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Intelligent Systems in Space Transportation Industry

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Master's in International Management

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“Non est ad astra mollis e terris via”

Lucius Annaeus Seneca

Abstract

Intelligent systems, and artificial intelligence specifically, have taken center stage in public squares. New technological developments have led to the fomentation of high optimism around its future. In last decade with the *New Space*, has been disrupting the traditional space transportation industry dynamics by reducing the cost of launching per kilogram, thereby increasing accessibility to space.

The primary aim of this investigation is to evaluate the role and impact of intelligent systems within the space transportation industry. It seeks to comprehend their contribution to the industry's transformation and assess the outlook for this technology in the future of space transportation.

The research, conducted through interviews, revealed mixed perspectives on their technological prevalence but underscores machine learning as a dominant technology. Intelligent systems excel in navigation and control, design, and monitoring. They offer significant advantages such as speed, autonomous problem-solving, and cost reduction, although with challenges related to explicability, verifiability, and safety. These systems enhance cost efficiency, particularly through precise design and navigation/control. They hold potential for applications like collision avoidance, improved prototyping, and debris removal, with a future which are expected to drive fully autonomous transportation while supporting space exploration and colonization. In essence, intelligent systems are preparing to shape a more efficient, autonomous, and scientifically productive future in space transportation.

Keywords: Intelligent Systems, Artificial Intelligence, Space Transportation, Technological Innovation, International Business Administration

JEL Classification:

O320 – Management of Technological Innovation and R&D

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Resumo

Sistemas inteligentes, e a inteligência artificial em particular, estão no palco principal das praças públicas. Novos desenvolvimentos tecnológicos têm gerado grande otimismo em relação ao seu futuro. Na última década, o surgimento do *New Space*, tem disruptivo as dinâmicas tradicionais da indústria do transporte espacial, reduzindo o custo de lançamento por quilograma e, assim, aumentando a acessibilidade ao espaço.

O principal objetivo desta investigação é avaliar o papel e o impacto dos sistemas inteligentes na indústria do transporte espacial. Procura-se compreender a contribuição desses sistemas para a transformação da indústria e avaliar as perspectivas desta tecnologia no futuro do transporte espacial.

A pesquisa, conduzida por meio de entrevistas, revelou perspectivas mistas sobre a prevalência tecnológica desses sistemas, mas destaca a aprendizagem de máquina como a tecnologia dominante. Os sistemas inteligentes destacam-se em áreas como navegação e controlo, design e a monitorização. Eles oferecem vantagens significativas, como a rapidez, a capacidade de resolução autónoma de problemas e de redução de custos, ainda que enfrentem desafios relacionados à explicabilidade, verificabilidade e segurança. Esses sistemas aprimoram a eficiência de custos, especialmente por meio de um design preciso e pela navegação/controlo. Eles têm ainda o potencial para aplicações como prevenção de colisões, melhoria de prototipagem e remoção de detritos, com as perspectivas de impulsionar um transporte totalmente autónomo e ao mesmo tempo apoiar a exploração e colonização espacial. Em essência, os sistemas inteligentes estão a preparar-se para moldar um futuro mais eficiente, autónomo e cientificamente produtivo no transporte espacial.

Keywords: Sistemas Inteligentes, Inteligência Artificial, Transporte Espacial, Inovação Tecnológica, Gestão Internacional

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List of Acronyms

5Vs – In the context of Big Data, 5Vs are the 5 main characteristics of Big Data – Volume, variety, veracity, and value.

AI – Artificial Intelligence

DSRPAI - Dartmouth Summer Research Project on Artificial Intelligence

NLP - Natural language processing

IoT – Internet of Things

ML – Machine Learning

NN – Neural Network

DL – Deep Learning

ES – Expert System(s)

NASA - National Aeronautics and Space Administration

ESA – European Space Agency

SpaceX - Space Exploration Technologies

ISS - International Space Station

BDS - Beidou Positioning and Navigation System

GPS - Global Positioning System

SRM - Solid Rocket Motor

SEP - Solar Electric Propulsion

NTR - Nuclear Thermal Rocket

km - Kilometres

kg - Kilograms

LEO - Low Earth Orbit

GEO – Geosynchronous Equatorial Orbit

SSTO - Single Stage to Orbit

GNSS - Global Navigation Satellite System

6G - Sixth Generation

CNSA - China National Space Administration

ULA – United Launch Alliance

ILS – International Launch Services

MITT - Moscow Institute of Thermal Technology

ISRO - Indian Space Research Organization

KARI Korea Aerospace Research Institute

ISA - Israel Space Agency

CASC - China Aerospace Science and Technology Corporation

NEHSA - Islamic Revolutionary Guard Corps Aerospace Force

MHI Launch Services - Mitsubishi Heavy Industries Launch Services

DARPA - Defense Advanced Research Projects Agency

DLR – German Aerospace Centre

GNC - Guidance, Navigation, and Control

Chapter 1 – Introduction

1.1. Framework

Intelligent systems, particularly artificial intelligence, have garnered global attention. The proliferation of vast amounts of data and improved access to computing power, facilitated by technologies like cloud computing, has cultivated an environment conducive to the advancement of AI. As a result, *Deep Learning* models, founded on *Neural Networks*, have commenced producing highly accurate predictive models. As these systems experience rapid advancements, the potential for transformation they hold is generating significant excitement about their future possibilities. They carry the potential to reshape industries and contribute to groundbreaking scientific discoveries. However, similarly to other times in the past, it remains uncertain whether they will fully realize the expectations given the challenges and ethical complexities that need to be navigated carefully.

On a different note, space transportation has reached a pivotal juncture in the past decades. The realm of space is no longer the exclusive domain of government defence and scientific agencies. The entry of profit-driven private enterprises has catalysed profound changes in the industry's landscape, ushering in a *New Space* era. This newfound presence has democratized space access and is powering the expansion of a space economy. Its valuation stood at \$386 billion USD in 2021 according to Bryce Tech (Bryce Tech, 2022) with conservative projections indicating it could escalate beyond a trillion USD by 2040 (George, 2019; Brukardt *et al.*, 2022). Key driving forces behind this evolution include emerging ventures such as space tourism, mining, the deployment of satellite constellations, and the establishment of advanced space stations.

The space industry is renowned for its proactive stance in adopting and fronting cutting-edge technologies, and the domain of space transportation is certainly no different. Due to its intricate multidisciplinary nature, addressing the demands of space transportation can necessitate the exploration of multiple approaches. Intelligent systems have already proved their presence and their validity in some areas of space transportation such as Guidance, Navigation, and Control (GNC), spacecraft health monitoring, design and planning. Nonetheless, despite potential hesitations and conservatism stemming from traditional industry principles emphasizing maximum reliability and accuracy, the evolving landscape of technological advancements in intelligent systems, combined with the emergence of the *New Space* era, have opened several avenues to further embed their presence within the industry.

1.2. Research Problem

As previously mentioned, the realm of intelligent systems technologies has undergone significant advancements in recent years. Anticipations are high that these technologies will find their application across various industries - as already started. Likewise, the space industry is undergoing profound shifts in its fundamental dynamics, poised not only to reshape our prospects in space but also to have a transformative impact on Earth.

From the literature review conducted, several articles have outlined the current and prospective applications of various intelligent system technologies within the space transportation industry. However, the existing literature does not offer a comprehensive understanding of the industry's current practices or provide practical insights into the general adoption of intelligent system technologies.

It is important to note that this research does not aim to technically identify the presence of every intelligent systems technologies within the industry. Instead, it serves as a “birth eyes” lens through which we can grasp the interplay between technological advancements and the unfolding possibilities in the realm of space transportation. This broader perspective underscores the research's focus on comprehending the dynamic relationship between technology's evolution, present opportunities, and future prospects in the field.

1.3. Research Goals

The primary aim of this dissertation is to gain a comprehensive understanding of the existing and potential role of intelligent systems in the realm of space transportation. This study seeks to identify the specific areas within the industry where such technologies are applicable and influential, while also envisioning the future landscape and possibilities they might offer.

Aligned with this overarching objective, the conducted investigation centers around four key research questions (RQ):

RQ1) What intelligent systems can we observe in space transportation?

RQ2) What are the risks inherent to the use of intelligent systems in space transportation?

RQ3) How can intelligent systems help reduce space transportation costs?

RQ4) What is the role of intelligent systems in the future of space transportation?

1.4. Thesis Structure

With the logic to answer the questions referred before and to achieve the investigation goal, this dissertation was divided 6 chapters.

The first chapter starts to introduce and contextualize the theme, through the presentation of a framework, the investigation problem, and its proposed goals.

Chapter two will encompass a comprehensive review of the literature concerning intelligent systems and the space transportation industry. The primary objective of this chapter is to establish contextual background and foundational concepts that will effectively underpin the subsequent chapter's interpretation and analysis. This exploration will be structured around three pivotal focal points. The first will delve into intelligent systems, the second will center on the space transportation industry, and the third will culminate in examining the intricate interconnections between the two. The initial two focal points share a similar structural approach, commencing with a historical contextualization and subsequently delving into core definitions and the contemporary state of the art within each domain. The third focal point will scrutinize the current state of the art while also projecting future prospects for the integration of intelligent systems within the space transportation landscape.

Building upon the literature review conducted in the previous chapter, the third chapter will endeavour to address the research questions by drawing insights from the existing body of literature.

In the fourth chapter, the methodology employed to conduct this investigation will be expounded upon. This will encompass the process by which the research questions were translated into interview questions. Furthermore, a concise overview will be provided regarding the general characteristics of the sample gathered.

Subsequently, the fifth chapter will engage in a thorough discussion of the results derived from the data analysis obtained during the interview process. These findings will be juxtaposed with the viewpoints identified in the literature review chapter, with the intent of validating or augmenting the current body of knowledge.

Concluding the thesis, the sixth chapter will present the main conclusions drawn from the conducted investigation. It will also address any limitations encountered during the research and provide recommendations for future studies.

Chapter 2 - Literature Review

2.1. Intelligent Systems

2.1.1. Historical and Conceptual context

An intelligent system is a type of computer system that is designed to simulate or replicate the cognitive abilities of human intelligence, such as perception, learning, problem-solving, decision-making, and natural language processing. Artificial Intelligence (AI) for instance is often used in Intelligent systems applications, it is used to analyse and interpret data from its environment (and from other systems), to take actions, and to adapt accordingly with their understanding of the data and the goals inputted (Salam *et al.*, 2022).

The concept of intelligent systems has evolved since his first definition in 1995 by Michael Wooldridge and Nicholas Jennings (referred at the time as intelligent agent) (Wooldridge & Jennings, 1995; Molina, 2022). However even nowadays, the definition is often not consensual among entities related in the area. For the University of Nevada intelligent systems these are simply characterized as machines that can perceive and interact with their environment (University of Nevada, s.d.). Recently, Marin Molina (2022), a Spanish professor from the department of Artificial Intelligence at Technical University of Madrid, tried to clarify the definition in an article, taking this checklist from two to four properties: (1) Works in an environment with other agents, (2) has primary cognitive abilities, (3) follows principles about rationality and social norms, (4) and has capacity to adapt itself (Molina, 2022). Despite being stricter, the definition seems to converse with other authors definitions. Despite this, the definition is far from being rigid, given the implicit philosophical characteristics in each of the properties such as the definitions of intelligence and even systems (Salam *et al.*, 2022).

The development of information technologies fields, big data, and cloud computing infrastructure has created the right set of conditions to fuel the growth of intelligent systems, which traditionally uses considerable computation power (Collins *et al.*, 2021; Molina, 2022). According with Ray Kurzweil (futuristic writer and inventor) this growth is far from its exponential peak. He claims that we will reach a technological “singularity” in the incoming few decades, mainly driven by the information technologies. This “singularity” will be a period of such rapid technological change that will impact deeply the human life. He even suggests that the “human intelligence” will become non-biological, consequence of merging the biological with machine intelligence (similarly to the cyborg conceptualization) (Kurzweil, 2014). Something that some

researchers have already noted in the way we use smartphones, which can be seen as a human's extension (Harkin & Kuss, 2021).

Trusting in the autonomy of intelligent systems, has been a slow developing process (Salam *et al.*, 2022). The firsts impressions of the system's success can be very determinant, nevertheless the trust can be tested and therefore improved through the general technological spreading (Tolmeijer *et al.*, 2021; Emaminejad & Akhavian, 2022). Which is somewhat accessible given the wide range of intelligent systems applications, from construction (Hu *et al.*, 2022; ThikraDawood *et al.*, 2022), healthcare and electronics (Liu *et al.*, 2020; Du *et al.*, 2022), to space exploration (Suszyński & Poczekajło, 2021) and robotics (Xu, 2022), finance (Shamima *et al.*, 2022) and transportation (Zheng *et al.*, 2022), among others (Collins *et al.*, 2021). However, to better understand this applicability it is relevant to understand what are the technologies that support and constitute intelligent systems: as supporting technologies it can be identified big data, cloud computing, internet of things (Shakhovska, 2017; Yacchirema *et al.*, 2018; Yassine *et al.*, 2019; Stergiou & Psannis, 2022), and virtual, augmented and mixed reality (Allal-Chérif, 2022; Lv *et al.*, 2022). As constituent intelligent systems technologies can be found artificial intelligence and its derived technologies (Collins *et al.*, 2021; Hoffmann, 2022).

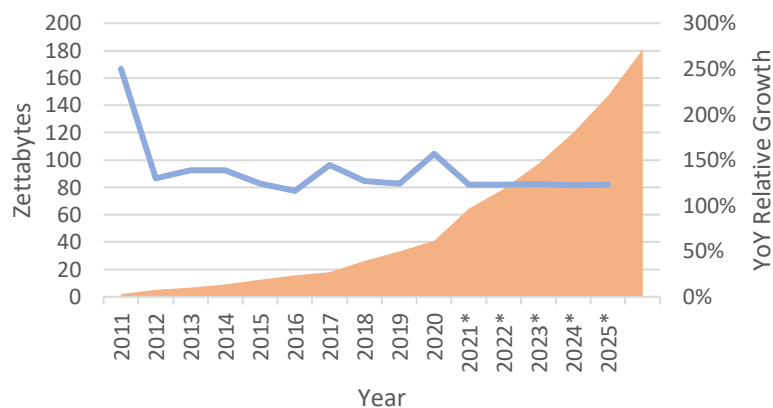
2.1.2. Supporting Technologies

2.1.2.1. Big Data

According with Cambridge dictionary data is information, facts, or numbers, that can assume an electronic form and stored in a computer (Cambridge Dictionary, 2022). As previous mentioned, *Big Data* has contributed greatly to the development of intelligent systems by increasing the accessibility of computing storage and data processing speed (Duan *et al.*, 2019). Its conceptualization can be seen as a particular set of conditions of this traditional concept of data commonly known as the 5Vs – volume, variety, veracity, and value (Singh *et al.*, 2022):

Volume: Refers to the quantity of information produced throughout time (will be addressed later). As can be seen in Figure 1, the total amount of data generated between 2010 until 2020 has exponentially grown, from 2 to 64.2 zettabytes respectively (one zettabyte equals approximately to one billion gigabytes, in European terms). It is projected by Statista that by 2025 that amount is going to be 181 zettabytes, almost 3 times the amount registered in 2020 (Statista, Seagate, IDC, 2022).

Figure 1 – Total amount of data created, captured, copied, and consumed globally (forecasted from 2021 until 2025)



Font: Adapted by the author from (Statista, Seagate, IDC, 2022)

Variety: Relates to the categorical structure of the information, like numerical, pictures, text, etc. The data sets can assume structured and unstructured formats, public or private, complete or incomplete, etc.

Velocity: The rate of information creation. Taking the graph above, we can observe this characteristic. From the year 2010 to 2011 the amount of data grew from 2 to 5 zettabytes, a 250% grow. This growth as relatively being less, setting to be around 123% from 2021 until 2025, what represents a combined increase of 117 zettabytes of data. If we compare this with the growth from 2016 until 2020 (49 zettabytes), this increase will more than double (Oussous *et al.*, 2018).

Veracity: This characteristic as to do with the precision of the information and uncertainty in the data, something it is not always verified what can lead to misleading conclusions, hence should be considered.

Value: From the analysis of such large datasets, can be inferred conclusions and insights that could be unnoticed from another way (Singh *et al.*, 2022).

The creation of such huge data sets, has been a result of the growth in data generation from diverse sources, taking for example social media, marketing, finance, and government but also from the wider use of IoT gadgets like smartphones and smartwatches (Oussous *et al.*, 2018). The emergence of Big Data was made possible through its symbiotic development and its

utilization across various fields. Firstly, within the realm of technology, advancements such as increased computing power and enhanced storage capabilities paved the way for the growth of *Big Data* technologies. Secondly, various sectors including science, manufacturing, business, telecommunications, IoT, social media, and healthcare have recognized the potential of Big Data applications and have begun integrating them into their respective domains (Demchenko *et al.*, 2014).

Big data is not exempt from future contests. As the volume of data increases it is needed to have servers to store and to run them, which necessitate high energetic consume, and consequently great needs for heat dissipation. Security may also be a concern. Even if the physical access is very restricted there is always the risk of someone trying to illegitimacy get access to the data remotely (Ashabi *et al.*, 2020).

2.1.2.2. Cloud Computing

The notion of cloud computing can be traced to 1983 when Sun Microsystems, a north American computer fabricant company, released their slogan "*The Network is the Computer*" backed by the vision that the desktop computer was just a window to the network. However, it was only in 2006 that Amazon launched a service that resembles with cloud computing is today. Even though, it was launched with a different name at the time "*elastic computing cloud services*" (Liu S. *et al.*, 2020). Even so, it was just later that year Eric Schmidt, Google's CEO at the time, proposed at a conference the concept of "cloud computing" (Liu S. *et al.*, 2020).

Cloud computing consists of creating conditions in a virtual environment that enables to its customers access to computing, storing, and network resources (Khan *et al.*, 2022). As a result, this digital access is provided through three main categories of services supplied, infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). IaaS gives the user virtual access to networking capabilities, computing power, and data storage, and takes the responsibility for its maintenance. PaaS consists in providing the underlying infrastructure management, software maintenance and other conditions to users so they can easily focus on the develop of their applications. Finally, SaaS, enables users to have their applications installed on the cloud, and to have access via internet (Malik *et al.*, 2018; Yassine *et al.*, 2019; Javaid *et al.*, 2022).

In 2021 the Cloud computing market was valued at 380.25 billion USD, in 2022, 446.61 billion USD and is projected that it will reach in 2030 around 1614 billion USD (Precedence Research, 2022). The developing of cloud services has been a consequence of rapid technological advancement in various fronts. On one hand there were some foundation

breakthroughs like the chip technology development, internet mainstreaming and speed increase. On another, there were relevant circumstantial developments in adjacent technologies such as Big Data which can be attributed as one of the main forces responsible for the rise of Cloud Computing, since it makes an ideal platform for Big Data (El-Seoud *et al.*, 2017). Their rapid development and level of integration between both has even been reason to consider changes in the computer science and information technology curriculums (Deb & Fuad, 2021). The increase in demand for high storage capacity and for computing capacity, has forged the opportunity for companies to create the infrastructures needed and provide that resources remotely systems that could offer such needs (Singh *et al.*, 2022). Big tech companies are the main players that took advantage of their position to invest heavily in the cloud services. Among them, we can identify Google Cloud Platform, Microsoft's Azure, and the market leader Amazon's Amazon Web Services AWS (AWS) (Lee *et al.*, 2018).

The services provided by the technology offer a wide range of benefits to its customers, starting from the cost savings, adjusted scalability and flexibly to their businesses, synchronization, and convenience since it can be accessible through any basic computer (Naved *et al.*, 2022). The increasing accessibility to cloud computing services, has created particularly favourable conditions to small organizations and individuals that in past simply didn't had at their reach such powerhouse, whereas in the past to get those conditions, they would need to do a big investment in the construction of the whole computing infrastructure - something that was only in reach of the wealthier organizations (Attaran & Woods, 2019; Hassan *et al.*, 2022; Pallathadka *et al.*, 2022).

Nevertheless, the future of Cloud computing is full of endeavours. The most direct one is the lack of regulation to preserve the provider's responsibility with governance loss by the consumers, which is something that happens when the service provider doesn't comply with a task that can only be done by them. Another big challenge security in data access. Even though the server's usual remote locations, since the access the information is done remotely, some threats can be presented to the costumer's data when it comes to access the information remotely, which can target of hacker's attacks (even from inside hackers), by phishing, botnets (used in DDoS attacks), and other types of schemes (Naved *et al.*, 2022; Pallathadka *et al.*, 2022).

Cloud computing provides virtually to his costumers computing, storage, and networking services. Its development is consequence of many technological breakthroughs and contextual timing, particularly in the growth of Big Data. Cloud services have been creating abundant benefits to its customers, through many industries. Its simple access, cost efficiency and high scalability are some of the big advantages of the technology (El-Seoud *et al.*, 2017). Even so,

governance and security concerns are some challenges fronts to address, and progress in the future (Stergiou *et al.*, 2018).

2.1.2.3. Internet of Things (IoT)

Internet of Things is a concept which has gathered considerable attention since the beginning of the 21st century. Due to that reason, it is often expressed among the academics the perception of IoT is often misunderstood and associated with very different concepts, and technologies which don't necessarily have to do with IoT (Atzori *et al.*, 2017; Abadía *et al.*, 2022; Shirvani & Masdari, 2023; Aryavalli & Kumar, 2023). IoT is a conceptual framework that leverages physical device's connective capabilities, enabling them to collect, analyse and share information between each other (Atzori *et al.*, 2017). Those devices can be separated in three main categories: General devices – are the main components of IoT, whose are connected and responsible for carrying the main functions of the system, for example the Roomba robot vacuum cleaner; Sensing devices – are mainly used to take diverse measurements from their environment, such as humidity, motion, temperature, light, wind speed, which ultimately contributes general devices action; Data capturing devices – objects that use technologies such as radio frequency identification (RFID) or Near Field Communication (NFC), like bank terminals (Elkhodr *et al.*, 2013).

The adoption of IoT, can be observed across many sectors such as transportation, financial services, manufacturing, healthcare, energy, retail, education (Clarysse *et al.*, 2022; Ahmad *et al.*, 2022; Fernández *et al.*, 2023; Shirvani & Masdari, 2023). In fact, the worldwide spending as reached 750 billion dollars in 2019, a growth of 15% from 2018 amount (Clarysse *et al.*, 2022). IoT has a crucial role on the fourth industrial revolution and can offer even more relevance when combined with other technologies such as *AI*, *cloud computing*, and *big data* (Ushakov *et al.*, 2022; Abadía *et al.*, 2022).

The future of IoT will according with the north American company CISCO, be more integrative. In 2012 CISCO introduced the concept of Internet of Everything (IoE), by setting it with promising change the reality of how we work and interact. According with the company, IoE connects people, processes, data, and things (Schatten *et al.*, 2016). While IoT had encouraged the widespread adoption of wirelessly linked devices, IoE enables their integration, merging, and analysis of data to make better, more individualized forecasts and judgments as well as to conduct meaningful actions (Langley *et al.*, 2021).

Nevertheless, giving the wide nature of IoT systems, is not exempted from facing security adversities, like breaches and attacks, similarly to conventual. At the end of 2022 a picture taken

by iRobot's Roomba - a vacuum cleaner robot (a great example of a blend between AI and IoT), was leaked on the internet where could be seen a woman sit on toilet (Guo, 2022; Louder, 2022; Harker, 2022). The robot uses its camera to map the house so that it can clean in a more efficient way, however it is still not clear, to what else it could be used. This comes in line with several security and trusting concerns that have been raised among the academics (Tewari & Gupta, 2020; Clarysse *et al.*, 2022; Ramkumar *et al.*, 2022; Shirvani & Masdari, 2023). However, hopefully new solutions proposed aimed to protect IoT data by recurring to machine learning (Tahsien *et al.*, 2020), mindsets (Rekha *et al.*, 2021) and regulations (Mantelero & Vaciago, 2015; Kounoudes & Kapitsaki, 2020) which can help in the future to mitigate and prevent those type of drawbacks.

2.1.2.4. Virtual, Augmented and Mixed Reality

Virtual reality (VR), augmented reality (AR), and mixed reality (MR) take advantage of hardware and software to evoke a simulated certain degree of presence in a virtual reality and/or virtual objects in physical reality. VR consists in creating an entire new three-dimensional virtual world, where the user can interact in seemingly way to the physical world by creating an immersive sensory experience (Kardong-Edgren *et al.*, 2019). AR takes user's perception of the real world and integrates a virtual layer of interactive content (Rauschnabel *et al.*, 2022). MR combines both virtual and augmented technologies characteristics and provides immersive interaction between real and virtual environments (Dehghani *et al.*, 2020; Holt, 2023).

Typically this technologies have been seen most relevance among the gaming industry, however there are several current and potential applications from these technologies across a wide economic sectors, such as healthcare (Kok *et al.*, 2022), education (Park *et al.*, 2020), manufacturing (Angelino *et al.*, 2023), and construction. They have the capability to enable new processes such as remote engineering (Lee & Kundu, 2022) and surgery (Ogunseiju *et al.*, 2022) (Bernard & Bijlenga, 2022), training by simulations (Song *et al.*, 2022), and enabling even virtual tourism (including space) (Verma *et al.*, 2022; Holt, 2023).

VR, AR and MR, technologies have reached a world market value of 38.85 billion USD in 2021 and have the potential to achieve around 770 billion USD by 2030. Though there are more optimistic cases which present a worldwide market value of between 8 to 13 trillion USD for the same year, according with Citibank (Bernard & Bijlenga, 2022; Aharon *et al.*, 2022). Meta, or Facebook before the rebranding, is one of the big investors in the technology. Like many other technological companies, they believe this set of technologies have potential to revolutionize many aspects of our society. They gave new relevance to the term *Metaverse* that was somehow

forgotten since its first coining in 1992, in the sci-fi novel *Snow Crash* by Neal Stephenson (Joshua, 2017). The term is useful in the sense that its aspects aggregate VR, AR and MR terms, and also describes several levels of virtual integration. *Metaverse* conceptualization proposes therefore a new universe with a mixture of real and virtual worlds, where users share a virtual space through the internet, in which they can work, socialise, and have fun with a deep feeling of immersion through avatars and their interactions (Zhang *et al.*, 2022; Buchholz *et al.*, 2022; Oleksy *et al.*, 2023).

2.1.3. Intelligent Systems Technologies

2.1.3.1. Artificial Intelligence

2.1.3.1.1. AI Placement

Artificial Intelligence, or in short AI, is a multidisciplinary field that has seen major interest from businesses and public in general, taking it into today's public squares as one of most common expressions (Melley & Sataloff, 2022). John McCarthy (known as the father of AI) gave one of the first definitions of AI - "*the science and engineering of making intelligent machines*" (McCarthy, 1958), nevertheless other definitions have been given over the time with different approaches. An example to that view is Stephen DeCanio's definition where he takes a more practical standpoint - "*the broad suite of technologies that can match or surpass human capabilities, particularly those involving cognition*" (DeCanio, 2016). The diverse scientific nature of AI research and the multiple perspectives sources, brings unclarity to its definition (Dwivedi *et al.*, 2021; Berente *et al.*, 2021; Uren & Edwards, 2023). Furthermore, the absence of a clear definition can also be attributed to philosophical subjectivity and human unfamiliarity with certain attributes commonly associated with AI, such as the concepts of intelligence, ethics, and consciousness (Chrisley, 2008; Bennett & Maruyama, 2022; Hoffmann, 2022).

AI is being framed with high hopes for numerous different industries (Dwivedi *et al.*, 2021; Ramkumar *et al.*, 2022; Melley & Sataloff, 2022; Uren & Edwards, 2023) which can be evidenced by the measurement of global spending. It is estimated that the amount spent on AI, will achieve 98 billion dollars mark in 2023, doubling the 2019's value (Collins *et al.*, 2021). Still the success of AI is not only dependent of the amount spent on its development. Historically there was some boom-and-bust cycles (or as called by some authors AI springs) about some AI technologies (analysed with greater detail ahead), which had never achieved their expectations. The success of the new wave will depend not only on the technology's development but, as findings suggest,

particularly in the degree which organizations will transpose the technical capabilities into business functions (Uren & Edwards, 2023).

2.1.3.1.2. The Birth of AI

The origin of the AI concept is older than what might seem from today's trend. In fact, the concept of AI can be traced back to 1942, when Isaac Asimov published the fictional story *Runaround*, that marked the first time where appeared the *Three Laws of Robotics*, that would shape the ethics of AI in the future: "(1) A robot may not injure a human being or, through inaction, allow a human being to come to harm. (2) A robot must obey orders given it by human beings except where such orders would conflict with the First Law. (3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law" (Haenlein & Kaplan, 2019). His works inspired entire generations of scientists to pursue academic careers in fields of science such as computer science, AI, and Robotics (Haenlein & Kaplan, 2019). Around the same time as *Runaround* was published an English mathematician called Alan Turing, was taking a rather practical approach.

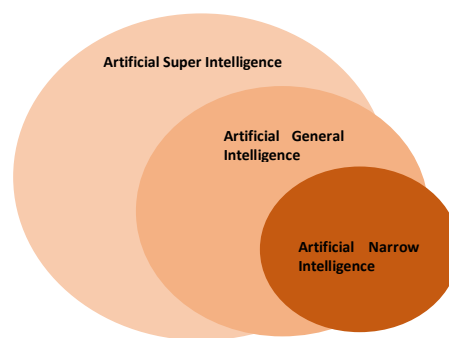
At peak World War 2, Turing was working on a machine that had the goal to (and it would eventually) break the code of the Nazi communications encryption machine called *Enigma*, a task that was seen as impossible even to the best mathematicians at the time. This achievement provoked a massive change on the tide of the war, and such breakthrough had led Turing wondering about the intelligence of the machines. It was in the year of 1950 when Turing presented a way to test the machine's intelligence with the nowadays so-called in AI research field, *Turing Test* – consisted in evaluate if a machine can imitate human thinking so that a human couldn't distinguish if is interacting with a machine or another human. He predicted in his work that by the end of the 20th century, the test would probably be passed (Turing, 1950). Despite some criticism and the variations in the approach, is still considered today as a valid test to evaluate an artificial system (Epstein *et al.*, 2008; Vorobiev & Samsonovich, 2018). The term "artificial Intelligence" was later coined by the scientist John McCarthy and Marvin Minsky in 1956, within context of the event *Dartmouth Summer Research Project on Artificial Intelligence (DSRPAI)* – organized by McCarthy, Minsky and other scientists such as Nathaniel Rochester (architect of the IBM 701 - the first commercial computer) and Claude Shannon (often called as the father of information theory) (Dick, 2019; Collins *et al.*, 2021). At the time, McCarthy was a mathematics professor at Dartmouth College, and dissatisfied with the lack of novelty on academic papers regarding the potential of computers processing intelligence, he decided to promote an event with the aim to gather the attention of researchers for the subject. Despite

the project did not meet all expectations, due to lack of collaboration and consensus, the field of AI research was launched by the common vision that computers would perform intelligent actions (Moor, 2006; Benkő & Lányi, 2009).

2.1.3.1.3. AI Staging

After the initial kick off in *Dartmouth Summer Research Project*, the expectations that AI could match human intelligence in a few years were high. However, this turned out to be a more difficult task than first expected.

Figure 2 – Stages of Artificial Intelligence



Font: Created by the author, adapted from (Haenlein & Kaplan, 2019)

In point of fact, the research in the past two decades had been focused on *Artificial Narrow Intelligence* (ANI) systems, or first-generation AI, which are the main current the AI applications nowadays (2022) (Garis & Goertzel, 2009; Kaplan & Haenlein, 2019; Karhade & Schwab, 2021).

