DIPLOMA

THESIS

Establishing Framework Conditions for Project Innovation Management in Rocket Industry through Standardisation in Organisation with Limited Financial Resources

STUDY DEGREE PROGRAMME

Innovation Project Management

THESIS SUPERVISOR

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2023

MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

Master's thesis title in English:

Establishing Framework Conditions for Project Innovation Management in Rocket Industry through Standardization in Organization with Limited Financial Resources

Master's thesis title in Czech:

Zavedení rámcových podmínek pro řízení inovací projektů v raketovém průmyslu pomocí standardizace v organizaci s omezenými finančními prostředky

Guidelines:

The main goal of this work is to analyze the latest trends in Project Innovation Management in the rocket industry with a focus on introducing standardization and analysis of its influence, using structured methods that optimize time, minimize risks and reduce costs in the innovation process. A partial goal is to analyze the processes of the chosen standardization in the context of financial management, planning, and systems engineering in a selected organization with limited financial resources, operating under the auspices of an academic institution. The specific data acquisition processes include logical induction, description, comparison of foreign literature and user manuals of individual standardizations, analysis of preparation, and management of projects in the rocket industry. The gained data will lead to the creation of an innovation framework for the basics of Project Innovation Management, the selection, and implementation of standardization in the environment of the selected organization.

Bibliography / sources:

DARRIN, M. Ann Garrison and STADTER, Patrick A. (eds.), 2017. Aerospace Project Management Handbook. 1st edition. Boca Raton: CRC Press. ISBN 9781498776523.

NIETO-RODRIGUEZ, Antonio, 2021. Harvard Business Review project management handbook: how to launch, lead, and sponsor successful projects. Boston, MA: Harvard Business Review Press. Harvard Business Review handbooks series. ISBN 9781647821272.

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Date of master's thesis assignment: **09.12.2023** Deadline for master's thesis submission: **27.04.2023**

Assignment valid until: ______________

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III. Assignment receipt

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Date of assignment receipt Student's signature

MARVAN, Ondřej. Establishing Framework Conditions for Project Innovation Management in Rocket Industry through Standardisation in Organisation with Limited Financial Resources. Praha: CTU 2023. Diploma thesis. Czech Technical University in Prague, Masaryk Institute of Advanced Studies.

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Acknowledgement

I would like to extend my sincere gratitude to doc. Ing. Marek Jemala, Ph.D., for his invaluable advice, insightful feedback, and unwavering support during the consultations and preparation of my diploma thesis. His expertise, dedication, and commitment to my academic success have been instrumental in shaping this research project and my personal development.

I would also like to express my profound thankfulness to my loving wife, Ing. Mgr. Izabela Marvan, whose unwavering encouragement, patience, and understanding have been a constant source of strength and motivation throughout the course of my studies. Her faith in my abilities and her endless support has played an invaluable role in the completion of this thesis. I am genuinely grateful for her companionship, love, and belief in me, even during the most challenging times.

Further, I would like to convey my sincerest thanks to my parents, who have provided me with unwavering love, guidance, and encouragement from the very beginning of my academic journey. Their sacrifices, nurturing, and belief in my potential have been the foundation upon which my achievements have been built. I am eternally grateful for their constant support, understanding, and the countless opportunities they have given me to grow and succeed.

Last but not least, I would also like to express my gratitude to the enthusiastic team at CTU Space Research, who generously provided me with an incredible opportunity to be a part of their inspiring community. Their passion for innovation, collaboration, and the pursuit of knowledge has greatly enriched my academic experience and personal growth. I am deeply grateful for their guidance, support, and the opportunity to contribute to their groundbreaking work.

Abstract

The main objective of this thesis is to analyse the latest trends in the Project Management of Innovation in the rocket industry by introducing standardisation and analysing its impact on structured methods that optimise time, minimise risks, and reduce costs in the innovation process. The sub-objective is to analyse the chosen standardisation in contrast to financial management, planning, and systems engineering in a selected organisation with limited financial resources, operating under the auspices of an academic institution.

Specific objectives include logical induction, descriptions, comparison of foreign literature and user manuals of each standardisation, and analysis of project preparation and management in the rocket industry. The data obtained will lead to the development of an innovative framework for project management fundamentals, selecting and implementing an appropriate standardisation in the environment of the selected organisation.

The process of analysing the organisation will be based on specific structured interviews, available resources and technical documentation.

Keywords

ECSS, Innovation Project Management, NTSS, Rocket Industry, Standardisation, Student organisation

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Introduction

The rocket industry is an ever-evolving field, constantly pushing the boundaries of innovation and technology. Due to the democratisation of the market and the entry of new players made possible by cost-cutting and open innovation, the rapidly expanding aeronautical and rocket industry has recently seen a significant boom. As a result, organisations, especially those with limited financial resources, have a growing need for effective processes and management strategies. This environment is slowly but surely taking into account student rocketry teams shading well-established and commercialised companies. In addition, student rocketry teams are providing the entire rocket and space industry with accessible solutions.

The value of this topic lies in its potential to implement project management tools, system engineering, and standardisation in the aerospace and space industry to streamline processes within student rocket organisations. By introducing standardisation and analysing its impact on the innovation process within the context of financial management, planning, and system engineering, this diploma thesis, titled "Establishing Framework Conditions for Project Innovation Management in the Rocket Industry through Standardisation in Organisation with Limited Financial Resources," aims to address this need.

The diploma thesis begins with an extensive look at the history, development, and impact of standardisation on performance and quality. Following an analysis of the various standards and organisations involved in this industry, it dives into the characteristics, origins, innovations, and inventions of the aerospace and rocket industry. The study also discusses quality control, innovation project management, and project management methodologies, all of which are crucial elements of a successful framework for project innovation management.

The analysis of student organisations operating under the auspices of academic institutions is a key element of this research, as these organisations often have limited financial resources. The purpose of this thesis is to create a framework for project innovation management in rocket industry organisations, especially those with limited financial resources. The objective is to introduce standardisation, analyse its impact on the innovation process, and analyse the most recent trends in the industry. The goal of the thesis is to help these organisations compete successfully in the quickly expanding market by optimising time, minimising risks, and reducing costs.

The thesis presents a case study of CTU Space Research, a student organisation with limited funding, and explores its participation in competitions as a means of project validation. After examining the suitability, accessibility, and cost implications of various standards and standardisations, the study concludes with a comprehensive analysis of the standardisation chosen for implementation at CTU Space Research.

The adaptation of standards at CTU Space Research, including the establishment of handbooks, road maps, project management tools, and the innovation project management framework, is the focus of the thesis' final section. Despite its limited financial resources, the organisation is able to manage projects within the rocket industry thanks to this all-encompassing approach.

By thoroughly examining the role of standardisation and its influence on project innovation management, this thesis provides valuable insight for organisations operating in the rocket industry, particularly those with limited financial resources. The proposed framework conditions, combined with a practical case study, offer a robust foundation for the implementation of project innovation management within these organisations. The aim of the thesis is to empower organisations to successfully implement project innovation management and contribute to ongoing growth and innovation within the rocket industry by offering useful insights and a solid foundation.

THEORETICAL PART

1 Standardisation, Standards, Performance and Quality

Standards, quality, and performance are related concepts that refer to the ways in which products, services, and systems are evaluated and compared. A standard is an agreed-upon way of doing something and can be seen as a uniform set of measures, agreements, conditions, or specifications between parties. These parties can include buyers and sellers, manufacturers and users, governments and industries, retailers and consumers, and other parties involved in commerce and trade (Spivak, Brenner 2017, pp. 1–3).

Standards are developed and implemented to promote efficiency, consistency, interoperability, safety, and quality in products, services, and systems. They provide a common reference point that can be used to compare and evaluate different options and help ensure that products and services meet specific minimum requirements. Standards can also help facilitate trade and cooperation between countries and industries by establishing standard guidelines and criteria.

1.1 Definition

Standardisation, as a process of developing and implementing standards, is often used to improve the quality, reliability, safety, and efficiency of products, services, or systems, as stated above. A complete set of definitions for standardisation and standards, as well as terms related to performance, testing and certification, laboratory accreditation, and quality control, can be found in a sourcebook on standards information. There are various versions of these definitions, as they can be applied to any product, service, or system.

The International Organisation for Standardisation (ISO 2016) defines the standardisation process as the "activity of establishing concerning actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context. Note: In particular, the activity consists of formulating, issuing and implementing standards."

Correspondingly, the ISO definition of a standard (ISO 2016) is a "Document, established by consensus and approved by a recognised body, that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context."

1.2 History of Standardisation and Standards

The process of standardisation and the creation of standards have played a crucial role throughout human history, influencing the advancement of civilisations by promoting uniformity, dependability, and effectiveness. The present chapter examines the historical development of standardisation, spanning across diverse epochs and analysing the influence of standards on multiple facets of human existence.

1.2.1 Through the Ages with Standards

The early stages of standards development were marked by people's need to measure things. As an illustration, when a man left the fields and established cities, he required a certain amount of length to construct palaces and temples as well as a certain amount of volume to tithe grain to the priests and kings. The need to allocate space and things with reasonable and practical value led to the development of standards. Of course, barter was the primary form of early trade, and there was no need for precise measurements of quantity. However, by 3000 BC, weighing had begun to play a role in trade. Simple weights and measures as national references were deposited in the principal temples (Singer, Raper 1954, p. 774 cited in Spivak, Brenner 2017, p. 7). Around 2500 BC, small balances were created for measuring gold dust and by 1350 BC, these balances were commonly used in trade (Spivak, Brenner 2017, pp. 7–14).

In the earliest societies, the dimensional standards were taken from the human anatomy, frequently the king's body. The "cubit" was the distance from the elbow to the wrist and has been found to vary from 0.641 metres for the Roman cubit to 0.444 metres for the Palestinian cubit among at least eight different cubits (NIST 1995 cited in Spivak, Brenner 2017). Two typical shorter lengths were the "span," the length from the tip of the thumb to the tip of the pinkie with fingers extended, and the "hand". The latter measurement is still used to specify a horse's height, in other words, a tall number of hands.

From the Middle Ages until the early Renaissance, the royal tradition of adopting the king's body as a baseline for standard measures persisted. It is significant to remember that Henry I of England established the ell as the distance between his left shoulder and the spike of his extended left hand in 1120. The ell is a traditional textile measurement. Eventually, the ell became the basis for the yard (0.91 m) (Spivak, Brenner 2017, p. 9).

Weighing precious metals or gems was done on a wooden balance arm suspended by leather thongs or yarn at the midpoint with containers suspended from the arm ends. Weights were grains or seeds; the carob seed was the forerunner of the carat, the unit of weight used to measure modern gems. The troy system for weighing precious metals was developed in the Middle Ages by Henry III, who reigned from 1216 to 1272.

It was based on the pennyweight, which was equivalent to 32 grains of wheat. The name was inspired by the Troyes Fair's weights and coins, which were used there (Spivak, Brenner 2017, p. 8).

Research has suggested that even in the prehistoric era, humans may have had some standards. This theory is supported by the surprising similarity seen in the stone tools of some cultures. For instance, each Clovis point has a distinct scalloped edge. However, it is not believed that the application of standards in the contemporary sense led to these parallels. Instead, they likely represent the influence of a knowledgeable or influential teacher who demonstrated the "correct" technique to novices, or they could result from long-standing traditions. (Spivak, Brenner 2017, p. 8).

1.2.2 Early Identification and Protection Against Dishonesty

As evidenced by various religious texts, accepting moral standards has been essential to society since the beginning of time. The Bible, for instance, emphasizes the value of maintaining precise measurements. The prohibition against manipulating measurements and the requirement to use accurate balances, weights, and units of capacity are found in Leviticus 19:35–36, according to Spivak & Brenner (2017, pp. 8–9), Proverbs 11:1 emphasizes that a just weight is preferred while a false balance is despised.

This emphasis on integrity is not exclusive to biblical texts, but is also present in ancient Indian literature. As an example, the Sanskrit scripture Manusmriti, which dates back to around 400 BC, contains similar references. Manu, considered a divinely inspired lawgiver, provided a table of 13 units of weights and their interrelationships. Furthermore, Manu advised that the king should inspect the weights and measures, stamp them every six months, and penalise those who cheat or use dishonest practices (Spivak, Brenner 2017, p. 9).

