact of space weapons per the effects-based typology

	Earth-to-Orbit	Orbit-to-Orbit	Orbit-to-Earth
Irreversible destruction	**Excessive** *1, 2, 4, 6*	**Excessive** *1, 2, 3, 4, 5*	**Excessive** *1, 2, 3, 4, 5*
Permanent disablement	**Limited** *6*	**Significant** *4, 5*	**Excessive** *3, 4, 5*
Temporary disruption	**Limited** *6*	**Significant** *4, 5*	**Excessive** *3, 4, 5*

In the normative sense, further refinement of the hazardous impact index may contribute to the ongoing but largely deadlocked space arms control negotiations in the United Nations First Committee (see for example First Commission, 2021). While disarmament and the prohibition of all space weapons may not be achievable at this time given the legitimate security desire for self-defence capabilities, focussing on the regulation of the 'Excessive'- and 'Significant'-impact weapons instead may prove fruitful as states' interests are more aligned.

7. Conclusion

Building upon the conceptualisation of the security dilemma in Chapter 2, I have proposed three indicators for Jervis's offence-defence theory to explore the depth of the security dilemma in Earth orbit and its likely development in the coming years. In the respective chapters, I have described how the peculiarities of outer space and how it is understood as a domain; states' posturing and activities in space; and the nature of space weapons and the development thereof have all contributed to the further deepening of the space security dilemma. Based on these discussions, it can be concluded that space has not merely become a military domain. More importantly, it is one with an inherent offensive advantage that is correctly perceived as a source of vital security threats, which incentivises aggressive and non-cooperative state behaviour, while states cannot discern other states' offensive space weapons from defensive ones (that is, if they can identify these as space weapons or even active space assets at all). It is therefore my conclusion that the space security dilemma is driven by the worst possible combination possible in Jervis's offence-defence theory, the 'doubly dangerous' scenario, in which the status quo is unstable, arms races are likely, and cooperation is difficult (Jervis, 1978, pp. 211–212). Should the situation escalate further, then the logic of the security dilemma will cease to function as we find ourselves in the grey zone of Tang's spiral continuum. As previously described, we would then face the broader spiral model's worrisome yet perfectly rational logic: the best defence for the status-quo power (the United States) would be a decisive first strike, and for the status-quo challengers the best defence against such a strike (Russia and China) would be a first strike as well. Should it come to this point, then even genuine security-maximising states would best turn towards malign, aggressive posturing under the broader spiral model.

All is not lost, however. In the previous chapter, I have set out why the use of space weapons would be potentially catastrophic due to the fragility of the space environment. In addition, having set out an effects-based typology of space weapons in Chapter 5, I proposed a hazardous impact index to compare the nine categories of space weapons in six characteristics discussed in this thesis: the potential for mass destruction, the risk of aggravating the Kessler syndrome, the proportionality of a pre-emptive strike against the weapon, the potential for a first-strike ability, the possibility of concealment and misattribution, and the risk of proliferation. The resulting index shows that, when the intended effects of disablement and disruption are afflicted from Earth on a space-based threat, this would be fitting for state self-defence purposes. Space weapons that inflict such infects have seen recent development in the United States. To the contrary, I have concluded the seven other categories – of which two are known to currently be in development and three more were tested or operationally deployed during the Cold War – cannot be characterised as such. Finally having labelled the latter categories as space weapons with either a significant or excessive hazardous impact on international security, I proposed for prospective arms control negotiations to focus on regulating these categories of weapons first; this could prevent the most harmful potential consequences of the space arms race, and perhaps, alleviate the security dilemma to a limited extent.

7.1. Discussion

The late Robert Jervis (1978) warned that the "security dilemma is at its most vicious when commitments, strategy, or technology dictate that the only route to security lies through expansion", forcing status-quo powers to act aggressively (p. 187). Indeed, in this thesis I have argued that this is true for the security dilemma in Earth orbit. This poses two urgent issues: a destabilising security situation that is increasing the likelihood of hostilities between the world's leading military powers, and the harm this may cause to space as the province of all humankind.

In some ways, space weapons have strong similarities with the issue of nuclear weapons, and it is too easily forgotten that the Cold War also saw a space arms race as an extension of the ICBM competition. In other ways, maritime analogies and lessons from the cyberspace domain may prove useful in understanding the outer space issue at hand and seeking international cooperation. But if any aspect is underrecognized, it is the notion that the ongoing weaponisation of the space domain is simultaneously unique and highly problematic. Unlike the annual discussions in the United Nations First Committee, we should no longer discuss the prevention of an arms race in outer space – rather, we should further explore the arms race that is already taking place and improve our understanding of the security dilemma that is driving states to participate in it.

Returning to Jervis, it is for this reason that I do not believe aggression, whether to preserve or to defeat the status-quo, is the only route forward for increasing any state's space security. At the same time, increasing security through the cooperative channels of arms control, international governance, and peaceful dispute resolution will undoubtedly prove to be a vast challenge. Yet we have little choice: Continuing on the current path will certainly be a self-defeating endeavour. If the international community is to transform the current Prisoner's Dilemma in Earth orbit into a space Stag Hunt, it will need to alleviate the deep security dilemma presented in this thesis: cooperate and disarm, not defect and escalate.