In the Figure 2 it is shown the different stages of AI, starting with the Artificial Narrow Intelligence (Haenlein & Kaplan, 2019). This type of AI is characterized by the utilization AI capabilities only for specific areas/tasks, with the same level of success as humans or even with some outperformances, even though it is unable to learn by itself how to solve problems exterior to the specific area. Examples of such systems that achieved a high degree of success are Deepmind's AlphaZero and AlphaGo which have won to their human's world champions peers (outperforming humans) in the game of chess and Go respectively (*Chao et al., 2018; Shuai et al., 2023*). The level of human intelligence can be theoretically achieved by an *Artificial General Intelligence* (AGI) system, by using it's AI capabilities applied to several areas, with the same performance of humans or even outperform them and are able to learn by itself how to solve problems in other areas. In the case of *Artificial Super Intelligence* (ASI), it conceptualizes a stage of AI, where it can use AI capabilities to any area, and can learn how to solve problems in any area, always outperforming humans (Haenlein & Kaplan, 2019).

2.1.3.1.4. AI Derived Intelligent Systems

As like what happens with AI definition, there isn't also a clear conceptualization of what is the AI function that theoretically should be. As previously described, AI is a broad field that encompasses a wide range of technological capabilities and applications that can be used to build autonomous systems with practical benefits. Some key technological capabilities within AI includes learning, perception, reasoning. These capabilities are usually (but not necessary) result from a combination of various AI fields of applications, including expert systems, machine learning, robotics, natural language processing, machine vision, and speech recognition. Nevertheless, it's worth noting that this list is not exhaustive and there may be other technologies or applications that could be included for an AI discussion (Dejoux & Léon, 2018; Collins *et al.*, 2021).

Following, it will be extrapolated some notions of those AI applications mentioned above.

2.1.3.1.4.1. Expert Systems

An expert system (ES) has the capability to imitate the human problem-solving (Collins *et al.*, 2021). It is used to distribute knowledge by helping users solving complex problems that otherwise would be too complex for a human to solve manually. There are three main characteristics on these systems. (1) It is a knowledge-based systems, that is it relies on a database, which aggregates the information that is needed to address the issue. (2) Has the capability to imitate the human expert decision-making process – inference engine. (3) As an AI application, it provides the technical solutions in a user interface (Saibene *et al.*, 2021). Examples of such systems are DENDRAL – used to analyse chemicals with the goal to predict a molecular structure (Saibene *et al.*, 2021); MYCIN – used to identify various bacteria in an organism, that might cause infections (Chang, 2020); and the computer Aided Detection Tandem (CADeT) that is used to identify rectal cancer un the earlier stages (Brown *et al.*, 2020).

2.1.3.1.4.2. Machine Learning

Like AI, Machine Learning (ML) is also a recent big buzzword among public in general, but also among the academics. In recent research (2021) it was analysed the content of 98 primary studies from Information Systems Journals, and 69 of them were about Machine Learning (Expert systems came in second with 11) (Collins *et al.*, 2021). This is partly due to the abundance of data the need to interpret it, and partly due the ML wide technological applicability, from recognising and classifying objects in images, converting speech into text, or matching online

user preferences (ads, articles, search results, etc) (LeCun *et al.*, 2015). Reason that led ML and also AI, to turn into the big buzzwords that they are today. On balance, since they are closely related, those two are often mistaken by one another or by something in between. Therefore, is relevant to distinguish that AI is a broader field when compared with ML, whereas the first has the capability to simulate cognition, and human behaviour, it has not the competence to learn from experience or data and adapt their programmed parameters. In this point, the definition of ML will be briefly teased, as well for its learning approaches (Mahesh, 2020; Shute *et al.*, 2023).

The machine learning term was presented in the 1950s, when a north american computer scientist called Arthur Samuel, created a computer software that had not only the capability to play checkers, but also to learn from previous games (Desaire *et al.*, 2022). In consequence of this endeavour, he released a paper where he defines ML as “the area of study that seeks to give computers the capacity to learn without being explicitly programmed” (Samuel, 1959). This gave conceptualization that computers were no longer restricted to the rules programmed, instead they had the ability to modify its rules. Later in 1997 Tom Mitchell, also a north american computer scientist, defined ML as “a computer program is said to learn from experience (E) with respect to some task (T) and some performance measure (P), if its performance on (T), as measured by (P), improves with experience (E)” (Mitchell, 1997). This later definition brought not only a deeper focus on the experience needed to train the software, but also a caveat that there’s only learning if performance increases with experience.

There are three main ML approaches to algorithmic programming. Those approaches are significant different between them, even though all of them comply with the core definition of improving performance on a task, based on experience, they differ in terms of target task, the type of data used for training and the way to measure performance (Collins *et al.*, 2021). Hence the different types of approaches are more suited to certain problems than others (Mahesh, 2020). Following there will be a brief description from each one of them:

2.1.3.1.4.2.1. Supervised Learning

As the name implies, *Supervised Learning* is learning under supervision, by indicating to the program what is correct or incorrect – data labelling (Lee *et al.*, 2018). The quality of data used is crucial for the success of this approach, which represents some limitations regarding the bias in data labelling and the high amount of human work required to develop the process (LeCun *et al.*, 2015).

This is one of the most widely used approaches of ML with particular interest in prediction and forecasting problems and depending on the type of problem *Supervised Learning* can even

be divided into regression and classification. Regression is used to predict something that can be described on a continuous numerical scale. On another hand, classification can be used to predict a variable that is described by set of classes or categories, with finite scale of values (sometimes not numerical) (Shute *et al.*, 2023).

2.1.3.1.4.2.2. *Unsupervised Learning*

Once again, as the name suggest, *Unsupervised Learning* occurs when the learning is done without supervision, therefore no correct answer. The program learns by recognising recurring patterns in the unlabelled data and the connections between those patterns, recurring to techniques as clustering or feature reduction. A resultant limitation of the approach is less accuracy of the results when compared with the alternatives (Aldarmaki *et al.*, 2022).

This approach is used when it is not possible to obtain a labelled dataset, either because it is not practical to create a labelled dataset (for example in a huge dataset), or when it is not clear what categories should be used or even what to look for. Hence there is an intention to find similarities between data elements and consequently, which of them are distinct from each other, even if there is not a clear definition of what is being sought (Shute *et al.*, 2023).

2.1.3.1.4.2.3. *Reinforcement Learning*

This category of machine learning, the system is composed by the agents, environments, actions, states, and rewards. In this case, the system learns by interacting with its environment, while maximizing the goal of positive rewards (Elguea-Aguinaco *et al.*, 2023). The process (also known as Markov decision process) starts with the agent (computer) taking a certain action in a determined environment. Then, the resulted change in the state of the environment can lead to rewards, positives or negatives. This will lead the system to make corrections to the next action that will maximize the number of positive rewards (Shute *et al.*, 2023).

On balance, *Reinforcement Learning* is most valuable when dealing with decision-making problems. This type of learning is used when the purpose is to build a system that learns how to make decisions (Shute *et al.*, 2023).

The three approaches described above can be applied to train diverse algorithmic structures, where each of them can capitalize their respective advantages. Example of such structures are *Neural Networks* (NN) which are known to be inspired by the human brain. It is used to define the network in which the information is transmitted from the input layer (that receives the data), through nodes, into output layer, hence similarly to the human neuron function. NN have the capability to adapt the nodes given a change in the input data. (LeCun *et al.*, 2015).

Nevertheless, there are several different types of NN architectures, some more suitable to certain AI applications than others. Example of those architectures are Convolutional Neural Networks, Recurrent Neural Networks, Transformers, Autoencoders, Generative Adversarial Networks (LeCun *et al.*, 2015; Mahesh, 2020). Transformers in particular, is an architecture that has seen greater attention in recent years after its introduction in 2017 by a group of Google researchers (Vaswani *et al.*, 2017). It's called a "transformer" because it uses self-attention mechanisms to transform input data into different representations, which makes it well-suited specially for tasks like language translation and text summarization (Pfeiffer *et al.*, 2020).

2.1.3.1.4.2.4. Deep Learning

DL is a class of techniques that can be used in all ML approaches, in which the system learns by a hierarchical multilayer level – therefore the “deep”. Typical ML is limited in its ability to process high volumes of raw data, which requires precision engineering and high domain expertise (LeCun *et al.*, 2015; Melo *et al.*, 2022). With the hierarchy arrangement, the system can understand more complex concepts, by building their definition out of simpler others, than it would do with just ML (Kwang, 2016). NN architecture is the base for DL has the ability to furthering the nodes layering, creating a further convoluted and connective path between the input layer and the output layer (Bonaccorso, 2018).

2.1.3.1.4.3. Robotics

This type of AI application is concerned with a connection of different engineering fields, that includes, besides AI, mechanical engineering, kinematics, among others (Sinha *et al.*, 2022). Robotics regards the motion control of physical objects by computers (Collins *et al.*, 2021). Driven by the increased adoption of automation in end-use and high precision industries, this application is projected to be one of the technologies with higher growth (Elguea-Aguinaco *et al.*, 2023). Examples of such technology can be found in exploration rovers, robots (such as *Boston Dynamic's* or *Roombas*), and robotic limbs (Abbey *et al.*, 2019).

2.1.3.1.4.4. Natural Language Processing (NLP)

NLP's field intersects with the fields of computer science, linguistics, and AI. It focuses on how machines interact with human languages, particularly by assisting the processing and analysis of enormous volumes of natural language data by machines, hence it is the base for *Speech Recognition* (Collins *et al.*, 2021).

NLP is considered to be one of the most promising areas of AI, and in particular on the perspective of how such technology help humans to identify pattern and take knowledge from textual data. Examples of NLP use are chatbots, like Google's BERT or IBM's Watson (Chen *et al.*, 2022), and OpenAI's Generative Pretrained Transformer (commonly known as Chat-GPT) what is considered by some as "the most impressive model as of today" (Zhang & Li, 2021), including also a mention on the "Top 10 Breakthrough Technologies" by MIT Technology Review in 2021 (Zhang & Li, 2021).

2.1.3.1.4.5. Machine Vision

This type of AI technology takes form by analysing large amounts of data containing images and provide automations. Due to its instrumentation simplicity and smartness. Machine Vision, or as sometimes called, computer vision, can be seen as development maker, especially in manufacturing processes such as inspection, process of control, and guidance (Kaushik *et al.*, 2022). The integration can rapidly be done by incorporating a camera with computer software and sensors, leading consequently to better product quality and less production time (Kim *et al.*, 2002). The Machine Vision process is composed by five procedures: (1) Image capturing – The process starts with the capturing of images; (2) Image acquisition – The image is transformed into digital images; (3) Image processing – Treatment of pixel values of an image. This step will appropriate the information in the image to the right format; (4) Feature extraction – Here is identified the image's intrinsic characteristics; (5) Pattern classification – It is done the pattern classification from the information gathered (Hashmi *et al.*, 2022). Examples of such appliances are self-driving cars (Badue *et al.*, 2021), image creator software (such as OpenAI's DALL-E) (MatthewSparkes, 2022), and facial recognition applications (Liu *et al.*, 2023).

2.1.3.1.4.6. Speech Recognition

Speech Recognition is a technology which its process consists in identifying patterns in speech longitudinal wave. These patterns can be perceived from speaker's speech are the respective identity, language, and emotions. To achieve this, the technology relies to other technologies such as *Natural Language Processing*, particularly convert the patterns in human speech (Collins *et al.*, 2021). Despite the various potential capabilities, the translation of spoken words into text is the one that has taken bigger attention in recent times (Aldarmaki *et al.*, 2022). The examples of appliances are voice commands (call routing, voice search), speech-to-text systems including with deaf people (Zhao *et al.*, 2022), and voice assistants (such as Apple's Siri or Google Home).

2.1.3.1.5. AI technologies Gartner Hype Cycle situation

As previously described, AI is sometimes a buzzword that has historically been involved in great hype accompanied with high hopes. Following the Table 1, we can take some insights from Gartner Hype Cycle, on where do we stand for some AI technologies. The Gartner Hype Cycle describes the expectation around a technology over time and it's divided in five parts: (1) Technology trigger – is the first stage of development, that occurs when there's any big breakthrough or event regarding the technology, in which creates relevant interest from press and/or industry; (2) Peak of inflated expectations – the second stage of the cycle, where there are over expectations and over optimism around the technology, due the limitations of information around it and how it will be applied in organizations; (3) Trough of disillusionment – following the over hyped stage, it is understood the technology cannot live to the expectations and the expectations around the technology decreases to the most pessimistic levels; (4) Slope of enlightenment – in this stage, the technology start to being realistically assessed and the best practices are adopted by some industries; (5) plateau of productivity – at this last stage, the organizations and industries realize the potential of the technology and the adoption is general (E.O'Leary, 2008; Karhade & Schwab, 2021).

On the first column, in the technological trigger phase, we can find AGI which is expected to take more than 10 years to achieve the plateau of productivity. It may also be found AI Engineering which is a discipline focused on developing conditions, such as tools and systems that enables the application of AI (Chen *et al.*, 2019). On the second column, in the peak of inflated expectations, we can find smart robots which are robots capable of developing complex tasks that require an advanced computational resources and technologies, like IoT, cloud computing, AI and synthetic data which is artificially generated data (Liu Z. *et al.*, 2022; Melo *et al.*, 2022). On the same stage we can find synthetic AI, which consists in using ML to generate artificial data from real world data (Rajotte *et al.*, 2022). Passing through the trough of disillusionment, we can find technologies like *Deep Learning*, which is between 2 to 5 years from the plateau, autonomous vehicles that are from plateau by more than 10 years, and NLP that are between 5 to 10 years. Finally in the slope of enlightenment we find with less than 2 years to the plateau, computer vision, and between 2 to 5 years data labelling and annotation.

Table 1 - Gartner Hype Cycle for Artificial Intelligence technologies in 2022 (years to achieve plateau of productivity)

Innovation Trigger	Peak of Inflated Expectations	Trough of Disillusionment	Slope of Enlightenment
Artificial General Intelligence (more than 10 years)	Smart Robots (5 to 10 years)	Deep Learning (2 to 5 years)	Computer Vision (less than 2 years)
AI Engineering (5 to 10 years)	Responsible AI (5 to 10 years)	Autonomous Vehicles (more than 10 years)	Data Labelling (2 to 5 years)
Operational AI Systems (5 to 10 years)	Synthetic data (2 to 5 years)	Natural Language Processing (5 to 10 years)	Data Annotation (2 to 5 years)

Font: Adapted by the author from (Wiles, 2022))

2.1.4. Intelligent systems conclusion

The development of big data, cloud computing, IoT, artificial intelligence and the metaverse realities has been a result convergent advance. They all have multiple interconnections, and all represent a technological era that certainly is more automated and digital than the ones before. The reason for this is that they all are addressed to deal with data. The huge sums of data generated by IoT or the metaverse, will be saved in big data servers, AI will analyse it with resource to cloud computing capabilities, providing solutions and insights capable of creating intelligent systems (Deng & Yu, 2014).

2.2. Space Industry

Space industry is generally recognized by nations with great strategic relevance. Numerous studies have indicated the positive economic and social outcome of space investments. The industry development can impact not only the defence capability and sovereign security, but also the growth of transportation, communications, and other economic sectors (Chebukhanova & Zimakov, 2022).

The industry has been changing from its traditional centralized planning to a *New Space* approach, driven by an exponential growth in private market share. Despite these changes, the statal support still has a crucial role on industry development, followed by the technological progress in the overall economy, and the accessibility of qualified workforce (Chebukhanova & Zimakov, 2022; El-Shawa *et al.*, 2022).

Space industry origins can be arguably traced way back to the work done by the 3 fathers of rocketry Hermann Oberth, Robert Goddard, and Konstantin Tsiolkovsky (Winter, 2016).

Nevertheless, it got particular attention with the end of World War II (WWII) (George, 2019; Pillai, 2022).

2.2.1. Industry Roots

In May of 1945, Nazi Germany surrendered, putting an end to World War II. With Europe in ruins, two great world powers have consolidated – United States (US) and Soviet Union. The US created the Marshall Plan in 1948, an act designed to with a goal to rebuild west and southern European countries, but also with goals to sustain the survive of liberal democratic institutions and promote their development (Steil, 2019; McCourt & Mudge, 2022). On another hand, the Soviet Union had a strategic interest in maintaining the control in eastern Europe, even if it was only to protect themselves from any resurgence from Germany. In addition, likewise their American peers, the Soviets were interested in spreading and establish their ideologies worldwide and affirm themselves as a world power (Harper, 2013; W. Luke, 2020).

With such similar interests and with such different ideals, what follows are a set of measures to conquer their respective spheres of influence leading to competition in various fronts, peaked by a period of geopolitical tensions know as the *Cold War*. One of the main fronts where these two superpowers were competing furiously was in the technological front, particularly in the military domain. Their technological achievements were intended to show the resources and capabilities at their disposal in case of direct conflict (Steil, 2019; W. Luke, 2020).

By the end of the WWII both Soviet Union and United States were already nuclear superpowers. Their nuclear warheads could be delivered by bombers or by short (by today's standards) range ballistic missiles, meaning that in case of conflict, they should be strategically placed beforehand, enabling them to reach the intended target - requirement that almost sparked the third world war during what became known as the Cuban missile crisis (W. Luke, 2020).

Both powers had been trying to develop long range missiles for some decades by the end of WWII, however without major successes. With the fall of Nazi Germany, the Americans managed to bring to the US some German scientists through a series of operations like "Operation Paperclip" (Slayton, 2019). Among them they retrieved most team that had worked on the German V2 rocket to help them on the development of rocket technology. In the 1940's the V2 rocket was the one with longest range (Winter, 2016; Jaeger, 2022). Nevertheless, the Soviets had also managed to deport some rocket scientists from Germany, by similar measures for example the so called "Operation Osoaviakhim" (Siddiqi, 2009). Despite the lack of Soviet major successes of long-range missiles, they were at the time, ahead of the Americans. In 1955

both powers announced their determination to launch satellites to Earth's orbit, and the first space race was on. Launch vehicles capable to achieve orbit meant that they could de-orbit to anywhere on earth, therefore removing the missile range constraints (Haeuplik-Meusburger & Bannovab, 2023).

The race became serious in 1957, when the Soviet Union launched the first artificial satellite to Earth's orbit, *Sputnik*, meaning that they now had the capability of putting a nuclear warhead anywhere in American soil (Guarnieri, 2019). Under the leadership of Nikita Khrushchev and the engineer Sergei Korolev (often called as the father of soviet space program), the Soviet's capabilities appeared to rather obfuscate the American peers (Erickson, 2018). The American public opinion was led on mass hysteria by the soviet achievement. Particularly after the New York Times referred that the US was now on a race for survival, and the public declarations from Senator Lyndon Johnson in which he mentioned that who controlled the space would control the world. Across the rest of the West, great praises were given to Soviet triumph – In England, the *Manchester Guardian* said “the achievement is immense. It demands a psychological adjustment on our part towards Soviet military capabilities...”, in France the *Le Figaro*, announced that “Myth has become reality” (Cadbury, 2005; Muir-Harmony, 2017). Immerse in such appraisals, the Soviets wanted to elevate the bar even more. One month later, the Soviets were able to launch another rocket, this time with a living creature that would stay in orbit for several days – a dog called *Laika*. Despite the dog dead in consequence of overheating just after six hours into flight, the Soviet propaganda emancipate that she had survived four days in orbit, which led again to great ovation from the international entities for such achievement. The American humiliation was placed (Harper, 2013; Weinzierl, 2018).

After several setbacks the United States were finally capable of launching a satellite to orbit in February 1958 – the *Explorer I*, and the public opinion went off the roof (Baker & Kissock, 2017). As often defended by the Soviets the race was won later in 1961, when they were able to launch Yuri Gagarin, the first human into space (Aliberti & Lisitsyna, 2019). From here on, there was a set of pioneering from the Soviets, and respective reactive accompaniments from the Americans (Weinzierl, 2018; Erickson, 2018).

The tide only changed for the Americans after big investments with their Apollo program and took special expression after President Kennedy announced the decision to go to the moon. Not only that, but also the fact that the soviets started to face serious consequences of the political pressure that tended to hasten the rocket manufacturing and research, leading to inadequate standardization processes and weak quality control (Muir-Harmony, 2017; Erickson, 2018). Nevertheless, the 60's decade was the one in which both superpowers fought in the extreme Cold War competitiveness with the moon as the background goal (especially if you had

asked to the American side). On July 1969, an era with no handheld calculators or smartphones, Neil Armstrong, Edwin “Buzz” Aldrin and Michael Collins are launched aboard a Saturn V aiming the moon. 4 days after launch Armstrong became the first human to set foot on the moon (Taylor, 2017; Muir-Harmony, 2017).

After this achievement, and with the end of the Apollo program in 1972 no human as set foot on the moon since then, a period called by some as the “great retreat from the moon” (Taylor, 2017). Following years of government spending, mostly backed by military and national security interests, the relevance of pursuing rocket technology development had substantially decreased, the humankind had already by then, the firm capability to inflict severe destruction on itself, at the distance of a button (Weinzierl, 2018).

2.2.2. The New Space

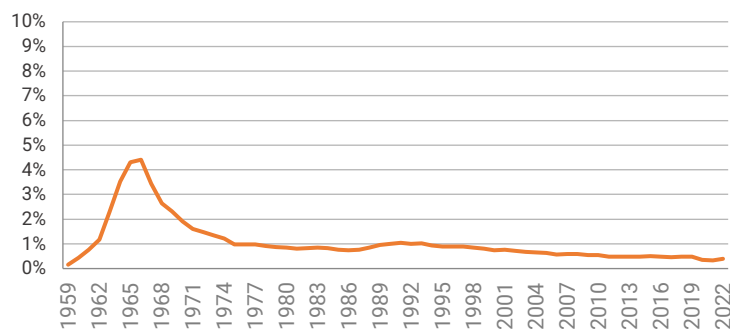
As previously described, the start of the last space race was fuelled by the Cold War circumstance. For this reason, the today called space transportation industry was purely backed by government subsidies and settled for militaristic purposes. However, after decades of centralized economic control, the industry had suffered major paradigm shifts. We can assist nowadays to a new type of space, led by the private sphere, addressing the industry with different approaches, where (in contrary to the previous race) with lesser obvious militaristic aspirations – in other words, the transition from the traditional, to the *New Space* (Weinzierl, 2018; Brukardt *et al.*, 2022). Nonetheless, it is important to not be misled. The deceptive dominance of commercial companies is heavy statal backed, as civil launch vehicles can also be used to serve state needs and interests (Hempsey, 2021).

In the space industry essence, space launch costs have been the main constrain for space exploration, and therefore to its economic proliferation (Jones, 2018). Nevertheless, with the increase of private launch entities, a bigger integration has resulted, besides the traditional space principles such as reliability and accuracy, commercial principles such as availability and affordability, through mean of reusability and scalability (Jo & Ahn, 2022). The increase of their presence leads also naturally to bigger competition and during the process of seeking a competitive advantage, to several innovations and efficiencies gains. The result is that private companies have already proved capability produce a reduction in launch costs, forging of new opportunities to be exploited by commercial users, as well by space agencies (Tugnoli *et al.*, 2019; Niederstrasser, 2022; Gonzalez, 2023).

Since the cooldown of the initial space race between the two great superpowers, there has been a relative percentual decrease from direct statal effort with space accessibility, relatively

to what was once during the 60's. Taking NASA's (National Aeronautics and Space Administration) budget in percent of the US gross domestic product (GDP) in Figure 3, we can clearly see that effect from the US perspective. Some disinterest combined with the lack of relevant competitors and given the reliability required by the militaristic heritage, lead to a fundamentally less cost driven industry (Weinzierl, 2018). Nevertheless, as mentioned, statal support still has a stimulus relevance role across the industry, even though further indirectly than in the past (Jones, 2018; Mazzucato & Robinson, 2018; Peeters, 2021).

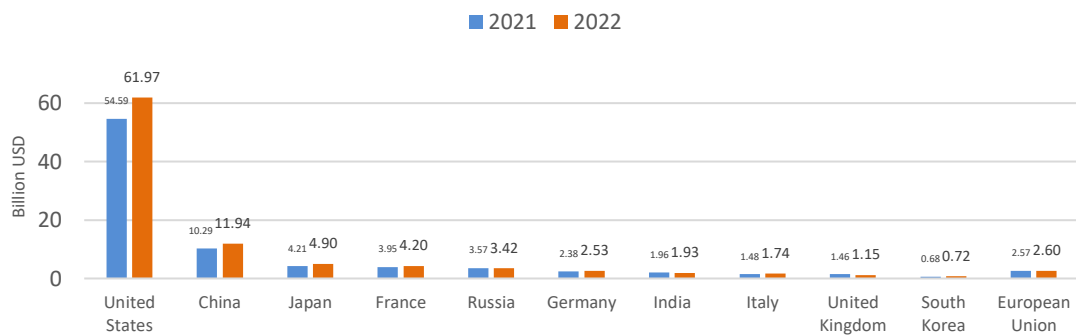
Figure 3 – NASA's budget in percent of US GDP, from 1959 to 2022



Font: Adapted by the author from (The Planetary Society)

As can be seen in Figure 4, despite the historical percentual decrease against their GDP, the world is spending more the US continues to be the nation with larger statal investment in the space industry. The global space programs expenditure has reached 103 billion USD in 2022. More than half, was contributed by the US (61.97 billion USD), followed by China, Japan, France and Russia.

Figure 4 – Top 10 biggest statal expense on space programs by country, and EU in billion USD



Font: Adapted from (Euroconsult, 2022)

This transition to the *New Space*, was only possible due to a change in statal policies. In this sense, the US has been the pioneer which other countries have been following, such as Japan, South Korea, European countries, and even China (Mazzucato & Robinson, 2018; Pelton, 2019; Tugnoli *et al.*, 2019; Jiwei & Bojian, 2020; Walker, 2022). Example of such reforms and restructurings in the US were the approvals of the Commercial Transportation Act in 1984, the

US National Policy on Commercial Space in 2008, the Obama Administration's Space Policy established in 2010, the Commercial Space Launch Competitiveness Act in 2015 and the NASA Transition and Authorization (Weinzierl, 2018). The policy change took firm practical expression with the end of the NASA's Shuttle program in 2011, which marked a fundamental change in NASA from their typical role of market creator, to a focused space and scientific exploration (Vernile, 2018; Robinson & Mazzucato, 2019). With the shutdown of the program, NASA had to recur fully to its launch partners in US and around the world. With the ongoing needs around the International Space Station (ISS) research and respective maintenance, meant that the only partner NASA was left, with capability of transporting astronauts to orbit, was the Russian Soyuz rocket. Whole of this context but not exclusively, contributed for alignment of the private proliferation in the industry (Mazzucato & Robinson, 2018; George, 2019).

China has been a big US competitor. The country has launched in 2020 the *Beidou Positioning and Navigation System* (BDS), their alternative to the US state owned *Global Positioning System* (GPS). Moreover, they China they have also finished their Tiangong space station (Yárnoz *et al.*, 2019). These, among other achievements have been partly achieved by their encouragement to the private entity development, through several policies and regulations (Jiwei & Bojian, 2020; Zhang Z. , 2021; Zhang & Yang, 2023).

Despite the policy changes in US, EU and China, Russia has been on a different track. Particularly with the fall of the Soviet Union, Russia has been suffered several economics constrains. Notwithstanding, in 2007 Vladimir Putin announced the commitment of making space as a strategic priority for Russia. In consequence of this announcement, the space budget raised from around 20 billion roubles to more than 120 billion roubles in 2014 (around 5 billion euros at the time), a value that have been decreasing since then. There are potential constrains for space innovation in Russia such as the centralized statal investment supports mostly big enterprises, which creates lack of commercial orientation and competitiveness around the industry (Chebukhanova & Zimakov, 2022). Moreover, the industry rigidity has constrained technological transfer, which also contributed to brain drain and poor workforce management, leading to poor productivity, and essentially to the industry decay (Aliberti & Lisitsyna, 2019).

2.2.2.1. Space Economy

2.2.2.1.1. Overview

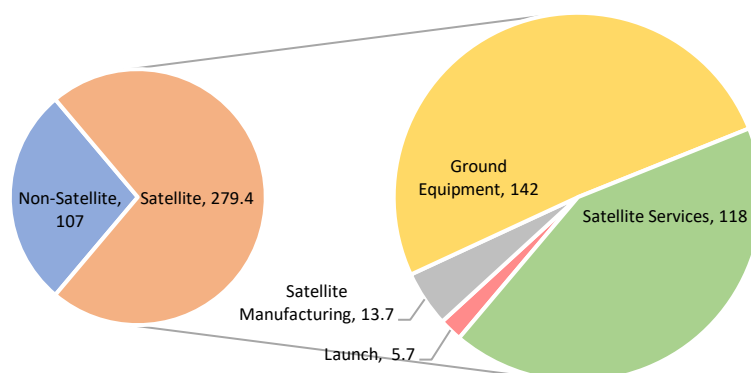
There are several difficulties to conceive the size and categorise the space economy. Starting by the underlying conceptual misunderstandings on definitions and passing through on what

should be considered with economical value or not (Davidian, 2022). The outcome is the existence of different approachable frameworks, each one presenting somewhat different results, given their respective advantages and disadvantages (Mani *et al.*, 2022; Highfill & MacDonald, 2022). Nevertheless, taking the approach of a north American consultancy company, Bryce Tech, the global space economy was worth 386 billion USD in 2021 (Bryce Tech, 2022).

The space economy can be divided into two major activities as identified in Figure 5. The satellite related industry and the non-satellite related industry. In the non-satellite category, we can find government space budgets and the commercial human spaceflight. The satellite related category is constituted by satellite manufacturing, satellite services (such as telecommunications, and television services), ground equipment (for example, global navigation satellite system (GNSS) equipment), and launching (George, 2019).

The non-satellite category was less than one third of the total industry economy, in which government budgets represented more than 90% of the total amount, led by the US government budget. On another hand, the satellite related activity, took 72% of the space economy, where the ground equipment led the category with nearly 51% of the share (mostly given the 109.7 billion USD on the GNSS equipment), followed by satellite services with 42% (highlighting the revenue 98.4 and 17.2 billion USD originated by consumers and enterprises respectively), satellite manufacturing with almost 5%, and last but not least the launch service providing with around 2% of the satellite related activities category (mostly taking place in the US) (Bryce Tech, 2022).

Figure 5 – Space industry economy by activity, in billions of USD



Font: Created by the author based on (Bryce Tech, 2022)

Some major banks like Morgan Stanley, Citi Bank, Bank of America and UBS expect an acceleration in the industry growth. By 2040, the economic output generated by the space industry will be reaching over a trillion USD, a rise of around 300% from the 2020's figures (George, 2019; Brukardt *et al.*, 2022).

Despite the several risks that space investment involves, the potential for new businesses exploration within the industry, and the greater space accessibility (described in greater depth in the next point), investment has been pouring in. *New Space* start-ups have raised almost 500 million USD per year on average, between 2001 to 2008. In 2020 that value set to be around 7.6 billion USD worldwide (more than 5 billion USD in the US alone) (Weinzierl, 2018). 64% of this investment came from venture capitalists, followed by 15% from the seed/prize, 13% from acquisitions, 6% in public offerings, 2% through debt and less than 0.1% from private equity. Regarding the biggest receivers of this investment we can identify some familiar companies in the industry: Space Exploration Technologies (SpaceX) (30% of the total amount), OneWeb (14%), Blue Origin (13%), Relativity (7%), Virgin Galactic (6%), CG Satellite (5%) and Landpsace (2%) (Pelton, 2019; Chebukhanova & Zimakov, 2022).

The reflection of the investment increase is also in the emergence of new types of businesses models. Some of them are related with activities such as space tourism, space mining, low orbit satellite constellations, space stations and small satellite markets (Weinzierl, 2018; Peeters, 2021; Zhang & Yang, 2023).