This focus on accurate and honest standards showcases the significance of these values in maintaining a fair and just society, a theme that resonates in the diploma thesis.

1.2.3 Archimedes' Principle

Archimedes' Principle has its roots in ancient times when concerns about fraudulent practices were prevalent. Around 215 BC, the Greek ruler Hiero II of Sicily suspected a gold crown he had purchased to be adulterated with silver. Without a known method to confirm this suspicion, he sought help from Archimedes. The mathematician and inventor realized that equal weights of gold and silver, due to their differing densities, would displace different volumes of water. This insight led to a method for testing the crown's composition, although the outcome of the experiment has not been recorded in historical accounts (Spivak, Brenner 2017, p. 9).

1.2.4 English Experiences: King John and the Magna Carta

On June 15, 1215, King John reluctantly signed the Magna Carta at Runnymede due to pressure from English Barons. The objective was to reclaim some of the rights granted by previous rulers or long-standing feudal customs that John had exploited for personal gain. Among the many clauses in the Magna Carta, Chapter 35 addressed "measures," stating that there should be uniform measures of wine, ale, corn, and cloth throughout the kingdom, as well as standard weights (Spivak, Brenner 2017, p. 9).

Before 1215, various regulations, known as assizes, had been issued to govern the sale of commodities, including beer, wine, and bread, and to establish standard weights and measures. Richard the Lionheart published the Assize of Cloth in 1197 to tackle the challenges faced by traders dealing with inconsistent standards as they moved goods between locations. This regulation aimed to prevent fraudulent activities under the guise of ambiguous weights and measures, requiring uniformity for commodities such as ale and corn. Dyed cloths were required to maintain consistent quality throughout the fabric. Merchants were also prohibited from displaying cloth or shields in a deceptive manner that could mislead buyers seeking good quality cloth (Spivak, Brenner 2017, p. 10).

1.2.5 Baker's Dozen: A Historical Perspective

During the 16th century in England, it was believed that bakers were not providing the total weight of bread to their customers. To avoid the harsh penalties enforced for this dishonest practice, the bakers started a custom of giving an extra loaf of bread for every 12 loaves purchased. This might be the origin of the term "Baker's Dozen" (Spivak, Brenner 2017, p. 10).

1.2.6 The Development of the Interchangeable System in the United States

In 1788, while serving as the American Minister to France, Thomas Jefferson wrote about an innovative technique developed by a gunsmith named LeBlanc. LeBlanc's method involved creating musket parts so precisely that any part could be used interchangeably with another musket. Jefferson believed this could be beneficial to the United States, as it would enhance the efficiency of manufacturing and maintenance of firearms (Spivak, Brenner 2017, pp. 10–11).

Fast forward to 1798, the United States Congress authorised Vice President Jefferson to collaborate with Eli Whitney, the cotton gin inventor, to implement the interchangeable manufacturing system for muskets. Whitney's vision was to create gun parts that were as similar as possible, much like the successive impressions of a copper-plate engraving. Unaware of LeBlanc's earlier work, Whitney faced little competition due to the lack of skilled machinists in the United States (Spivak, Brenner 2017, pp. 10–11).

Establishing a factory in New Haven, Connecticut, proved to be more time-consuming than anticipated. However, just as Congress began to express its dissatisfaction, Whitney successfully demonstrated the efficiency of the interchangeable system by assembling ten muskets using randomly selected parts. This marked the beginning of the American system of interchangeable manufacture, which would go on to revolutionise various industries in the country (Spivak, Brenner 2017, pp. 10–11).

1.2.7 The Metric System

During the final years of the 1700s, France, influenced by Talleyrand, initiated the creation of a metric system that aimed to establish standards grounded in nature's unchanging principles. After evolving over the course of 160 years, the International System of Units (SI) emerged. The detailed and intricate history of this development is beyond the scope of this diploma thesis, but it is worth noting that the process was ongoing (Spivak, Brenner 2017, p. 11).

1.2.8 Railway Track Gauge and Standardisation Challenges

The standardisation of railway track gauges has been a historically complex and challenging task. The standard railway gauge, 4 feet 8.5 inches, dates back to the Roman era, when William Jessop invented metal rails for transportation around 1795. Despite this, various gauges have been used in different countries throughout history, leading to significant challenges in railway operations (Spivak, Brenner 2017, pp. 11–12).

The U.S. Congress mandated the standard gauge of 4 feet 8.5 inches in 1863 to improve military logistics. However, it took 25 years to convert all U.S. lines to this gauge, and other countries like England and Canada adopted the standard gauge around 1892. Australia, which had five different railway gauges, finally allowed trains to traverse the continent on standard gauge rails in 1970 (Spivak, Brenner 2017, pp. 11–12).

The costly conversions experienced worldwide had notable economic consequences, as freight had to be unloaded and reloaded at junction points, and rolling stock could only be used for short trips. These avoidable costs often result from shortsighted judgment errors or deliberate choices of non-standard gauges for self-serving or preemptive reasons (Spivak, Brenner 2017, p. 12).

1.2.9 Screw Thread Standardisation

In the early nineteenth century, one major challenge to the adoption of the interchangeable manufacturing system was the absence of a screw thread standard. Joseph Whitworth played a pivotal role in standardising screw threads. He gathered and analysed screws from numerous workshops across England. In 1841, he presented a proposal to the Institution of Civil Engineers, suggesting a consistent 55° angle between thread sides and a specification for the number of threads per inch based on screw diameters. The Whitworth thread remained the engineering standard until 1948 (Spivak, Brenner 2017, p. 12).

1.2.10 Automotive Parts and Global Standards

In the automotive industry, American car manufacturers have largely adopted the metric system for every component, except for wheel and tyre diameters. This decision allows manufacturers worldwide to easily buy and sell parts from one another. Similarly, a single set of standards for aircraft parts worldwide ensures their accessibility. The history and role of standards throughout time are genuinely fascinating. To learn more about the development of technology and standards from the Stone Age to the twentieth century, one can explore the extensive five-volume History of Technology (Spivak, Brenner 2017, p. 14).

1.3 Intention

Standardisation refers to the process of developing and implementing technical or operational standards. It is a way of promoting consistency, efficiency, safety, and interoperability in various fields (Anon. 2013).

Standardisation can enhance the quality of products or services, which is considered one of its primary advantages. Through the establishment of transparent and uniform criteria, entities can guarantee that their offerings get specific benchmarks of excellence and efficacy. Ensuring consistent quality is of the highest priority in specific industries, particularly in manufacturing, as it directly impacts customer satisfaction and the business's overall success.

Standardisation has the potential to enhance efficiency. By optimising processes and minimising variability, organisations can improve their operational efficiency and effectiveness. This phenomenon has the potential to result in reduced expenses and enhanced competitiveness.

Furthermore, the implementation of standardisation can improve safety. The implementation of standards can serve as a means of guaranteeing the safety of products or services, thereby mitigating the likelihood of accidents or injuries. Ensuring safety is of utmost significance in industries such as healthcare.

Finally, and certainly not least, standardisation can encourage interoperability. Standards can promote communication and collaboration by ensuring compatibility and interoperability among diverse products or systems. Interoperability holds significant importance in industries such as technology, owing to its crucial role in ensuring the seamless operation of intricate systems.

1.4 Benefits of Standardisation

Standardisation plays a vital role in various industries and businesses around the world, according to Niels (2020a). It involves the establishment of rules and guidelines that make the process or product more clarified and predictable to ensure the safety, efficiency, and interoperability of products and processes. This text will discuss some of the benefits of standardisation:

- Improved safety: Standardisation helps to guarantee that products and processes fulfil specific safety standards, lowering the risk of accidents and damages.
- Boosted efficiency: Standardisation allows for the smooth exchange of goods and services between different countries, diminishing the need for customisations and simplifying the supply chain. This leads to more indirect benefits, such as waste reduction and success in the case of sustainability.
- Enhanced interoperability: Standardisation allows different systems and appliances to work together seamlessly, improving operations' efficiency and effectiveness.
- Greater market access: Standardisation helps companies to access new markets quicker, as they can sell their products to a broader range of customers.
- Cost savings: Standardisation can lead to economies of scale, as companies can mass-produce products in high demand, leading to lower production costs.
- Improved quality: Standardisation ensures that products meet particular quality standards, improving reliability and customer satisfaction.

1.5 Limitations of Standardisation

To give a complete perspective to the standardisation process, it is essential to note that standardisation is a wide range of activities that may and may not positively affect the company. Limitations are listed below:

- Time-consuming: One of the major disadvantages of adhering to standards is time consumption related to additional activities in which the company needs to invest its person-hour. Moreover, according to Arora (2018), a hierarchical strategy for introducing standards implies that policies originate from the organisation's upper echelons. The benefit of this top-down method is that it guarantees policy alignment with the company's overall strategy. However, a drawback is that it is a lengthy process that requires considerable time for implementation. An alternative approach is the bottom-up implementation policy. This method is comparatively faster, as it begins by considering the input and concerns of employees, thereby addressing their operational issues. As a result, standards developed using the bottom-up approach are built upon carefully assessed risks.

- Training Requirements: The standardisation structure needs to be adjusted, and a board (team in the case of a student organisation) needs to get familiar with it. Training can be done with outside suppliers who specialise in providing organisational consulting services and vendors who can help with rapid deployments. Unfortunately, every consultation is related to additional expenditures (Arora 2018).

- Reduced Creativity: - Standardizing operational processes can occasionally constrain creativity and innovation by establishing fixed procedures that employees must adhere to. To address this, it is essential to clarify the objectives of standardisation, which focus on eliminating inefficiencies rather than suppressing creativity. By attentively considering and acting on employee suggestions for enhancing standard operating procedures, new insights and improvements can be integrated, ensuring that standardisation remains a dynamic and evolving process (Niels 2020b).

1.6 When to Apply Standards

The determination of whether to implement standards within an organisation is dependent on multiple variables, such as the size and character of the business, the sector in which it functions, and the particular aims and objectives of the enterprise. Certain enterprises are obligated to adhere to standards that may be subject to legal regulations or supplier conditions. For instance, the European Space Agency requires that its commercial associates comply with its standards to be eligible for contractual engagement. An illustration of this scenario is when an entity undertakes a complicated project that requires a substantial financial investment and is at risk of being unsuccessful. Failing to establish quality and process standards is deemed prohibited as it poses a potential hazard to oneself.

In a more nuanced way, the use of standards can help organisations achieve their goals and objectives more efficiently and effectively. For example, if an organisation aims to reduce costs, using standards can help streamline processes and eliminate waste, leading to cost savings.

The complexity of operations is also an important consideration. If the organisation's operations are complex, handling standards can help simplify and standardise the processes, making them more manageable and reducing the risk of errors. Additionally, the use of standards can also help ensure that employees are trained and equipped to perform their tasks effectively, mainly if the organisation employs inexperienced or untrained employees.

Cost considerations are also a significant aspect to take into account when deciding whether to use standards or not. Implementing and maintaining standards can require a significant investment of time and resources. The organisation should carefully consider the costs involved in implementing standards and weigh these against the potential benefits.

In conclusion, the decision of whether to use standards within an organisation is complex and depends on various factors, including industry regulations, organisational goals and objectives, the complexity of operations, employee expertise, and cost considerations. Organisations should carefully consider these factors and weigh the pros and cons of using standards before making a decision.

1.7 Standardisation as Innovation Enabler or Barrier?

Standardisation is a complex issue in the field of innovation, with both enabling and constraining effects on the development and deployment of new technologies and innovations. Standardisation can provide a common framework for developing and deploying new technologies and innovations, facilitating interoperability and compatibility. Creating compatibility can foster innovation by optimising the integration of various systems and products, leading to enhanced efficacy and reduced costs.

On the other hand, standardisation can also act as a barrier to innovation by limiting the flexibility and creativity of companies and individuals in developing new products and services. In some cases, strict adherence to standards can prevent the exploration of new and alternative solutions, stifling innovation. The strict adherence to established standards may restrict the potential for radical innovation, particularly in the context of new and emerging technologies.