7.2. Limitations

An important limitation of primarily relying on a literature review for this thesis was that few primary sources are available due to military confidentiality, with a majority of these primary sources being (military) state actors. As was the case during the secretive Cold War space race, and as is assumedly still true today regarding cutting-edge military research and development projects, it proved difficult to observe and analyse some events as they are taking place using knowledge in the public domain only. As Joan Johnson-Freese (2007) noted in depth, this obstacle is further worsened by the fact that (American) military space actors have been obscuring the issue of space weaponisation, hindering independent analyses, and downplaying criticism. However, more transparent cases such as the European Commission's January 2022 launch of its space security strategy within its Strategic Compass framework clearly exemplify the existence of shifting geopolitical priorities due to the existence of a space security dilemma. Such significant policy changes present us with readily observable phenomena within an evolving field that until recently was largely inaccessible to 'outsider' researchers. Whereas the theoretical discussions on space weapons have been quite lively since the Cold War, it was inevitable that the empirical aspects of writing this thesis would prove to be a challenge.

Perhaps this difficulty may decrease over the coming years as the space weaponisation debate becomes more salient and the military necessity or political desirability for secrecy decreases.

Similarly, the fact that scarce public information on military space activities predominantly relies on Western government-provided data poses an obstacle to independent verification. The only widely used primary source is the unclassified space situational awareness (SSA) data provided by the United States Space Command via the Space-Track.org website, part of a long-standing tradition of similar US government data sharing practices dating back to the 1970's. However, SSA data subject to American national security interests, including practically all active US government-operated assets in space, is generally not shared with non-governmental licensees (United States Space Command, n.d.). In addition, in part due to the American Space Surveillance Network's legacy as a component of American ballistic missile defence, the SSA data is prone to 'blind spots' when tracking objects further removed from Earth or placed in orbits not visible from any of the stations typically monitoring space objects above the geographical territory of the United States (Kelso, n.d.). The resulting American-biased and incomplete primary source data constrains researchers' independent gathering and verification, and data diversification would be desirable.

I should therefore take a moment to praise the authors that have made great contributions to circumventing this limitation. For instance, Thomas Kelso (n.d.) uses the positional data provided by satellite operators to account for *Space-Track.org* errors and omissions in his popular open-access *CelesTrak* dataset and visualiser. Kelso's calculations and visualisations of anti-satellite missile tests have predicted debris-generating effects as they were still taking place, and have had significant educational value in informing broader audiences of such events in an accessible format and independent of government authorities (for his discussion on the 2007 Chinese weapons test, see Kelso, 2012a). Documenting military space activities including the testing of space weapons, Brian Weeden and the rest of the Secure World Foundation team have established a large collection of diverse primary and secondary sources including declassified United States and (Soviet) Russian military documents, assessments produced by non-governmental organisations and forensic experts, and incident reports of international organisations and commercial enterprises. The extensive and thorough work by the SWF, published in their annual reports and datasets, has certainly contributed to greater information accessibility on space weaponisation – including for this thesis.

7.3. Recommendations

Further research is needed to develop international security in outer space as a mature research topic within international relations. As the scholarly debate on space weaponisation is likely to expand in the face of increases in the number and diversity of space activities, solving the aforementioned limitations of few and biased sources will be important for the further development of this emerging field. Simultaneously, there will be a sufficient number of novel and exciting aspects to explore that could further develop our understanding. In my view, three such aspects warrant particular attention in future studies:

First, the mechanisms of the security dilemma in space should be utilised to identify opportunities for both alleviating the dilemma in general and controlling the arms race specifically. In doing so, scholars can and should contribute to the further development of the international governance of space, as has happened before with the nuclear weapons regime, the law of war, and the law of the sea. Space governance would certainly benefit from a greater understanding of the role of space weapons in national military policies and their relationship with the international balance of power.

Second, from a more theoretical perspective, the weaponisation of space begs the question what role the deterrence and collective security theories will have in this new domain. With space weapons now being a separate issue rather than subordinate to the Cold War nuclear weapons debate, traditional assumptions may no longer apply. Is the concept of space deterrence logically sound, or are the overwhelming offensive advantage and unique nature of space weapons so dissimilar to nuclear forces that a 'space weapons balance' is unachievable? And what security role can regional alliances such as NATO, as well as the supranational European Union play in the space domain? Translating our traditional theories to the space domain could certainly deliver useful insights.

Finally, I encourage other authors to explore the possibility that the intensity of the security dilemma may actually decrease in the near future. Perhaps the commercialisation of outer space and its peaceful activities may in fact lower the costs of cooperation while increasing the costs of states' non-cooperative posturing. In addition, state militaries' growing presence in space concurrently with the increasing trend of relying on dual-use assets may paradoxically lead to the demilitarisation of space. As the necessity for military actors to be directly involved in the space domain decreases civilian-governmental and commercial space actors may become dominant instead; as happened historically with human spaceflight and space science as well. Indeed, one could question the state-centric approach to space security I have taken in this thesis. I would therefore welcome alternative perspectives, such as the security of corporate mega-constellations and the growing space capabilities of private military and security companies.

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