2.2.2.1.2. Emergent industries

2.2.2.1.2.1. Space Tourism

Space tourism has begun to really take off in the recent years. The first space tourist was the American businessman Dennis Tito, which in 2001 paid 20 million USD to fly aboard a Russian Soyuz to the ISS. Since then, some companies like Space Adventures have been using Soyuz vehicle for ISS space tourism (Florom-Smith *et al.*, 2022). Space tourism has come from a long way since then. In 2021 it was beat the record of non-astronauts that flew into space. Each one of the three main players in this activity, Virgin Galactic, Blue Origin, and Space X, took rather different approaches, and experience offer, however with some common ground (all American companies backed by billionaires) (Platt *et al.*, 2020; Leslie, 2022; Maiwald, 2023).

Virgin Galactic, launched by Richard Branson, has sold around 700 tickets for 450 000 USD each, but ultimately, they will be selling at 250 000 USD each. The passenger is carried on board of the spaceplane named SpaceShipTwo (powered by a hybrid rocket engine), capable of carrying six tourists (plus two pilots), which by itself is carried out by an aircraft until 15 km of altitude, where then the spaceplane is released and thanks to its rocket engine it will reach the suborbital altitude of 86 km, delivering a sensation of weightless for four minutes (in a nearly 60 min trip) (Leslie, 2022; Maiwald, 2023).

Blue Origin was founded by Jeff Bezos. Bezos, announced that has sold more than 100 million USD in tickers. Concerning the ticket prices even though their value was not officially disclosed there are evidence it depends on the passenger identity. Blue Origin has created a fully reusable single stage vertical rocket powered by a liquid propelled engine with a capsule capable of transporting six passengers to a suborbital altitude of around 100 km, delivering microgravity felling during three minutes (in a nearly 10 minute trip) (Wilson, 2019; Leslie, 2022; Maiwald, 2023).

SpaceX is a company founded by Elon Musk. It is a more matured company, that has a secondary activity of space tourism. As off this thesis date, they are the only American company capable of carrying astronauts to the ISS, meaning that it is only one of the two capable of transporting tourists to orbit (the other system is the Soyuz rocket as previously mentioned). Aboard of their astronaut carrying Dragon capsule and the two-stage liquid engine powered Falcon 9 rocket, they launched in 2021 their “Inspiration4” mission which consisted of four private citizens go on a three-day trip around Earth orbit, paying an undisclosed amount. Moreover, it was announced in 2018 the mission “dearMoon”, financed by the Japanese millionaire Yusaku Maezawa, will consist of carrying Yusaku and other 8 artists passengers in a trip around the moon, on board of SpaceX’s Starship, a super heavy vehicle still in development (Leslie, 2022; Maiwald, 2023).

2.2.2.1.2.2. Space Mining

Space mining consists of mining resources from celestial bodies like asteroids, planets, or other celestial bodies. With the advent of the New Space, mining in space reserves not only a potential for direct business creation but as well as a key enabler of several others (Jakhu *et al.*, 2017).

Directly speaking, mining can generate huge changes on our commodity’s economic dynamics, hence resource rationalization and resultant limitations. There are asteroids with high metallic properties, some of them rare on Earth, worthing billions of USD at today’s markets. Some few actors exploring this ramification are Planetary Resources Inc, Deep Space Industries and Shackleton Energy (Andreas M. Hein, 2020; Dallas *et al.*, 2020).

Indirectly, mining can help other adjacent industries such as space transportation. Other celestial bodies can have the raw resources needed that can be used to produce propellants, and therefore increase the transportation capability. This type of mining makes part of SpaceX’s vision for sustainable Mars colony (Jakhu *et al.*, 2017; Andreas M. Hein, 2020; Dallas *et al.*, 2020).

2.2.2.1.2.3. Satellite Constellations

Large LEO satellite constellations have already been placed and new ones announced (Wekerle *et al.*, 2017). The existing constellations mostly consist in providing telecommunications and navigation services (like GPS or BDS) however, the new wave of small satellite constellations propose to deliver internet directly from the satellite. These constellations have therefore the goal to provide global, high-speed, and low latency internet, enabling access from any remote location. It is considered as an essential part of the sixth generation (6G) network. Nevertheless, there are several concerns with the impact of such constellations may have on astronomical observations (Hossein *et al.*, 2022; Cui & Xu, 2022). There are among other projects (Abashidze *et al.*, 2022), three main constellations in development, SpaceX's Starlink, OneWeb constellation, and Blue Origin's Kuiper (Zhang *et al.*, 2022; Abashidze *et al.*, 2022).

Launching sixty per launch, Falcon 9 has been the launch vehicle responsible for the more than 3000 Starlink satellites already in orbit, however the goal consists in taking 12 000 satellites into an altitude of 550 km until 2027 (with a possible extension to 42 000 satellites) (Zhang *et al.*, 2022; Abashidze *et al.*, 2022; Osoro & Oughton, 2022).

OneWeb constellation is being launched across diverse launch vehicles including the Russian Soyuz 2.1b, Indian LVM 3 and Falcon 9. The constellation counts with more than 500 satellites placed in orbit, and given it is placed at a higher altitude than Starlink it is expected to have less satellites (720) (Abashidze *et al.*, 2022; Osoro & Oughton, 2022).

The Kuiper constellation still don't have any satellite in orbit, even though it is expected to be composed by 3236 satellites, and to be launched on board of the still in development New Glenn launch vehicle (Zhang *et al.*, 2022; Osoro & Oughton, 2022).

There are also constellations proposed relying in the use of cubesats (satellites with less than 1 litre of volume) (Wu *et al.*, 2021). These constellations intend to address several valences, such as marine and air traffic monitoring (Wu *et al.*, 2021), disaster management (Giancarlo Santilli, 2018) and hurricane monitoring (Chadalavada & Dutta, 2022), or IoT support (Kak & Akyildiz, 2021). Example of those are Terra-Bella and Planet constellations (Giancarlo Santilli, 2018).

2.2.2.1.2.4. Space Stations

The ISS has been one of the largest projects with most successful international cooperation. Despite the initial lifespan expectation 15 years of operation, it counts with more than 20, and with expected decommissioning (Walsh & Gorman, 2021; Pace, 2022). Meanwhile, the Chinese

space agency, China National Space Administration (CNSA), has also launched their Tiangong space station (Shengli Jiang, 2021; Wilkins, 2022). Mostly leveraging on ISS opportunities and with also the opportunities created with its decommissioning, several New Space stations have been announced and others are being designed on earth's LEO and beyond. They will intend to not only provide space access to diverse national agencies but as well as to commercial clients. These projects will nurture among other activities, space tourism and space manufacturing (Patane *et al.*, 2017; Florom-Smith *et al.*, 2022).

Announced in 2019 as part of its Artemis program, NASA, will be construct and place a multipurpose orbital outpost called Gateway, that will be orbiting the moon. The spacecraft is going to be constructed by NASA, along with ESA, CSA, JAXA, and their commercial partners. The primary purpose will be to support not only human permanent research and exploration of the moon's surface, but also to support spaceflight to other celestial bodies on our solar system, such as Mars. Nevertheless, its capabilities can be leveraged to refine opportunities for commercial entities (Smith *et al.*, 2020; Ehrenfried, 2020).

On the commercial front, players like Axiom Space, Nanoracks, Lockheed Martin, Blue Origin, and Sierra Space, have shared the vision to construct space stations on Earth's LEO.

Axiom Space wants to create a substitute to the ISS by constructing the first world's commercial space station. Composed by 3 modules, the first one is intended to be attached to the ISS and will be dedicated to provide research and manufacturing capabilities. The other two modules will increase its capacity, which will also enable the modules to operate as an independent space station. With this infrastructure, they intend to create the space infrastructure fly commercial passengers and utilities for scientific, touristic, and industrial purposes (Patane *et al.*, 2017; Florom-Smith *et al.*, 2022; Maender *et al.*, 2022).

Nanoracks along with Lockheed Martin, are likewise developing a commercial space station called StarLab with the goal to provide access to research and manufacturing opportunities in LEO. Similarly, to the ISS, it will be a modular station, that at least in the initial phase, will leverage on ISS existent operations. The firsts modules will be placed near of the ISS, enabling the service as a complementary test platform to the it and given the cargo resupply to ISS, crafts could also deliver the StarLab clients payloads (Smith *et al.*, 2021)

Blue Origin in a partnership with Sierra Space, have announced plans to deploy a commercial space station Orbital Reef in LEO. Like the other two projects, this station aims to provide the right conditions to researchers, manufacturers, and visitors. It is expected to be operational by 2027 and it will be launched on board of Blue Origin's New Glen (Williams & Mosher, 2022).

2.2.3. Rocketry 101

Rocket science is tendentiously often referred as a dreadful and tough science. Its complexity is a consequence of its multi-faceted affluence between different sciences and engineering disciplines (Chunna & Hai, 2020; Bhattacharjee & Roy, 2021).

In physics, a launch vehicle is a generator of Newton's third law – for every action there is an equal and opposite reaction. Concisely, the technology used today in launch vehicles are based in chemical rockets, which are propelled typically by a combustion engine, producing thrust by expelling mass. This type of vehicle is used to transport and deliver a given mass or payload to a given location – suborbital, orbital, or interplanetary (Taylor, 2017; Hempzell, 2021).

Following the typical system hierarchy, a launch vehicle is a major element of the space launch system (AIAA, 2012). The launch system, aggregates besides the vehicle itself, all the interrelated infrastructures required to achieve the common goal of delivering the payload in the desired location. This includes the ground facilities, the vehicle himself, and all the processes involved, like assembly, testing, and launching. On another had the launch vehicle is composed by diverse parts and by complex subsystems, which can incarnate different configurations and aspects (American Institute of Aeronautics and Astronautics, 2012; Kosiakoff *et al.*, 2020). Nevertheless, has it will be described next, it can be majorated into four major, structural, payload, guidance, and propulsion (Pillai, 2022).

2.2.3.1. Structural

The structure of a rocket act like a fuselage, by supporting and carrying all the rocket components. Besides the role of protection of all the subsystems including the payload (protected by what is called as fairing) in extreme conditions, the structure also provides stabilization to the rocket during its journey by recurring to fins. Some structures can assume the shape of a plane, like NASA's Shuttle. Others can assume vertical cylindrical shapes. Either way the structure itself can be separated in various sections or stages (Taylor, 2017; Chunna & Hai, 2020).

Staging is the process of separating multiple sections of the launch vehicle. It has the primary goal to release weight along the itinerary. Each section has their own propellant tanks and engine(s), therefore the stages are released since the propellants on those are consumed, achieving a better performance. The vehicle stages can be arranged in a serial or parallel configuration. In serial staging the stages are stacked on top of each other. They will burn

sequentially from bottom to top (Koch, 2019). On parallel staging, some boosters are strapped on to the core vehicle that carries the payloads, representing the lower stages. Example of this was the Space Shuttle SRB's as previously described (Curtis, 2020; Pedro *et al.*, 2022).

2.2.3.2. Propulsion

Propulsion is one of the main roots for differences between rockets. The traditional forms of propulsion are based on chemical combustion like solid, liquid and hybrid engines. With these forms, propellant (fuel and oxidizer) tanks are what most mass represents in launch vehicles, assuming several different physical stages, as previously seen, given the exact propellants and/or propulsion methodology. These are broadly used, specially to escape earth's gravity. Nevertheless, there are several different alternatives, particularly for in space propulsion such as, among others, pressure fed, electric, solar, nuclear, laser, and antimatter propulsion. All of them have the intention to expel a mass faster as possible (Taylor, 2017; Curtis, 2020).

Following there will be a brief description of what characterizes the different rocket engines and engine concepts (Taylor, 2017; Heister *et al.*, 2019).

2.2.3.2.1. Solid Rocket Engines

The roots of the main materials used on this type of rockets, can be dated to the use of the black powder. Nevertheless, solid rocket motors or SRMs are a common type of rockets engines still used today. They also are often called among the community as solid rocket booster (SRBs) when the intention is to refer to the entire sub system, being also a heritage from the Space Shuttle in which it was used two of them strapped to the central tank acting as auxiliary boosters. Nevertheless, nowadays "booster" can be used to describe any of the lower stages independently the type of engine that they use (Taylor, 2017; Rohini *et al.*, 2022).

This type of rocket engine is characterized by its the mixture of propellants in a solid form (known as the grain), protected by a case that can take many shapes and forms (Heister *et al.*, 2019). Once ignited, it cannot be stopped until it consumes all the propellants. Because it has few moving parts, and due to its high fuel density, it is relatively simple and inexpensive machine to operate, when compared with the alternatives. Still, its manufacturing process is very risky since any spark can ignite all the grain, and besides given its lack of throttle control and low efficiency, the use of liquid engines is sometimes preferable (Taylor, 2017; Mason & Roland, 2019).

2.2.3.2.2. Liquid Rocket Engines

Also oftentimes called simply as rocket engine, is the most used type of rocket engine. In this type of rocket engines, the propellants are reserved in the liquid state, each one in a separated tank, and pumped into the combustion chamber where they are mixed, and combustion occurs (Taylor, 2017). There are two predominant ways of flowing liquid propellant to the combustion chamber, open cycle and closed cycle:

2.2.3.2.2.1. Open Cycle

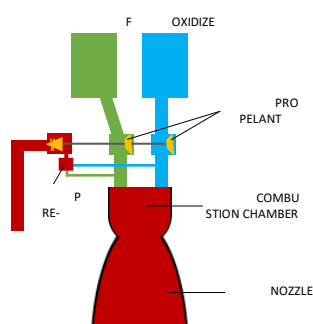
In this cycle, also known as gas-generator cycle, the propellants are released into a pre-burner and exhausted without passing through the combustion chamber. This flow will rotate a turbine which, consequently, will rotate the propellants pumps, taking the fuel and oxidizer into the combustion chamber, and expel them through the nozzle. Example of this was the Saturn V's F-1 engine and is Falcon 9's Merlin (Heister *et al.*, 2019) .

2.2.3.2.2.2. Closed Cycle

This cycle is characterized by the inexistence of propellant waste, but the fuel or/and oxidizer flow in a rich form, which is pre-burned and send it to the combustion chamber. Examples are the RD 180 used in Atlas 5 (fuel rich) and the SpaceX Starship full flow Raptor engine (enrich both fuel and oxidizer) (Heister *et al.*, 2019; Cha *et al.*, 2019; Seedhouse, 2022).

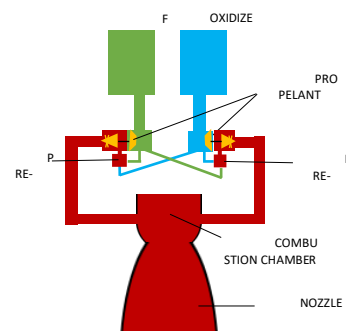
As a summary of their differences, in the Figure 6 and Figure 7, it can be seen a general overview of both predominant types of liquid propelled rocket engines.

Figure 6 – Simplified overview of a close cycle Gas-generator cycle engine



Font: Created by the author, based on (Kwak *et al.*, 2018)

Figure 7 – Simplified overview of a full flow closed cycle engine



Font: Created by the author, based on (Sergio Pérez-Roca *et al.*, 2019)

Given the existing throttling control and steerability, liquid rocket engines offer high versatility when compared with other types of rocket engine. It is therefore, used in different phases in the space vehicles transportation trajectory, that is to escape earth gravity, or in galactic voyages. However, is more complex and henceforth expensive, nevertheless as will be discussed further in this paper, reusability can dramatically help to decrease its cost in the future (Taylor, 2017; Li *et al.*, 2021).

2.2.3.2.3. Hybrid Rocket Engines

The hybrid rocket engines mechanism is essentially a merge between solid and liquid rocket engines characteristics. Specifically, this engine uses a solidified fuel and flows oxidizer in liquid or gas state, stored in through the perforation in the solid fuel. An untypical version of this engine is the reverse hybrid in which the oxidizer is on solid form and the fuel in liquid or gas. Hybrid engines attempt to grasp the liquid and solid engines advantages, since it has thrust and steering controllability, and when compared with liquid engines at lesser complexity and lower cost. Example of this engines are the RocketMotorTwo from Virgin Galactic's SpaceShipTwo, and Dream Chaser engine (Okninski *et al.*, 2021; Hashmi *et al.*, 2022).

2.2.3.2.4. Pressure Fed Rockets Engines

The key principle in this type of rocket engine, is that the tank pressure is higher than the surrounding environment. The propellant is expelled since the pressure moves high to low. The state of this propellant is used in cold gas, monopropellant, and bipropellant pressure fed engines. Given their simplicity, reliability, and the capacity for quick activation and deactivation, they are typically applied to reaction control systems (manoeuvring and direction). It has hence, an important role in refine space manoeuvring, for tasks like coupling and trajectory orientation (Bhattacharjee & Roy, 2021).

2.2.3.2.5. Other Rocket Engines

As previously mentioned, the types of rocket engines stated before, are the ones usually used to escape earth gravity. Nevertheless, is not too much to note that this can be changed in the future. Next there it will be designated the types which are mainly used and developed for transportation in space, followed by some concepts that are not still an operational reality today (Heister *et al.*, 2019).

2.2.3.2.5.1. Electric

There are two common variations of these engines, the arcjet and electrothermal thruster (ion thruster). The first uses electric energy to heat a gas, which is then expelled to generate thrust. The second uses the electricity to heat a conductive fluid, such as a liquid metal, which will ionize and hence produce ions, that therefore are accelerated by an electric field and expelled to create thrust (Heister *et al.*, 2019; Pelton, 2019).

This type of propulsion is highly efficient and has the capability to enable a complementation with other technologies to act as energy source producers, through solar (or nuclear, for instance). Nevertheless, it requires a great amount of energy and deliver a very small thrust force. For that reason, these engines are used for satellite manoeuvring and interplanetary travel (Heister *et al.*, 2019).

2.2.3.2.5.2. Nuclear

Nuclear rocket technology (provided by the fission or fusion of the nucleoids) can be used in two categories. *Nuclear electric rocket*, which produce electricity in order to produce thrust through electric rocket principles, as previously referred. This is one of the most promising technologies for future interplanetary transportation (Morrison, 2021). The second category is *nuclear thermal rocket* (NTR), a concept proposed since the beginning of the space race. In this category, a certain fluid is reserved in a tank, pumped through a high temperature nuclear reactor, and expelled as hot gas (Heister *et al.*, 2019; Graham, 2021).

2.2.3.2.5.3. Solar

As the name suggest, this type of propulsion, uses solar energy as a power source. One relatively matured technology is the *solar electric propulsion* (SEP). As mention before, solar technology can be used to produce electricity, hence enabling electric propulsion (Takao *et al.*, 2021). Moreover, there are other concepts, like *solar sail* and *solar heating* that can use the solar technology. The first consists in using the sunlight photonic momentum to generate propulsion. The photons are captured by a large sail, converting it in momentum to propel a very light spacecraft. Example of experiences using this technology are the Japanese Space Agency (JAXA) IKAROS, and Planetary Society's LightSail (Pelton, 2019). The second concept involves focusing the solar energy through mirrors to heat a given fluid to high temperature, which is thereafter exhausted at high speed (Heister *et al.*, 2019).

2.2.3.2.5.4. Antimatter

Antimatter rocket engine is a concept that has been theoretical proved. It has been discovered in 2018 that antimatter is theoretically the highest energy dense fuel (Semyonov, 2018). The engine comes from the principle that when antimatter comes into contact with matter, it releases vast amounts of energy. The main issue with this concept is given the lack of knowledge regarding antimatter properties, which constrain our technical understand, on how to contain or manufacture antimatter for instance (Heister *et al.*, 2019; Lafleur, 2022).

2.2.3.3. Guidance Navigation and Control

Guidance Navigation and Control (GNC) is what enables the vehicle to orientate himself to the desired destination, including control his own route. Incorporates diverse sensors, computers, actuators, within its systems like the attitude control system (ACS) and the previous described reaction control systems, to promote stability and trajectory precision (Pillai, 2022).

Mission destinations can vary, however there are some earth orbital ranges commonly used. It is important to note that there isn't a clear line where earth atmosphere ends and space begins, though it is often to use the Karman line as a reference to define the border - space starts at an altitude of 100 kilometres (km) (Hempsell, 2021).

- Low Earth orbit (LEO) – less than 2000 km of altitude (Nazarenko & Usovik, 2022);
- Medium Earth orbit (MEO) – around 10000 km of altitude (Kikuchi *et al.*, 2017);
- Geosynchronous equatorial orbit (GEO) – a orbit with about 36000 km of altitude (Capuano *et al.*, 2017);
- Transfer orbits – Is a temporary of orbit used to reach an higher desired orbit. Example of this is Geotransfer orbit (GTO) (around the same altitude as MEO) which is used to reach GEO (Skog *et al.*, 2019);
- Polar orbit – It's a specific orbit that passes over Earth's poles (Chatzopoulos-Vouzoglanis *et al.*, 2023);
- Sun-Synchronous Orbit (SSO)– A orbit that enables satellites or a given object to pass over the same Earth's location at the same local solar time, usually between a altitude of 600 km to 800 km (Kikuchi *et al.*, 2017).

2.2.3.4. Payload

A rocket is built in consequence of the need to transport a payload. It is the means to accomplish the intended mission, that could be to deliver, satellites, humans, nuclear warheads, or other objects, on a given location (Taylor, 2017).

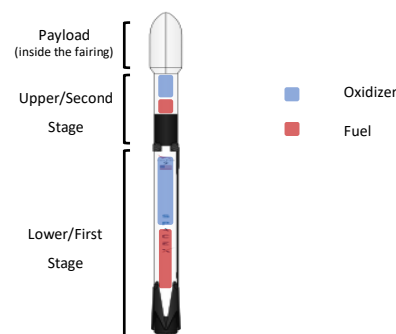
Orbital launch vehicles can be classified according with their payload lift capacity. This classification can change according with the agency who classifies. Nevertheless, the classification conferring with NASA, divides launch vehicles in five categories depending on the payload capacity to LEO:

- Small – vehicles capable of delivering less than 2 000 kg (Zheng *et al.*, 2020);
- Medium – vehicles with payload capacity between 2 000 kg and 20 000 kg (Mowry & Grasso, 2020);
- Heavy – Capability of carrying between 20 000 kg and 50 000 kg (Mowry & Grasso, 2020);
- Super Heavy – Capability of carrying more than 50 000 kg (McConnaughe *et al.*, 2012; Mowry & Grasso, 2020).

2.2.3.5. Debriefing

Taking the below example of a Falcon 9 rocket in the Figure 8, we can identify some of concepts previously mentioned. Falcon 9 is divided in two stages, both propelled by liquid rocket engine (Merlin engine). The lower stage or the first stage usually does the heavy duty of caring the vehicle until high atmosphere, and because of this usually represents the biggest section of the rocket. The upper stage is the last stage of the launch vehicle that will deliver the payload, (which in this case is also the second stage), hence it will do most of his work to achieve the desired orbit, placing the payload in the wanted trajectory.

Figure 8 – Example of a launch vehicle



Font: Adapted by the author – SpaceX's Falcon 9 rocket (Lucabon, 2018)

Overall, depending on what are the payload constraints, usually the best launch vehicle means being the one that maximizes reliability, while minimizing costs (Morgado *et al.*, 2022).

2.2.4. Space Transportation Industry

2.2.4.1. Overview

Space transportation incorporates all activities that involve the movement of payloads to, in, and from space. Nevertheless, the today's industry is mainly characterized by the launch of payloads into orbit, around Earth or any other celestial body (George, 2019; Hempzell, 2021).

Table 2 - Orbital launch attempts by country, from 2015 to 2022

	2015	2016	2017	2018	2019	2020	2021	2022
USA	20	22	29	31	21	37	45	69
Russia	26	17	19	17	22	12	16	21
China	19	22	18	39	34	39	56	64
Europe	12	11	11	11	9	10	15	6
South Korea	0	0	0	0	0	0	1	1
North Korea	0	1	0	0	0	0	0	0
India	5	7	5	7	6	2	2	5
Japan	4	4	7	6	2	4	3	1
Iran	1	0	0	0	2	2	2	1
Israel	0	1	0	0	0	1	0	0
New Zealand	0	0	1	3	6	7	6	18
TOTAL	87	85	90	114	102	114	146	186

Font: Created by the author based on (Bryce Tech, 2023; McDowell, 2022; Carbajales-Dale & Murphy, 2023)

From the Table 2 it can be analysed that in 2022 there was 186 launch attempts into orbit. From those attempts, 86 of them were operated by states, 34 were state procured for commercial services, and 66 were conducted entirely by commercial entities (Bryce Tech, 2023). Worldwide, we can observe a clear increase in the number of launches, which have grown around 214% from 2015 until 2022. This general increase is mainly due to the USA market, and particularly SpaceX, which was responsible of 61 out of 69 launches in 2022. Nevertheless, this trend can somehow obfuscate some other individual markets trends. In 2015, Russia was the country hosted most attempts, leading with 26 launch attempts followed by USA (20) and China (19). However, the difficulties that the whole industry has been faced previously described, can also be reflected in the country's launch attempts (Aliberti & Lisitsyna, 2019). In 2022 Russia has been far surpassed by US and China, whose count with 69 and 64 launch attempts respectively, against the 21 attempts from Russia soil (McDowell, 2022).

The space industry as a whole is, as previously stated, enabled by the increase launch capabilities. The private presence particularly in space transportation was the driven force that has been enabling to achieve greater space assessability, by decreasing the launch costs to as low as 1500 dollars per kilogram (kg) in 2022 (for LEO), which from what can be observed on the table below, is less than the same cost NASA attained with their Space Shuttle Aircraft by a factor of more da 30 times, aligned with what Citibank reports (Sippel *et al.*, 2019; Citi GPS: Global Perspectives & Solutions, 2022; Nebylov *et al.*, 2022). In the Table 3 will be presented the various rockets active as of today (2023), some of them that contributed for the decreasing in launch costs.

Table 3 - Orbital class launch vehicles currently active

Organization	Ownership	Country	Launch Vehicle	Payload to LEO (Kg)	Launch cost	Cost/Kg (USD)
NASA	State	USA	Space Shuttle (Decomissioned)	27,500	1,500,000,000	54,545
SpaceX	Private	USA	Falcon 9 (Block 5)	15,600	28,200,000 (When reused)	1,808
SpaceX	Private	USA	Falcon Heavy (Block 5)	27,500	48,600,000 (When reused)	1,767
ULA	Private	USA	Delta IV Heavy	28,790	188,580,000	6,550
ULA	Private	USA	Atlas V 551	20,520	112,540,000	5,484
Northrup Grumman	Public	USA	Antares	8,000	100,000,000	12,500
Northrup Grumman	Public	USA	Minotaur C (Taurus)	1,458	47,099,232	32,304
Northrup Grumman	Public	USA	Minotaur I	580	40,000,280	68,966
Northrup Grumman	Public	USA	Minotaur IV	1,750	46,000,500	26,286
Northrup Grumman	Public	USA	Minotaur V	1,000	55,000,000	55,000
Northrup Grumman	Public	USA	Pegasus XL	468	39,999,960	85,470
RocketLab	Public	USA	Electron	225	4,900,050	21,778
GV Launch Services/ Starsem / Arianespace	Private	Russia	Soyuz-2.1a	7,020	79,999,920	11,396
GV Launch Services/ Starsem / Arianespace	Private	Russia	Soyuz-2.1b	7,800	76,096,800	9,756
TsSKB Progress	Private	Russia	Soyuz-2.1v	2,850	39,999,750	14,035
Khrunichev	Private	Russia	Angara 1.2	3,000	Not disclosed	-
Khrunichev	Private	Russia	Angara A5	24,500	129,997,000	5,306
ILS	Private	Russia	Proton M	23,000	85,160,000	3,703
Russian Navy	State	Russia	Shtil	140	2,200,000	15,714
MITT	State	Russia	Star-1	632	12,290,000	19,446
MITT	State	Russia	Strela	1,560	14,340,000	9,192
Russian Navy	State	Russia	Volna	140	1,570,000	11,214
SIS/Yuzhnoye	State	Russia	Zenit 3SL	7,300	115,770,000	15,859
ISC Kosmotras	State	Russia	Dnepr-1	4,500	11,000,000	2,444
ISRO	State	India	LVM3	10,000	30,020,000	3,002
ISRO	State	India	SSLV	500	4,400,000	8,800
ISRO	State	India	PSLV	3,700	18,250,000	4,932
ISRO	State	India	GSLV	5,000	42,580,000	8,516

KARI	State	South Korea	Nuri (KSLV-II)	2,600	Not disclosed	-
ISA	State	Israel	Shavit	800	20,490,000	25,613
Expace Technology	State	China	Kuaizhou	1,500	14,500,500	9,667
CASC	State	China	Jielong 1	200 (SSO)	6,000,000	30,000
CASC	State	China	Kaituozhe-2 (KT-2)	350	Not disclosed	-
CASC	State	China	Long March 2C	3,850	29,999,200	7,792
CASC	State	China	Long March 2D	3,500	29,998,500	8,571
CASC	State	China	Long March 2F	8,400	68,100,000	8,107
CASC	State	China	Long March 3A	8,500	69,997,500	8,235
CASC	State	China	Long March 3B	12,000	69,996,000	5,833
CASC	State	China	Long March 3C	12,000	69,996,000	5,833
CASC	State	China	Long March 4B	4,200	30,000,600	7,143
CASC	State	China	Long March 4C	4,200	30,000,600	7,143
CASC	State	China	Long March 5B	23,000	150,100,000	6,526
CASC	State	China	Long March 6	1,500	13,050,000	8,700
CASC	State	China	Long March 7A	13,500	87,450,000	6,478
CASC	State	China	Long March 11 (CZ 11)	700	6,090,000	8,700
iSpace	Private	China	Hyperbola - 1 (SQX-1S)	300	Not disclosed	-
LandSpace	Private	China	Zhuque-2	300	6,000,000	20,000
Galactic Energy	Private	China	Ceres-1	350	4,000,000	11,400
OneSpace	Private	China	OS-M1	250	3100000	15,000
Virgin Orbit	Private	USA	LauncherOne	500	10,000,000	20,000
Arianespace	Private	France	Vega	1,500	25,630,000	17,087
NEHSA	State	Iran	Qased	40	Not disclosed	-
NEHSA	State	Iran	Simorgh	250	Not disclosed	-
MHI Launch Services	Private	Japan	H2A 2025	11,730	103,410,000	8,816
MHI Launch Services	Private	Japan	H2B	16,500	142,420,000	8,632
MHI Launch Services	Private	Japan	Epsilon	1,200	38,000,000	31,667
Blue Origin	Private	USA	New Shepherd (Sub-Orbital)	6 (Persons)	Not disclosed	-
Virgin Galactic	Public	USA	Spaceship 2 (Sub-Orbital)	8 (Persons)	2,700,000	-

Font: Created by the author (all the references used can be found in Table 16)

From the analysis compressed in the table above, there are 55 orbital class launch vehicles active distributed across 27 organizations. Among them, 28 of those vehicles come from statal ownership, 19 are private belonging, and 8 from public transacted companies. Aggregating by country, China leads with 19, followed by USA and Russia both with 12. China is the country with most statal controlled launch vehicles (15 in total). The US is home SpaceX's Falcon Heavy, the rocket with lowest cost/kg ratio (when its three boosters are reused) (Tománek & Hospodka, 2018) Russia has the world's most reliable rocket family - Soyuz (Seedhouse, Spacecraft and Launch Vehicles, 2017; Uyanna & Najafi, 2020).

With the demand increase for delivering small satellites in orbit, various launch companies have been created to fulfil the need. Some of those satellites are carried in heavier launchers, though as a secondary payload, hence restricted to the trajectory of the primary payload. Given this restriction, some companies have been taking the opportunity to deliver space access through their small launch vehicles - vehicles capable of delivering less than 2 000 kg into LEO (Zheng *et al.*, 2020). Given that some costumers want to deliver their small satellites in a particular trajectory, with such launch providers it is possible to deliver the satellite into a particular orbit, by a relatively adjusted cost, when compared with the freight for the same requirement in heavier launch providers (Kulu, 2021; Niederstrasser, 2022). From the table above it is evident that there are already some providers addressing this niche. Following in Table 4, will be presented a table of orbital class launch vehicles currently in development, including the vehicles addressing small satellite niche.