The impact of standardisation on innovation is a complex and multifaceted issue that is the subject of ongoing debate among scholars and practitioners. According to Swann (2010), cited by Mentel and Hajduk-Stelmachowicz (2020, p. 487), "Several studies highlighted that it can help companies demonstrate the features of their innovative products and increase the creation of business value." Caetano (2017, pp. 8–14) contributes to the previous statement in his writing but is more restrained to "only" a positive correlation between innovation and standardisation. He argues that "Different types of standards can produce distinctive effects also depending on several factors, such as dimension, technological intensity, culture, and strategy, just to mention a few, influencing its adoption. Nevertheless, standardisation diffuses knowledge, increases predictability, thus reducing uncertainty and risk, and facilitates a state-of-the-art dissemination to companies, benefiting SMEs" (Caetano 2017, p. 8).

Moreover, the correlation between standardisation and innovation is measured at the national level by Mentel and Hajduk-Stelmachowicz (2020, pp. 489–498). From several statistical methods, they have recognised standardisation as a strengthener of innovation activities. A ranking of European countries was also produced based on the chosen features (e.g. number of standardisations per capita and Summary Innovation Index), using all of the features as stimulants (the higher an indicator's value, the better). The mid-rank method was employed to achieve the result in Table 1.

Country	Ranking	Country	Ranking
Switzerland	1	Spain	19
Sweden	2	Hungary	20
Netherland	3	Italy	21
United Kingdom	4	Greece	22
Denmark	5	Slovakia	23
Luxembourg	6	Portugal	24
Iceland	7	Latvia	25
Germany	8	Lithuania	26
Ireland	9	Malta	27
Finland	10	Croatia	28
Norway	11	Bulgaria	29
Czech Republic	12	Serbia	30
Austria	13	Poland	31
Belgium	14	Romania	32
Cyprus	15	Turkey	33
Slovenia	16	Macedonia	34
France	17	Ukraine	35
Estonia	18		

Table 1 Ranking of the innovation activity
Source: Own elaboration based on data from "Does standardisation have an impact on innovation activity in different countries?" (Mentel, Hajduk-Stelmachowicz 2020, p. 496)

As indicated in Table 1, Czechia ranks 12th out of 35 countries. Czechia ranks first among the countries of the former Soviet bloc. This piece of information potentially carries favourable implications for the selected entity, CTU Space Research, which conducts operations within the Czech Republic and its market.

The effect of standardisation on innovation is conditioned by circumstances and can be subject to the influence of multiple variables, such as the level of technological advancement, the extent of market competition and the regulatory framework. Porter (1990), as cited in Mentel and Hajduk-Stelmachowicz (2020, p. 486), posits that an industry's competitiveness is linked to its ability to integrate advancements and enhancements. This highlights the complex relationship between innovation, standardisation, and competitiveness, which can be altered by various factors such as technological progress, market rivalry, and regulatory structures.

In summary, standardisation shows both enabling and constraining effects in the realm of innovation, rendering it a double-edged sword. Achieving the advantages of standardisation and innovation necessitates a meticulous equilibrium between the two. Achieving success in this area requires in-depth knowledge of the complicated relationship between standardisation and innovation and the capacity to maintain a subtle equilibrium between the imperative for compatibility and the imperative for originality. Continued investigation on this matter is imperative to gain a deeper understanding of the correlation between standardisation and innovation and to establish effective approaches for advancing both.

2 Aerospace and Rocket Industry

The fields of aerospace and rocketry are delicate areas that involve a diverse array of technical and scientific disciplines. To comprehend the attributes of these domains, it is imperative to contemplate the historical progression of aerospace and rocketry alongside the present status of the industry.

2.1 Characteristics

One of the key characteristics of aerospace and rocketry is their interdisciplinary nature. Aerospace and rocketry involve the integration of various fields, such as aerodynamics, propulsion, materials science, structural mechanics, and guidance and control systems. This interdisciplinary nature requires a high level of collaboration and coordination between different teams and individuals with diverse areas of expertise.

Another important characteristic of aerospace and rocketry is the need for advanced technologies and materials. Aerospace and rocketry demand high-performance materials and components that withstand extreme temperatures, pressures, and loads. The development and integration of these advanced technologies and materials is a critical factor in the success of aerospace and rocketry endeavours.

A third characteristic of aerospace and rocketry is their reliance on numerical simulation and modelling. The development and testing of aerospace and rocket systems require the use of advanced numerical simulations to predict and analyse their performance. These simulations and models help engineers and scientists understand the behaviour of complex systems and make informed design decisions.

2.2 History

The closer we approach the modern era, the more we talk about advanced technology, the growing size of rockets, and their increased dependability, which is influenced by factors such as the quality of craftsmanship and the use of better grade materials. For this thesis, the rocket industry is the only area analysed in this chapter. According to Brief History of Rockets (Anon. 2021), the brief history of the rocket industry and exploration is following:

1232 – Chinese fire arrows – The Chinese construct the first real rocket. Fire arrows are employed to resist the invading Mongols.

1591 – First multistage rocket – Johann Schmidlap, a German fireworks manufacturer, creates the two-stage rocket to fly higher. A little rocket is carried by a larger rocket. This defines the first and second stage of the rocket.

1687 – Newton's Laws of Motion published – The Principia, a book by Sir Isaac Newton that contains his three principles of motion and establishes the theoretical framework for contemporary rocketry, is published.

1792 and 1799 – Rocket revival – Indians use rockets against the British military, and that keeps the attention of Colonel William Congreve. Rockets are subsequently developed for military use by the British military afterwards.

1844 – Spin stabilisation invented – Jet vents are invented at an angle, making the rocket spin, much like a bullet, making them more stable and precise.

1898 – Space exploration proposed – Konstantin Tsiokovsky, a Russian educator, proposes the use of rockets for space exploration. He claims that liquid propellants would have a broader operating range.

1926 – Successful liquid-propellant rocket – Robert H. Goddard (USA) pilots a rocket propelled by liquid oxygen and gasoline. Goddard continues to develop larger and more powerful rockets.

1942 – V-2 rockets – During the Second World War, German engineers under Wernher von Braun developed ballistic missiles. One ton of oxygen and alcohol is burned by them every 7 seconds. This is the first rocket capable of reaching space.

1946 – First atmospheric testing – The United States started using V-2 (refer to Image 1) rockets as sounding rockets to take measurements of the atmosphere at great altitudes with the aid of captured German rocket engineers. Before this, little was known about the atmosphere.

Image 1 Launch of German V-2 rocket in USA (1950)
Source: NASA (2015)

1950s – Intercontinental ballistic missiles – The US space programme begins with the development of various medium- and long-range missiles. At some point, astronauts would be sent into space by missiles like Redstone, Atlas, and Titan.

1957 – First satellite – Sputnik 1 – The Soviet Union launches the first Earth-orbiting artificial satellite. The two superpowers of the world's space race have now achieved their first notable victory.

1958 – NASA founded – The United States formally organises its space programme and calls it the National Aeronautics and Space Administration.

1961 – First man to orbit Earth – Yuri Gagarin becomes the first person to orbit the Earth.

1962 – Mariner probes to Venus – The first successful interplanetary probes are launched. Mariner 2 probes travel to Venus (see Image 2).

Image 2 Mariner 2 probe
Source: ThePlanetsToday (2023)

1961 to 1966 – Ranger series – Nine probes were sent to the moon to take pictures of its surface in advance of a moon landing.

1969 – Moon landing – The first space mission to set foot on the Moon was Apollo 11. The flight was done by rocket Saturn V, see Image 3. The first astronaut to set foot on the moon was Neil Armstrong. In six missions, twelve astronauts make lunar landings. In 1972, Ed Cernan became the final person to set foot on the moon.

Image 3 Saturn V launch
Source: Mohon (2019)

1981 – First Space Shuttle launch – Launch of the first Space Shuttle by NASA. These are intended to be reusable vehicles that would improve orbital accessibility. The International Space Station was built, and many satellites were launched into orbit using space shuttles. In July 2011, the final shuttle launch took place.

2010 – First private launch into Earth orbit – SpaceX, a private company working towards commercial space travel, launches Falcon 9. This unmanned capsule orbits the Earth twice before landing in the Pacific Ocean.

2020 – First launch of a private crewed flight – Private company Space X, in partnership with NASA, launches a two-person crewed spacecraft, Dragon Crew, to the International Space Station (ISS), see Image 4.

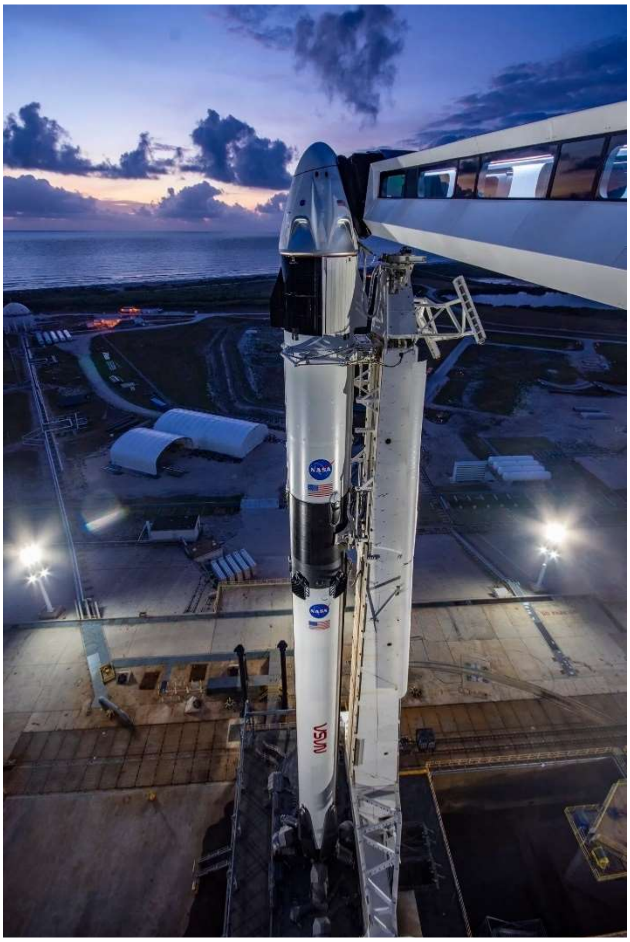

Image 4 Rocket Falcon 9 with Dragon Crew on a launchpad
Source: USA TODAY (2023)

2.3 Innovations and inventions

The rocket sector has been instrumental in the progression of human comprehension and awareness of the universe through the pursuit of space exploration. The advancement and utilisation of rockets have facilitated humanity's ability to transcend our planet's limitations and investigate the cosmos' expanse. The mentioned enquiry has broadened our comprehension of the universe and resulted in many technological advancements and scientific discoveries.

Space exploration has been a driving force behind the development of new technologies in areas such as propulsion systems, materials science, and guidance and control systems. The harsh environment of space has challenged engineers and scientists to develop new solutions to meet the demands of operating in this environment. The development of these technologies has had far-reaching impacts beyond the realm of space exploration, with numerous applications in fields such as medicine, communication, and environmental science.

Likewise, space exploration has encouraged innovation by opening up possibilities for research and commercialisation. New study fields have emerged as a result of the discovery of novel occurrences and the advancement of innovative technology in space, as well as brand-new markets for business activities. For instance, the need for satellite-based communication and navigation services has played a significant role in the rise of the satellite business. The graphic below shows the size and complexity of the satellites that orbit the planet. The United Nations Office for Outer Space Affairs (UNOOSA) reports that there are currently 8,261 satellites orbiting the Earth, with 4,852 of them being active (Kaushik 2022). The remaining satellites are considered orbital debris. The aforementioned statement can be seen in Image 5. Note that the debris objects are shown at an exaggerated size to make them visible at the scale shown.