Table 4 - Orbital class launch vehicles in development

Organization	Ownership	Country	Launch Vehicle	Payload to LEO (Kg)	Launch cost	Cost/Kg in USD
SpaceX	Private	USA	Starship	150,000	8,000,000 (When reused)	53
NASA	State	USA	Space Launch System	130,000	500,000,000	3,846
ULA	Private	USA	Vulcan	20,000	90,000,000	4,500
RocketLab	Public	USA	Neutron	8,000	Not announced	-
MHI Launch Services	Private	Japan	H3-24L	17,500	42,700,708 (190 billion Won)	2,440
Astra Space	Private	USA	Astra 4	600	3,950,000	6,583
Blue Origin	Private	USA	New Glenn	35000 (When reused)	Not announced	-
German Aerospace Centre	State	Germany	SpaceLiner	26,150	10,000,000 (Euros)	-
Boeing	Public	USA	X-37	227	Not disclosed	-
Sierra Nevada Corporation	Private	USA	Dream Chaser	5,500	Not announced	-
Firefly Aerospace	Private	USA	Alpha	1,000	15,000,000	15,000
ABL Space Systems	Private	USA	RS1	1200	12,000,000	10,000
TiSpace	Private	Taiwan	Hapith-V	390	Not announced	-
Galactic Energy	Private	China	Pallas	5,000	Not announced	-
HyImpulse	Private	Germany	SL1	500	4,100,000	8,200
Interstellar Technologies	Private	Japan	Zero	150 (SSO)	Not announced	-
MLS	Public	Canada	Cyclone-4M	3,700	45,000,000	12,162
RFA	Private	Germany	RFA One	1,300	3,600,000	2,769
Orienspace	Private	China	Gravity-1	6,500	Not announced	-
Orienspace	Private	China	Gravity-2	15,500	Not announced	-
Orienspace	Private	China	Gravity-3	30,600	Not announced	-
Relativity Space	Private	USA	Terran 1	1,250	12,000,000	9,600
Relativity Space	Private	USA	Terran R	20,000	Not announced	-
Phantom Space	Private	USA	Daytona	450	4,000,000	8,900
Perigee Aerospace	Private	South Korea	BlueWhale	50	1,000,000	20,000
Rocket Pi	Private	China	Darwin-1	2,200	Not announced	-

Orbex	Private	UK	Prime	180	Not announced	-
Roscosmos (JSC SRC Progress)	State	Russia	Irtys (Soyuz-5)	6,500	Not announced	-
Deep Blue Aerospace	Private	China	Nebula-1	500	Not announced	-
Isar Aerospace	Private	Germany	Spectrum	1,000	10000000 (Euros)	10,000
PLD Space	Private	Spain	Miura 5	300	14,000,000	47,000
Gilmour Space	Private	Australia	Eris	380	Not announced	-
Agnikul Cosmos	Private	India	Agnibaan	100	1,000,000	10,000
Roscosmos	State	Russia	Amur	10,500	20,000,000	1,905
Arianespace	Private	France	Ariane 62	10,300	80,000,000	7,767
Arianespace	Private	France	Ariane 64	21,600	130,000,000 (Euros)	6,019
ARCA Space Corporation	Private	USA	Haas 2CA	100	1,400,000	14,000
Aevum	Private	USA	Ravn X	100	5,000,000	50,000
Aphelion Aerospace	Public	USA	Helios	20	750,000	-
B2Space	Private	UK	Colibri	200	Not announced	-
Bagaveev Corporation	Private	USA	Bagaveev	12	1,200,000	100,000
Bellatrix Aerospace	Private	India	Chetak	150 (\$SO)	1,999,950	13,333
Black Arrow Space Technologies	Private	UK	Black Arrow-2	500	6,600,000	13,200
bluShift Aerospace	Private	USA	Red Dwarf 50	50	1,300,000	25,000
C6 Launch Systems	Private	Canada	C6	100 (\$SO)	Not announced	-
Comisión Nacional de Actividades Espaciales	State	Argentina	Tronador II	300	Not announced	-
CubeCab	Private	USA	Cab-3A	5	300,000	50,000
Dawn Aerospace	Private	Netherlands/New Zeland	Mk-3	150	Not announced	-
Departamento de Ciência e Tecnologia Aeroespacial	State	Brazil	VLM-1	150	10,000,000	66,700
Equatorial Space Industries	Private	Singapore	Volans Block I	150	1,000,000	6,667
ESA	State	Europe	Space Rider	800	32,000,000	40,000
Gilmour Space Technologies	Private	Australia/Singapore	Eris-S	305	4,100,000	23,000
Gloyer-Taylor Laboratories	Private	USA	ACE	100	900,000	6,000
Independence-X Aerospace	Private	Malaysia	DNLV	200	4,500,000	22,500
Innovative Rocket Technologies (iRocket)	Private	USA	Shockwave	150 (\$SO)	Not announced	-
Interorbital Systems	Private	USA	Neptune N1	8	300,000	39,700
Launcher Space	Private	USA	Launcher Light	150	10,000,000	66,700
LEO Launcher	Private	USA	Chariot	681	Not announced	-
Linkspace Aerospace Technology Group	Private	China	NewLine-1	202	4,300,000	21,300
Orbital Access	Private	UK	Orbital 500R	500	15,000,000	30,000
Pangea Aerospace	Private	Spain	Meso	150	3,000,000 (Euros)	20,000 (Euros)
Pythom	Private	USA	Eiger	150	1,500,000	10,000
RocketStar	Private	USA	Starlord	300	6,000,000	20,000
Skyroot Aerospace	Private	India	Vikram I	480	Not announced	-
Skyroot Aerospace	Private	India	Vikram II	595	Not announced	-
Skyroot Aerospace	Private	India	Vikram III	815	Not announced	-
Skyrora	Private	UK/Ukraine	Skyrora XL	315	7,245,000 (Pounds)	23,000 (Pounds)

SpinLaunch	Private	USA	SpinLaunch	100	500,000	5,000
STAR Orbitals	Private	India	Phoenix	150	Not announced	-
TiSpace	Private	Taiwan	HAPITH V	390	Not announced	-
TLON Space	Private	Argentina	Aventura 1	10	100,000	2,000
Vaya Space	Private	USA	Dauntless	500	Not announced	-
Latitude	Private	France	Zephyr	100	Not announced	-
X-bow	Private	USA	X-bow	Not announced	Not announced	-
Calestia Aerospace	Private	Spain	Sagittarius Space Arrow CM	16	Not announced	-
DARPA	State	USA	ALASA	45.4	1,000,000	22,026

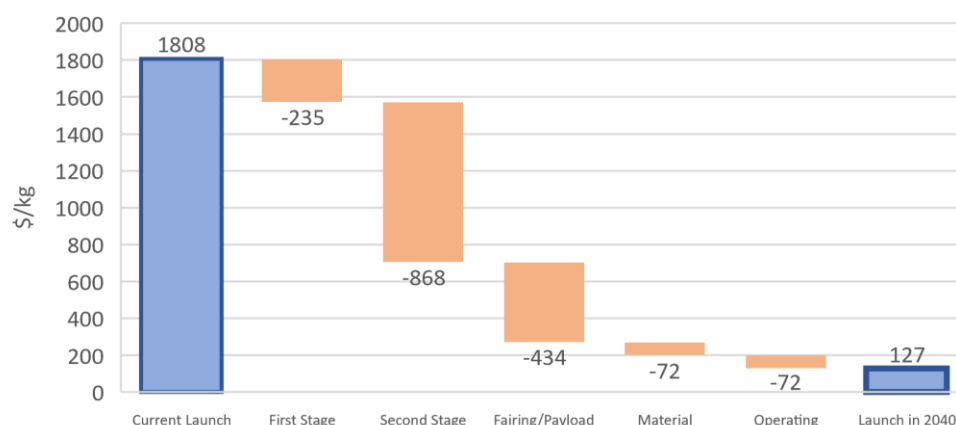
Font: Created by the author (all the references used can be found at Table 16)

Distributed along 69 organizations, there are currently in development 76 orbital launch vehicles. Regarding their organizational ownership, 64 of these vehicles have private origin, 8 state owned and 4 public transacted companies. These organizations are dispersed across 23 countries/regions (including 4 partnerships), in which USA ranks the highest with 30 based, followed by 14 in European countries, 7 Chinese, and 6 in Indian soil.

2.2.4.2. Lower Costs

There are still many reasons to believe that launch costs will go even lower. Evidently, there is still more room to improve first stage reusability alone. But not only that will drive the costs even more downwards (Jones, 2018; Nebylov *et al.*, 2022).

Figure 9 – Projecting the variation of the cost of launching one kilogram to LEO, from 2022 to 2040 (values in USD)



Font: Adapted from (Citi GPS: Global Perspectives & Solutions, 2022)

According with Citi Bank (2022) a combination of diverse measures (observed in the Figure 9), can decrease the launch costs around 95% 100 USD per kilogram to LEO in 2040 or to as low as 30 USD in a bullish scenario. Still, Elon Musk goes even far and propose 10 USD per pound (approximately 0.45 Kg) by 2025 (Sippel *et al.*, 2019). The main characteristics enabling this to

be possible will be according with Citi Bank the increase the second stage reusability and the reusability of the payload. Both can be connected if design reuses the hole upper stage, similarly to what theoretically would happen with the Space Shuttle (Jones, 2018; Citi GPS: Global Perspectives & Solutions, 2022).

Behind the recent decrease of costs there was essentially, technical, and institutional constrains from which the commercial approaches have preceded. Moreover, the increase in private presence and consequence decrease in launch costs, suggests that the institutional barriers were constraining potential technical improvements. Following there will be a description of some of the major changes in space transportation industry that have been enabling to decrease costs but also that are behind the potential decrease presented before – institutional arrangement, materials choice, and reusability (Jones, 2018; Citi GPS: Global Perspectives & Solutions, 2022).

2.2.4.2.1. Institutional Arrangement

From using different production and organizational approaches, the private institutional arrangement has enabled the technical breakthroughs. A common approach from the private entities to reduce production costs, is by the increasing the vertical integration. The production of launch vehicles typically demands a very complex supply chain, given among others, its length or the design relation complexity, which is translated in cost and time. Example of that was NASA's Space Shuttle, which was initially designed to be a reusable vehicle, projected to decrease the launch cost per kg to LEO. However, due to its development complexity, the expectations were shorted lived - it integrated more than 10000 contractors and 1000 civil services. The operational intricacy and the deep supply chain was just some of the other contributors to lay down the economical premise. In 2010, NASA predicted how much would have cost them to develop Falcon 9, taking their traditional models. The results showed that for developing the launch vehicle it would cost around 1383 million USD, while SpaceX's costs were estimated around 443 million USD, 68% less. The main reasons appointed for such difference were a smaller workforce, hence fewer management layers, higher vertical integration, by producing many components in-house, less infrastructure, and commercial development culture (Jones, 2018).

To address the complexities that come from the supply chain some rocket manufacturers have been recurring also to different materials and production techniques. 3d printing technology have been also used recently by some companies to produce some of the components in house, others took different approaches and decide to create entire launch

vehicles relying only on 3d printing technology. Example of that is the Relativity Space's Terran 1 launch vehicle (Xiong, 2020; Kuntanapreeda, 2021; Niederstrasser C. , 2021).

2.2.4.2.2. Materials

Materials choice has been an essential key feature to enable weight loss and reusability. Traditionally, aluminium-titanium alloys along with kerosene-fuelled engines have been used across industry. These are chosen because they can maximize reliability while minimizing weight. Nevertheless, new materials such as stainless steel, carbon composites, and methane-fuelled engines are some new entrants to the industry, enabling reusability and specially affordability (Citi GPS: Global Perspectives & Solutions, 2022; Tiwary *et al.*, 2022).

Stainless steel has some disadvantages when compared with other alloys such as aluminium-titanium or carbon composites. The big relative disadvantage is the lower strength/weight ratio. However, its higher thermal resistance offers a new set of reusability and affordability opportunities. The first one is given its higher operation temperature, more extirpation from protective materials for atmospheric re-entry. Secondly, the higher thermal resistance means less energy transfer from storing of the cold propellants. Finally, its cost is around 65% cheaper than aluminium-titanium alloys and around 95% less than carbon composites (Henson, 2019; Citi GPS: Global Perspectives & Solutions, 2022). One example of vehicle in development that will enforce this material is SpaceX's Starship (Seedhouse, 2022).

Carbon composites offer some advantages compared to the alternatives. It has a higher strength/weight ratio and higher operating temperatures. Nevertheless, the epoxy resins that constitute these composites, are unable to resist to atmospheric re-entries temperatures. Besides the falling of costs in recent years, and the ongoing research it is still far from being affordable when compared with the alternatives (Citi GPS: Global Perspectives & Solutions, 2022; Niederstrasser C. G., 2022; Tiwary *et al.*, 2022). Example of launch vehicle that mainly uses this material is Rocket Lab's Electron (Xiong, 2020; Werken *et al.*, 2020).

Methane a fuel that has its own advantages and disadvantages when compared with the alternatives. It is easier to use than hydrogen but harder than kerosene (RP-1). However, it is more energy denser than kerosene but less than hydrogen. Moreover, when compared with kerosene it is more affordable and it produces a cleaner exhaust gas, which is something that creates more reusability opportunities. Comparing with both alternatives it is easier to extract and refine in space enabling even a possible production and propellant resupply on Mars (Salotti, 2022). Example of engine that uses methane as fuel is the Starship's full flow Raptor engine (Seedhouse, 2022).

2.2.4.2.3. Reusability

As previously stated, rocket reusability is something that it's not new. The Space Shuttle or the Russian Buran, were designed to be both reusable, leveraging the architecture of the airplane to bring the spaceship back to earth (Astorg, 2017; Baiocco, 2021). Today there are private entities that achieved major reusability breakthroughs with their space planes but also on their vertical rocket's lower stages and fairings reusability. On space planes, example are the Virgin Orbit SpaceShipTwo and the Boeing X-37 (Gorn & Chiara, 2021; Leslie, 2022). On vertical rockets examples of such come from Elon Musk's SpaceX, Peter Beck's Rocket Lab or Jeff Bezos's Blue Origin. SpaceX's Falcon 9 rocket is capable of landing in solid ground or off the coast in an autonomous ship platform, Rocket Lab's Electron rocket first stage parachutes slowly into the ocean, and Blue Origin's New Shepard can land in solid ground (Stappert *et al.*, 2019; Bailey, 2020; Rutishauser *et al.*, 2021; Nebylov *et al.*, 2022).

Several rockets have been proposed to be capable to achieve fully vehicle reusability somewhere in the future. Among others, SpaceX's Starship (Carbajales-Dale & Murphy, 2023), Rocket Lab's Neutron (Sun, 2022), and German Aerospace Centre's (DLR) SpaceLiner (Sippel *et al.*, 2019).

2.3. Intelligent Systems in Space Transportation Industry

As mentioned before, the complexity of rocket science and aerospace systems are given by their interdisciplinary nature. Hence the industry offers a wide range of areas where intelligent systems can be applied, on space robotics, designs, communications, etc. Nevertheless, the industry dynamics such as the pursue for maximum reliability and accuracy can create reluctance to the applicability of some technologies as AI (Weinzierl, 2018; Tom Eelbode, 2021). Even though the traditional industry conservatism approach, with the development of the technology and with the growth of the *New Space* approach, it can infer more space and new opportunities for the application of such technologies (Bousedra, 2023).

2.3.1. State of the art

One of the shining points of intelligent systems and AI in particular, is the capability to analyse large amounts of data. Presently, one huge challenge facing space explorations is not reaching unsettled places but manage and analyse the data generated from space missions. All the satellites, spacecrafts, and other systems can generate vast amounts of data during their life

from telemetry, censoring and imagery. Yet, the sheer volume and complexity of this data can be overwhelming for human operators to process and comprehend in a timely manner. AI-powered systems can relatively quickly sift through these massive datasets, identify its patterns, and trends that might be imperceptible to human analysts. These insights have the potential to enhancing the efficiency and overall success of space transportation endeavours (Girimonte & Izzo, 2007; Oche *et al.*, 2021).

The use of intelligent systems in space has been integrated in several areas of space systems (Tipaldi *et al.*, 2020). Rovers and satellites imagery for example rely heavily on the AI Computer Vision capabilities to analyse and operate in their routinely tasks. A radio signal takes around twenty-two minutes to travel from Earth to Mars (depending on where they are in their respective orbits), hence it would be completely unfeasible to live control a rover on Mars while its operator is on Earth (Masahiro Ono, 2022; Heckel, 2023).

Nonetheless to what concerns transportation, there are some areas such as Guidance, Navigation, and Control (GNC), spacecraft health monitoring, design, and planning (Zhuang *et al.*, 2020) (Heckel, 2023).

2.3.1.1. Guidance, Navigation, and Control

GNC are a set of systems that represents a pivotal domain where intelligent systems are actively driving progress. Guidance provides the desired trajectories of the spacecraft, navigation accesses the current state and positioning, and control executes the commands necessary to navigate in accordance with guidance instructions. According with ESA, GNC systems play a vital role in computing and fine-tuning the spacecraft's most advantageous path throughout its mission, as they assimilate critical parameters including positioning, velocity, and angular rates, ensuring the optimal trajectory adjustments at every mission stage (Heckel, 2023). However, these measurements are susceptible to diverse forms of noise, necessitating the integration of estimation algorithms to effectively account for these perturbations. When used, AI algorithms (and in particularly *Neural Networks*) can optimize the desired trajectory not only by analysing the sensory data but also by being integrated in the estimation of potential data perturbations (Habib, 2022).

Some spacecrafts by recurring to intelligent systems, can autonomously adjust their trajectory at any point of their mission, for situations such as non-catastrophic propulsion failures (for example the loss of one or more engines) or other flight anomalies (Feng *et al.*, 2020).

Recent advances in intelligent GNC systems have enabled remarkable achievements in earth-to-orbit operations. As previously stated, the first stage of SpaceX's Falcon 9 (and Falcon Heavy) can perform autonomous manoeuvring, re-entry, controlled descent, and landing on a designated target with a success rate of over 80% (and rising) (Jo & Ahn, 2022; Heckel, 2023).

2.3.1.2. Spacecraft Health Monitoring

Spacecraft health monitoring concerns all the technical diagnosis during the lifespan of the spacecraft, and it is another significant domain where intelligent systems can be acknowledged. As mentioned before, safety and reliability are two of the most crucial concerns of the space transportation industry. Today, intelligent systems are extensively utilized for spacecraft maintenance and troubleshooting purposes. For instance, by detecting during flight occurrences of component degradation or by detecting any other onboard anomaly, the spacecraft can trigger a safe mode, allowing ground operations can handle with the issue manually. On another hand it can perform a troubleshoot sequence automatically, and providing suggestions for adjustments and repairs, leading to minimum ground intervention (Tipaldi *et al.*, 2020; Habib, 2022; Heckel, 2023).

AI again as also a role before launch, as some methods can run autonomously fault diagnosis, capable of detecting technical faults before launch, avoiding risks – often called as unmanned intelligent launch control (Feng *et al.*, 2020).

2.3.1.3. Design and Planning

Intelligent systems are not only applied to the operation and control of spacecrafts or launch vehicles, but also to their design and planning processes. For example, NN, genetic algorithms, and fuzzy logic can be used to optimize the shape, structure, and performance of the spacecraft or launch vehicle. Moreover, intelligent systems can help to plan the mission objectives, trajectories, and manoeuvres, taking into account the constraints and uncertainties of the space environment. Example of just that is the use of a rule based expert system as a design engineering assistant, which gave essentially a better accessibility to access knowledge from past experiences, reports, publications, etc (Girimonte & Izzo, 2007; Berquand *et al.*, 2019).

2.3.2. Future perspectives

There are various ongoing and future projects that aim to leverage and expand on the AI capabilities in space transportation domain. Most of them come as substitutes for existing

methods, enabling better accuracy and robustness to the overall systems functions. Others will come from developments in adjacent areas that may impact the space transportation industry (Zhang Z. *et al.*, 2023).

GNC is not only an area where intelligent systems can be already observed. There are several new applications proposals, particularly with recurrence to AI. Autonomous entry or re-entry, and landing on Earth can be hard, but it is possible. However, the same doesn't apply to every other celestial body, given the relative difficulty in acquiring data, landing on their surfaces without human intervention presents a whole new range of challenges. Nevertheless, there are already some proposals to achieve this by relying on intelligent systems (Jiang *et al.*, 2019; Viola *et al.*, 2020; Paolo Lunghi, 2022; Chekakta *et al.*, 2022; Yao *et al.*, 2023; Chase *et al.*, 2023). Another proposed application is regarding GPS positioning. guidance systems that rely in such technology can be passive to outages periods, hence NN methods can be used to mitigate gaps by estimating the velocity and position errors during those timespans (Sabbagh *et al.*, 2023).

Some of the spacecraft health monitoring proposals includes leveraging on NNs for new fault detection, and injector calibration methods in liquid propellant rocket engines (Chandra *et al.*, 2022; Zhang Z. *et al.*, 2023).

The future of design in space transportation is set to have bigger presence of intelligent systems. Also, as the use of intelligent systems increases its presence in other complementary domains such as the design of new materials, which could impact significantly in future spacecrafts shielding capabilities and overall performance (Smirnov, 2020). Meanwhile, some techniques using NN, have been proposed to find optimal solutions to create better integration in the space transportations subsystems (Berquand *et al.*, 2019; Soon-Young Park, 2020).

Chapter 3 – Methodological Approach

Following the literature review conducted in the preceding chapter, and the insights gathered from the analysis of intelligent systems and the space transportation industry, four distinct research questions have been created. These questions serve as the foundation upon which the following study is conducted, leaning to a deeper understanding of the subject matter.

In the exploration of the first point in literature review, on intelligent systems, various technologies emerged, with a notable emphasis on AI. Furthermore, it was pointed the evident the pervasive use of AI and ML terminologies in contemporary discourse (Collins *et al.*, 2021; Melley & Sataloff, 2022). Additionally, during the examination of the point dedicated to “Intelligent Systems in the Space Transportation Industry” underscored the substantial presence of ML technology in discussions concerning the role of intelligent systems in this industry (Girimonte & Izzo, 2007; Oche *et al.*, 2021; Habib, 2022). Nevertheless, it remains uncertain whether this prominence is primarily driven by the buzzword phenomenon also within the literature or is genuinely rooted in the technological capabilities themselves. Therefore, it is important to understand if intelligent systems are present in the industry and how can we encounter them. This leads to pose the initial question: **RQ1) What intelligent systems can we observe in space transportation?**

Throughout the literature review on the second point, which portrays the space transportation industry, it has been discerned a notable evolution in its fundamental principles. Historically, this industry has been anchored in the pursuit of high reliability and precision, as elucidated by Jo and Ahn (2022). However, this paradigm has undergone a significant transformation with the emergence of private entities and the advent of the *New Space* era (Weinzierl, 2018; Brukardt *et al.*, 2022). In today's landscape, the risks associated with Intelligent systems, particularly in the context of their future advancements, have gained unprecedented prominence. This shift emphasizes a pressing need for addressing a range of technological challenges already confronting intelligent systems (Breda *et al.*, 2023). Given the industry dynamics, it remains uncertain to what extent intelligent system technologies impact the space transportation as a whole. Consequently, our second research question arises: **RQ2) What are the major impacts of using intelligent systems in space transportation?**

As highlighter in the second point of the literature review, the significance of achieving lower space transportation costs extends far beyond mere significance. Affordable space access, and in particular, the reduction of launch costs, stands as the pivotal factor for nurturing the expansion of the space economy (Jones, 2018; Nebylov *et al.*, 2022).

Despite the potential to identify several prospective applications for intelligent systems in the future in the space transportation industry, as discussed in the third point of the literature review, the extent of their influence on space transportation costs remains unclear. Consequently, the third research question: **RQ3) How can intelligent systems help reduce space transportation costs?**

As mentioned previously, intelligent systems and AI have undergone significant technological advancements in recent years, leading to their widespread adoption across various industries (Collins *et al.*, 2021). Nevertheless, their future trajectory development is anything but far from being a mere replication of the present technologies. The availability of improved computing capabilities and a wealth of high-quality data is creating a fertile environment for scaling machine learning, especially deep learning models (El-Seoud *et al.*, 2017; Melo *et al.*, 2022). With the emergence of larger and powerful models, it can be anticipated solutions to solve numerous problems, yet not without ushering in a new set of challenges.

Simultaneously, space transportation field, as previously mentioned, has experienced its own transformative shifts. Given the evolving landscapes of both intelligent systems and space transportation, and the elevated expectations associated with them, it becomes imperative to comprehend the entangled future of these domains amid the prevailing noise and hype. Therefore, the fourth and final question of this research: **RQ4) What is the role of intelligent systems in the future of space transportation?**

Chapter 4 – Methodology

In this chapter it will going to be expressed the research methodologies used to conduct the research on this thesis and their justifications. Moreover, it will be described the characteristics of the data sample gathered during the construction of primary data sources.

4.1 Research Methodology

Research involves “a scientific and systematic search for pertinent information on a specific topic” (Kothari, 2004). It is seen by some as a purposeful and meaningful path for discovery. Moreover, research is based on empirical evidence, data or information that can be observed, measured, or verified by using appropriate methods (Song D.-W. , 2021). To conduct the research, it is fundamental to develop a research problem that may be identified by a gap in scientific literature (Kothari, 2004).

In line with the previously discussed limitations of the existing literature, this work is confined to a specific scope. The literature reviewed fails to provide an all-encompassing understanding of the ongoing practices in the industry or practical insights into the broader integration of intelligent system technologies. Consequently, this study adopts an exploratory research approach, as the topic has not yet been comprehensively understood or defined.

In response to the identified gap, the primary objective of this research is to "Understand the contribution of intelligent systems in space transportation." This objective is designed to address the aforementioned limitations and delve into the role of intelligent systems within the context of space transportation.

To comprehensively examine this phenomenon, the research employed a research model divided in three key parts, encompassing both primary and secondary sources of information.

The initial part involved researching and processing secondary sources of information from the available literature on the topic. The information derived from these secondary sources, were analysed, and discussed in the second chapter of this study. This analysis of secondary data culminated in the formulation of four research questions closely aligned with the primary research goal. The relation between these research questions and the main investigation objective can be visualized in the

Table 5.

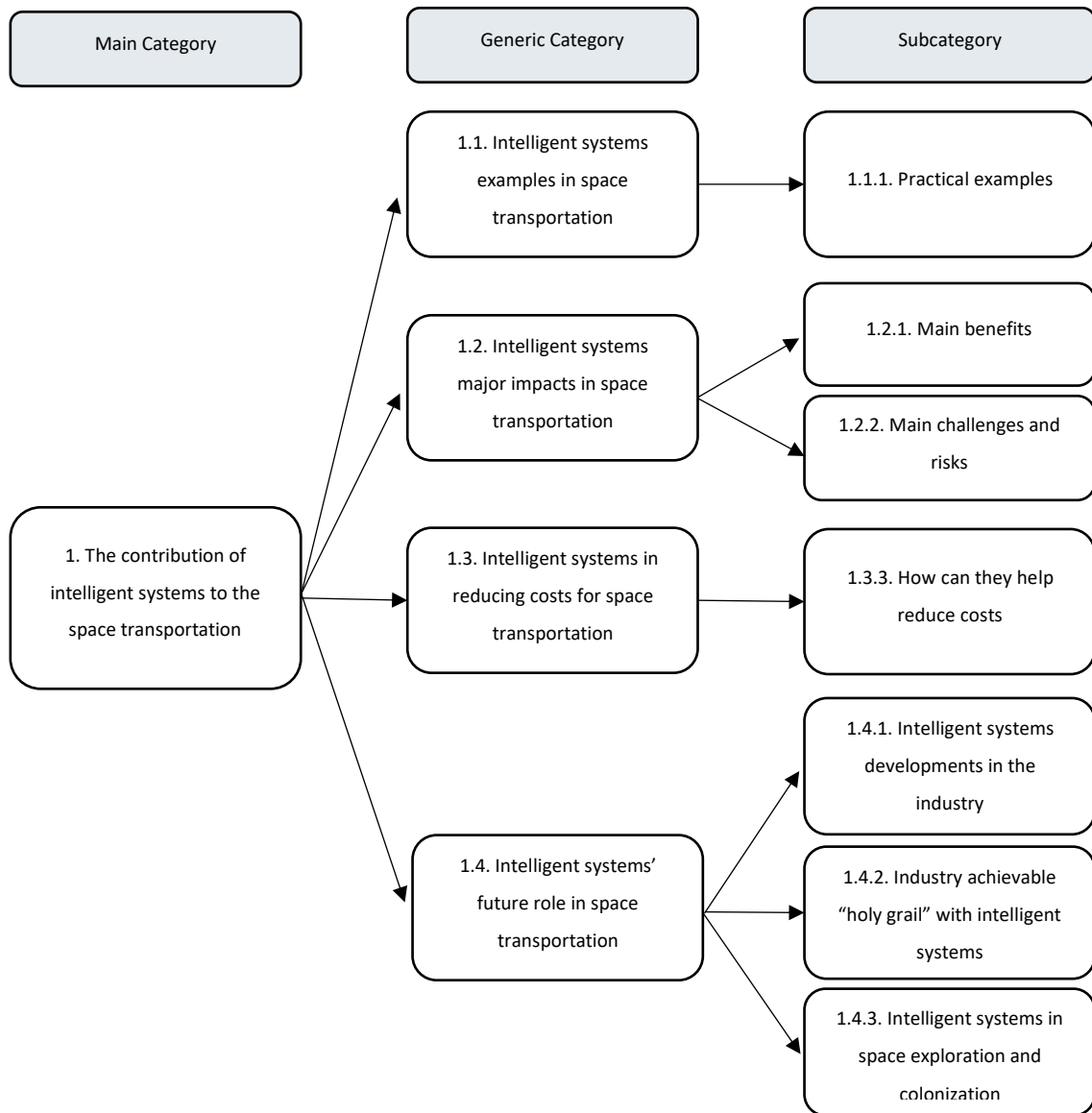
Table 5 - Relation between investigation objectives and research questions

Objective	Research Questions	Literature Review
Understand the contribution of intelligent systems to the space transportation	(Q1). What intelligent systems can we observe in space transportation?	(Girimonte & Izzo, 2007; Oche <i>et al.</i> , 2021; Habib, 2022; Chandra <i>et al.</i> , 2022; Feng <i>et al.</i> , 2020; Soon-Young Park, 2020)
	(Q2). What are the major impacts of using intelligent systems in space transportation?	(Kharchenko <i>et al.</i> , 2022; Haddaji <i>et al.</i> , 2022; Breda <i>et al.</i> , 2023)
	(Q3). How can intelligent systems help reduce space transportation costs?	(Heckel, 2023; Girimonte & Izzo, 2007; Paolo Lunghi, 2022) (Stappert <i>et al.</i> , 2019)
	(Q4). What is the role of intelligent systems in the future of space transportation?	(Jiang <i>et al.</i> , 2019; Stappert <i>et al.</i> , 2019; Chouker <i>et al.</i> , 2021; Viavattene <i>et al.</i> , 2022; Shirazi <i>et al.</i> , 2022; Nikitin <i>et al.</i> , 2022)

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Secondly, information was collected through primary sources, specifically by conducting semi-structured interviews. These interviews were carried by a one to one for each interviewee with a support of a questionnaire consisting of seven open-ended questions (the questionnaire's can be found in the appendices, Table 15). The questionnaire structure was built upon the research objective and questions which led to the formulation its corpus categorization and codification, as shown in Figure 10.

Figure 10 - Categorization and codification of the qualitative interview



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The third and final part of this work, the interviews were transcribed, and its respective analysis carried out using qualitative methods. The outcomes of this analysis are deliberated in the subsequent chapter.

4.2 Sample Characteristics

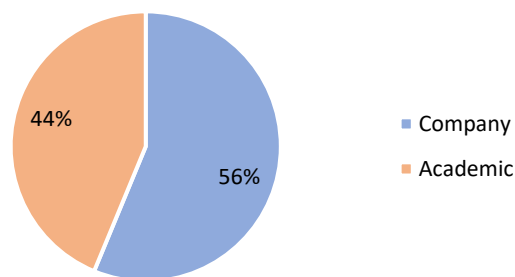
The selection of participants followed a non-random sampling approach, relying on volunteers for participation, accessible through convenience. Nevertheless, their inclusion was confined to individuals with a relevant background, namely among academy and professional specialists. Therefore, all participants are connected, either through research or work, to both intelligent systems and space transportation. This strategic approach was adopted to solicit insights from

a range of individuals possessing expertise in these domains. All identities were confidentially preserved.

The sample gathered has a size of 16 participants. According with Vilelas (2020), the number of interviews required to carry a certain degree of acceptance for such type of research, is between 15 to 20. Moreover, it's important to recognize that the selection requirements based on certain specialized expertise to effectively address the interview questions which imposes a noteworthy limitation on the potential pool of participants. All the participants identities were codified and encrypted by letters from a) to p).

As depicted in the Figure 11, 44% of respondents are academically affiliated, primarily as professors or researchers engaged in university-related activities, while the remaining 56% hold corporate affiliations, meaning that are actively involved in specialized professional roles within various companies.

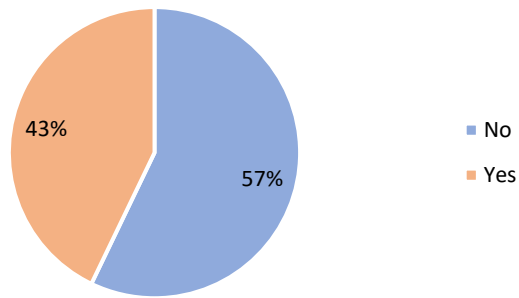
Figure 11 – Sample Interviewees' affiliation



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Among those with academic affiliations, it's worth noting that 43% have prior professional experience in organizations connected to the field of space transportation, whereas the remaining 57% do not possess such professional experience in this domain as identified in Figure 12.

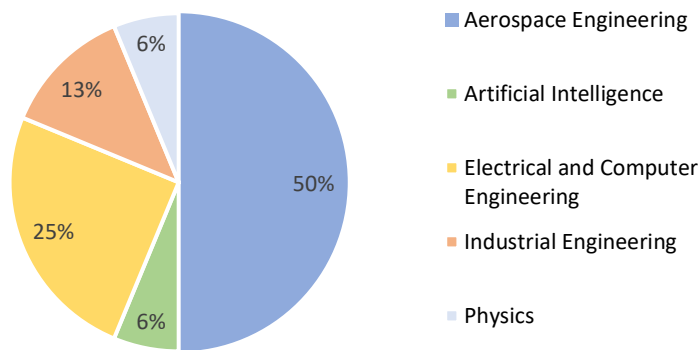
Figure 12 – Sample professional experience among academic's sphere



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The educational backgrounds of all interviewees are illustrated in the Figure 13. 50% of them come from aerospace engineering, 25% from electrical and computer engineering, 13% from industrial engineering, 6% from Artificial Intelligence, and another 6% from Physics.

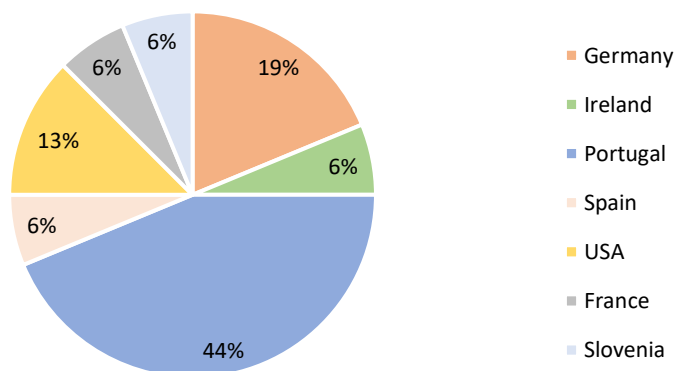
Figure 13 – Sample educational background



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Finally, the Figure 14 shows the interviewees geographic distribution, in which 44% resided in Portugal, 19% in Germany, 13% in the USA, while the remaining 24% were evenly dispersed among Ireland, Slovenia, France, and Spain.

Figure 14 – Sample interviewees' geographic residence



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Chapter 5 - Discussion of Results

In this chapter, it will be analysed the data obtained during by primary means, namely interviews. Moreover, this data it will be integrated in alignment with the literature review conducted in Chapter 2, all with the objective of gaining a deeper understanding of the role of intelligent systems in the space transportation industry.

Given the diverse realms of intelligent systems technologies and the multifaceted nature of space transportation, it was adopted a managerial perspective, providing a “birds eye view” on the issues at investigated. The neglection to a certain more granular detail, it was what turn out possible to grasp insights desired to pursue the goal of this research. This deliberate focus on a broader perspective, rather than delving into granular details, has allowed to uncover valuable insights that would otherwise constrain the pursue of the research objectives. As a result, the following section presents the key findings of the research.

5.1 How intelligent systems are observed in space transportation

The first research question aims to explore the extent of the intelligent systems presence in the industry, what respective types of technologies utilized and their corresponding domains of application.

Table 6 - Overall sentiment towards the use of intelligent systems in space transportation

Responses	Interviewees	Times mentioned
Intelligent systems are present almost in all parts of space transportation as a tool, directly and indirectly	a; c; e;	3
There isn't much application in space transportation or exist in a very limited way	f; h; k	3

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From the Table 6, it can be inferred some polarization on the overall sentiment regarding the presence of intelligent systems on the space industry. Three interviews explicitly referred that intelligent systems are generally present across all parts of the industry directly and indirectly as a tool. On another hand, also three interviewees referred that there isn't much application in space transportation or exist in a very limited way.

Table 7 - Intelligent systems present in space transportation

Responses	Interviewees	Times mentioned
Machine Learning	a; c; d; e; f; g; h; i; j; k; l	11
Expert systems	b;	1

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Examining the data presented in the Table 7, a predominant consensus emerges among the interviewees, highlighting ML as the most prevalent intelligent systems technology employed in space transportation. This viewpoint aligns with insights gleaned from the literature review, as echoed by scholars such as Paul Oche (2021) and Girimonte & Izzo (2007) in their respective works. This convergence of perspectives underscores the significance of machine learning in the space transportation sector.

However, it's essential to acknowledge the challenges associated with defining concepts, particularly when attempting to establish these definitions during interviews. This difficulty in conceptual clarity was also evident in the academic literature, as highlighted by Salam *et al.* (2022), who discussed the challenges of defining intelligent systems, and the confusion that sometimes arises between AI and ML concepts, as observed in studies by Shute *et al.* (2023) and Mahesh (2020). To mitigate potential confusion and streamline the interview process, it was adopted in this research the Molina's (2022) intelligent systems definition in the literature review, which closely aligns with that of AI. As a result, interviewees were expected to provide examples of AI technologies in their responses. Additionally, if any discrepancies or misunderstandings regarding the examples provided arose, interviewees were prompted to focus on AI technologies to maintain conceptual clarity.

In the Table 8 it can be found classified by category, the main areas within space transportation where intelligent systems can be identified.

Table 8 - Space transportation areas where intelligent systems are present

Responses	Category	Interviewees	Times mentioned
Trajectory planning	Design	a; b; c; d; e; i; j; k	8
Component monitorization during operation	Monitorization	a; c; d; e; i; l; k; m	8
Trajectory control	Navigation/ Control	a; b; d; e; g; j	6
Ground approximation problems	Navigation/ Control	a; c; f; e; j; m	6
Component design and respective testing	Design	a; c; e; i; m	5
In orbit approximation problems	Navigation/ Control	f; g; e; m	4
Situational awareness	Monitorization	d; h; i	3

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The most frequently discussed category among respondents was "navigation and control" (mentioned 16 times), followed by "design" (mentioned 13 times) and "monitoring" (mentioned 11 times). Notably, these categories had all been previously identified in the third point of the literature review (Berquand *et al.*, 2019; Feng *et al.*, 2020; Oche *et al.*, 2021; Habib, 2022; Heckel, 2023).

Within the navigation/ control category, two particular aspects garnered the most attention: trajectory control and ground proximity issues.

When it comes to trajectory control, it was provided instances where adjustments to engine thrust were necessary due to engine failures or inefficiencies, as highlighted in the study by Feng *et al.* (2020) and Shirazi *et al.* (2022). Additionally, respondents provided examples of automated engine gimbaling, a technique employed to make precise corrections and ensure the intended trajectory is maintained.

In the context of ground proximity issues, it was given the illustrative case in which the Mars Perseverance mission, featured automated processes for atmospheric entry and the selection of a landing site, with machine vision playing a pivotal role, as discussed by Chase *et al.* (2023). Furthermore, two interviewees mentioned the computer-assisted landing of SpaceX boosters, as detailed in Heckel's work (2023).

However, it's worth noting that not all perspectives aligned on this matter. A third interviewee expressed the view that the technology enabling the booster's landing was not necessarily an intelligent system or had an AI application integrated. This discrepancy in viewpoints drove further exploration. Consequently, by directly questioning subsequent interviewees regarding the technology utilized in the Falcon 9 booster's landing process to assess their perceptions on the topic, a total of four interviewees explicitly asserted that the achievement could be attributed to optimization algorithms that were distinct from AI technologies.

Going to the second most mentioned category, design, the trajectory planning emerged as the most frequently mentioned aspect, which aligns with the findings of Zhuang *et al.* (2020) work, followed by second most commonly cited area pertained to component design and the subsequent testing process.

Within the third category, two predominant themes surfaced. The first revolved around component monitoring during operation, encompassing both terrestrial and onboard monitoring, something mentioned by Habib (2022) and Heckel (2023). The second focal point within this category was situational awareness, encompassing the monitoring of potential obstacles along the trajectory and in the implementation of collision avoidance measures.

5.2 Major impacts of using Intelligent systems in space transportation

The second research question aims to explore how shifts in the dynamics of the space transportation industry either facilitate or hinder the impact and acceptance of intelligent systems technological applications.

The Table 9 reflects the beneficial aspects of using intelligent systems in space transportation in, interviewees perception.

Table 9 - Main benefits of using intelligent systems in space transportation

Responses	Interviewees	Times mentioned
Quickness	a; b; c; d; g; h; j; l; o	9
Complexity resolution	a; c; d; i; j; l; m; n	8
Reduce costs	c; h; j; l; m; o	6
Better precision	b; c; f; j; p	5
Better navigation and planning systems	c; i; j; m; p	5
Autonomy	g; j; k; o; p	5
Increased security and reliability	j; n; o	3
Versatility	c; n	2

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From the collected sample, it can be inferred that the primary advantage of utilizing intelligent systems in space transportation is their speed and rapid decision-making capabilities. This advantage, however, does not exist in isolation. According to the gathered data, the swiftness enabled by intelligent systems allows for the execution of tasks that would be exceptionally challenging for a human operator. A notable example of this is when a spacecraft encounters a rapid sequence of events, occurring too quickly for human intervention.

Which lead us to the second most significant benefit identified, the capacity to tackle complex problems, particularly those that would be exceedingly challenging to resolve using alternative methods. Beyond the limitations imposed by human biology, communication with a spacecraft positioned far from Earth can introduce delays, preventing real-time interaction. In response to this, artificial intelligence models can be developed to confer a degree of autonomy to the spacecraft. A prime illustration of this capability was evident during the Mars Perseverance mission, as previously described, as previously stated by Jiang (2019).

Another significant benefit is cost reduction. This is achieved, for instance, by enhancing mission precision, particularly concerning orbits. Improved precision results from the implementation of superior navigation systems and planning. Additionally, intelligent systems

can enhance overall spacecraft security and reliability by detecting potential cyberattacks and initiating immediate measures to prevent harm, concerns also shared by Camp & Peeters (2022).

In summary, the benefits outlined above provide a comprehensive understanding of why versatility is also considered a key advantage of incorporating intelligent systems into space transportation.

To understand the impact of intelligent systems in the industry is not only important to access its beneficial effects on the industry but also are the constraints that prevent further technological integration. Following in the Table 10 it will be displayed what are the main challenges and risks of using intelligent systems in the space transportation industry, according with the sample retrieved.

Table 10 - Main challenges and risks of using intelligent systems in the space transportation industry

Responses	Interviewees	Times mentioned
Explicability problem	a; b; c; f; d; h; e; j; k; l; m; n; p	13
Verificability problem	a; b; d; g; i; k; m; n	8
Safety	a; b; c; f; d; g; h	7
Biases in training data	a; d; e; g; p	5
Challenge of being accepted	h; n; m	3
Human risk	i; h; l	3
Data confidentiality	d; e	2

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The most frequently highlighted challenges and risks identified by interviewees included the explicability problem, mentioned 13 times, the verificability problem, discussed 8 times, and safety concerns, which came up 7 times. According to the insights provided by those interviewed, the first two challenges are interrelated and give rise to safety concerns.

The explicability problem revolves around the difficulty in comprehending and elucidating the rationale behind an AI's decision, often referred to as the "blackbox" issue. On the other hand, the verificability problem arises from the challenge of ensuring that AI outputs are not only reliable but also consistently deterministic. These two challenges, can potentially pose safety risks, particularly in the context of space transportation. Nevertheless, as suggested by 4 interviewees, those problems and concerns can be mitigated by recurring to redundancy.

It was also mentioned some unease with the data used for training the models, 5 times regarding the biases in the training data (due to data insufficiency and other issues) and 2 times on the data confidentiality used to train those models.

Last but certainly not least, there was explicitly 3 mentions related to the acceptance of intelligent systems in space transportation. Despite its relatively infrequent mentioning, the

responses from other interviewees also helped to detect important distinctions within the industry that determine or condition the degree of acceptance of intelligent systems.

One primary factor influencing the varying degrees of acceptance is the nature of the payload. Acceptance levels diverge depending on whether the payload involves human or non-human space transportation. In the context of human space transportation, intelligent systems can play a pivotal role in assisting spacecraft pilots but still they are capable of taking control or initiating abort procedures when necessary. A notable example given by an interviewee was the Apollo 11 mission, where Neil Armstrong had to assume manual control due to the main computer's failure during the moon landing. In contrast, for non-human transportation, intelligent systems can enjoy greater autonomy in their operations, making their use more readily embraced. This is because, despite mission risks, they do not carry the aggravating risk of human lives.

Another root for different intelligent systems acceptance is the organization nature. As explored during the literature review, inspired by Weinzierl (2018), Jo & Ahn (2022), and Brukardt *et al.*, (2022) new space private entities tend to be less risk adverse, and more open to adopting technological advancements when compared to space agencies and other heavily government-backed companies. This inclination towards innovation ultimately creates more opportunities for integrating advanced technology into their transportation systems.

A third factor that conditions the degree of acceptance is cultural differences. Various cultures, such as the Russian space program, often exhibit a more conservative approach, as they have a big preponderance to use extensively already proven techniques and technologies, and therefore take less risk or less time improving already working systems. As one interviewee succinctly put it, 'Why fix it if it's not broken?'.

5.3 Intelligent systems contribution in reducing space transportation costs

On this research question it intended to understand how intelligent systems influence space transportation costs. It is crucial to commence by acknowledging the underlying fallacy in this question of assuming the intelligent systems contribution for reducing the costs, as highlighted by two interviewees who reluctantly asserted that intelligent systems would neither presently nor in the future exert a significant impact on space transportation costs. However, the majority of respondents offered concrete examples demonstrating how intelligent systems have already contributed to cost reduction in space operations and how their influence is expected to grow in the future. These insightful observations can be found in Table 11.

Table 11 - Areas of intelligent systems application that contribute for reducing space launch costs

Responses	Category	Interviewees	Times mentioned
Overall increased efficiency	Otimization	a; c; h; k; l; n	6
Components design	Design	a; c; d; j; l; m	6
Spacecraft control	Navigation/ Control	a; c; h; i; n; m	6
Personal reduction	Personal	h; i; j; k; m	5
Mission planning	Design	b; c; d; m	4
Navigation	Navigation/ Control	b; c; h	3
Prototyping	Design	a; d; j	3
Spacecraft managing	Monitorization	a; c; m	3
Autonomous navigation	Navigation/ Control	b; c; j	3
Improved comunication	Comunication	b; d	2
Mission documentation research	Accessability	d; g	2

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From the collected responses, it became evident that more precise, reliable, and faster systems play a significant role in extending the spacecraft's lifecycle and enhancing operational efficiencies.

The design category, navigation and control, were once again frequently emphasized by the interviewees as already noted during the literature review (Berquand *et al.*, 2019; Feng *et al.*, 2020; Oche *et al.*, 2021; Habib, 2022; Heckel, 2023).

Design has had a substantial impact on various aspects of reducing space transportation costs. Examples ranged from the engineering design of spacecraft components, which enables more extensive prototyping iterations by facilitating virtual design and testing in simulated environments that replicate mission conditions, thereby allowing for quicker fault detection also similarly to what Berquand *et al.* (2019) reported. Additionally, improved design capabilities were noted to contribute to enhanced mission planning, facilitating the development of more efficient trajectories aimed at optimizing resource utilization.

On navigation and control, the interviewees highlighted the importance of spacecraft control systems that enable precise control of thrusters to make corrections for optimal fuel consumption, as observed by Heckel (2023). Additionally, spacecraft navigation systems, were noted for their ability to autonomously determine their own position.

Furthermore, interviewees underscored how intelligent systems applications contributes to autonomy which have played a significant role in cost reduction. These systems have been instrumental in facilitating landings, fine-tuning space approaches, and making trajectory corrections as it was suggested by Heckel (2023), all of which contribute to a more efficient and cost-effective space missions.

Additional mentions from the interviewees included personnel reduction, particularly in the context of monitoring operations. Intelligent systems have helped streamline and automate monitoring tasks, reducing the need for extensive human intervention.

Enhanced communication was also highlighted, with examples of intelligent systems assisting in accessing and transmitting relevant data back to Earth more efficiently. This improved communication not only aids in mission success but also contributes to cost reduction by optimizing data transfer processes.

Furthermore, spacecraft management was noted as another area of impact. Intelligent systems can help maintain spacecraft at the correct temperature and manage various onboard systems more effectively, ensuring their longevity and reducing maintenance costs.

5.4 Future Intelligent systems role in space transportation

The final research question aimed to discern how the influence of intelligent systems would manifest within the realm of space transportation, considering the prevalent noise and hype surrounding this technological advancement.

Recent advancements in intelligent systems, particularly in AI, are driving the creation of numerous applications across various industries. As previously mentioned, the utilization of large datasets for training, enhanced computing power, and the emergence of sophisticated deep learning architectures like transformers have raised considerable expectations for the future of AI applications. Amid the excitement surrounding these developments, Table 12 provides a glimpse into some of the anticipated applications based on the sampled data.

Table 12 - How the developments in intelligent systems technologies are going to be applied in space transportation

Responses	Interviewees	Times mentioned
Autonomous collision avoidance	a, b; e; h; j; p	6
Prototyping	a; c; d; l	4
Debris detection and removal	c, d; i;	3

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As per insights from 5 interviewees, the increasing problem of space debris in Earth's orbit calls not only for strategies to conduct a safe passage but also by innovative solutions for conducting operations within this environment. They highlighted the critical significance, if not the outright necessity, of collision avoidance measures. These experts pointed out that spacecraft equipped with autonomous capabilities and advanced computer vision models are pivotal, enabling swift detection and proactive responses to mitigate the risks of potential

collisions. This approach is essential for safeguarding spacecraft and valuable assets operating in the challenging realm of space debris-laden orbits.

Another promising application in this context involves enhancing the prototyping process. While intelligent systems are currently in use for this purpose, advancements in AI models hold the potential to revolutionize simulations used even further. This could significantly reduce the number of physical prototypes required to develop in order to achieve a final product, streamlining the iteration process and improving overall efficiency. An illustrative example is the utilization of simulations to attain optimal combustion calculations, as detailed by Nikitin *et al.* (2022).

Finally, it was also mentioned the debris detection and removal which was also discussed by Viavattene *et al.* (2022). Seemingly to collision avoidance interviewees stressed that this is likely to become a requirement for governments and companies operating in space. Given the rising number of deactivated satellites and other debris in Earth's orbit, intelligent systems may offer viable solutions for their removal in the future, contributing to the long-term sustainability of space activities in Earth's orbit.

In the Table 13 it is expressed what is the industry holy grail that can be achieved through the use intelligent systems in the future.

Table 13 - Industry holy grail achieved by intelligent systems

Responses	Interviewees	Times mentioned
Full autonomous	f; g; e; h; n; m; p	7
Autonomous collision avoidance	d; e; j	3
Lowering costs	c, i; k	3
Broadly speaking there isn't one	a; m	2

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Despite the opinion of two interviewees suggesting the absence of a singular solution, a majority of 14 interviewees identified various challenges that they believe intelligent systems can address in the coming years or decades.

The most frequently cited challenge, mentioned by 7 respondents, is achieving fully autonomous transportation, ideally with minimal to no human intervention. For some, the inclusion of collision avoidance systems in this context would be a critical achievement, considering it a significant capability for spacecraft. Furthermore, several interviewees emphasized that intelligent systems have the potential to enhance the reusability of vehicle hardware, by achieving complete reusability. This approach is seen as pivotal in reducing the overall cost of space transportation.

Following in Table 14, it is described is intelligent systems' future role in space exploration and colonization.

Table 14 - Intelligent systems future role in space exploration and colonization

Responses	Interviewees	Times mentioned
Autonomous robotic exploration	a, b; c; f; g; h; j; k; m	9
Conducting autonomous science	a; c; f; d; h; j	6
Will support human transportation	a; c; g; j; k; m	6

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The consensus among the majority of interviewees underscores the pivotal role that intelligent systems are expected to play in future space exploration endeavours. These systems are poised to take center stage in autonomous robotic exploration, demonstrating their relevance not only during space transportation but also in the field of planetary exploration, where rovers and other autonomous vehicles will benefit from their advanced capabilities.

Beyond navigation and mobility, intelligent systems are envisioned to facilitate autonomous scientific exploration. They will be instrumental in analysing collected samples and identifying points of interest. This could significantly enhance our understanding of extraterrestrial environments and their potential for scientific discovery.

Moreover, these systems are seen as indispensable when contemplating human space transportation for ambitious missions such as solar system colonization. In this context, concepts like hibernation, as explored by Chouker *et al.* (2021) come into play. Intelligent systems would be crucial for managing life support systems, monitoring health, and ensuring the safety of astronauts during extended journeys and lengthy stays on other celestial bodies.

In sum, intelligent systems are poised to revolutionize the future of space exploration, making it not only more autonomous but also more scientifically productive and, potentially, enabling humanity to venture further into the cosmos.

Chapter 6 - Conclusions

6.1. Final Considerations

This last chapter aims to aggregate the final considerations from the results acquired through the research conducted.

The first research question elicited mixed opinions regarding the prevalence of intelligent systems in the space transportation industry. While three interviewees firmly asserted the widespread use of these systems across all industry aspects, both directly and indirectly, another three interviewees held a contrasting view, suggesting a limited or negligible presence.

It became evident that the predominant technology discussed by interviewees is machine learning (ML), aligning with insights gathered from the literature review. Additionally, the research identified the most prevalent categories within space transportation where intelligent systems play a significant role. "Navigation and control" emerged as the most frequently discussed category, encompassing topics like "trajectory control" and "ground proximity issues." The second notable category is "design," which includes aspects like "trajectory planning" and "component design and testing." Lastly, the "monitoring" category comprises two dominant themes: "component monitoring during operation" and "situational awareness."

Notably, there were discrepancies in perspectives, particularly regarding the technology utilized in SpaceX booster landings. Some interviewees believed it involved optimization algorithms distinct from AI technologies, prompting further exploration and clarification.

In summary, the first research question provides insights into the presence and technology utilization of intelligent systems in space transportation. While variations in perspectives exist, the prevalence of machine learning and its application in navigation, control, design, and monitoring emerged as noteworthy trends in the space industry.

As previously stated, the second research question aimed to explore the impact of intelligent systems on the space transportation industry and how changes in industry dynamics have either facilitated or hindered their acceptance and application.

The research findings underscore the significant advantages that intelligent systems bring to space transportation. These advantages encompass their remarkable speed and ability to make rapid decisions, their aptitude for autonomously addressing complex challenges, and their potential to reduce mission costs significantly. Moreover, their adaptability and versatility were widely acknowledged as valuable assets in this context.

Nevertheless, the integration of intelligent systems into the space transportation industry also presents notable challenges and associated risks. These challenges revolve around explicability, verifiability, safety, and concerns related to data quality and confidentiality. Furthermore, acceptance of intelligent systems within the industry varies, influenced by factors such as payload type, organizational structure, and cultural disparities. This intricate landscape adds layers of complexity to the incorporation of intelligent systems into space transportation, necessitating careful consideration as the industry continues to evolve.

The third research question aimed to explore how intelligent systems influence space transportation costs. It was possible to conclude that while a couple of interviewees expressed scepticism about their cost-saving potential, a majority provided examples demonstrating their contribution to cost reduction in current space transportation and their potential for future impact.

Key findings highlighted the crucial role of more precise, reliable, and faster systems in extending spacecraft lifespans and enhancing operational efficiencies, ultimately reducing costs. The design category emerged as a prominent factor, closely followed by navigation and control. Intelligent systems enable extensive prototyping iterations and improve mission planning, optimizing trajectories for resource-efficient missions. Navigation and control systems play a vital role in cost-effective missions, ensuring precise thruster control and autonomous spacecraft positioning. These systems also contribute to autonomy, streamlining landings, space approaches, and trajectory corrections for greater mission efficiency and cost-effectiveness. Additionally, intelligent systems automate monitoring operations, enhance communication, and effectively manage spacecraft, all of which collectively lead to cost savings in the space transportation industry.

Moreover, it was noted that the scalability of such applications would be a determinant factor to produce economies of scale. Today's missions have a high specific tailoring particularly done for that mission. However, if the applications mentioned above could scale as a utility across several spacecrafts, the cost reductions would greatly increase.

At last, the fourth research question explored the impact of intelligent systems in the realm of space transportation amid the growing excitement surrounding the technological advancement. It was possible to identify some of the anticipated applications of intelligent systems in space transportation, including collision avoidance, improved prototyping, and debris detection and removal.

Interviewees emphasized the pressing issue of space debris in Earth's orbit, highlighting the importance of collision avoidance measures. Autonomous spacecraft equipped with advanced computer vision models are seen as vital for quick detecting and responding to potential

collisions, safeguarding spacecrafts operating in those orbits. Another promising application lies in enhancing the prototyping process, where intelligent systems can further streamline simulations and reduce the need for physical prototypes.

Concerning the industry's aspirations to when it comes to the use of intelligent systems, achieving fully autonomous transportation is a primary goal. The majority of interviewees identified various challenges that intelligent systems can address in the future, including collision avoidance, complete vehicle hardware reusability, and other miscellaneous cost efficiency applications. Additionally, it was possible to understand that intelligent systems are expected to play in future space exploration and colonization, offering enhanced autonomy, scientific productivity, and support for ambitious missions like solar system colonization. In summary, intelligent systems hold tremendous potential to shape the future of space transportation, making it more efficient, autonomous, and scientifically productive.

6.2. Academic and Industry Contributions

This work bridges the gap between academia and industry, enabling a holistic view of the role played by intelligent systems technologies in the space transportation industry. From an academic perspective, this research provides a comprehensive overview of the foundational elements that underly the expansive domains of intelligent systems and space transportation industry. Moreover, it provides clarity on the industry dynamics, and distinct some of the factors that shape the acceptance of intelligent systems while pinpointing specific areas within space transportation where these technologies find their most profound applications.

On the industry front, the research aligns and consolidates industry perspectives, supporting professionals in understanding the current landscape. It validates the importance of ML technology, providing the industry with concrete evidence (even with some limitations). Insights into cost reduction strategies and scalability underscore the potential for enhancing operational efficiency and cost-effectiveness in space missions. Additionally, it highlights safety and reliability concerns, offering valuable guidance to industry professionals as they navigate the integration of intelligent systems into space transportation practices. Moreover, the research sheds light on industry aspirations from future intelligent systems applications, including fully autonomous transportation and broader applications in space exploration and colonization.

6.3. Limitations

The research approach employed was exploratory, aimed at enriching the academic understanding of the subject matter. However, it's essential to recognize that the findings are based on a relatively limited sample size and specific perspectives gathered through interviews. Consequently, these findings should not be generalized to represent the entire population or considered universally applicable, as the nuances and perspectives within the realm of space transportation can vary significantly.

The decision to adopt a unified definition for intelligent systems and AI in cases where varying definitions could lead to misunderstandings was a prudent one, given the complexity and potential for differing interpretations within the theme, as discussed in detail in Section 5.1. However, it's crucial to acknowledge that despite the effort to harmonize definitions, there may still be a degree of potential misunderstanding or misalignment among interpretations present in the interviewee responses.

Additionally, space transportation is an exceptionally broad and intricate subject. The research's primary objective was to provide an overall perspective on the role of technology within space transportation. Nevertheless, it is clear that there is a multitude of details and areas for further investigation within this expansive field.

6.4. Suggestions for Future Research

The current excitement surrounding intelligent systems, particularly AI, prompts important questions about whether these technologies will meet the high expectations set for them. Undoubtedly, intelligent systems have already brought about profound transformations across various industries, reshaping the way they operate. While this research primarily focuses on space transportation, it's equally pertinent to explore the broader landscape to gain insights into where this technology is heading in the coming decades.

Furthermore, within the context of space transportation, there is ample room for more detailed exploration. The role of intelligent systems in this industry is multifaceted and warrants in-depth analysis. Factors such as organizational types, cultural differences, and distinctions between human and non-human space transportation all contribute to nuanced perspectives on the integration and impact of intelligent systems. These complexities should be further examined to gain a comprehensive understanding of the evolving landscape in space transportation.