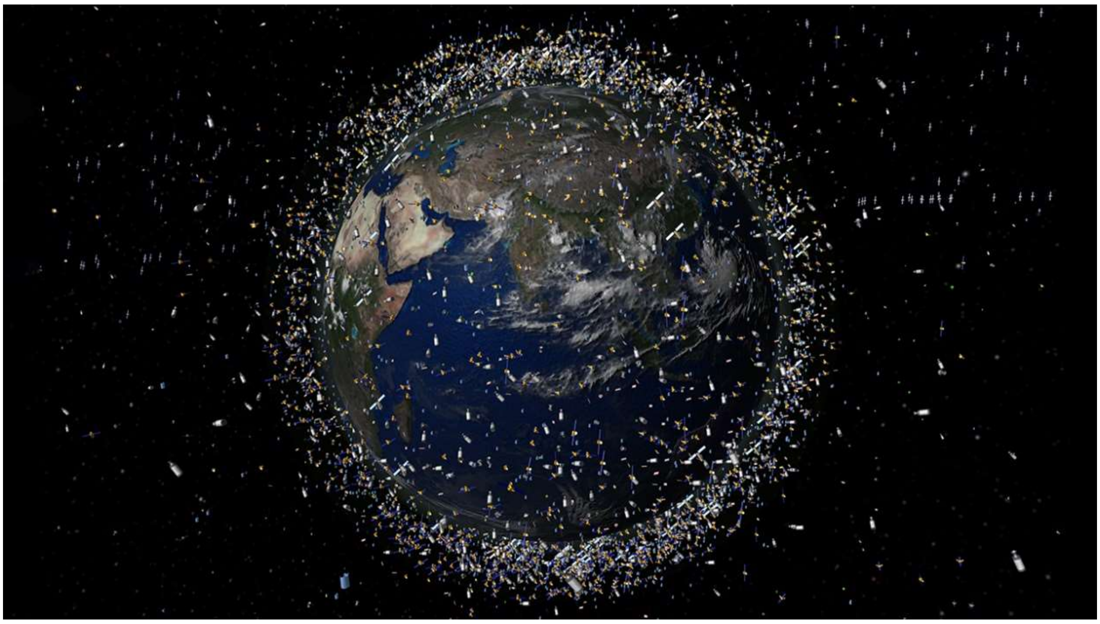

Image 5 Satellite Clusters and Orbital Debris Pollution Surrounding Earth
Source: Sokol (2021)

In finalisation, there is a close relationship between the rocket business and space exploration. We have been able to explore the cosmos thanks to the creation and use of rockets, which has led to a number of technical and scientific advances. The future of our species will be significantly influenced by the rocket industry's continuous expansion, which will be essential in advancing future space travel and discoveries.

2.4 Growing market

The cost of launching rockets into space has decreased in recent years due to technological advances and the emergence of new players in the industry. The decreasing cost of launch is having a significant impact on the rocket industry, which is a growing market, making space exploration and commercial operations more accessible and affordable.

One of the primary reasons for the decreasing launch cost is the development of reusable rockets. Traditional rockets were designed for single use and were discarded after each launch. However, the development of reusable rockets, such as those developed by SpaceX, has made it possible to recover and reuse rocket components, reducing the cost of each subsequent launch. The decreasing character of rocket launch costs and the impact of reusable rockets is visible in Image 6[1].

[1] From the image, you can deduct the Space Shuttle project's significant expenditure and the SpaceX rockets' cost-effectiveness based on its reusability.

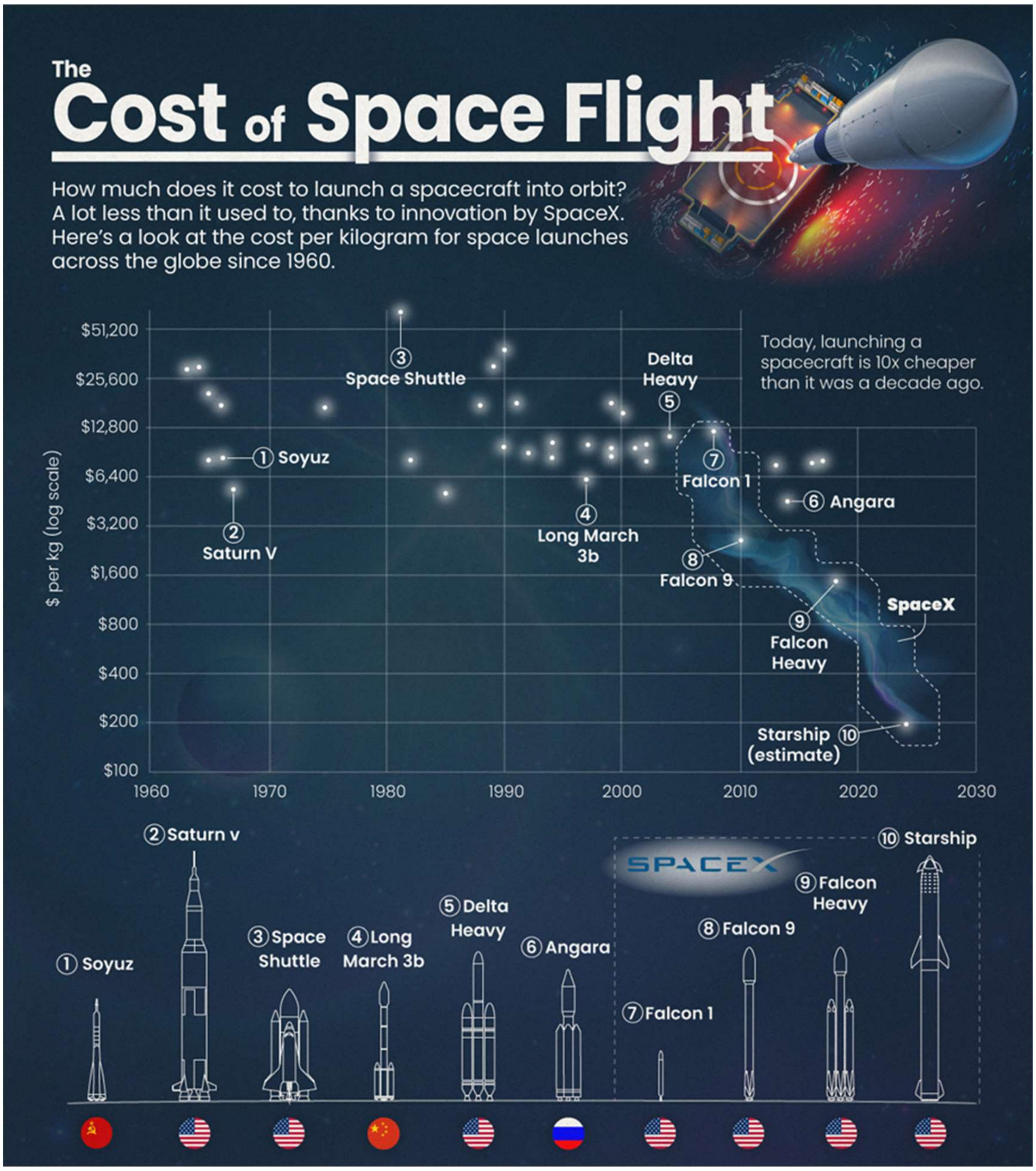

Image 6 The Cost of Space Flight Before and After SpaceX
Source: Venditti (2022)

Another reason for the decreasing cost of launch is the increased competition in the industry. The entry of new players, such as small satellite companies and new space launch providers, has increased competition and driven down the cost of launches. Increased competition has also led to the development of new launch vehicles and technologies that are more cost-effective and efficient.

The use of commercial and government partnerships has also contributed to the decreasing cost of launch. By pooling resources and expertise, these partnerships have reduced the cost of launches and promoted more efficient and cost-effective operations.

The market for rockets is expanding, and the dropping launch cost is one factor in this expansion. Greater access to space is made feasible by the availability of cheaper launch choices, which raises demand for launches and spurs the creation of new services and applications. Access to technology is made simpler, enabling start-up businesses and new entrepreneurs to join markets with less capital and production capacity. Image 7 shows more than 15 independent European producers of smaller rockets that, depending on their carrying capacity, can deliver payloads to LEO[2] or MEO[3].

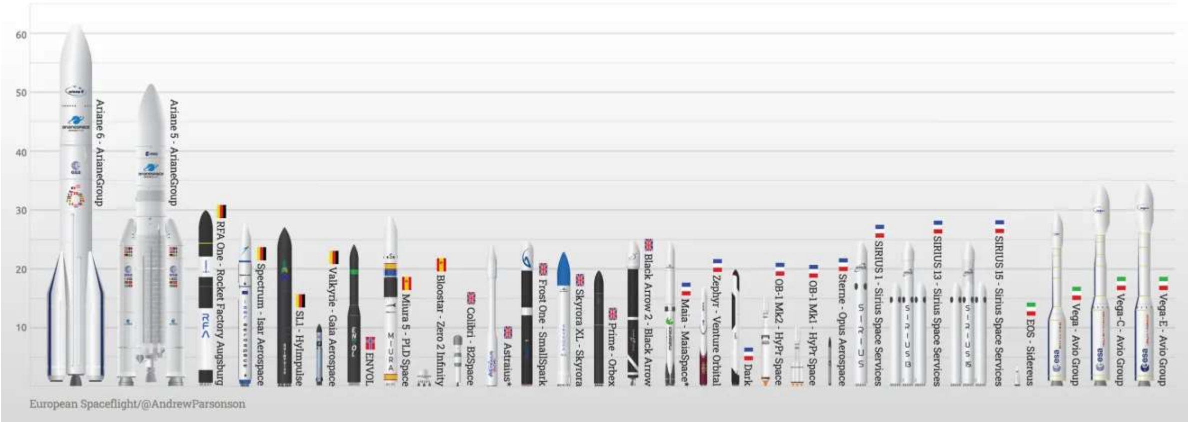

Image 7 Commercial rockets across the Europe

Source: Parsonson (2023)

The rocket industry is a growing market, driven in part by the increasing demand for scientific and commercial launches. Space tourism is another emerging market for the rocket industry. With the development of new technologies and the decline in launch costs, space tourism is becoming an increasingly attractive possibility for individuals and private companies. Space tourism presents new opportunities for commercial development and will likely encourage the expansion of the rocket industry in the coming years. As one of the many upcoming examples of space tourism, the company Blue Origin has demonstrated the use of its rocket New Shepard (Blue Origin 2023) for space tourism purposes. Its reusable rocket reaches the Karman line but is unable to achieve earth orbit. Even though it is a leading innovator, it demonstrates that space exploration is accessible to people of any age who lack cosmonautics and aerospace expertise.

The decreasing cost of launch in the rocket industry is due to a combination of factors, including the development of reusable rockets, increased competition, and the utilisation of commercial and governmental partnerships. These innovations substantially affect the expanding rocket industry, making space exploration and commercial operations more accessible and affordable.

[2] LEO stands for low Earth orbit
[3] MEO stands for medium Earth orbit

2.5 Project Management

The field of rocketry poses distinctive complexity and obstacles that necessitate the implementation of resilient project management methodologies to guarantee effective project implementation. The present chapter delves into the essential principles and methodologies of project management in the rocketry sector, as outlined in Darrin's and Stadter's Aerospace Project Management Handbook (2017). The initial segment of the manual, which is titled Aerospace Project Development Topics, establishes the basis for this discourse.

According to Darrin and Stadter (2017, pp. 5–9), the life cycle of a rocketry project is comprised of various phases, including conceptual design, preliminary design, detailed design, production, testing, and operation. During the various stages of a project, effective project management is crucial in ensuring the timely and cost-effective achievement of project goals. The significance of well-defined project requirements and effective communication and coordination among diverse stakeholders has been highlighted by Darrin and Stadter (2017).

Risk management is a crucial component of project management within the field of rocketry due to the intrinsically hazardous nature of such endeavours (Darrin, Stadter 2017, pp. 14–16). The significance of recognising, evaluating, and handling risks during the course of a project is also highlighted. This involves the creation of a risk management plan that encompasses the identification, analysis, response planning, and monitoring and control of risks.

The successful implementation of rocketry projects is contingent upon the essentiality of efficient project planning and scheduling. Darrin and Stadter (2017, pp. 5–18) examine a range of planning tools and techniques, including Gantt Charts. This tool helps to define the scope of the project, establish project milestones, and identify dependencies among various tasks. Consequently, project managers can allocate resources efficiently and monitor progress effectively.

Effective resource management is a crucial element of project management within the field of rocketry, as it has a direct influence on the project's financial implications, timeline, and overall achievement (Darrin, Stadter 2017, pp. 164–166). The importance of efficient allocation and use of resources, encompassing personnel, equipment, materials, and facilities, in reducing project delays and cost overruns.