Bibliography

- Abadía, J. J., Walther, C., Osman, A., & Smarsly, K. (2022). A systematic survey of Internet of Things frameworks for smart city applications. *Sustainable Cities and Society*, 83. <https://doi.org/10.1016/j.scs.2022.103949>
- Abashidze, A., Chernykh, I., & Mednikova, M. (2022). Satellite constellations: International legal and technical aspects. *Acta Astronautica*, 196, 176-185. <https://doi.org/10.1016/j.actaastro.2022.04.019>
- Abbey, W., Anderson, R., Beegle, L., Hurowitz, J., Williford, K., Peters, G., Morookian, J. M., Collins, C., Feldman, J., Kinnett, R., Jandura, L., Limonadi, D., Logan, C., McCloskey, S., Melko, J., & Okon, A. (2019). A look back: The drilling campaign of the Curiosity rover during the Mars Science Laboratory's Prime Mission. *Icarus*, 319, 1-13. <https://doi.org/10.1016/j.icarus.2018.09.004>
- Aevum. (2023). *Space Transport Services*. Aevum: <https://www.aevumspace.com/toSpace>
- Aharon, D. Y., Demir, E., & Siev, S. (2022). Real returns from unreal world? Market reaction to Metaverse disclosures. *Research in International Business and Finance*, 63. <https://doi.org/10.1016/j.ribaf.2022.101778>
- Ahmad, S., Umirzakova, S., Jamil, F., & Whangbo, T. K. (2022). Internet-of-things-enabled serious games: A comprehensive survey. *Future Generation Computer Systems*, 136, 67-83. <https://doi.org/10.1016/j.future.2022.05.026>
- AIAA. (2012). Overview of the Systems Engineering and Vehicle Design Process. *Design Methodologies for Space Transportation Systems*, 1-44. <https://doi.org/10.2514/5.9781600861734.0001.0044>
- Aldarmaki, H., Ullah, A., Ram, S., & Zaki, N. (2022). Unsupervised Automatic Speech Recognition: A review. *Speech Communication*, 139, 76-91. <https://doi.org/10.1016/j.specom.2022.02.005>
- Aliberti, M., & Lisitsyna, K. (2019). *Russia's Posture in Space*. Springer Cham. <https://doi.org/10.1007/978-3-319-90554-9>
- Allal-Chérif, O. (2022). Intelligent cathedrals: Using augmented reality, virtual reality, and artificial intelligence to provide an intense cultural, historical, and religious visitor experience. *Technological Forecasting and Social Change*, 178. <https://doi.org/10.1016/j.techfore.2022.121604>

- American Institute of Aeronautics and Astronautics. (2012). Overview of the Systems Engineering and Vehicle Design Process. *Design Methodologies for Space Transportation Systems*, 1-44. <https://doi.org/10.2514/5.9781600861734.0001.0044>
- Andreas M. Hein, R. M. (2020). A techno-economic analysis of asteroid mining. *Acta Astronautica*, 168, 104-115. <https://doi.org/10.1016/j.actaastro.2019.05.009>
- Angelino, A., Martorelli, M., & Tarallo, A. (2023). An Augmented Reality Framework for Remote Factory Acceptance Test: An Industrial Case Study. *International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing*, 768-779. https://doi.org/10.1007/978-3-031-15928-2_67
- Aphelion. (2023). *Helios Launch Vehicle*. Aphelion: <https://static1.squarespace.com/static/56eefa11c2ea5104511e19eb/t/5b56440a8a922dbc85ead83f/1532380170721/Helios+Datasheet.pdf>
- Arca Space. (2023). *HAAAS 2CA*. Arca Space: <https://www.arcaspace.com/haas>
- Aryavalli, S. N., & Kumar, H. (2023). Top 12 layer-wise security challenges and a secure architectural solution for Internet of Things. *Computers and Electrical Engineering*, 105. <https://doi.org/10.1016/j.compeleceng.2022.108487>
- Ashabi, A., Sahibuddin, S. B., & Haghighi, M. S. (2020). Big Data: Current Challenges and Future Scope. *IEEE 10th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, 131-134. <https://doi.org/10.1109/ISCAIE47305.2020.9108826>
- Astorg, J.-M. (2017). Issues and Perspectives on Space Launch Vehicles' Development. In C. Al-Ekabi, B. Baranes, P. Hulsroj, & A. Lahcen, *Yearbook on Space Policy 2015* (pp. 147–152). Springer, Vienna. https://doi.org/10.1007/978-3-7091-4860-0_3
- Astra. (2022). *ROCKET 4*. Astra: <https://astra.com/wp-content/uploads/2022/11/Rocket-4-Payload-Users-Guide-v1.1-November-22.pdf>
- Attaran, M., & Woods, J. (2019). Cloud computing technology: improving small business performance using the Internet. *Journal of Small Business & Entrepreneurship*, 31(6). <https://doi.org/10.1080/08276331.2018.1466850>
- Atzori, L., Iera, A., & Morabito, G. (2017). Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm. *Ad Hoc Networks*, 56, 122-140. <https://doi.org/10.1016/j.adhoc.2016.12.004>
- B2 Space. (2023). *Colibri Programme*. B2 Space: <https://b2-space.com/colibri-programme/>
- Badikov, G. A., & Bebenina, A. A. (2021). Modeling costs for launching modern launch vehicles in China. *XLIV Academic Space Conference*, 2318(1). <https://doi.org/10.1063/5.0036016>
- Badue, C., Guidolini, R., Carneiro, R. V., Azevedo, P., Cardoso, V. B., Forechi, A., Jesus, L., Berriel, R., Paixão, T. M., Mutz, F., Veronese, L. d., Oliveira-Santos, T., & Souza, A. F. (2021).

- Self-driving cars: A survey. *Expert Systems with Applications*, 165. <https://doi.org/10.1016/j.eswa.2020.113816>
- Bae, J., Koo, J., & Yoo, Y. (2017). Development Trend of Low Cost Space Launch Vehicle and Consideration of Next Generation Fuel. *J. of The Korean Society for Aeronautical and Space Science*, 45(10), 855 - 862. <https://doi.org/10.5139/JKSAS.2017.45.10.855>
- Bailey, M. (2020). Frequent and Reliable Launch for Small Satellites: Rocket Lab's Electron Launch Vehicle and Photon Spacecraft. In J. N. Pelton, & S. Madry, *Handbook of Small Satellites* (pp. 453–468). Springer Cham. https://doi.org/10.1007/978-3-030-36308-6_91
- Baiocco, P. (2021). Overview of reusable space systems with a look to technology aspects. *Acta Astronautica*, 189, 10-25. <https://doi.org/10.1016/j.actaastro.2021.07.039>
- Baker, D., & Kissonock, H. (2017). *Rockets*. Av2.
- Benkő, A., & Lányi, C. S. (2009). History of Artificial Intelligence. In M. Khosrow-Pour, *Encyclopedia of Information Science and Technology, Second Edition* (p. 4). New York: Information Resources Management Association. <https://doi.org/10.4018/978-1-60566-026-4.ch276>
- Bennett, M. T., & Maruyama, Y. (2022). Philosophical Specification of Empathetic Ethical Artificial Intelligence. *IEEE Transactions on Cognitive and Developmental Systems*, 14(2), 292-300. <https://doi.org/10.1109/TCDS.2021.3099945>
- Berente, N., Gu, B., Recker, J., & Santhanam, R. (2021). Managing Artificial Intelligence. *MIS Quarterly*, 45(3), 1433-1450. <https://doi.org/10.25300/MISQ/2021/16274>
- Bernard, F., & Bijlenga, P. (2022). Defining Anatomic Roadmaps for Neurosurgery with Mixed and Augmented Reality. *World Neurosurgery*, 157, 233-234. <https://doi.org/10.1016/j.wneu.2021.09.125>
- Berquand, A., Murdaca, F., Riccardi, A., Soares, T., Generé, S., Brauer, N., & Kumar, K. (2019). Artificial Intelligence for the Early Design Phases of Space Missions. *2019 IEEE Aerospace Conference*, 1-20. <https://doi.org/10.1109/AERO.2019.8742082>
- Bhattacharjee, D., & Roy, S. S. (2021). A Simplified Guide To Rocket Science and Beyond – Understanding The Technologies of The Future. *Reports on Synthetic Gravity and Rocket Science*. <https://doi.org/10.6084/m9.figshare.15365547.v1>
- Blackmore, L. J. (2007). *Robust execution for stochastic hybrid systems*. Massachusetts: Massachusetts Institute of Technology.
- Bommakanti, K. (2020). Strengthening the C4ISR Capabilities of India's Armed Forces: The Role of Small Satellites. *Observer Research Foundation*.
- Bonaccorso, G. (2018). *Machine Learning Algorithms - Second Edition* (2 ed.). Birmingham: Packt.

- Boonel, T. R., & Miller, D. P. (2016). Capability and Cost-Effectiveness of Launch Vehicles. *New Space*, 4(3), 168-189. <https://doi.org/10.1089/space.2016.0011>
- Bousedra, K. (2023). Downstream Space Activities in the New Space Era: Paradigm Shift and Evaluation Challenges. *Space Policy*, 64. <https://doi.org/10.1016/j.spacepol.2023.101553>
- Braun, R., & Manning, R. (2006). Mars Exploration Entry, Descent and Landing Challenges. *IEEE Aerospace Conferenc*, 18. <https://doi.org/10.1109/AERO.2006.1655790>
- Breda, P., Markova, R., Abdin, A. F., Manti, N. P., Carlo, A., & Jha, D. (2023). An extended review on cyber vulnerabilities of AI technologies in space applications: Technological challenges and international governance of AI. *Journal of Space Safety Engineering*. <https://doi.org/10.1016/j.jsse.2023.08.003>
- Brown, J. R., Gross, S. A., Sengupta, N., Berzin, T. M., Mansour, N. M., Wang, P., Chuchuca, M. A., Minchenberg, S. B., Liu, L., & Chandnani, M. (2020). Deep Learning Computer-aided Polyp Detection Reduces Adenoma Miss Rate: A United States Multi-center Randomized Tandem Colonoscopy Study (CAdET-CS Trial). *Clinical Gastroenterology and Hepatology*, 20(7), 1499-1507. <https://doi.org/10.1016/j.cgh.2021.09.009>
- Brukardt, R., Klemper, J., Pachthod, D., & Stokes, B. (2022). *The role of space in driving sustainability, security, and development on Earth*. McKinsey & Company.
- Bryce Tech. (2022). *State of the Satellite Industry Report*. Satellite Industry Association.
- Bryce Tech. (2023). *2022 Orbital Launches Year in Review*. Bryce Tech.
- Buchholz, F., Oppermann, L., & Prinz, W. (2022). There's more than one metaverse. *Oldenbourg Wissenschaftsverlag*, 21(3), 313-324. <https://doi.org/10.1515/icom-2022-0034>
- Byr'ka, A., K.G., B., Kosyakov, D., & Shpigun, O. A. (2010). Application of analytical methods for estimating contamination of atmospheric air during launch of carrier rockets of different classes from the Plesetsk Cosmodrome. *Inorganic Materials*, 46, 1627-1631. <https://doi.org/10.1134/S0020168510150057>
- C6 Launch. (2023). *Reliable. Cost Effective. Dedcated.* C6 Launch: <https://www.c6launch.com/our-rocket/>
- Cadbury, D. (2005). *Space Race: The Epic Battle Between America and the Soviet Union for Dominion of Space*. HarperCollins. <https://doi.org/ISBN10: 0060845538>
- Cambridge Dictionary. (2022, November). *Data*. Cambridge Dictionary: <https://dictionary.cambridge.org/dictionary/english/data>
- Camp, C. V., & Peeters, W. (2022). A World without Satellite Data as a Result of a Global Cyber-Attack. *Space Policy*, 59. <https://doi.org/10.1016/j.spacepol.2021.101458>

- Capuano, V., Shehaj, E., Botteron, C., Blunt, P. D., & Farine, P.-A. (2017). GNSS/INS/Star Tracker Integration for Real-Time On-Board Autonomous Orbit and Attitude Determination in LEO, MEO, GEO and Beyond. *68th International Astronautical Congress (IAC)*. Adelaide: International Astronautical Federation (IAF). <https://infoscience.epfl.ch/record/264859>
- Carbajales-Dale, M., & Murphy, T. W. (2023). The environmental and moral implications of human space travel. *Science of The Total Environment*, 856(2). <https://doi.org/10.1016/j.scitotenv.2022.159222>
- Cavataio, P., & Rus, G. (2019). Industria Espacial 2019. *Latam Satelital*, 55. <http://www.oink.com.ar/>: https://bibliotecadigital.ciren.cl/bitstream/handle/20.500.13082/29282/AR_Industria_Espacial_2019_OiNK_esp.pdf?sequence=1&isAllowed=y
- Celestiaaeropasce. (2023). *Sagittarius Launch System*. Celestiaaeropasce: <https://celestiaaerospace.com/>
- Cha, J., Ko, S., Park, S.-Y., & Jeong, E. (2019). Fault detection and diagnosis algorithms for transient state of an open-cycle liquid rocket engine using nonlinear Kalman filter methods. *Acta Astronautica*, 163(A), 147-156. <https://doi.org/10.1016/j.actaastro.2019.03.075>
- Chadalavada, P., & Dutta, A. (2022). Regional CubeSat Constellation Design to Monitor Hurricanes. *IEEE Transactions on Geoscience and Remote Sensing*, 60, 1-8. <https://doi.org/10.1109/TGRS.2021.3124473>
- Chandra, G., B., V., U., S. R., G., U., & M., U. (2022). Recurrent Neural Network based Soft Sensor for flow estimation in Liquid Rocket Engine Injector calibration. *Flow Measurement and Instrumentation*, 83. <https://doi.org/10.1016/j.flowmeasinst.2021.102105>
- Chandra, G., B., V., U., S. R., G., U., & M., U. (2022). Recurrent Neural Network based Soft Sensor for flow estimation in Liquid Rocket Engine Injector calibration. *Flow Measurement and Instrumentation*, 83. <https://doi.org/10.1016/j.flowmeasinst.2021.102105>
- Chandrashekar, S. (2022). China's Launch Vehicle Programme. *China's Space Programme*, 245-290. https://doi.org/10.1007/978-981-19-1504-8_14
- Chang, A. C. (2020). Chapter 3 - History of Artificial Intelligence in Medicine. (A. C. Chang, Ed.) *Intelligence-Based Medicine*, 29-42. <https://doi.org/10.1016/B978-0-12-823337-5.00003-2>
- Chao, X., Kou, G., Li, T., & Peng, Y. (2018). Jie Ke versus AlphaGo: A ranking approach using decision making method for large-scale data with incomplete information. *European Journal of Operational Research*, 265, 239-247. <https://doi.org/10.1016/j.ejor.2017.07.030>

- Chase, T., Gnam, C., Crassidis, J., & Dantu, K. (2023). You Only Crash Once: Improved Object Detection for Real-Time, Sim-to-Real Hazardous Terrain Detection and Classification for Autonomous Planetary Landings. *CoRR*, *abs/2303.04891*. <https://doi.org/10.48550/arXiv.2303.04891>
- Chatzopoulos-Vouzoglani, K., Reinke, K. J., Soto-Berelov, M., & Jones, S. D. (2023). One year of near-continuous fire monitoring on a continental scale: Comparing fire radiative power from polar-orbiting and geostationary observations. *International Journal of Applied Earth Observation and Geoinformation*, *117*. <https://doi.org/10.1016/j.jag.2023.103214>
- Chebukhanova, L. V., & Zimakov, A. M. (2022). Resource support of innovative small and medium-sized enterprises for space industry development in Russia. *Acta Astronautica*, *200*, 626-634. <https://doi.org/10.1016/j.actaastro.2022.09.033>
- Chekakta, Z., Zenati, A., Aouf, N., & Dubois-Matra, O. (2022). Robust deep learning LiDAR-based pose estimation for autonomous space landers. *Acta Astronautica*, *201*, 59-74. <https://doi.org/10.1016/j.actaastro.2022.08.049>
- Chen, J., Hu, P., Zhou, H., Yang, J., Xie, J., Jiang, Y., Gao, Z., & Zhang, C. (2019). Toward Intelligent Machine Tool. *Engineering*, *5*(4), 679-690. <https://doi.org/10.1016/j.eng.2019.07.018>
- Chen, X., Xie, H., & Tao, X. (2022). Vision, status, and research topics of Natural Language Processing. *Natural Language Processing Journal*, *1*. <https://doi.org/10.1016/j.nlp.2022.100001>
- Chen, Y.-S. (2019). Development of Hapith Small Launch Vehicle based on Hybrid Rocket Propulsion. *AIAA Propulsion and Energy 2019 Forum*. Indianapolis: American Institute of Aeronautics and Astronautics. <https://doi.org/10.2514/6.2019-3837>
- Cho, S., Lee, K., & Sun, B.-C. (2016). Development Directions of Succeeding Launch Vehicles of KSLV-II and Outlooks for Technology Advancement. *Journal of the Korean Society for Aeronautical & Space Sciences (한국항공우주학회지)*, *44*(8), 668-674. <https://doi.org/10.5139/JKSAS.2016.44.8.668>
- Chouker, A., Ngo-Anh, J., Biesbroek, R., Heldmaler, G., Heppener, M., & Bereiter-Hahn, J. (2021). European space agency's hibernation (torpor) strategy for deep space missions: Linking biology to engineering. *Neuroscience and Biobehavioral Reviews*, *131*, 618-626. <https://doi.org/10.1016/j.neubiorev.2021.09.054>
- Chrisley, R. (2008). Philosophical foundations of artificial consciousness. *Artificial Intelligence in Medicine*, *119*-137. <https://doi.org/10.1016/j.artmed.2008.07.011>

- Chunna, L., & Hai, F. &. (2020). Development of an efficient global optimization method based on adaptive infilling for structure optimization. *Struct Multidisc Optim*, 62, 3383-3412. <https://doi.org/10.1007/s00158-020-02716-y>
- Citi GPS: Global Perspectives & Solutions. (2022). *SPACE The Dawn of a New Age*. New York: Citi GPS: Global Perspectives & Solutions.
- Clarysse, B., He, V. F., & Tucci, C. L. (2022). How the Internet of Things reshapes the organization of innovation and entrepreneurship. *Technovation*, 118. <https://doi.org/10.1016/j.technovation.2022.102644>
- Cocchiara, C. M., Nigro, G. L., Roma, P., & Ragusa, A. (2022). *What, Where, Who and How a Quadruple Perspective and a Research Agenda for the New Space Economy in the 21st Century: Focus on the "What"*. SSRN.
- Collins, C., Dennehy, D., Conboy, K., & Mikalef, P. (2021). Artificial intelligence in information systems research: A systematic literature review and research agenda. *International Journal of Information Management*, 60. <https://doi.org/10.1016/j.ijinfomgt.2021.102383>
- Cost Estimation and Development Approach of the EURASTROS Concept. (2022). *9TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS)*, 14. <https://elib.dlr.de/187777/>
- Cottom, T. S. (2022). A Review of Indian Space Launch Capabilities. *New Space*, 10(1), 42-50. <https://doi.org/10.1089/space.2021.0064>
- Cui, Z., & Xu, Y. (2022). Impact simulation of Starlink satellites on astronomical observation using worldwide telescope. *Astronomy and Computing*, 41. <https://doi.org/10.1016/j.ascom.2022.100652>
- Curtis, H. D. (2020). Chapter 13 - Rocket vehicle dynamics. *In Aerospace Engineering*, 705-735. <https://doi.org/10.1016/B978-0-08-102133-0.00013-1>
- Dallas, J., Raval, S., Gaitan, J. A., Saydam, S., & Dempster, A. (2020). Mining beyond earth for sustainable development: Will humanity benefit from resource extraction in outer space? *Acta Astronautica*, 167, 181-188. <https://doi.org/10.1016/j.actaastro.2019.11.006>
- Davidian, K. (2022). Operationalizing the definition of "Commercial Space". *Acta Astronautica*, 198, 541-549. <https://doi.org/10.1016/j.actaastro.2022.06.040>
- Day, J., Ingham, M., Murray, R., Reder, L., & Williams, B. (2015). Engineering Resilient. *Insight*, 18, 23-25.

- Deb, D., & Fuad, M. (2021). Integrating big data and cloud computing topics into the computing curricula: A modular approach. *Journal of Parallel and Distributed Computing*, 157, 303-315. <https://doi.org/10.1016/j.jpdc.2021.07.012>
- DeCanio, S. J. (2016). Robots and humans – complements or substitutes? *Journal of Macroeconomics*, 49, 280-291. <https://doi.org/10.1016/j.jmacro.2016.08.003>
- Dehghani, M., Lee, S. H., & Mashatan, A. (2020). Touching holograms with windows mixed reality: Renovating the consumer retailing services. *Technology in Society*, 63. <https://doi.org/10.1016/j.techsoc.2020.101394>
- Dejoux, C., & Léon, E. (2018). *Métamorphose des managers*. Ville Montreuil, Montreuil, France: Pearson France.
- Demchenko, Y., De Laat, C., & Membrey, P. (2014). Defining Architecture Components of the Big Data. *2014 International Conference on Collaboration Technologies and Systems* (pp. 104-1112). Minneapolis: IEEE Computer Society. <https://doi.org/10.1109/CTS.2014.6867550>
- Deng, L., & Yu, D. (2014). Deep Learning: Methods and Applications. *Foundations and Trends® in Signal Processing*, 7(1932-8346), 197-387. <https://doi.org/10.1561/20000000039>
- Desaire, H., Go, E. P., & Hua, D. (2022). Advances, obstacles, and opportunities for machine learning in proteomics. *Cell Reports Physical Science*, 3(10). <https://doi.org/10.1016/j.xcrp.2022.101069>
- Dick, S. (2019). Artificial Intelligence. *Harvard Data Science Review*, 1. <https://doi.org/https://doi.org/10.1162/99608f92.92fe150c>
- Du, Z., Chen, S., Anduv, B., Zhu, X., & Jin, X. (2022). IoT intelligent agent based cloud management system by integrating machine learning algorithm for HVAC systems. *International Journal of Refrigeration*. <https://doi.org/10.1016/j.ijrefrig.2022.10.022>
- Duan, Y., Edwards, J. S., & Dwivedi, Y. K. (2019). Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. *International Journal of Information Management*, 63-71. <https://doi.org/10.1016/j.ijinfomgt.2019.01.021>
- Dumont, E., Bussler, L., Karl, S., Porrmann, D., Manfletti, C., Krause, D., Clark, V., Bozic, O., & Poppe, G. (2016). Analysis of the Ariane 62/64 and Vega-C launcher family. *Engineering*. <https://elib.dlr.de/103509/>
- Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, V., Janss, M., Jones, P., Kar, A. K., Kizgin, H., Kronemann, B., Lal, B., & Lucini, B. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice

- and policy. *International Journal of Information Management*, 57. <https://doi.org/10.1016/j.ijinfomgt.2019.08.002>
- E.A., R., V.V., K., & V.A., B. (2023). Analysis of Ultra-Light Missiles. *Achievements Of Science And Technology*, 40-46.
- E.O'Leary, D. (2008). Gartner's hype cycle and information system research issues. *International Journal of Accounting Information Systems*, 9(4), 240-252. <https://doi.org/10.1016/j.accinf.2008.09.001>
- Ehrenfried, M. “. (2020). *The Artemis Lunar Program*. Springer Cham. <https://doi.org/10.1007/978-3-030-38513-2>
- Elguea-Aguinaco, Í., Serrano-Muñoz, A., Chrysostomou, D., Inziarte-Hidalgo, I., Bøgh, S., & Arana-Arexolaleiba, N. (2023). A review on reinforcement learning for contact-rich robotic manipulation tasks. *Robotics and Computer-Integrated Manufacturing*, 81. <https://doi.org/10.1016/j.rcim.2022.102517>
- Elkhodr, M., Shahrestani, S., & Cheung, H. (2013). A contextual-adaptive Location Disclosure Agent for general devices in the Internet of Things. *38th Annual IEEE Conference on Local Computer Networks - Workshops*, 848-855. <https://doi.org/10.1109/LCNW.2013.6758522>
- El-Seoud, S. A., El-Sofany, H. F., Abdelfattah, M., & Mohamed, R. (2017). Big Data and Cloud Computing: Trends and Challenges. *Journal of Interactive Mobile Technologies* , 11(2), 34-52. <https://doi.org/10.3991/ijim.v11i2.6561>
- El-Shawa, S., Alzurikat, M., Alsaadi, J., Sona, G. A., & Shaar, Z. A. (2022). Jordan Space Research Initiative: Societal Benefits of Lunar Exploration and Analog Research. *Acta Astronautica*, 200, 574-585. <https://doi.org/10.1016/j.actaastro.2022.08.019>
- Emaminejad, N., & Akhavian, R. (2022). Trustworthy AI and robotics: Implications for the AEC industry. *Automation in Construction*, 139. <https://doi.org/10.1016/j.autcon.2022.104298>
- endeavour. (2023). *Darwin*. endeavourockets: <https://www.endeavourockets.com/projects/darwin>
- Epstein, R., Roberts, G., & Beber, G. (2008). *Parsing the Turing Test: Philosophical and Methodological Issues in the Quest for the Thinking Computer*. New York: Springer Publishing Company. https://doi.org/http://doi.org/10.1007/978-1-4020-6710-5_12
- Erickson, A. S. (2018). Revisiting the U.S.-Soviet space race: Comparing two systems in their competition to land a man on the moon. *Acta Astronautica*, 148, 376-384. <https://doi.org/10.1016/j.actaastro.2018.04.053>

- Euroconsult. (2022). *Government Space Programs, 22nd edition*. Euroconsult. Retrieved January 31, 2023, from <https://digital-platform.euroconsult-ec.com/product/government-space-programs/>
- Evans, B. (2022). *Antares 330 Targets NET Mid-2024 Launch, SpaceX to Fly Three Cygnus Missions*. AmericaSpace: <https://www.americaspace.com/2022/08/12/new-antares-rocket-targets-net-mid-2024-launch-major-performance-increase/>
- Feng, W., Xiu-luo, L., Jia, W., Yao, L., Gang, A., & Long, C. (2020). Research on Space Transportation Intelligence Control. *2020 International Conference on Computer Engineering and Intelligent Control (ICCEIC)*, 271-274. <https://doi.org/10.1109/ICCEIC51584.2020.00058>
- Fernández, P. d., Candás, J. L., & Arboleya, P. (2023). Internet of Things (IoT) for power system applications. *Encyclopedia of Electrical and Electronic Power Engineering*, 486-496. <https://doi.org/10.1016/B978-0-12-821204-2.00072-6>
- Florom-Smith, A. L., Klingenger, J. K., & DiBiase, C. P. (2022). Commercial space tourism: An integrative review of spaceflight participant psychological assessment and training. *REACH*, 25-26. <https://doi.org/10.1016/j.reach.2021.100043>
- Galactic Energy. (2023). *PALLAS-1 LIQUID PROPELLANT LAUNCH VEHICLE*. <https://doi.org/https://www.galactic-energy.cn/index.php/En/List/cid/15>
- Garis, H. d., & Goertzel, B. (2009). Report on the First Conference on Artificial General Intelligence. *AI Magazine*, 30, 121. <https://doi.org/10.1609/aimag.v30i1.2151>
- George, K. W. (2019). The Economic Impacts of the Commercial Space Industry. *Space Policy*, 47, 181-186. <https://doi.org/10.1016/j.spacepol.2018.12.003>
- Giancarlo Santilli, C. V. (2018). CubeSat constellations for disaster management in remote areas. *Acta Astronautica*, 145, 11-17. <https://doi.org/10.1016/j.actaastro.2017.12.050>
- Gilmour Space. (2023). *Eris orbital launch vehicles*. Gilmour Space: <https://www.gspacetechnology.com/launch>
- Gilmour Space. (2023). *Our Launch Services*. Gilmour Space: <https://www.gspace.com/launch>
- Girimonte, D., & Izzo, D. (2007). Artificial Intelligence for Space Applications. In A. J. Schuster, *Intelligent Computing Everywhere* (pp. 235–253). Springer London. https://doi.org/10.1007/978-1-84628-943-9_12
- Gonzalez, S. (2023). The Astropreneurial Co-creation of the New Space Economy. *Space Policy*, 64. <https://doi.org/10.1016/j.spacepol.2023.101552>
- Gorn, M. H., & Chiara, G. D. (2021). *X-Planes from the X-1 to the X-60*. Springer Cham. <https://doi.org/10.1007/978-3-030-86398-2>

- Gorn, M. H., & Chiara, G. D. (2021). *X-Planes from the X-1 to the X-60*. Springer Cham. <https://doi.org/10.1007/978-3-030-86398-2>
- Graham, C. (2021). The History of Nuclear Thermal Rocket Development. *Encyclopedia of Nuclear Energy*, 290-302. <https://doi.org/10.1016/B978-0-12-819725-7.00059-3>
- Guarnieri, M. (2019). 21 July 1969 [Historical]. *IEEE Industrial Electronics Magazine*, 13, 55-61. <https://doi.org/10.1109/MIE.2019.2910874>
- Guo, E. (2022, December 19). *A Roomba recorded a woman on the toilet. How did screenshots end up on Facebook?* Retrieved January 7, 2023, from Technology Review: <https://www.technologyreview.com/2022/12/19/1065306/roomba-irobot-robot-vacuums-artificial-intelligence-training-data-privacy/>
- Habib, T. M. (2022). Artificial intelligence for spacecraft guidance, navigation, and control: a state-of-the-art. *Aerospace Systems*, 5(4), 503–521. <https://doi.org/10.1007/s42401-022-00152-y>
- Haddaji, A., Ayed, S., & Fourati, L. C. (2022). Artificial Intelligence techniques to mitigate cyber-attacks within vehicular networks: Survey. *Computers and Electrical Engineering*, 104. <https://doi.org/10.1016/j.compeleceng.2022.108460>
- Haenlein, M., & Kaplan, A. (2019). A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence. *SAGE Journals*, 5-14.
- Haeuplik-Meusburger, S., & Bannovab, O. (2023). Reflections on early lunar base design – From sketch to the first moon landing. *Acta Astronautica*, 202, 729-741. <https://doi.org/10.1016/j.actaastro.2022.09.021>
- Haex, T. (2020). *Dawn Aerospace Mk-III: An exploration of cost driven mission scenarios of a winged Two Stage to Orbit semi-Reusable Launch Vehicle integrated in the common airspace*. TuDelft. <http://resolver.tudelft.nl/uuid:1a3bcc22-4b92-41c1-ae21-55bf4de3d259>
- Harker, J. (2022, December 21). *Roomba hoover takes picture of woman on toilet which ends up being shared on Facebook*. Retrieved January 7, 2023, from Unilad: <https://www.unilad.com/technology/roomba-takes-picture-woman-facebook-905490-20221221>
- Harkin, L. J., & Kuss, D. (2021). “My smartphone is an extension of myself”: A holistic qualitative exploration of the impact of using a smartphone. *Psychology of Popular Media*, 10(1), 28-38. <https://doi.org/10.1037/ppm0000278>
- Harper, J. L. (2013). *The Cold War*. Oxford: Oxford University Press. <https://doi.org/ISBN:0199237018,9780199237012>

- Hashmi, A. W., Mali, H. S., Meena, A., Khilji, I. A., Hashmi, M. F., & Saffe, S. N. (2022). Machine vision for the measurement of machining parameters: A review. *Materials Today: Proceedings*, 56(4), 1939-1946. <https://doi.org/10.1016/j.matpr.2021.11.271>
- Hassan, A., Bhatti, S. H., Shujaat, S., & Hwang, Y. (2022). To adopt or not to adopt? The determinants of cloud computing adoption in information technology sector. *Decision Analytics Journal*, 5. <https://doi.org/10.1016/j.dajour.2022.100138>
- Heckel, J. (2023). Uses of Artificial Intelligence in Space Travel. 7. <https://doi.org/10.13140/RG.2.2.17381.17125>
- Heister, S. D., Anderson, W. E., Pourpoint, T. L., & Cassady, R. J. (2019). *Rocket Propulsion*. Cambridge University Press. <https://doi.org/10.1017/9781108381376>
- Hempsell, M. (2021). Space Transportation. *International Encyclopedia of Transportation*, 638-645. <https://doi.org/10.1016/B978-0-08-102671-7.10497-X>
- Hendrickx, B. (2022). Russia and Iran expand space cooperation. *The Space Review*. <https://www.thespacereview.com/article/4475/1>
- Hendrickx, B. (2022, December). The secret payloads of Russia's Glonass navigation satellites. *The Space Review*. The Space Review: <https://www.thespacereview.com/article/4502/1>
- Henson, G. (2019). Chapter 7: Materials for Launch Vehicle Structures. In B. N. Bhat, *Aerospace Materials and Applications* (pp. 435-504). <https://doi.org/10.2514/4.104893>
- Highfill, T. C., & MacDonald, A. C. (2022). Estimating the United States Space Economy Using Input-Output Frameworks. *Space Policy*, 60(101474). <https://doi.org/10.1016/j.spacepol.2021.101474>
- Hoffmann, C. H. (2022). Is AI intelligent? An assessment of artificial intelligence, 70 years after Turing. *Technology in Society*, 68. <https://doi.org/10.1016/j.techsoc.2022.101893>
- HOLLINGSWORTH, N. C. (2014). Small Satellite Launch to LEO: A Review of Current and Future Launch Systems . *TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUTICAL AND SPACE SCIENCES*, 12(29). https://doi.org/10.2322/tastj.12.Tf_39
- Holt, S. (2023). Virtual reality, augmented reality and mixed reality: For astronaut mental health; and space tourism, education and outreach. *Acta Astronautica*, 203, 436-446. <https://doi.org/10.1016/j.actaastro.2022.12.016>
- Horbulin, V., Shekhovtsov, V. S., & Shevtsov, A. (2018). Ukrainian-Canadian rocket and space complex "Zyklon-4M": ways of creation and expected results. 2(47). https://chtyvo.org.ua/authors/Shevtsov_Anatolii/Ukrainsko-kanadskyi_raketno-kosmichnyi_kompleks_Tsyklon-4M/
- Horton, J., Reynolds, C. B., Reynolds, C. B., Noble, R., & Morris, D. (2020). 43rd Annual AAS Guidance and Control Conference. *Gateway Logistics Services Using High TRL Advanced*

- Propulsion and Flight Proven ISS Cargo Elements*. Breckenridge.
https://www.researchgate.net/publication/344657842_Gateway_Logistics_Services_Using_High_TRL_Advanced_Propulsion_and_Flight_Proven_ISS_Cargo_Elements
- Hossein, S. H., Cimino, L., Rossetti, M., Zarcone, G., Mariani, L., Curianò, F., Bucciarelli, M., Seitzer, P., Santoni, F., Cecco, A. D., & Piergentili, F. (2022). Photometric characterization of Starlink satellite tracklets using RGB filters. *Advances in Space Research*.
<https://doi.org/10.1016/j.asr.2022.07.082>
- Hu, M., Bingjian, W., Wenbo, Z., Huiming, W., Gang, L., Jing, L., Gang, Y., & Yuan, Q. (2022). Self-driving shield: Intelligent systems, methodologies, and practice. *Automation in Construction*, 139. <https://doi.org/10.1016/j.autcon.2022.104326>
- Interstellar Technologies. (2023). *ZERO Microsatellite Launch Vehicle*. Interstellar Technologies:
<https://www.istellartech.com/launch/zero>
- iSpace. (2023). *Hyperbola-1*. iSpace: <http://www.i-space.com.cn/statics/ispace/doc/Hyperbola-1%20User%20Manual.pdf>
- Jaeger, S. (2022). Ambiguous Narratives of World War Technologies in Contemporary Military History Museums. *Journal of Educational Media, Memory, and Society*, 14(1), 33-54.
<https://doi.org/10.3167/jemms.2022.140103>
- Jakhu, R. S., Pelton, J. N., & Nyampong, Y. O. (2017). *Space Mining and Its Regulation*. Springer Cham. <https://doi.org/10.1007/978-3-319-39246-2>
- Javaid, M., Haleem, A., Singh, R. P., Rab, S., Suman, R., & Khan, I. H. (2022). Evolutionary trends in progressive cloud computing based healthcare: Ideas, enablers, and barriers. *International Journal of Cognitive Computing in Engineering*, 3, 124-135.
<https://doi.org/10.1016/j.ijcce.2022.06.001>
- Jiang, X., Li, S., & Furfaro, R. (2019). Integrated guidance for Mars entry and powered descent using reinforcement learning and pseudospectral method. *Acta Astronautica*, 163, 114-129. <https://doi.org/10.1016/j.actaastro.2018.12.033>
- Jiwei, Q., & Bojian, L. (2020). *China's Space Industry: Background, Recent Developments and Challenges*. East Asian Institute, National University of Singapore.
- Jo, B.-U., & Ahn, J. (2022). Optimal staging of reusable launch vehicles for minimum life cycle cost. *Aerospace Science and Technology*, 127.
<https://doi.org/10.1016/j.ast.2022.107703>
- Jones, H. W. (2018). The Recent Large Reduction in Space Launch Cost. *48th International Conference on Environmental Systems*, 10. <http://hdl.handle.net/2346/74082>

- Joshua, J. (2017, March). Information Bodies: Computational Anxiety in Neal Stephenson's *Snow Crash*. *Interdisciplinary Literary Studies*, 19(1), 17-47. <https://doi.org/10.5325/intelitestud.19.1.0017>
- Kak, A., & Akyildiz, I. F. (2021). Designing Large-Scale Constellations for the Internet of Space Things With CubeSats. *IEEE Internet of Things Journal*, 8(3), 1749-1768. <https://doi.org/10.1109/JIOT.2020.3016889>
- Kaplan, A., & Haenlein, M. (2019). Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons*, 62(1), 15-25. <https://doi.org/10.1016/j.bushor.2018.08.004>
- Kardong-Edgren, S. (., Farra, S. L., Alinier, G., & Young, H. M. (2019). A Call to Unify Definitions of Virtual Reality. *Clinical Simulation in Nursing*, 31, 28-34. <https://doi.org/10.1016/j.ecns.2019.02.006>
- Karhade, A. V., & Schwab, H. J. (2021). Introduction to The Spine Journal special issue on artificial intelligence and machine learning. *The Spine Journal*, 21(10), 1601-1603. <https://doi.org/10.1016/j.spinee.2021.03.028>
- Kaushik, S., Jain, A., Chaudhary, T., & Chauhan, N. (2022). Machine vision based automated inspection approach for clutch friction disc (CFD). *Materials Today: Proceedings*, 62(1), 151-157. <https://doi.org/10.1016/j.matpr.2022.02.610>
- Keller, S., & Collopy, P. (2013). Value Modeling for a Space Launch System. *Procedia Computer Science*, 16, 1152-1160. <https://doi.org/10.1016/j.procs.2013.01.121>
- Kellner, J. (2022, November 17). *Precious Payload and Rocket Factory partner to offer upcoming RFA launches from Europe online via Launch.ctrl platform*. RFA Rocket Factory: <https://www.rfa.space/precious-payload-and-rocket-factory-partner-to-offer-upcoming-rfa-launches-from-europe-online-via-launch-ctrl-platform/>
- Khan, T., Tian, W., Zhou, G., Ilager, S., Gong, M., & Buyya, R. (2022). Machine learning (ML)-centric resource management in cloud computing: A review and future directions. *Journal of Network and Computer Applications*, 204, 1084-8045. <https://doi.org/10.1016/j.jnca.2022.103405>
- Kharchenko, V., Illiashenko, O., Fesenko, H., & Babeshko, I. (2022). AI Cybersecurity Assurance for Autonomous Transport Systems: Scenario, Model, and IMECA-Based Analysis. *Communications in Computer and Information Science*, 1689, 66-79. https://doi.org/10.1007/978-3-031-20215-5_6
- Kikuchi, S., Howell, K. C., Tsuda, Y., & Kawaguchi, J. (2017). Orbit-attitude coupled motion around small bodies: Sun-synchronous orbits with Sun-tracking attitude motion. *Acta Astronautica*, 140, 34-48. <https://doi.org/10.1016/j.actaastro.2017.07.043>

- Kim, J.-H., Moon, D.-K., Lee, D.-W., Kim, J.-s., Kang, M.-C., & Kim, K. H. (2002). Tool wear measuring technique on the machine using CCD and exclusive jig. *Journal of Materials Processing Technology*, 130-131, 668-674. [https://doi.org/10.1016/S0924-0136\(02\)00733-1](https://doi.org/10.1016/S0924-0136(02)00733-1)
- Ko, J., & Cho, S. Y. (2016). Space Launch Vehicle Development in Korea Aerospace Research Institute. *SpaceOps - AIAA*. <https://doi.org/10.2514/6.2016-2530>
- Koch, A. D. (2019). Optimal staging of serially staged rockets with velocity losses and fairing separation. *Aerospace Science and Technology*, 88, 65-72. <https://doi.org/10.1016/j.ast.2019.03.019>
- Kok, D. L., Dushyanthen, S., Peters, G., Sapkaroski, D., Barrett, M., Sim, J., & Eriksen, J. G. (2022). Virtual reality and augmented reality in radiation oncology education – A review and expert commentary. *Technical Innovations & Patient Support in Radiation Oncology*, 24, 25-31. <https://doi.org/10.1016/j.tipsro.2022.08.007>
- Kossiakoff, A., Biemer, S. M., Seymour, S. J., & Flanigan, D. A. (2020). *Systems Engineering Principles and Practice* (3 ed.). John Wiley & Sons.
- Kothari, C. R. (2004). *Research methodology methods & techniques*. New Age International Publishers.
- Kounoudes, A. D., & Kapitsaki, G. M. (2020). A mapping of IoT user-centric privacy preserving approaches to the GDPR. *Internet of Things*, 11. <https://doi.org/10.1016/j.iot.2020.100179>
- Kulu, E. (2021). Small Launchers - 2021 Industry Survey and Market Analysis. *International Astronautical Congress*.
- Kuntanapreeda, S. (2021). Opening Access to Space by Maximizing Utilization of 3D Printing in Launch Vehicle Design and Production. *Applied Science and Engineering Progress*, 14(2), 143–145. <https://doi.org/10.14416/j.asep.2020.12.002>
- Kurzweil, R. (2014). The Singularity Is Near. *Ethics and Emerging Technologies*, 393-406. https://doi.org/10.1057/9781137349088_26
- Kwak, H.-D., Kwon, S., & Choi, C.-H. (2018). Performance assessment of electrically driven pump-fed LOX/kerosene cycle rocket engine: Comparison with gas generator cycle. *Aerospace Science and Technology*, 77, 67-82. <https://doi.org/10.1016/j.ast.2018.02.033>
- Kwang, K. G. (2016). Deep Learning. *Healthc Inform Res*, 22(4), 2093-3681. <https://doi.org/10.4258/hir.2016.22.4.351>
- Lafleur, T. (2022). Evaluation of solid-core thermal antimatter propulsion concepts. *Acta Astronautica*, 191, 417-430. <https://doi.org/10.1016/j.actaastro.2021.10.045>

- Langley, D. J., Doorn, J. v., Ng, I. C., Stieglitz, S., Lazovik, A., & Boonstra, A. (2021). The Internet of Everything: Smart things and their impact on business models. *Journal of Business Research*, 122, 853-863. <https://doi.org/10.1016/j.jbusres.2019.12.035>
- Latitude. (2023). *Say hello to Zephyr*. Latitude: <https://www.latitude.eu/zephyr>
- LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, 521, 436-444. <https://doi.org/10.1038/nature14539>
- Lee, J. H., Shin, J., & Realff, M. J. (2018). Machine learning: Overview of the recent progresses and implications for the process systems engineering field. *Computers & Chemical Engineering*, 114, 111-121. <https://doi.org/10.1016/j.compchemeng.2017.10.008>
- Lee, J., & Kundu, P. (2022). Integrated cyber-physical systems and industrial metaverse for remote manufacturing. *Manufacturing Letters*, 34, 12-15. <https://doi.org/10.1016/j.mfglet.2022.08.012>
- Leslie, M. (2022). Space Tourism Begins to Take Off. *Engineering*, 10, 4-6. <https://doi.org/10.1016/j.eng.2022.01.005>
- Li, Y., FANG, J., Sun, B., LI, K., & Cai, G. (2021). Index allocation for a reusable LOX/CH₄ rocket engine. *Chinese Journal of Aeronautics*, 34(2), 432-440. <https://doi.org/10.1016/j.cja.2020.04.017>
- Lima, B., Kim, C., Lee, K.-O., Lee, K., Park, J., Ahn, K., Namkoun, H.-J., & Yoon, Y. (2021). Development Trends of Liquid Methane Rocket Engine and Implications. *Journal of the Korean Society of Propulsion Engineers*, 25(2), 119-143. <https://doi.org/10.6108/KSPE.2021.25.2.119>
- Liu, C., Hirota, K., & Dai, Y. (2023). Patch attention convolutional vision transformer for facial expression recognition with occlusion. *Information Sciences*, 619, 781-794. <https://doi.org/10.1016/j.ins.2022.11.068>
- Liu, S., Liu, J., Wang, H., & Xian, M. (2020). Research on the Development of Cloud Computing. *2020 International Conference on Computer Information and Big Data Applications (CIBDA)*, 212-215. <https://doi.org/10.1109/CIBDA50819.2020.00055>
- Liu, Y., Bao, R., Tao, J., Li, J., Dong, M., & Pan, C. (2020). Recent progress in tactile sensors and their applications in intelligent. *Science Bulletin*, 65(1), 70-88. <https://doi.org/10.1016/j.scib.2019.10.021>
- Liu, Z., Liu, Q., Xu, W., Wang, L., & Zhou, Z. (2022). Robot learning towards smart robotic manufacturing: A review. *Robotics and Computer-Integrated Manufacturing*, 77. <https://doi.org/10.1016/j.rcim.2022.102360>
- Louder, T. (2022, December 21). *The Sun*. Retrieved January 7, 2023, from Robot vacuum snapped photos of woman on toilet – and then they were shared on Facebook:

- <https://www.the-sun.com/tech/6966370/robot-vacuum-photographs-woman-on-toilet-shares-to-facebook/>
- Lucabon. (2018, February 7). *Falcon9 rocket family*. Wikimedia Commons: https://commons.wikimedia.org/wiki/File:Falcon9_rocket_family.svg
- Lv, Z., Marfia, G., Poiesi, F., Vaughan, N., & Shen, J. (2022). Virtual-reality and intelligent hardware in Digital Twins. *Virtual Reality & Intelligent Hardware*, 4(6). <https://doi.org/10.1016/j.vrih.2022.12.002>
- Maender, C., Aspiotis, J., Clemens, R., Gupta, A., Panchanathan, D., Zuniga, D., & Stoudemire, J. (2022). Beyond the ISS : The World's First Commercial Space Station. In *In-Space Manufacturing and Resources: Earth and Planetary Exploration Applications* (pp. 319-337). John Wiley & Sons, Ltd. <https://doi.org/10.1002/9783527830909.ch17>
- Magnani, L. (2022). *Eco-Cognitive Computationalism* (Vol. 43). Pavia, Italy: Springer. <https://doi.org/10.1007/978-3-030-81447-2>
- Mahesh, B. (2020). Machine Learning Algorithms -A Review. *International Journal of Science and Research*, 9(1), 6. <https://doi.org/10.21275/ART20203995>
- Maiwald, V. (2023). Frameworks of sustainability and sustainable development in a spaceflight context: A systematic review and critical analysis. *Acta Astronautica*, 204, 455-465. <https://doi.org/10.1016/j.actaastro.2023.01.023>
- Malik, M. I., Wani, S. H., & Rashid, A. (2018). CLOUD COMPUTING-TECHNOLOGIES. *International Journal of Advanced Research in Computer Science*, 6(2), 6. <https://doi.org/10.26483/ijarcs.v9i2.5760>
- Mani, S., Dadhwal, V., & Shaijumon, C. (2022). India's Space Economy, 2011–12 to 2020–21: Its Size and Structure. *Space Policy*. <https://doi.org/10.1016/j.spacepol.2022.101524>
- Mantelero, A., & Vaciago, G. (2015). Data protection in a big data society. Ideas for a future regulation. *Digital Investigation*, 15, 104-109. <https://doi.org/10.1016/j.diin.2015.09.006>
- Masahiro Ono, B. R. (2022). Chapter 9 - Machine learning for planetary rovers. In M. D. Joern Helbert, *Machine Learning for Planetary Science* (pp. 169-191). Elsevier. <https://doi.org/10.1016/B978-0-12-818721-0.00019-7>
- Mason, B. P., & Roland, C. M. (2019). SOLID PROPELLANTS. *RUBBER CHEMISTRY AND TECHNOLOGY*, 92(1), 1-24. <https://doi.org/10.5254/rct.19.80456>
- MatthewSparkes. (2022). AI art tool covertly alters requests. *New Scientist*, 255(3397), 10. [https://doi.org/10.1016/S0262-4079\(22\)01329-X](https://doi.org/10.1016/S0262-4079(22)01329-X)
- Mazzucato, M., & Robinson, D. K. (2018). Co-creating and directing Innovation Ecosystems? NASA's changing approach to public-private partnerships in low-earth orbit.

- Technological Forecasting and Social Change*, 136, 166-177.
<https://doi.org/10.1016/j.techfore.2017.03.034>
- McCarthy, J. (1958). Programs with common sense. In *Proceedings of the symposium on mechanisation*, 77-84.
- McConnaughe, P. K., M. G., Koelfgen, S. J., & Lepsch, R. A. (2012). NASA's Launch Propulsion Systems Technology Roadmap. *Space Propulsion*. Bordeaux.
<https://ntrs.nasa.gov/api/citations/20120014957/downloads/20120014957.pdf>
- McCourt, D. M., & Mudge, S. L. (2022). Anything but Inevitable: How the Marshall Plan Became Possible. *Politics and Society*. <https://doi.org/10.1177/00323292221094084>
- McDowell, J. (2022). *Space Activities in 2021*. Jonathan McDowell.
- Melley, L. E., & Sataloff, R. (2022). Beyond the Buzzwords: Artificial Intelligence in Laryngology. *Journal of Voice*, 36(1), 2-3. <https://doi.org/10.1016/j.jvoice.2021.03.001>
- Melo, C. M., Torralba, A., Guibas, L., DiCarlo, J., Chellappa, R., & Hodgins, J. (2022). Next-generation deep learning based on simulators and synthetic data. *Trends in Cognitive Sciences*, 26(2), 174-187. <https://doi.org/10.1016/j.tics.2021.11.008>
- Mills, C., & Butchard, P. (2021). *The militarisation of space*. House of Commons Library.
<https://commonslibrary.parliament.uk/research-briefings/cbp-9261/>
- Mitchell, T. M. (1997). *Machine Learning*. McGraw-Hill Science/Engineering/Math.
<https://doi.org/ISBN: 0070428077>
- Molina, M. (2022). What is an intelligent system? *arxiv*.
<https://doi.org/10.48550/arXiv.2009.09083>
- Moor, J. (2006). The Dartmouth College Artificial Intelligence Conference: The Next Fifty Years. *AI Magazine*, 27(4). <https://doi.org/https://doi.org/10.1609/aimag.v27i4.1911>
- Morgado, F. M., Marta, A. C., & Gil, P. J. (2022). Multistage rocket preliminary design and trajectory optimization using a multidisciplinary approach. *Structural and Multidisciplinary Optimization*, 65(192). <https://doi.org/10.1007/s00158-022-03285-y>
- Morrison, C. (2021). Nuclear Electric Propulsion for Rapid Transportation Within the Solar System. *Encyclopedia of Nuclear Energy*, 321-342. <https://doi.org/10.1016/B978-0-12-819725-7.00137-9>
- Mowry, C., & Grasso, M. (2020). The Evolution of Medium/Heavy-Lift and Reusable Launch Vehicles and Its Implications for Smallsat Access to Space. In J. N. Pelton, & S. Madry, *Handbook of Small Satellites: Technology, Design, Manufacture, Applications, Economics and Regulation*" (pp. 469-477). Springer International Publishing.
https://doi.org/10.1007/978-3-030-36308-6_92

- Muir-Harmony, T. (2017). The Space Race and American Foreign Relations. *Oxford Research Encyclopedia of American History*, 25. <https://doi.org/10.1093/acrefore/9780199329175.013.274>
- N., N. (2021). *Policies Governing Space Start-Ups in India - Legal Issues and Challenges*. ResearchGate. <https://doi.org/10.13140/RG.2.2.33938.38081>
- Naved, M., Sanchez, D. T., Cruz, A. P., Peconcillo, L. B., Peteros, E. D., & Tenerife, J. J. (2022). Identifying the role of cloud computing technology in management of educational institutions. *Materials Today: Proceedings*, 51(8), 2309-2312. <https://doi.org/10.1016/j.matpr.2021.11.414>
- Nazarenko, A., & Usovik, I. (2022). Space debris in low earth orbits region: Formation and reduction process analysis in past decade. *Acta Astronautica*, 194, 383-389. <https://doi.org/10.1016/j.actaastro.2021.12.001>
- Nebylov, A. V., Nebylov, V. A., & Panferov, A. I. (2022). The concept of winged space vehicle marine horizontal landing by docking with ekranoplane. *Acta Astronautica*. <https://doi.org/10.1016/j.actaastro.2022.09.004>
- NewSpace . (2023). *HyImpulse* - SL1. NewSpace : <https://www.newspace.im/launchers/hyimpulse>
- Newspace. (2023). *STAR Orbitals* - Phoenix. Newspace: <https://www.newspace.im/launchers/star-orbitals>
- Niederstrasser, C. (2021). Small Launchers in a Pandemic World - 2021 Edition of the Annual Industry Survey. *Small Satellite Conference*. Logan. <https://digitalcommons.usu.edu/smallsat/2021/all2021/162/>
- Niederstrasser, C. (2022). A Small Launch Per Month? - 2022 Edition of the Annual Industry Survey. *Small Satellite Conference*. <https://digitalcommons.usu.edu/smallsat/2022/all2022/122/>
- Niederstrasser, C. G. (2022). The small launch vehicle survey a 2021 update (The rockets are flying). *Journal of Space Safety Engineering*, 9(3), 341-354. <https://doi.org/10.1016/j.jsse.2022.07.003>
- Niederstrasser, C., & Frick, W. (2015). Small Launch Vehicles – A 2015 State of the Industry Survey. *Small Satellite Conference*. Dulles. <https://digitalcommons.usu.edu/smallsat/2015/all2015/12/>
- Nikitin, V. F., Karandashev, I., Malsagov, M. Y., & Mikhilchenko, E. (2022). Approach to combustion calculation using neural network. *Acta Astronautica*, 194, 376-382. <https://doi.org/10.1016/j.actaastro.2021.10.034>

- Oche, P. A., Ewa, G. A., & Ibekwe, N. (2021). Applications and Challenges of Artificial Intelligence in Space Missions. *IEEE Access*, 1. <https://doi.org/10.1109/ACCESS.2021.3132500>
- Ogunseiju, O. R., Gonsalves, N., Akanmu, A. A., Bairaktarova, D., Bowman, D. A., & Jazizadeh, F. (2022). Mixed reality environment for learning sensing technology applications in Construction: A usability study. *Advanced Engineering Informatics*, 53. <https://doi.org/10.1016/j.aei.2022.101637>
- Okninski, A., Kopacz, W., Kaniewski, D., & Sobczak, K. (2021). Hybrid rocket propulsion technology for space transportation revisited - propellant solutions and challenges. *FirePhysChem*, 1(4), 260-271. <https://doi.org/10.1016/j.fpc.2021.11.015>
- Oleksy, T., Wnuk, A., & Piskorska, M. (2023). Migration to the metaverse and its predictors: Attachment to virtual places and metaverse-related threat. *Computers in Human Behavior*, 141. <https://doi.org/10.1016/j.chb.2022.107642>
- Orbex. (n.d.). *Orbex Prime*. Orbex: <https://orbex.space/launch-vehicle>
- Orienspace. (2023). "Gravity" series launch vehicles. Orienspace: <https://www.orienspace.com/productPage>
- Osoro, B., & Oughton, E. (2022). Universal Broadband Assessment of Low Earth Orbit Satellite Constellations: Evaluating Capacity, Coverage, Cost, and Environmental Emissions. *SSRN*, 30. <https://doi.org/10.2139/ssrn.4178732>
- Oussous, A., Benjelloun, F.-Z., Lahcen, A. A., & Belfkih, S. (2018). Big Data technologies: A survey. *Journal of King Saud University - Computer and Information Sciences*, 30(4), 431-448. <https://doi.org/10.1016/j.jksuci.2017.06.001>
- Pace, S. (2022). Alternative futures for crewed space cooperation after the international space station. *Journal of Space Safety Engineering*. <https://doi.org/10.1016/j.jsse.2022.11.002>
- Pallathadka, H., Sajja, G. S., Phasinam, K., Ritonga, M., Naved, M., Bansal, R., & Quiñonez-Choquecota, J. (2022). An investigation of various applications and related challenges in cloud computing. *Materials Today: Proceedings*, 51(8), 2245-2248. <https://doi.org/10.1016/j.matpr.2021.11.383>
- Pangea Aerospace. (2018). *Pangea Aerospace - Launch Vehicles for small satellites (payload capacity up to 150kg), wich provide affordable access to space tailored to the micro/nano satellite market*. Cordis. <https://doi.org/10.3030/828301>
- Paolo Lunghi, P. D. (2022). Semi-analytical adaptive guidance computation for autonomous planetary landing. *Acta Astronautica*, 195, 265-275. <https://doi.org/10.1016/j.actaastro.2022.03.005>

- Park, J. J., Park, M., Jackson, K., & Vanhoy, G. (2020). Remote Engineering Education under COVID-19 Pandemic Environment. *International Journal of Multidisciplinary Perspectives in Higher Education*, 5(1), 16-166. <https://doi.org/ISSN-2474-2546>
- Patane, S., Joyce, E. R., Snyder, M. P., & Shestople, P. (2017). Archinaut: In-Space Manufacturing and Assembly for Next-Generation Space Habitats. *AIAA SPACE and Astronautics Forum and Exposition*. <https://doi.org/10.2514/6.2017-5227>
- Pedro, O.-C., Guilherme, R., Carlos, U., Uxia, G.-L., Pablo, R., & Fernando, A.-A. (2022). Optimization of the Conceptual Design of a Multistage Rocket Launcher. *Aerospace* 2022, 9(6). <https://doi.org/10.3390/aerospace9060286>
- Peeters, W. (2021). Evolution of the Space Economy: Government Space to Commercial Space and New Space. *The International Journal of Space Politics & Policy*, 19(3), 206-222. <https://doi.org/10.1080/14777622.2021.1984001>
- Pelton, J. N. (2019). The Longer Term Future of Launch and Propulsion Systems. *Space 2.0*, 1(11), 145-155. https://doi.org/10.1007/978-3-030-15281-9_11
- Pelton, J. N. (2023). Small Satellites: Glossary of Terms and Listing of Acronyms. In S. M. Joseph N. Pelton, *Handbook of Small Satellites* (pp. 1–26). Springer. https://doi.org/10.1007/978-3-030-20707-6_86-1
- Perigee. (2023). *OUR MISSION*. Perigee: <https://perigee.space/mission/>
- Pfeiffer, J., Rücklé, A., Poth, C., Kamath, A., Vulić, I., Ruder, S., Cho, K., & Gurevych, I. (2020). AdapterHub: A Framework for Adapting Transformers. *Systems Demonstrations*. <https://doi.org/10.48550/arXiv.2007.07779>
- Phen, A. (2022). *The realization of a study on the current*. <https://www.diva-portal.org/smash/get/diva2:1715413/FULLTEXT01.pdf>
- Pillai, A. S. (2022). *Introduction to Rocket Science and Space Exploration*. CRC Press. <https://doi.org/10.1201/9781003323396>
- Platt, C. A., Jason, M., & Sullivan, C. J. (2020). Public Perceptions of Private Space Initiatives: How Young Adults View the SpaceX Plan to Colonize Mars. *Space Policy*, 51. <https://doi.org/10.1016/j.spacepol.2019.101358>
- Powell, G. L. (2022). Brave New Worlds? *The Engineer*, 302(7929). [https://doi.org/10.12968/S0013-7758\(22\)90546-X](https://doi.org/10.12968/S0013-7758(22)90546-X)
- Precedence Research. (2022). *Cloud Computing Market Size to Surpass USD 1,614.10 BN by 2030*. Precedence Research. <https://www.precedenceresearch.com/cloud-computing-market>
- Python Space. (2023). *Eiger Rocket*. Python: <https://www.pythomspace.com/eiger>

- Qian, J., & Liu, B. (2020). *China's Space Industry: Background, Recent Developments and Challenges*. <https://research.nus.edu.sg/eai/wp-content/uploads/sites/2/2021/08/EAIBB-No.-1571-Chinas-space-industry-2.pdf>
- Rajotte, J.-F., Bergen, R., Buckeridge, D. L., Emam, K. E., Ng, R., & Strome, E. (2022). Synthetic data as an enabler for machine learning applications in medicine. *iScience*, 25(11). <https://doi.org/10.1016/j.isci.2022.105331>
- Ramkumar, P. N., Pang, M., Polisetty, T., Helm, M., & Karnuta, J. (2022). Meaningless Applications and Misguided Methodologies in Artificial Intelligence–Related Orthopaedic Research Propagates Hype Over Hope. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 38(9), 2761-2766. <https://doi.org/10.1016/j.arthro.2022.04.014>
- Rauschnabel, P. A., Babin, B. J., Dieck, M. C., Krey, N., & Jung, T. (2022). What is augmented reality marketing? Its definition, complexity, and future. *Journal of Business Research*, 142. <https://doi.org/10.1016/j.jbusres.2021.12.084>
- Ravikumar, K., Chiranjeevi, P., Devarajan, N. M., Kaur, C., & Taloba, A. I. (2022). Challenges in internet of things towards the security using deep learning techniques. *Measurement: Sensors*, 24. <https://doi.org/10.1016/j.measen.2022.100473>
- Rekha, S., Thirupathi, L., Renikunta, S., & Gangula, R. (2021). Study of security issues and solutions in Internet of Things (IoT). *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2021.07.295>
- Robinson, D. K., & Mazzucato, M. (2019). The evolution of mission-oriented policies: Exploring changing market creating policies in the US and European space sector. *Research Policy*, 48(4), 936-948. <https://doi.org/10.1016/j.respol.2018.10.005>
- Rohini, D., Sasikumar, C., Samiyappan, P., Dakshinamurthy, B., & Koppula, N. (2022). Design & analysis of solid rocket using open rocket software. *Materials Today: Proceedings*, 64(1), 425-430. <https://doi.org/10.1016/j.matpr.2022.04.787>
- Rolley, R., Potter, R., Zusack, S., & Saikia, S. (2017). Life Cycle Cost Estimation of Conceptual Human Spaceflight Architectures. *AIAA SPACE and Astronautics Forum and Exposition*. <https://doi.org/10.2514/6.2017-5257>
- Rutishauser, D., Ramadorai, R., Prothro, J., Fleming, T., & Fidelman, P. (2021). Nasa and blue origin collaborative assessment of precision landing algorithms and computing. *AIAA Scitech 2021 Forum*, 1-11.
- Sabbagh, M. S., Maher, A., Abozied, M. A., & Kamel, A. M. (2023). Promoting navigation system efficiency during GPS outage via cascaded neural networks: A novel AI based approach. *Mechatronics*, 94. <https://doi.org/10.1016/j.mechatronics.2023.103026>

- Saccani, L. (2020). The Dream Chaser Spacecraft: Changing the Way the World Goes to Space. In S. Ferretti, *Space Capacity Building in the XXI Century* (pp. 123–128). Springer, Cham. https://doi.org/10.1007/978-3-030-21938-3_11
- Saibene, A., Assale, M., & Giltri, M. (2021). Expert systems: Definitions, advantages and issues in medical field applications. *Expert Systems With Applications*, 177. <https://doi.org/10.1016/j.eswa.2021.114900>
- Salam, A. F., Pervez, S., & Nahar, S. (2022). Trust in AI and Intelligent Systems: Central Core of the Design of Intelligent Systems. *AMCIS 2021 Proceedings*.
- Salotti, J.-M. (2022). Launcher size optimization for a crewed Mars mission. *Acta Astronautica*, 191, 235-244. <https://doi.org/10.1016/j.actaastro.2021.11.016>
- Samuel, A. L. (1959). Some Studies in Machine Learning Using the Game of Checkers. *IBM Journal of Research and Development*, 3(3), 210-229. <https://doi.org/10.1147/rd.33.0210>
- Schatten, M., Ševa, J., & Tomičić, I. (2016). A roadmap for scalable agent organizations in the Internet of Everything. *Journal of Systems and Software*, 115, 31-41. <https://doi.org/10.1016/j.jss.2016.01.022>
- Seedhouse, E. (2017). Spacecraft and Launch Vehicles. In E. Seedhouse, *Spaceports Around the World, A Global Growth Industry* (pp. 59–72). Springer, Cham. https://doi.org/10.1007/978-3-319-46846-4_5
- Seedhouse, E. (2022). *SpaceX - Starship to Mars – The First 20 Years*. Praxis Cham. <https://doi.org/10.1007/978-3-030-99181-4>
- Semyonov, O. G. (2018). Pros and cons of relativistic interstellar flight. *Acta Astronautica*, 151, 736-742. <https://doi.org/10.1016/j.actaastro.2018.07.012>
- Sergio Pérez-Roca, J. M.-L., Langlois, N., Farago, F., Galeotta, M., & Gonidec, S. L. (2019). A survey of automatic control methods for liquid-propellant rocket engines. *Progress in Aerospace Sciences*, 107, 63-84. <https://doi.org/10.1016/j.paerosci.2019.03.002>
- Shakhovska, N. (2017). *Advances in Intelligent Systems and Computing*. Springer Cham. <https://doi.org/10.1007/978-3-319-45991-2>
- Shamima, A., Muneer, M. A., Anis, E., & Helmi, H. (2022). Artificial intelligence and machine learning in finance: A bibliometric review. *Research in International Business and Finance*, 61. <https://doi.org/10.1016/j.ribaf.2022.101646>
- Sharafi, M., Rahbar, N., Moharrampour, A., & Kashaninia, A. (2022). Performance Analysis of the Vectorized High Order Expansions Method in the Accurate Landing Problem of Reusable Boosters. *Advances in Space Research*. <https://doi.org/10.1016/j.asr.2022.10.057>