Ensuring optimal standards of quality is imperative for the success and security of endeavours pertaining to rocketry. Darrin and Stedter (2017, pp. 17–18) highlight the importance of quality management in meeting or exceeding customer expectations. This involves the creation of a quality management plan, the initiation of quality assurance procedures, and the integration of quality control measures throughout the duration of the project.

The rocketry industry requires successful project management, contingent upon effective communication and stakeholder management. The importance of creating unambiguous communication channels and promoting cooperation among various stakeholders, such as project teams, suppliers, customers, and regulatory agencies, through the formulation of a communication management plan, frequent progress reports, and the prompt resolution of any project-related concerns (Darrin, Stadter 2017).

Although the Aerospace Project Management Handbook provides an in-depth methodology for project management in the field of rocketry, its implementation within CTU Space Research, a university rocketry team operating under financial constraints, may not yield the same degree of advantages. The complicated nature of the principles and methodologies defined in the handbook may not be entirely appropriate for a student team with limited resources and capabilities. Hence, CTU Space Research needs to find a balance between the complexity of the project management methodologies defined in the handbook and their usability in the team's particular context. CTU Space Research can optimise the efficiency and effectiveness of its projects by customising and streamlining fundamental project management principles to suit their specific requirements, all while ensuring a harmonious equilibrium between complexity and simplicity.

3 Standards within the Aeronautical and Rocket Industry

The decreasing cost of launch in the rocket industry is due to a combination of factors, including the development of reusable rockets, increased competition, and the utilisation of commercial and government partnerships. These innovations substantially affect the expanding rocket industry, making space exploration and commercial operations more accessible and affordable. In a recent presentation at the Prague Observatory on November 8, 2022, Garry Lai (2022) highlighted the critical need for enhanced safety measures through standards in the context of space travel. According to Lai (2022), the current probability of dying during a space trip stands at approximately 3%, a figure that must be significantly reduced to facilitate the growth of space tourism and exploration. Paradoxically, the irresponsible accumulation of debris in Earth's orbit increases the likelihood of fatal failures during spacecraft launches, emphasising the urgency for comprehensive standards and responsible practices within the industry.

To address these concerns and establish guidelines that promote safe and efficient operations, even in the case of small student rocketry teams, a range of international and national organisations have developed standards specific to the rocket and aerospace industries.

The following sections will discuss multiple widely used standards in more detail, providing insight into their objectives, scope, and impact on the safety, performance, and sustainability of the rocket industry.

The rocket and space industry is governed by a set of standards and regulations designed to guarantee the safety and dependability of launches and space missions. Adherence to these standards is crucial in upholding the industry's credibility and ensuring the secure and accountable execution of launches and missions.

3.1 Types of Standards

The rocket and space industry is governed by various standards and regulations that guarantee the safety and dependability of launches and space missions. These requirements serve as a reference point for assessing the level of excellence and security within the field, thereby guaranteeing that space launches and expeditions are executed with a sense of accountability and caution. Several crucial standards in the rocket and space sector encompass.

These include the International Organisation for Standardisation (ISO), International Telecommunication Union (ITU), International Astronautical Federation (IAF), NASA Technical Standards, European Cooperation for Space Standardisation (ECSS), European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), International Council on Systems Engineering (INCOSE), China National Space Administration (CNSA), American Institute of Aeronautics and Astronautics (AIAA), and Japan Aerospace Exploration Agency (JAXA). In addition, it is vital to develop standards and best practises for the engineering of systems applicable to the aerospace sector.

3.2 International Organisation for Standardisation (ISO)

International Organisation for Standardisation (ISO) standard, especially those for space systems and operations, provides guidelines for the design, development, and operation of space systems, including launch vehicles, satellites, and ground systems.

The ISO is an impartial and non-governmental organisation comprising members of National Standards Bodies (NSBs) of 163 countries. Its purpose is to advocate for international standards that apply to trade, communication, and manufacturing. The creation of a standard generally takes place within one of the ISO's Technical Committees (TCs) or Sub-Committees (SCs), which are responsible for its development (Stokes et al., 2020, pp. 326–327).

These standards aim to provide guidance, promote best practises, and ensure quality and safety in various industries and disciplines. The naming convention for ISO standards typically consists of the acronym "ISO" followed by a unique numerical identifier, often separated by a hyphen. This numerical identifier is indicative of the standard's chronological order of publication or development, as well as its relation to other standards within the same domain. In some cases, the name may include additional alphanumeric codes or abbreviations to represent specific subcategories, revisions, or amendments (ISO 2023). In general, the ISO naming system facilitates the easy identification, referencing, and organisation of the vast array of standards, allowing stakeholders to efficiently implement and comply with these internationally recognised guidelines.

3.3 International Telecommunication Union (ITU)

International Telecommunication Union (ITU) standard for the allocation of radio frequency spectrum for satellite services. This standard provides guidelines for the use of radio frequency spectrum for satellite communications, including the use of satellites for voice and data communications, television and radio broadcasting, and meteorology according to the International Telecommunication Union (ITU 2023) and International Telecommunication Regulations (ITR 1988, pp. 3–11).

3.4 International Astronautical Federation (IAF)

The International Astronautical Federation (IAF) adheres to a comprehensive set of criteria for the evaluation and certification of space-related products and services. This rigorous process ensures the reliability, functionality, and integrity of key space assets, including launch vehicles, satellite systems, and terrestrial infrastructure (IAF 2023).

Although the IAF is a well-known and essential standard within the aerospace industry, the Czech Technical University (CTU) Space Research's rocket development process is not significantly impacted by the IAF's adoption. The CTU Space Research rocket launches are done in accordance with unique rules that do not need the adoption of IAF criteria. More specifically, CTU Space Research's rocket launches are planned inside specified military zones under the supervision of the competition's organisers, who provide authorization to begin rocket launches with onboard communication devices.

3.5 NASA Technical Standards

The NASA Technical Standards (NTSS), sponsored by the NASA Chief Engineer, strives to bolster technical excellence and ensure mission success by enhancing the agency's technical capabilities through standardisation. The programme actively participates in the development and adaptation of voluntary consensus standards to address NASA's unique needs, as well as manages the creation of NASA-specific technical standards, specifications, and handbooks. By providing the NASA community with a single access point to essential documentation, application notes, lessons learnt, and engineering tools, the programme streamlines workflows, promoting compatibility, interchangeability, and commonality across the agency and in alignment with industry practises (Bailey 2023a).

In addition to the general standardisation efforts, the NTSS programme encompasses diverse specialised fields. These areas include but are not limited to aerospace, electrical, electronic and electromechanical (EEE) components, environmental, fracture control, ground systems, materials, mechanical and structural, safety and mission assurance, software, and systems engineering. By covering such a broad spectrum of disciplines, the programme ensures that NASA's activities consistently adhere to rigorous standards, resulting in enhanced safety, efficiency, and innovation (Bailey 2023b).

This extensive range of standards primarily addresses NASA's technical requirements, ensuring consistent adherence to rigorous benchmarks, fostering compatibility, and driving innovation across the agency. Through its unwavering commitment to standardisation, the programme contributes significantly to the overall safety, efficiency, and effectiveness of NASA's efforts.

NTSS can be seen in practise in some of the student rocketry teams, not only those operating in the USA and participating at Spaceport America Cup.

3.6 European Cooperation for Space Standardisation (ECSS)

This standard offers guidance for the design, development, and operation of space systems, such as launchers, satellites, and ground systems.

The European Cooperation for Space Standardisation (ECSS) is a collaborative effort between European space agencies, industry partners, and research organisations to develop and maintain a coherent and consistent set of standards for space projects and activities. Established in 1993, ECSS is a cooperative initiative of the European Space Agency (ESA), national space agencies of ESA member states, and other related organisations, including the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) (Gammal, Kriedte 1996, p. 43).

ECSS standards encompass a wide range of disciplines, including system engineering, electrical, electronic, and electromechanical (EEE) components, mechanical and thermal engineering, materials, processes, testing, and software engineering. These standards are organised into three main branches, as depicted in Image 8: management (ECSS-M), product assurance (ECSS-Q), and engineering (ECSS-E) (ECSS Secretariat, n.d.). By providing a comprehensive framework for the development, procurement and operation of space systems, ECSS aims to improve the efficiency, reliability, and safety of European space projects and facilitate cooperation and interoperability among participating organisations (ECSS Secretariat 2023).

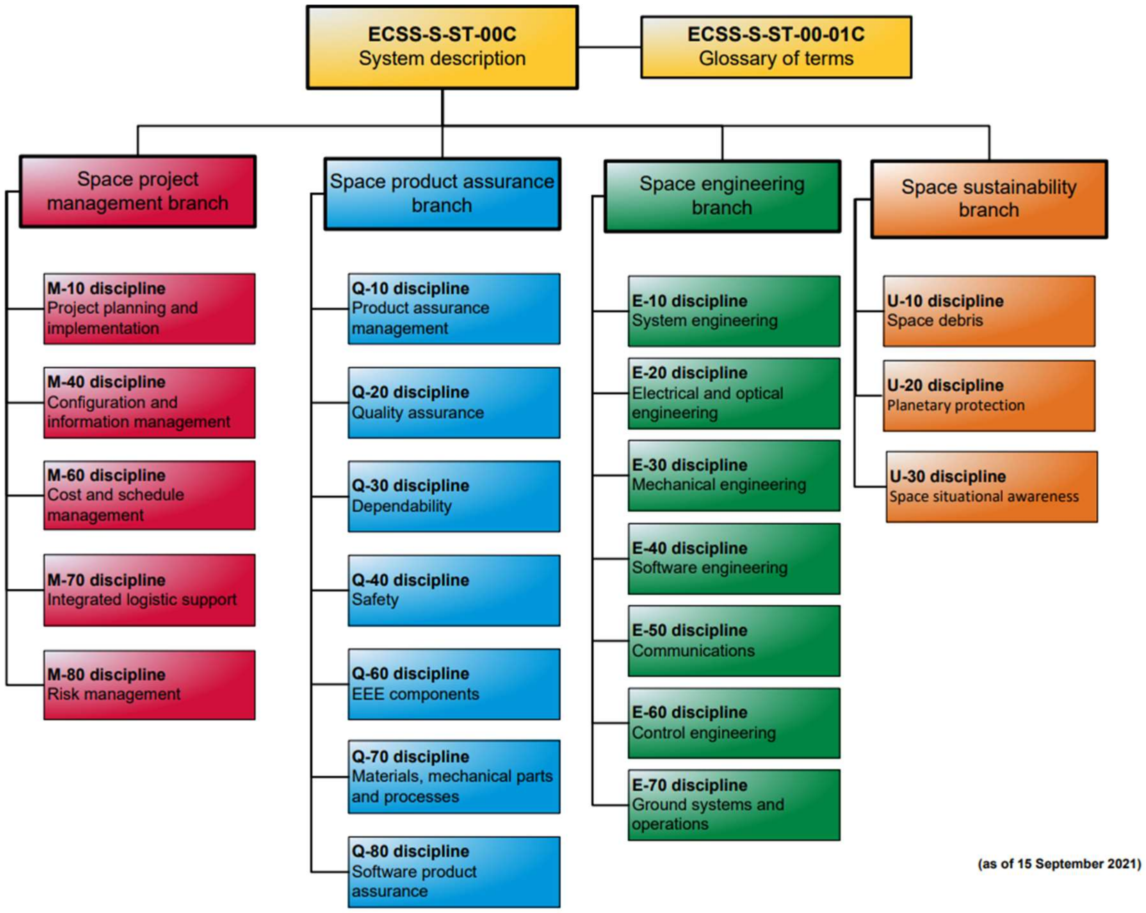

Image 8 European Cooperation for Space Standardisation Disciplines (architecture tree)
Source: ECSS (2022)

Scope of ECSS Standards

The scope of ECSS standards encompasses various aspects of space projects and applications, including project management requirements, design, development, manufacturing, verification, and operational space systems and their constituent parts, as well as technical requirements for assemblies, equipment, subsystems, and systems employed in space missions. These standards apply to any party involved in the definition, development, manufacturing, verification, or operation of assemblies, equipment, subsystems, systems, or services utilised for a European element of any space mission (Gammal, Kriedte 1996, p. 44).

In the context of a student rocketry team, the theoretical applicability of ECSS standards could provide a valuable framework for managing projects, designing and developing rocket components, and ensuring the safety and reliability of the team's endeavours. By adhering to these established standards, the student rocketry team would benefit from industry-proven methodologies, potentially enhancing their projects' efficiency, performance, and success rate.

Moreover, the adoption of ECSS standards by a student rocketry team may facilitate collaboration with other teams, industry partners, and space agencies by ensuring a consistent approach to project management and technical development. Such alignment with established best practises could also better prepare students for future careers in the space industry, as they would gain familiarity with the processes and requirements expected within the professional domain.

The adoption of ECSS standards has become a common practise in the European space industry, ensuring that projects conform to a consistent set of quality and performance benchmarks. Furthermore, these standards facilitate knowledge transfer and promote best practises across various organisations and projects, leading to more efficient and cost-effective solutions. As the space industry continues to evolve, ECSS plays a vital role in maintaining the competitiveness of European space activities and fostering innovation in the sector.

The European Cooperation for Space Standardisation (ECSS) stands as the closest and most suitable for CTU Space Research and its scope of activities. The ECSS standards provide a comprehensive framework for the development and implementation of space projects within Europe and have been adopted by many European space organisations, including the European Space Agency (ESA). These standards address various aspects of space systems and operations, such as management, engineering, quality assurance, and environmental requirements, making them an appropriate choice for CTU Space Research to adhere to in a reduced manner.

3.7 European Union Aviation Safety Agency (EASA)

These standards are commonly used by rocket manufacturing companies that cooperate with the European Space Agency and operate in Europe. On the other hand, these standards are more related to the general aeronautical industry and do not specify rules of safety and security for rockets' manufacturing and flights.

These standards and rules include, for example, collision avoidance, flight plans, visual flight rules (VFR), air traffic services, alerting service, onboard transponder, and voice communication procedures (EASA 2023, pp. 7–99). Therefore, even with the wide spread of these standards across European space companies, they do not play a crucial role for a student rocketry team like CTU Space Research.

3.8 Federal Aviation Administration (FAA)

The Federal Aviation Administration (FAA) is a United States government agency responsible for overseeing civil aviation within the country. Established in 1958, the FAA operates under the jurisdiction of the U.S. Department of Transportation. The agency's primary objectives include ensuring the safety and efficiency of the aviation system and fostering the development of the civil aeronautics industry. The FAA sets standards for pilot and air traffic controller certification, aircraft manufacturing and maintenance, and airport and airspace management, among other areas (FAA 2023).

As a regulatory body, the FAA plays a vital role in developing and implementing aviation-related rules, regulations, and standards. The FAA's Office of Commercial Space Transportation, for instance, is responsible for licencing and regulating commercial space transportation activities within the United States. This includes overseeing the safety of space launches and re-entries and the operation of non-federal launch and re-entry sites (FAA 2023).

3.9 International Council on Systems Engineering (INCOSE)

The International Council on Systems Engineering (INCOSE) is a non-profit organisation established in 1990, focussing on the development and promotion of systems engineering principles and practises. As a global community, INCOSE comprises professionals, academics, researchers, and students from diverse industries and domains. The primary goal of INCOSE is to employ systems engineering techniques to address multifaceted challenges, thus enhancing individuals' and societies' quality of life (INCOSE 2023).

Systems engineering is a multidisciplinary approach that emphasises the design, integration, and management of complex systems throughout their lifecycle. It involves the application of engineering principles, methods, and tools to tackle challenges in various sectors, including defence, aerospace, transportation, energy, and healthcare. System engineering is essential for developing innovative solutions, optimising processes and ensuring system performance, reliability, and safety.

INCOSE plays a crucial role in shaping the field of systems engineering by providing a platform for networking, fostering professional development, encouraging knowledge sharing, developing standards, and advocating for the value of systems engineering. Its standards might go into direct synergy with ECSS standards related to system engineering by its similarities.

All things considered, these are some of the essential standards and regulations in the rocket and space industry that help to ensure the safety and reliability of launches and missions. These standards provide a benchmark for quality and safety in the industry and are essential for maintaining the integrity of the industry and ensuring that launches and missions are carried out in a responsible and safe manner.

3.10 Other International Space Standardisations

There exist various Standards and Standardisations that have connections with particular space agencies, predominantly active in the Asian and American regions, which may hold limited practical significance for a student rocketry team situated in Europe. Thus, these findings are incompletely analysed and consolidated into a single headline.

As a first mentioned standardisation is China National Space Administration (CNSA 2023): CNSA is a Chinese government agency that conducts space exploration and research and sets standards for the design and operation of space systems. The CNSA was formed in 1993 and was correlated with the official start of the Chinese space programme in 1992. While the China National Space Administration (CNSA) is not as transparent or publicly accessible as some space agencies like NASA or ECSS, it shares some information with the public. As the national space agency of China, CNSA is responsible for specific project completion through divisions of General Planning, System Engineering, Science, Technology, Quality Control, and the Department of Foreign Affairs.

The second named standardisation is the American Institute of Aeronautics and Astronautics (AIAA 2020), a professional society that promotes the advancement of aerospace science and technology through research, education, and professional development. AIAA was founded in 1963 as a fusion of two rocket societies that date back to the first half of the twentieth century.

As the third standardisation – Japan Aerospace Exploration Agency (JAXA 2023), The Japanese government agency conducts space exploration and research and sets standards for the design and operation of space systems. JAXA works mainly for the Japanese space programme and its business partners that operate worldwide.

There is no evidence that the China National Space Administration, the American Institute of Aeronautics and Astronautics, and the Japan Aerospace Exploration Agency have been documented within any student rocketry team operating on the European market these days.

4 Project Management Methodologies

Documenting overarching standard protocols relevant to student groups functioning within financial limitations is imperative. These standards have a broader scope and are not limited to the aerospace sector. They focus on achieving project completion rather than strictly adhering to technical standards in the aeronautical and rocket industries. However, strict adherence to these guidelines can potentially satisfy student rocketry teams' demands, guaranteeing project success and upholding quality standards.

For example, the International Project Management Association (IPMA) and PRINCE2 (Projects IN Controlled Environments) methodologies offer comprehensive frameworks for project management that can be adapted to various industries and project types, including student rocketry teams.

IPMA provides a competency-based approach to project management, focusing on the skills, knowledge, and behaviours required for effective project management. It offers a four-level certification system that allows project managers to gain recognition for their expertise and demonstrate their commitment to continuous improvement. The IPMA approach is detailed in the Individual Competence Baseline (ICB), which serves as a global standard for project management competencies, according to International Project Management and its Individual Competence Baseline publication (IPMA 2021, pp. 7–30).

PRINCE2, on the other hand, is a process-driven project management methodology developed by the UK government. It provides a structured approach to project management, emphasising planning, controlling, and delivering projects on time and within budget. PRINCE2 is widely used in various industries and is supported by a suite of qualifications and certifications, enabling project managers to improve their skills and knowledge in best practises in project management, as stated by AXELOS (2017, pp. 18–35).

In conclusion, obtaining certifications in project management standards such as IPMA and PRINCE2 can be beneficial for developing skills and knowledge in best practises for managing projects. However, it is essential to consider that obtaining these certifications might be exponentially expensive and potentially out of budget for organisations with limited constraints, such as student rocketry teams.

Furthermore, while these methodologies provide valuable guidance for general project management, they may not offer specific advantages for rocket-orientated projects, as they are not tailored to address the unique challenges and technical requirements of the aeronautical and rocket sectors.

Therefore, while implementing general project management standards can contribute to overall project success, student rocketry teams should weigh the costs and benefits of obtaining such certifications and consider whether the investment would yield a significant return on investment for their specific projects and organisational goals. Last but not least, based on the previous facts, it was decided not to implement directly IPMA or PRINCE2 methodologies within CTU Space Research.

5 Quality Management

The practise of keeping an eye on all the tasks and activities necessary to maintain a specific level of excellence is known as quality management. A quality policy must be decided upon, and quality planning and assurance must be developed and put into practise. Quality management also includes procedures for quality control and quality improvement, ensuring that all facets of a project or organisation constantly achieve high-performance requirements (Barone 2022).

Quality management is closely related to the ISO 9001 Standard and creates seven principles of management, according to Sherrer (2022):

5.1 Customer focus

Customer focus is a fundamental aspect of quality management systems, playing a pivotal role in ensuring the long-term success of any business. Prioritising customer satisfaction can enhance a company's reputation, increase sales, and improve its bottom line. This chapter will discuss the significance of customer focus in quality management systems and how top management can demonstrate leadership and commitment in this area, conforming to ISO 9001 (2015, pp. 2–3).

Customer satisfaction is the ultimate objective of every quality management system since repeat consumers are crucial for a company's success. Companies may find areas for development by collecting consumer feedback, which encourages a positive feedback cycle and continual progress, according to Sherrer (2022). High customer satisfaction boosts a company's competitive position in the market, increases sales and profits, and encourages client loyalty.

5.2 Leadership

In order to successfully establish and maintain quality management systems, leadership is a key component. The system's success is greatly influenced by the top management's commitment to quality management. The quality management initiatives of a company will fail if the executives do not support it or do not make it a strategic priority. Because of this, ISO 9001 lists leadership as the second quality management concept. The organisation's leadership must be committed to quality management (ISO 2015, pp. 1–21).

Strong leadership include the C-suite[4] and other supervisors establishing the company's quality management objectives and fostering a culture of quality from the top down. Businesses will not achieve their quality management objectives if executives do not have a clear vision.

5.3 Engagement of people

The effectiveness of quality management systems depends on involving employees at all levels. To promote a culture of continuous improvement, encourage open communication, the development of skills, and active engagement. Employee engagement increases the likelihood of offering insightful suggestions and showing initiative in the quality management process (ISO 2015, p. VII–25).

For quality management to be successful, a culture that empowers staff and values their efforts must be created. Organisations may unlock the potential of their employees by offering chances for professional advancement and fostering a feeling of ownership, which will lead to a more effective and dynamic quality management system.

[4] C-suite refers to the executive-level managers within a company. E.g., chief executive officer (CEO), chief financial officer (CFO).

5.4 Process approach

Utilising processes to manage resources and activities is known as a process approach. Organisations can better allocate resources, spot inefficiencies, and boost performance by understanding the connections between various activities. Process-based quality management solutions provide more efficient and productive operations (ISO 2015, p. VI–VII).

A process approach makes operations more efficient and fosters a better knowledge of how an organisation functions as a whole. This viewpoint enables better resource allocation, more well-informed decision-making, and a comprehensive assessment of the organisation's effectiveness. The long-term viability of quality management systems depends on a process approach.

5.5 Improvement

Successful quality management systems are built on the principle of continuous improvement. Organisations must periodically evaluate their performance and look for areas to improve. Businesses may keep ahead of the competition, adjust to shifting market conditions, and ensure continued success by developing a culture of improvement (ISO 2015, p. 25).

Adopting a mindset of continual development is essential for adjusting to the market environment's constant change. Fostering an innovative culture inside the organisation may be accomplished by accepting change and seeing obstacles as chances for development. This kind of thinking aids companies in staying one step ahead of rivals and retaining a dominant position within their respective sectors.

5.6 Evidence-based decision-making

Effective quality management depends on making well-informed judgements. For the purpose of guiding their decision-making, organisations should collect and analyse data from many sources. Businesses may guarantee that their decisions are supported by facts by using an evidence-based strategy, which will improve results and boost efficiency (ISO 2015, pp. 7, 26).

Making decisions based on data is essential for avoiding potential hazards from intuition or subjective judgement. Organisations may enhance their strategic planning and more efficiently manage risks by basing choices on objective facts. As a result, evidence-based decision-making is a crucial element in assuring the dependability and performance of quality management systems.

5.7 Relationship management

Building and maintaining solid relationships with stakeholders, including suppliers, customers, and partners, is essential for the success of quality management systems. Collaboration with these stakeholders may help organisations achieve win-win results, spur innovation, and improve overall performance (ISO 2015, p. VII–IX).

According to the author, building connections with stakeholders is crucial for generating long-term value and promoting progress for both parties. A focus on relationship management may promote improved communication, creative alliances, and a more resilient corporate environment. As a result, businesses must spend time and effort developing and sustaining robust bonds with their stakeholders.