- Shengli Jiang, Y. Z. (2021). China's National Space Station: Opportunities, Challenges, and Solutions for International Cooperation. *Space Policy*, 57. <https://doi.org/10.1016/j.spacepol.2021.101439>
- Shirazi, A., Generio, J., & Lozano, J. (2022). Trajectory optimization of space vehicle in rendezvous proximity operation. *Engineering Applications of Artificial Intelligence*, 117. <https://doi.org/10.1016/j.engappai.2022.105523>
- Shirvani, M. H., & Masdari, M. (2023). A survey study on trust-based security in Internet of Things: Challenges and issues. *Internet of Things*, 21. <https://doi.org/10.1016/j.iot.2022.100640>
- Shuai, H., Li, F., She, B., Wang, X., & Zhao, J. (2023). Post-storm repair crew dispatch for distribution grid restoration using stochastic Monte Carlo tree search and deep neural networks. *International Journal of Electrical Power & Energy Systems*, 144. <https://doi.org/10.1016/j.ijepes.2022.108477>
- Shute, V. J., Fulwider, G. C., Liu, Z., & Rahimi, S. (2023). Machine learning. (R. J. Tierney, F. Rizvi, & K. Ercikan, Eds.) *International Encyclopedia of Education (Fourth Edition)*, 83-91. <https://doi.org/10.1016/B978-0-12-818630-5.14013-8>
- Siddiqi, A. A. (2009). Germans in Russia: Cold War, Technology Transfer, and National Identity. *Osiris*, 24(1), 120-143. <https://doi.org/10.1086/605972>
- Singh, J., Singh, G., & Verma, A. (2022). The Anatomy of Big Data: Concepts, Principles. 8th *International Conference on Advanced Computing and Communication Systems* (pp. 986-990). Coimbatore: Institute of Electrical and Electronics Engineers Inc. <https://doi.org/10.1109/ICACCS54159.2022.9785082>
- Sinha, A., Garg, N., Singh, N., Kumar, B., Banerjee, P., & Verma, A. K. (2022). Space robotics hybrid conceptual model for tracking and estimation using IoRT and AI-based control system. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2022.09.099>
- Sippel, M., Stappert, S., & Koch, A. (2019). Assessment of multiple mission reusable launch vehicles. *Journal of Space Safety Engineering*, 6(3), 165-180. <https://doi.org/10.1016/j.jsse.2019.09.001>
- Sippel, M., Trivailo, O., Bussler, L., Lipp, S., & Valluchi, C. (2016). Evolution of the SpaceLiner towards a Reusable TSTO-Launcher. *International Astronautical Congress 2016*.
- Skog, I., Wahlberg, B., Larson, R., Bodin, P., & Rathsmann, P. (2019). GNSS ISL Based Navigation of Satellites in Geotransfer Orbits. 2019 *IEEE International Conference on Signal, Information and Data Processing (ICSIDP)*, 1-5. <https://doi.org/10.1109/ICSIDP47821.2019.9173154>

- Skyroot Aerospace. (2023). *VIKRAM Series*. Skyroot Aerospace: <https://skyroot.in/launch-services.html>
- Skyrora. (2023). *Skyrora Accompanying file*. Skyrora: <https://bold-awards.com/wp-content/uploads/2020/01/Skyrora-Accompanying-file-for-the-BOLD-Awards.pdf>
- Slayton, R. (2019). Our Germans: Project Paperclip and the National Security State. *Journal of American History*, 105(4), 1078-1079. <https://doi.org/10.1093/jahist/jaz133>
- Smirnov, N. (2020). Supercomputing and artificial intelligence for ensuring safety of space. *Acta Astronautica*, 176, 576-579. <https://doi.org/10.1016/j.actaastro.2020.06.025>
- Smith, M., Craig, D., Herrmann, N., Mahoney, E., Krezel, J., McIntyre, N., & Goodliff, K. (2020). The Artemis Program: An Overview of NASA's Activities to Return Humans to the Moon. 2020 IEEE Aerospace Conference, 1-10. <https://doi.org/10.1109/AERO47225.2020.9172323>
- Smith, M., Marsh, D., Cichan, T., & Bobby Biggs, N. B. (2021). Free-Flying StarLabs as Platforms for In-Space Developmental Test. AIAA SCITECH 2022 Forum. <https://doi.org/10.2514/6.2022-2515>
- Smith, P. M. (2018). A Review of the Competitive Space Transportation Industry, from Provider Options to Customer Needs. 2018 AIAA SPACE and Astronautics Forum and Exposition. <https://doi.org/10.2514/6.2018-5238>
- Song, D.-W. (2021). What is research? *WMU Journal of Maritime Affairs*, 20, 407-411. <https://doi.org/10.1007/s13437-021-00256-w>
- Song, L., Fei, W., Xin, L., & Qichuan, S. (2022). Development and validation of a confined space rescue training prototype based on an immersive virtual reality serious game. *Advanced Engineering Informatics*, 51. <https://doi.org/10.1016/j.aei.2021.101520>
- Soon-Young Park, J. A. (2020). Deep neural network approach for fault detection and diagnosis during startup transient of liquid-propellant rocket engine. *Acta Astronautica*, 177, 714-730. <https://doi.org/10.1016/j.actaastro.2020.08.019>
- Spinlaunch. (n.d.). *Space Systems*. Spinlaunch: <https://www.spinlaunch.com/>
- Stappert, S., & Sippel, J. W. (2018). Evaluation of European Reusable VTVL Booster Stages. AIAA SPACE and Astronautics Forum and Exposition. <https://doi.org/10.2514/6.2018-5239>
- Stappert, S., Wilken, J., Bussler, L., & Sippel, M. (2019). A Systematic Comparison of Reusable First Stage Return. 8TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS). <https://doi.org/10.13009/EUCASS2019-438>
- Statista, Seagate, IDC. (2022, September 8). *Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2020, with forecasts from 2021 to 2025*. Statista: <https://www.statista.com/statistics/871513/worldwide-data-created/>

- Steil, B. (2019). *The Marshall Plan - Dawn of the Cold War*. Simon & Schuster.
[https://doi.org/ISBN 9781501102370](https://doi.org/ISBN%209781501102370)
- Stergiou, C. L., & Psannis, K. E. (2022). Digital Twin Intelligent System for Industrial IoT-based Big Data Management and Analysis in Cloud. *Virtual Reality & Intelligent Hardware*, 4(4), 279-291. <https://doi.org/10.1016/j.vrih.2022.05.003>
- Stergiou, C., Psannis, K. E., Gupta, B. B., & Ishibashi, Y. (2018). Security, Privacy and Efficiency of Sustainable Cloud Computing for Big Data & IoT. *Sustainable Computing: Informatics and Systems*, 19, 174-184. <https://doi.org/10.1016/j.suscom.2018.06.003>
- Sun, Y. (2022). Proceedings of the 2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022). *Small Commercial Launch Vehicle Industry Analysis*. Atlantis Press. <https://doi.org/10.2991/aebmr.k.220307.138>
- Sun, Y. (2022). Small Commercial Launch Vehicle Industry Analysis. *International Conference on Financial Innovation and Economic Development*, 2352-5428. <https://doi.org/10.2991/aebmr.k.220307.138>
- Suszyński, R., & Poczekajło, P. (2021). The latest developments in computer science and their impact on space exploration. *Procedia Computer Science*, 192, 4386-4395. <https://doi.org/10.1016/j.procs.2021.09.215>
- Tahsien, S. M., Karimipour, H., & Spachos, P. (2020). Machine learning based solutions for security of Internet of Things (IoT): A survey. *Journal of Network and Computer Applications*, 161. <https://doi.org/10.1016/j.jnca.2020.102630>
- Takao, Y., Mori, O., Matsushita, M., & Sugihara, A. K. (2021). Solar electric propulsion by a solar power sail for small spacecraft missions to the outer solar system. *Acta Astronautica*, 362-376. <https://doi.org/10.1016/j.actaastro.2021.01.020>
- Taylor, T. S. (2017). *Introduction to Rocket Science and Engineering*. CRC Press. <https://doi.org/10.1201/9781315120959>
- Tewari, A., & Gupta, B. (2020). Security, privacy and trust of different layers in Internet-of-Things (IoTs) framework. *Future Generation Computer Systems*, 108, 909-920. <https://doi.org/10.1016/j.future.2018.04.027>
- The Planetary Society. (n.d.). *Historical NASA Budget Data*. The Planetary Society: https://docs.google.com/spreadsheets/d/e/2PACX-1vTU9FhDV4U6X4suHtvoiMLYDN-y56ipoGh-N7n9fNq7BW1PiMsx5fVlj10LsgvTYVbu3CiUDO_WD0We/pubhtml
- ThikraDawood, Elwakil, E., Zayed, T., & Zhu, Z. (2022). Data fusion of multiple machine intelligent systems for the condition assessment of subway structures. *Tunnelling and Underground Space Technology*, 126. <https://doi.org/10.1016/j.tust.2022.104512>

- Tipaldi, M., Feruglio, L., Denis, P., & D'Angelo, G. (2020). On applying AI-driven flight data analysis for operational spacecraft model-based diagnostics. *Annual Reviews in Control*, 49, 197-211. <https://doi.org/10.1016/j.arcontrol.2020.04.012>
- tiSpace. (2023). *Your new gateway in access to space*. tiSpace: https://www.tispace.com/index.php?option=com_sppagebuilder&view=page&id=1&Itemid=101
- Tiwary, A., Kumar, R., & Chohan, J. S. (2022). A review on characteristics of composite and advanced materials used for aerospace applications. *Materials Today: Proceedings*, 51(1), 865-870. <https://doi.org/10.1016/j.matpr.2021.06.276>
- Tlon. (2023). *About us*. Tlon: <https://tlon.space/about-us/>
- Tolmeijer, S., Gadiraju, U., Ghantasala, R., & Bernstein, A. (2021). Second chance for a first impression? Trust development in intelligent system interaction. *UMAP 2021 - Proceedings of the 29th ACM Conference on User Modeling, Adaptation and Personalization*, 77-87. <https://doi.org/10.1145/3450613.3456817>
- Tom Eelbode, P. S. (2021). Pitfalls in training and validation of deep learning systems. *Best Practice & Research Clinical Gastroenterology*, 52-53. <https://doi.org/10.1016/j.bpg.2020.101712>
- Tománek, R., & Hospodka, J. (2018). Reusable Launch Space Systems. *MAD*, 6(2). <https://doi.org/10.14311/MAD.2018.02.02>
- Tugnoli, M., Sarret, M., & Aliberti, M. (2019). *European Access to Space: Business and Policy Perspectives on Micro Launchers*. Springer Cham. <https://doi.org/10.1007/978-3-319-78960-6>
- Turing, A. (1950). Computing machinery and intelligence. *Mind*, LIX, 433 - 460. <https://doi.org/https://doi.org/10.1093/mind/LIX.236.433>
- University of Nevada. (n.d.). *What are intelligent systems?* University of Nevada: <https://www.unr.edu/cse/undergraduates/prospective-students/what-are-intelligent-systems>
- Uren, V., & Edwards, J. (2023). Technology readiness and the organizational journey towards AI adoption: An empirical study. *International Journal of Information Management*, 68. <https://doi.org/10.1016/j.ijinfomgt.2022.102588>
- Ushakov, D., Dudukalov, E., Kozlova, E., & Shatila, K. (2022). The Internet of Things impact on smart public transportation. *Transportation Research Procedia*, 63, 2392-2400. <https://doi.org/10.1016/j.trpro.2022.06.275>

- Uyanna, O., & Najafi, H. (2020). Thermal protection systems for space vehicles: A review on technology development, current challenges and future prospects. *Acta Astronautica*, 176, 341-356. <https://doi.org/10.1016/j.actaastro.2020.06.047>
- Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, Ł., & Polosukhin, I. (2017). Attention Is All You Need. *Advances in Neural Information Processing Systems*, 30. <https://doi.org/10.48550/ARXIV.1706.03762>
- VayaSpace. (2023). DAUNTLESS. VayaSpace: <https://www.vayaspace.com/dauntless?lang=pt>
- Verma, S., Warriar, L., Bolia, B., & Mehta, S. (2022). Past, present, and future of virtual tourism-a literature review. *International Journal of Information Management Data Insights*, 2(2). <https://doi.org/10.1016/j.ijime.2022.100085>
- Vernile, A. (2018). Dossier 2: Private Investment in Space. In A. Vernile, *The Rise of Private Actors in the Space Sector* (pp. 15-23). Springer, Cham. https://doi.org/10.1007/978-3-319-73802-4_2
- Viavattene, G., Devereux, E., Snelling, D., Payne, N., & Wokes, S. (2022). Design of multiple space debris removal missions using machine learning. *Acta Astronautica*, 277-286. <https://doi.org/10.1016/j.actaastro.2021.12.051>
- Vilelas, J. (2020). *Investigação - O Processo de Construção do Conhecimento*. Edições Sílabo.
- Viola, N., Fusaro, R., Vercella, V., & Saccoccia, G. (2020). Technology Roadmapping Strategy, TRIS: Methodology and tool for technology roadmaps for hypersonic and re-entry space transportation. *Acta Astronautica*, 179, 609-622. <https://doi.org/10.1016/j.actaastro.2020.01.037>
- Vorobiev, I., & Samsonovich, A. (2018). A Conceptually Different Approach to the Empirical Test of Alan Turing. *Procedia Computer Science*, 123, 512-521. <https://doi.org/https://doi.org/10.1016/j.procs.2018.01.078>
- W. Luke, T. (2020). Cold War. *International Encyclopedia of Human Geography (Second Edition)*, 309-313. <https://doi.org/10.1016/B978-0-08-102295-5.10455-X>
- Walker, T. (2022). Managing risk in space: The space industry regulations 2021 and the new UK legal framework. *Journal of Space Safety Engineering*, 9(2), 239-244. <https://doi.org/10.1016/j.jsse.2022.02.003>
- Walsh, J. S., & Gorman, A. C. (2021). A method for space archaeology research: the International Space Station Archaeological Project. *Cambridge University Press*, 95(383), 1331 - 1343. <https://doi.org/10.15184/aqy.2021.114>
- Weinzierl, M. (2018). Space, the Final Economic Frontier. *Journal of Economic Perspectives*, 32(2), 173-92. <https://doi.org/10.1257/jep.32.2.173>

- Wekerle, T., Filho, J. B., Costa, L. E., & Trabasso, L. G. (2017). Status and Trends of Smallsats and their Launch Vehicles — An up-to-date Review. *Journal of Aerospace Technology and Management*, 9(3), 269. <https://doi.org/10.5028/jatm.v9i3.853>
- Werken, N. v., Tekinalp, H., Khanbolouki, P., Ozcan, S., Williams, A., & Tehrani, M. (2020). Additively manufactured carbon fiber-reinforced composites: State of the art and perspective. *Additive Manufacturing*, 31. <https://doi.org/10.1016/j.addma.2019.100962>
- Wiles, J. (2022, September 15). *What's New in Artificial Intelligence from the 2022 Gartner Hype Cycle*. Gartner: <https://www.gartner.com/en/articles/what-s-new-in-artificial-intelligence-from-the-2022-gartner-hype-cycle>
- Wilkins, A. (2022). Science lab module joins China's Tiangong space station. *New Scientist*, 255(3397), 12. [https://doi.org/10.1016/S0262-4079\(22\)01332-X](https://doi.org/10.1016/S0262-4079(22)01332-X)
- Williams, V. A., & Mosher, T. J. (2022). Orbital Reef: A Low Earth Orbit Destination for Commercial Exploration Demonstration. *ASCEND* 2022. <https://doi.org/10.2514/6.2022-4366>
- Wilson, E. K. (2019). Space Tourism Moves Closer to Lift Off. *Engineering*, 5(5), 819-821. <https://doi.org/10.1016/j.eng.2019.08.006>
- Winter, F. H. (2016). Did the Germans learn from Goddard? An examination of whether the rocketry of R.H. Goddard influenced German Pre-World-War II missile development. *Acta Astronautica*, 127, 514-525. <https://doi.org/10.1016/j.actaastro.2016.03.003>
- Wooldrige, M., & Jennings, N. (1995, June). Intelligent agents: theory and practice. *The Knowledge Engineering Review*, 10(2), 115-152.
- Wu, S., Chen, W., Cao, C., Zhang, C., & Mu, Z. (2021). A multiple-CubeSat constellation for integrated earth observation and marine/air traffic monitoring. *Advances in Space Research*, 67(11), 3712-3724. <https://doi.org/10.1016/j.asr.2020.04.025>
- X-Bow. (2023). *A space revolution on a solid foundation*. X-Bow: <https://www.xbowsystems.com/>
- Xiong, S. (2020). Materials, Application Status and Development Trends of Additive Manufacturing Technology. *Materials Transactions*, 61(7), 1191-1199. <https://doi.org/10.2320/matertrans.MT-M2020023>
- Xu, Q., Hollingsworth, P., & Smith, K. (2019). Launch Cost Analysis and Optimization Based on Analysis. *TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUTICAL AND SPACE SCIENCES*, 62(4), 175-183. <https://doi.org/10.2322/tjsass.62.175>
- Xu, X. (2022). Application of Industrial Robot and Internet of Things in Intelligent Manufacturing System Supported by Software and Hardware. *2022 IEEE International Conference on*

- Electrical Engineering, Big Data and Algorithms*, 415-148.
<https://doi.org/10.1109/EEBDA53927.2022.9744902>
- Yacchirema, D. C., Sarabia-JáCome, E., D. a., & Esteves, M. (2018). A Smart System for Sleep Monitoring by Integrating IoT With Big Data Analytics. *IEEE Access*, 6, 35988-36001.
<https://doi.org/10.1109/ACCESS.2018.284982>
- Yao, Q., Jahanshahi, H., Moroz, I., Bekiros, S., & Alassafi, M. O. (2023). Indirect neural-based finite-time integral sliding mode control for trajectory tracking guidance of Mars entry vehicle. *Advances in Space Research*, 71(9), 3723-3733.
<https://doi.org/10.1016/j.asr.2022.11.059>
- Yárnöz, D. G., Kojima, A., & Pippo, S. D. (2019). Access to Space: Capacity-building for development through experiment and payload opportunities,. *Acta Astronautica*, 154, 227-232. <https://doi.org/10.1016/j.actaastro.2018.03.034>
- Yassine, A., Singh, S., Hossain, M. S., & Muhammad, G. (2019). IoT big data analytics for smart homes with fog and cloud computing. *Future Generation Computer Systems*91, 91, 563-573. <https://doi.org/10.1016/j.future.2018.08.040>
- Zhang, M., & Li, J. (2021). A commentary of GPT-3 in MIT Technology Review 2021. *Fundamental Research*, 1(6), 831-833. <https://doi.org/10.1016/j.fmre.2021.11.011>
- Zhang, M., & Yang, X. (2023). China's emerging commercial space industry: Current developments, legislative challenges, and regulatory solutions. *Acta Astronautica*, 202, 9-16. <https://doi.org/10.1016/j.actaastro.2022.10.011>
- Zhang, S., Li, X., & Yeung, K. L. (2022). Segment routing for traffic engineering and effective recovery in low-earth orbit satellite constellations. *Digital Communications and Networks*. <https://doi.org/10.1016/j.dcan.2022.09.022>
- Zhang, X., Chen, Y., Hu, L., & Wang, Y. (2022). The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.1016300>
- Zhang, Z. (2021). Space Science in China: A Historical Perspective on Chinese Policy 1957–2020 and Policy Implication. *Space Policy*, 58. <https://doi.org/Space Policy>
- Zhang, Z., Li, X., Li, Y., Hu, G., Wang, X., Zhang, G., & Tao, H. (2023). Modularity, reconfigurability, and autonomy for the future in spacecraft: A review. *Chinese Journal of Aeronautics*, 36(7), 282-315. <https://doi.org/10.1016/j.cja.2023.04.019>
- Zhao, J., Chen, D., Zhao, L., Shi, Y., Guo, S., Zhu, Z., Liu, J., Li, W., Lei, W., Chen, H., Chen, Y., Zhou, D., Wu, R., & Guo, W. (2022). Self-powered speech recognition system for deaf users. *Cell Reports Physical Science*, 3(12). <https://doi.org/10.1016/j.xcrp.2022.101168>

- Zheng, X., Chen, W., & Wang, F.-Y. (2022). Visual Human-Computer Interactions for Intelligent Vehicles and Intelligent Transportation Systems: The State of the Art and Future Directions. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 51(1), 253-265. <https://doi.org/10.1109/TSMC.2020.3040262>
- Zheng, Y., Fu, X., Xu, M., Li, Q., & Lin, M. (2020). Ascent trajectory design of small-lift launch vehicle using hierarchical optimization. *Aerospace Science and Technology*, 107. <https://doi.org/10.1016/j.ast.2020.106285>
- Zhuang, Y., Cai, M., Li, X., Luo, X., Yang, Q., & Wu, F. (2020). The Next Breakthroughs of Artificial Intelligence: The Interdisciplinary Nature of AI. *Engineering*, 6(3), 245-247. <https://doi.org/10.1016/j.eng.2020.01.009>

Annexes

Table 15 - Relation between research questions and interview questions

Objective	Research Questions	Interview Questions
Understand the contribution of intelligent systems to the space transportation	(RQ1). What intelligent systems can we observe in space transportation?	(IQ1). Can you provide examples of intelligent systems currently being used in space transportation that you are familiar with?
	(RQ2). What are the major impacts of using intelligent systems in space transportation?	(IQ2). What are the main benefits of using intelligent systems in space transportation? (IQ3). In your opinion, what are the biggest challenges and risks of using intelligent systems in space transportation?
	(RQ3). How can intelligent systems help reduce space transportation costs?	(IQ4). In your opinion, what applications of intelligent systems have the most potential for reducing space transportation costs, and why?
	(RQ4). What is the role of intelligent systems in the future of space transportation?	(IQ5). How do you see the development of intelligent systems evolving in the space transportation industry? (IQ6). What is the industry “holy grail” that you see intelligent systems helping to achieve in the coming years? (IQ7). What role do you think intelligent systems will play in the future of space exploration and colonization?

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Table 16 - References used in Tables 3 and 4

Launch Vehicle	References
Space Shuttle	(Jones, 2018; Baiocco, 2021)
Falcon 9 (Block 5)	(Tománek & Hospodka, 2018)
Falcon Heavy (Block 5)	(Carbajales-Dale & Murphy, 2023; Tománek & Hospodka, 2018)
Starship	(Carbajales-Dale & Murphy, 2023; Sippel <i>et al.</i> , 2019)
Space Launch System	(Carbajales-Dale & Murphy, 2023; Keller & Collopy, 2013)
Delta IV Heavy	(Boonel & Miller, 2016)
Atlas V 551	(Boonel & Miller, 2016)
Vulcan	(Rolley <i>et al.</i> , 2017)
Antares	(Carbajales-Dale & Murphy, 2023; Evans, 2022; Smith P. M., 2018)
Minotaur C (Taurus)	(Smith P. M., 2018)
Minotaur I	(Smith P. M., 2018)
Minotaur IV	(Smith P. M., 2018)
Minotaur V	(Smith P. M., 2018)
Pegasus XL	(Smith P. M., 2018; Niederstrasser C. , 2021)
Electron	(Smith P. M., 2018; Niederstrasser C. , 2021)
Neutron	(Sun, 2022)
Soyuz-2.1a	(Smith P. M., 2018; Hendrickx, 2022)

Soyuz-2.1b	(Carbajales-Dale & Murphy, 2023; Smith P. M., 2018; Hendrickx, 2022)
Soyuz-2.1v	(Smith P. M., 2018; Hendrickx, 2022; Aliberti & Lisitsyna, 2019)
Angara 1.2	(Smith P. M., 2018)
Angara AS	(Smith P. M., 2018)
Proton M	(Smith P. M., 2018; Hendrickx, 2022)
Shtil	(Xu <i>et al.</i> , 2019)
Star-1	(Xu <i>et al.</i> , 2019)
Strela	(Xu <i>et al.</i> , 2019)
Volna	(Xu <i>et al.</i> , 2019)
Zenit 3SL	(Xu <i>et al.</i> , 2019)
Dnepr-1	(Smith P. M., 2018)
LVM3	(Smith P. M., 2018)
SSLV	(Bommakanti, 2020; Cottom, 2022)
PSLV	(Boonel & Miller, 2016)
GSLV	(Boonel & Miller, 2016; Xu <i>et al.</i> , 2019)
Nuri (KSLV-II)	(Ko & Cho, 2016; Cho <i>et al.</i> , 2016)
Shavit	(Xu <i>et al.</i> , 2019)
Kuaizhou	(Smith P. M., 2018)
Jielong 1	(Niederstrasser C. G., 2022; Qian & Liu, 2020)
Kaituoze-2 (KT-2)	(Niederstrasser C. G., 2022; Chandrashekar, 2022)
Long March 2C	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 2D	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 2F	(Xu <i>et al.</i> , 2019)
Long March 3A	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 3B	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 3C	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 4B	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 4C	(Smith P. M., 2018; Badikov & Bebenina, 2021)
Long March 5B	(Xu <i>et al.</i> , 2019)
Long March 6	(Xu <i>et al.</i> , 2019; Smith P. M., 2018)
Long March 7A	(Xu <i>et al.</i> , 2019)
Long March 11 (CZ 11)	(Xu <i>et al.</i> , 2019)
Hyperbola - 1 (SQX-1S)	(iSpace, 2023; Qian & Liu, 2020)
Zhuque-2	(Qian & Liu, 2020; Cavataio & Rus, 2019)
Ceres-1	(Niederstrasser C. G., 2022)
OS-M1	(Cavataio & Rus, 2019; Niederstrasser C. , 2022; Phen, 2022)
LauncherOne	(Niederstrasser C. G., 2022; Phen, 2022)
Vega	(Boonel & Miller, 2016; Stappert & Sippel, 2018)
Qased	(Mills & Butchard, 2021)
Simorgh	(Tugnoli <i>et al.</i> , 2019)
H3-24L	(Horton <i>et al.</i> , 2020; Bae <i>et al.</i> , 2017)
H2A 2025	(Boonel & Miller, 2016; Xu <i>et al.</i> , 2019)
H2B	(Xu <i>et al.</i> , 2019)
Epsilon	(Xu <i>et al.</i> , 2019)
Astra 4	(Astra, 2022)

New Shepherd (Sub-Orbital)	(Wilson, 2019)
Spaceship 2 (Sub-Orbital)	(Leslie, 2022)
New Glenn	(Rolley <i>et al.</i> , 2017)
SpaceLiner	(Sippel <i>et al.</i> , 2016; Sippel <i>et al.</i> , 2019)
X-37	(Gorn & Chiara, 2021)
Dream Chaser	(Saccani, 2020; Yárnoz <i>et al.</i> , 2019)
Alpha	(Sun, 2022; Niederstrasser & Frick, 2015)
RS1	(Cavataio & Rus, 2019; Kulu, 2021)
Hapith-V	(Cavataio & Rus, 2019; Chen Y.-S. , 2019)
Pallas	(Galactic Energy, 2023)
SL1	(Niederstrasser C. G., 2022; NewSpace , 2023)
Zero	(Niederstrasser C. , 2022; Interstellar Technologies, 2023)
Cyclone-4M	(Horbulin <i>et al.</i> , 2018)
RFA One	(Kulu, 2021; Kellner, 2022)
Gravity-1	(Orienspace, 2023)
Gravity-2	(Orienspace, 2023)
Gravity-3	(Orienspace, 2023)
Terran 1	(Sun, 2022)
Terran R	(Powell, 2022)
Daytona	(Niederstrasser C. G., 2022)
BlueWhale	(Kulu, 2021; Perigee, 2023; E.A. <i>et al.</i> , 2023)
Darwin-1	(endeavour, 2023)
Prime	(Cavataio & Rus, 2019; Orbex, s.d.)
Irtys (Soyuz-5)	(Byr'ka <i>et al.</i> , 2010)
Nebula-1	(Cavataio & Rus, 2019)
Spectrum	(Cavataio & Rus, 2019; Cocchiara <i>et al.</i> , 2022)
Miura 5	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022)
Eris	(Tugnoli <i>et al.</i> , 2019; Gilmour Space, 2023)
Agnibaan	(Niederstrasser C. G., 2022)
Amur	(Lima <i>et al.</i> , 2021)
Ariane 62	(Ehrenfried, 2020; Dumont <i>et al.</i> , 2016)
Ariane 64	(Ehrenfried, 2020; Dumont <i>et al.</i> , 2016; Cost Estimation and Development Approach of the EURASTROS Concept, 2022)
Haas 2CA	(Niederstrasser C. G., 2022; Arca Space, 2023)
Ravn X	(Niederstrasser C. G., 2022; Aevum, 2023)
Helios	(Aphelion, 2023)
Colibri	(Niederstrasser C. G., 2022; B2 Space, 2023)
Bagaveev	(Pelton, Small Satellites: Glossary of Terms and Listing of Acronyms, 2023)
Chetak	(Tugnoli <i>et al.</i> , 2019; N., 2021)
Black Arrow-2	(Cavataio & Rus, 2019; Tugnoli <i>et al.</i> , 2019)
Red Dwarf 50	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022)
C6	(C6 Launch, 2023)
Tronador II	(Cavataio & Rus, 2019)

Cab-3A	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022; Tugnoli <i>et al.</i> , 2019)
Mk-3	(Haex, 2020)
VLM-1	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022)
Volans Block I	(Niederstrasser C. G., 2022)
Space Rider	(Niederstrasser C. G., 2022)
Eris-S	(Niederstrasser C. G., 2022; Gilmour Space, 2023)
ACE	(Niederstrasser C. G., 2022)
DNLV	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022; Tugnoli <i>et al.</i> , 2019)
Shockwave	(Niederstrasser C. , 2022)
Neptune N1	(Niederstrasser C. G., 2022)
Launcher Light	(Niederstrasser C. G., 2022)
Chariot	(Niederstrasser C. G., 2022)
NewLine-1	(Niederstrasser C. G., 2022)
Orbital 500R	(Niederstrasser C. G., 2022; Tugnoli <i>et al.</i> , 2019)
Meso	(Niederstrasser C. G., 2022; Pangea Aerospace, 2018)
Eiger	(Python Space, 2023)
Starlord	(Niederstrasser C. G., 2022)
Vikram I	(Skyroot Aerospace, 2023)
Vikram II	(Skyroot Aerospace, 2023)
Vikram III	(Skyroot Aerospace, 2023)
Skylora XL	(Cavataio & Rus, 2019; Skylora, 2023)
SpinLaunch	(Niederstrasser C. G., 2022; Spinlaunch, s.d.)
Phoenix	(Newspace, 2023)
HAPITH V	(Cavataio & Rus, 2019; tiSpace, 2023)
Aventura 1	(Cavataio & Rus, 2019; Niederstrasser C. G., 2022; Tlon, 2023)
Dauntless	(VayaSpace, 2023)
Zephyr	(Cavataio & Rus, 2019; Latitude, 2023)
X-bow	(X-Bow, 2023)
Sagittarius Space Arrow CM	(Niederstrasser C. , 2022; Celestiaaerospasce, 2023)
ALASA	(HOLLINGSWORTH, 2014)

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