6 Innovation Project Management

A subfield of project management called "Innovation Project Management" is responsible for planning, organising, executing, and controlling projects specifically focused on developing and implementing new ideas, products, services, or processes. The Project Management Institute (PMI 2023) claims that it combines conventional project management techniques with innovation-focused methods and tools to manage the particular difficulties and uncertainties involved in commercialising new ideas, promoting a creative culture, and promoting long-term organisational growth and success.

6.1 Introduction to Innovation Project Management

The concept of innovation is widely acknowledged and has been defined in various ways. The Oslo Manual Guidelines (OECD & Eurostat 2005 cited in Stošić, Milutinović 2017, p. 26) are widely acknowledged and frequently referenced for their framework, which characterises innovation as the execution of a novel or substantially enhanced product (commodity or service), procedure, or marketing or organisational approach. It is noteworthy that there exist four distinct categories of innovation and, as a result, innovation initiatives: namely, product/service innovations, process innovations, organisational innovations, and marketing innovations.

Innovation can be perceived through various lenses, including Drucker's conceptualisation of innovation as an exclusive instrument of entrepreneurship, Porter's perspective of innovation as a corporation's capacity to attain a competitive edge, and Freeman's depiction of industrial innovation as encompassing technical design, production, management, and commercial activities. Rothwell has delineated two distinct categories of innovation, namely radical innovation and incremental innovation (Stošić, Milutinović 2017, p. 26).

The success of innovation can be measured by its ability to facilitate a company's sustained growth through the processes of adaptation and continuity. An essential enquiry pertains to the methodology of innovation that ought to be adopted by a company, providing direction to the entity and its subordinate divisions in navigating the intricate innovation trajectory, spanning from ideation to the attainment of sales, revenues, and profits (Stošić, Milutinović 2017, pp. 26–28).

6.2 The Innovation Master Plan and the Integration of Project Management

The Innovation Master Plan developed by InnovationLabs consultant, Langdon Morris (Langdon 2011 cited in 2017, p. 27) presents a valuable framework that adheres to a straightforward structure consisting of five essential questions pertaining to innovation within an enterprise. The inquiries presented pertain to the strategic aspects of innovation, the creation and management of the innovation portfolio, the formulation of the innovation process, the identification of individuals involved in the innovation process, and the establishment of the infrastructure, support systems, and tools necessary for facilitating efficient participation in the innovation process.

In today's world, innovation is frequently perceived as an independent undertaking, with innovation management and project management emerging as two distinct fields of study. Empirical evidence suggests that project management is the most effective approach to overseeing the lifecycle of the innovation process. Consequently, it is unsurprising that the development of innovations predominantly employs the framework of project management, according to Stošić, Milutinović (2017, pp. 27–28).

6.3 Key Features and Classification of Innovation Projects

Unique features set innovation projects apart from traditional projects. The factors that can impact project success encompass indistinct or equivocal project objectives during the project's initiation, project teams that consist of members with heterogeneous expertise and proficiencies, the recognition of failure as a plausible outcome, and the necessity to persuade sponsors of the proposed ideas (Stosic 2013 mentioned in Stošić, Milutinović 2017, p. 27).

Innovation endeavours can be categorised according to the degree of innovation, namely, incremental and radical innovations. Around 80% of innovation investments made by companies are attributed to incremental innovations. The taxonomy can be expanded by establishing a correlation between the incremental and radical types and crucial attributes such as project aims and objectives, uncertainties, and the industrial domain. The classification in question encompasses the act of imitation, which is regarded as a creative endeavour aimed at the advancement of a particular product or service, according to Filippov, Mooi (2010 stated in Stošić, Milutinović 2017, p. 28).

6.4 Factors Influencing Innovation Project Success and Key Elements for Management

The contemporary business landscape necessitates the attainment of high project performance and exceptional project management skills. The efficient and effective utilisation of resources in projects is crucial for optimising stakeholder benefits. Innovation project success can be influenced by a range of factors, including but not limited to size, uniqueness, and complexity.

Effectively managing innovation projects at the organisational level requires the incorporation of fundamental components such as innovation strategy and organisation, creativity and idea management, innovation portfolio, innovation models, and risk management. Although it is not feasible to create a comprehensive checklist that applies to all projects, these components serve as a fundamental basis for overseeing and directing innovative projects towards success (Stosic 2013 in (Stošić, Milutinović 2017, p. 28).

6.5 Conclusion

Conclusively, the management of innovation projects is a vital component in driving growth and achievement in the current competitive corporate environment. Integrating innovation management and project management principles helps organisations navigate the intricate process of converting ideas into valuable products, services, or processes. Organisations can effectively devise and execute innovative strategies that are customised to their specific requirements and goals by comprehending the distinct categories of innovation, their salient characteristics, and the determinants that impact project triumph.

The implementation of the Innovation Master Plan and the categorisation of innovation initiatives are instrumental in enabling organisations to effectively administer their innovation procedures. Organisations can cultivate a culture of innovation that consistently contributes to growth, adaptation, and the achievement of strategic objectives by addressing critical enquiries and integrating essential components for effective management. The discipline of innovation project management continues to be crucial to enable organisations to remain ahead of the curve and maintain a competitive advantage in the constantly evolving business environment.

7 Student Organisations

Student organisations allow students to participate in various events that can advance their personal and professional development, making them an integral part of the university experience. This chapter aims to introduce student organisations and the advantages they provide students. The author also examines the financial side of these organisations, with a particular emphasis on how university funding and sponsorships enable them to survive.

On top of that, this chapter will assess the positive and negative aspects of student organisations, as well as the function that these organisations play within the framework of the community that exists within universities. Additionally, this chapter will discuss the role that student groups play within the framework of the community that exists within universities. In order to present a thorough picture of student organisations, the author will also determine factors in the SWOT analysis. This study will examine the strengths, weaknesses, opportunities, and threats of the organisation. This study will focus on the many opportunities, threats, strengths, and weaknesses organisations pose.

7.1 Overview

Student organisations are an integral part of the university experience, offering students a wide range of opportunities to get involved, develop new skills, and build relationships. These organisations are student-led and operate independently from the university, allowing students to pursue their interests, passions, and goals. The critical part of student organisations is its funding, which is mainly provided by the university but can also be substituted by sponsors that may benefit from the existence of student organisation, e.g. by the fact that members are developing in a practical way and make a positive impact on future activities of the company.

Student organisations come in many forms, including academic and professional organisations, cultural and diversity groups, service organisations, and recreational and hobby groups. These organisations offer a diverse range of experiences and opportunities, including leadership development, community service, and hands-on experience in a particular field. Student organisations vary according to the aim of the alma mater as the Czech Technical University accommodates more technical organisations that develop high-end technologies via formula (this community is demonstrated in Image 9), rocket teams and other technical organisations. On the other hand, the University of Economics in Prague, a more economic-orientated university, covers teams developing its members in accounting, banking, and international relations (e.g. AIESEC organisation).

Image 9 Formula Student competition
Source: Road Arrow (2023)

Participating in student organisations can profoundly impact a student's personal and professional development. Through their involvement in these organisations, students can develop their leadership and communication skills, build their network of contacts, and gain practical experience in their area of interest. As CTU Space Research's Team Lead, Viktor Hais (2022a) stated, "CTU strives to develop theoretical skills of their members and transform them to more practical skills and abilities that give them a unique advantage in the labour market during and after studies."

7.2 Purpose

One of the essential functions of student organisations is to provide opportunities for students to pursue their interests and passions outside of the classroom. These organisations allow students to explore new activities, develop new skills, and build relationships with like-minded individuals. By participating in student organisations, students are able to gain hands-on experience in areas that interest them and pursue their goals in a supportive and collaborative environment.

Another essential task of student organisations is to provide a platform for students to take on leadership roles and develop their leadership skills. Through their involvement in student organisations, students are able to gain experience in planning and executing events, managing budgets, and working with a team. These skills are valuable for future careers and can help to prepare students for leadership positions in their professional lives.

Student organisations also provide a valuable PR opportunity for the university, highlighting the strengths and achievements of its students and demonstrating the university's commitment to student development and engagement. By participating in student organisations, students can showcase their talents and skills and make meaningful contributions to the university community.

In verdict, student organisations serve multiple purposes, including providing opportunities for students to pursue their interests and passions, develop their leadership skills, and provide a valuable PR opportunity for the university. These organisations offer a wide range of activities that are designed to interest and engage students, and play a critical role in the personal and professional development of students.

7.3 Advantages and disadvantages

Student organisations offer a wide range of advantages for students, including opportunities to pursue their interests and passions, develop their leadership skills, and gain practical experience in their area of interest. These organisations provide a supportive and collaborative environment for students to explore new activities and pursue their goals.

However, student organisations can also present some challenges and disadvantages. One of these challenges is the lack of motivation resulting from unpaid jobs and responsibilities within the organisation. Many student organisations rely on volunteers to plan and execute events, which can lead to burnout and decreased motivation if students are not adequately compensated for their time and effort.

Another disadvantage of student organisations is the lack of funding and resources. Many student organisations are dependent on university funding and support, and a lack of resources can limit the organisation's ability to achieve its goals and carry out its activities. This can lead to decreased motivation and engagement among members and make it more difficult for the organisation to attract and retain members.

Finally, student organisations can also be limited by their dependence on the university. This dependency can make it difficult for organisations to operate independently and make decisions aligning with their goals and objectives. It can also limit the ability of organisations to respond to changing needs and demands, as they are bounded by university policies and procedures.

In conclusion, student organisations offer a wide range of advantages for students, including opportunities for personal and professional development. However, these organisations can also present challenges and disadvantages, including lack of motivation, lack of funding and resources, and dependence on the university. To maximise the benefits of student organisations, it is necessary to carefully consider these challenges and develop strategies to overcome them.

7.4 SWOT Analysis

A SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) analysis is a widely used tool for evaluating the performance and potential of organisations. This technique provides a framework for considering the internal and external factors that can impact the success of an organisation and are widely recognised as a valuable tool for decision-making and strategic planning. According to "Strategic Management: Concepts and Cases" by Fred R. David (2011, pp. 178–181), a SWOT analysis can help organisations identify their key strengths and weaknesses, understand the opportunities and threats they face, and develop strategies to use their strengths and overcome their weaknesses. By conducting a SWOT analysis, organisations can gain a comprehensive understanding of their current position and potential for growth and make informed decisions about their future direction and success.

The SWOT analysis for the student organisation focused on rocket building provides valuable insight into the strengths, weaknesses, opportunities, and threats faced by the organisation. By considering the strengths, such as opportunities for personal and professional development and hands-on experience in the field of rocketry, the organisation can identify areas where it can build on its success and continue to grow. By identifying its weaknesses, such as lack of funding and resources, the organisation can develop strategies to overcome these challenges and increase its effectiveness and efficiency.

The opportunities identified through the SWOT analysis, such as the potential for expansion into new areas of interest and the development of new partnerships and collaborations, provide valuable insights into the organisation's future direction. By taking advantage of these opportunities, the organisation can continue to grow and provide valuable benefits to its members and the broader university community. By considering threats, such as competition from other student organisations and changes in university policies, the organisation can develop contingency plans to mitigate these risks and ensure its continued success.

SWOT Analysis of student organisations	
Strengths	Weaknesses
▪ Opportunities for personal and professional development. ▪ Hands-on experience in a particular field. ▪ Development of leadership and teamwork skills. ▪ Networking opportunities with like-minded individuals and industry professionals.	▪ Lack of funding and resources. ▪ Dependence on university support. ▪ Unpaid responsibilities lead to burnout and decreased motivation. ▪ Difficulty in attracting and retaining members.
Opportunities	Threats
▪ Expansion into new areas of interest ▪ Development of new partnerships and collaborations. ▪ Increased visibility and recognition for the organisation and its members. ▪ Access to new technologies and resources.	▪ Competition from other student organisations. ▪ Changes in university policies and procedures. ▪ Decreased interest in the field or activity. ▪ Economic or political instability affecting funding and resources.

Table 2 SWOT analysis of student organisations
Source: Own elaboration

To put it all together, the SWOT analysis for the student organisation focused on rocket building provides a comprehensive overview of the organisation's current position and potential for growth. By considering the strengths, weaknesses, opportunities, and threats the organisation faces, the organisation can make informed decisions about its future direction and success and take steps to overcome any challenges it may face.

PRACTICAL PART

8 Analysis of the Selected Organisations

As the purpose and aim of the thesis indicate, the author strives to fit the diploma thesis to the environment of a student organisation that develops in the field of rocketry and space technologies with characteristics of a university incubator and limited financial resources.

The objective of this research is to undertake a detailed examination of a student organisation focusing on rocket construction and space technologies in order to evaluate the organisation's potential for development and success within the context of the university incubator. The organisation functions within the limits of having limited financial resources, and the chapter's goal is to identify the difficulties and possibilities that are presented as a result of these constraints, as well as to conduct an initial analysis in order to make suggestions for improvement and development in subsequent phases of the work.

To achieve the research objectives, a mixed methods approach will be used, incorporating both qualitative and quantitative data collection and analysis methods. The study begins with a SOAR (Strengths, Opportunities, Aspirations, and Results) analysis of the organisation, which provides a comprehensive overview of the organisation's current position and potential for growth. The SOAR analysis will consider a range of internal and external factors, including the organisation's structure, governance, operations, and financial resources, as well as its relationships with other university organisations and external stakeholders, including industry partners and funding agencies.

In addition to SWOT analysis, the study will employ qualitative data collection methods, such as in-depth interviews, to gather additional insights and perspectives on the organisation and its operations. Qualitative data will be analysed using thematic analysis techniques and will be used to complement and validate the findings of the SWOT analysis.

The study results will be used to develop recommendations for the organisation to improve its performance, increase its impact, and ensure its long-term success. These recommendations will consider the organisation's strengths and weaknesses and the opportunities and threats it faces, and will be grounded in best practises from within the rocket and space industry and the university incubator.

8.1 CTU Space Research as a student organisation with limited resources

The current chapter takes a deep dive into the internal operations of CTU Space Research, a student organisation that functions with limited resources. Following the introduction is a section that outlines the purpose and vision of the organisation, which comes after the introduction. Next, it examines the financial underpinnings of the organisation, as well as its fundraising activities and the many elements, both internal and external, that have an impact on the organisation. Insights about the organisation's strengths, prospects, goals, and outcomes may be gained via the execution of a complete SOAR study and an analysis of the competitive environment. Following that, the chapter discusses the numerous projects that the organisation has taken on, the methods of project management, and an innovation analysis in order to get a better understanding of its capabilities and prospects for development.

8.1.1 Introduction

CTU Space Research is a student rocketry organisation comprising university and college students passionate about space exploration. The team is committed to developing rocket technologies, testing them, and participating in student rocketry competitions.

If fully dedicated to their membership, team members experience significant professional development while embracing and integrating emerging technologies. Their employment options are subsequently increased as a result of their newfound expertise, which extends beyond the rocket industry's confines to include a wide range of industries.

The team is supported by the university, which provides access to resources and facilities necessary for rocket development and testing. This support has enabled the team to participate in several prestigious student rocketry competitions, such as the Spaceport America Cup and the European Rocketry Challenge, where they have competed and succeeded among other top-level rocketry teams.

Pushing the limits of rocket science has allowed them to become a leading force in the domestic student rocketry community with intentions to become an international player as well. The focus of the team on the development of its members, the supportive environment of the university, and collaboration with inspirative student rocketry teams from abroad have further advanced their knowledge and experience in the field.

For purposes and complexity of project task, the whole organisation is divided into the following segments:

Avionics

The Avionics system enables the rocket to determine its current statuses, such as position, speed, and acceleration, and transmit this information to the ground. It is responsible for initiating recovery processes, including deploying the parachute appropriately. Additionally, depending on the type of engine utilized, it can function as an intermediary between the propulsion systems and specific ground-based systems (EPFL Rocket Team 2023).

The Avionics department comes up with hardware and software solutions for the rocket and other related hardware (e.g., ground station) and software (databases, API[5]). The team consists of a variety of members with backgrounds in programming, electrotechnics, and circuit soldering. Further activities include:

- Designing and building a custom printed circuit board (PCB) for the avionics system.
- Developing and testing software to control the avionics system and collect data during the rocket launch.
- Selecting and integrating various sensors into the avionics system, such as accelerometers, altimeters, and gyroscopes.
- Integration of communication systems, such as radio transmitters and receivers, to allow telemetry and tracking of the rocket's flight.
- Conducting tests to verify the functionality and reliability of the avionics system, both on the ground and during actual launches.
- Collaborating with other teams on the rocketry project to ensure that the avionics system is properly integrated with other subsystems, such as the propulsion system and recovery system.

Avionics' extensive portfolio includes the following products:

- FC[6] Cimrman Mini V0;
- FC Cimrman Mini V1;
- FC Cimrman Mini V2;
- FC Cimrman A1 (see Image 10);
- FC Cimrman A2;
- Cimrman Test Board – Set of multiple hardware for measuring several values during propulsion testing;
- Communication Computer – Computer providing live data from the rocket;

[5] API stands for Application Programming Interface (e.g. invoice database, document storage)
[6] FC stands for flight computer

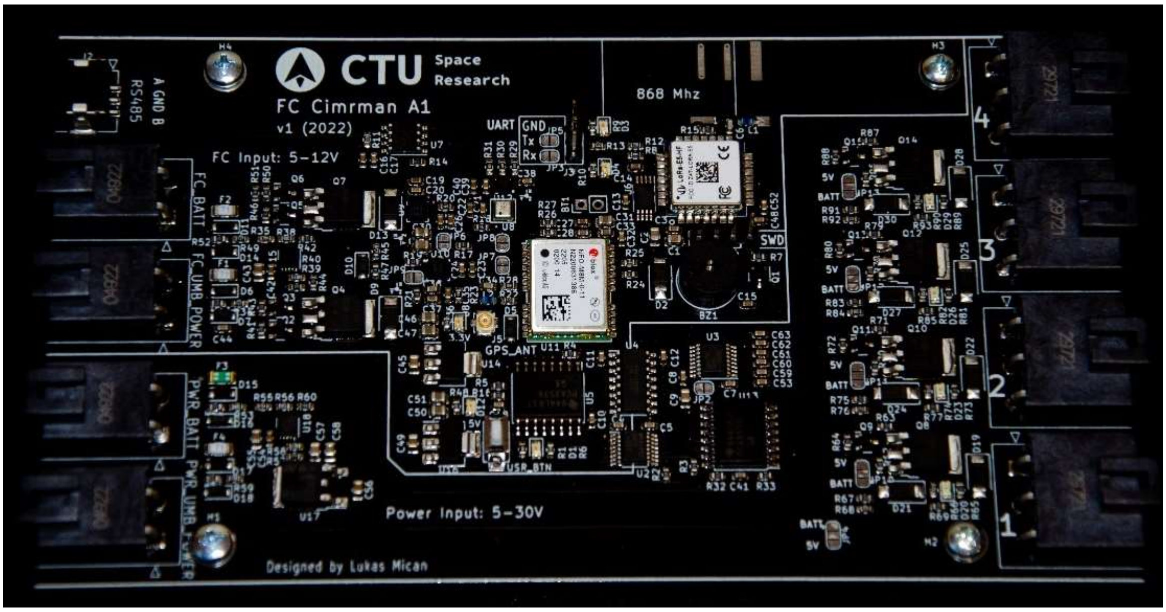

Image 10 Flight Computer Cimrman A1
Source: Own elaboration

The performance of the Avionics team is considered one of the leading teams of CTU Space Research based on their performance and achievements. The team is performing all its tasks and developing new projects with a lead over the other teams. Its leaders cooperate with academic staff, including professors and PhD students as well.

Propulsion

The propulsion team is responsible for designing and building the rocket's propulsion system, which includes the rocket engine and the fuel and oxidiser tanks. Some specific activities that a propulsion team might perform include:

- Designing and testing rocket engines, including selecting the appropriate fuels and oxidizers, and optimizing the engine's performance.
- Designing and building the fuel and oxidizer tanks, which must be strong enough to withstand the pressures and temperatures of the rocket launch.
- Conducting static tests of the rocket engine to measure its performance and validate computer simulations.
- Developing and testing systems to control fuel and oxidiser flow to the engine during launch, including valves, regulators, and plumbing.
- Collaborating with other teams on the rocketry project to ensure that the propulsion system is integrated with other subsystems, such as the avionics and recovery systems.
- Conducting launch tests to validate the functionality and reliability of the propulsion system.

The propulsion team is the one who is in charge of ensuring that the rocket has sufficient thrust and fuel capacity to reach the desired altitude and velocity, while also maintaining stability and control during the launch phase. Their work is critical to the success of the overall rocketry project.

The whole team is well known for remarkable innovations in the field of hybrid rocket propellers. The unique concept consisting of 3D printed fuel was developed by Viktor Hais (2021), the current leader of CTU Space Research and an ex-team leader of Propulsion. The concept is more developed in 8.1.1 Innovation Analysis.

Structures

The Structures Team holds a key role in conceiving a rocket's physical framework, encompassing the airframe, fins, and nose cone. The team undertakes a myriad of specialised tasks, such as:

- Conceptualising the rocket's overall form and dimensions, considering aerodynamic properties, stability, and mass factors.
- Identifying suitable materials for the airframe and supplementary structural elements, such as carbon fibre, 3D printed materials, or affordable solutions (paper, cardboard, plastic), while determining the requisite thicknesses and strength parameters.
- Engineering and constructing the fins, which serve as vital components in maintaining stability and governing the rocket's flight trajectory.
- Designing and fabricating the nose cone, which can be produced from an array of materials and geometries, is contingent upon the rocket's unique specifications.
- Performing comprehensive structural analyses to confirm the rocket's resilience against the forces encountered during launch and flight, including vibration, acceleration, and aerodynamic stresses.
- Collaborating with other specialized teams within the rocketry project to ensure seamless integration of structural components with ancillary subsystems, such as the propulsion and avionics systems.

The Structures Team's contributions are crucial in guaranteeing a robust, stable, and aerodynamically sound rocket capable of enduring the severities of launch and flight. Their expertise is indispensable to the overall success and safety of the rocketry endeavour.

Management

The Management Team of a student rocketry organisation plays a crucial role in orchestrating and overseeing the diverse aspects of the project to ensure its success. This team is responsible for a range of strategic and operational tasks, including:

- Defining the rocketry project's overall vision, objectives, and scope, aligning with the team's educational and developmental goals.
- Devising and implementing project management strategies, including allocating resources, scheduling, simple risk assessment, and contingency planning.
- Facilitating cross-functional communication and collaboration among various specialized teams, such as the Structures, Propulsion, Avionics, and Recovery teams, to ensure seamless integration of subsystems and project cohesion.
- Securing funding and resources for the rocketry project through grant applications, sponsorships, and fundraising initiatives, while managing the project's budget and financial affairs.
- Coordinating with external stakeholders, such as academic institutions, industry partners, and regulatory agencies, to ensure compliance with safety guidelines, legal requirements, and ethical standards.
- Implementing a robust quality assurance process to ascertain that the project adheres to established technical and safety benchmarks.
- Organizing training and development opportunities for team members to enhance their technical skills, leadership abilities, and interdisciplinary collaboration.
- Documenting and disseminating project progress, milestones, and achievements through various channels, such as presentations, reports, and social media, to engage the broader community and foster knowledge sharing.

The Management Team is instrumental in ensuring the effective planning, coordination, and execution of the project. The more projects we have, the more complex the control is above everything, and more people are required to keep up with deadlines. Tasks held on an operative level in the beginning, this strategy is unfortunately in conflict with a wide variety of tasks and the fact that management members are participating across other teams to help them with their tasks.

Public Relations

Last but not least, the Public Relations (PR) team is slightly outer of other teams due to its aim of managing the public image of CTU Space Research and communicating its goals, achievements and impact to various stakeholders. The PR team is responsible for a range of strategic and operational tasks, including:

- Developing and executing a comprehensive communication strategy that aligns with the organisation's vision, objectives, and values and effectively conveys its message to the target audience.
- Engaging with external stakeholders, such as media outlets (as shown in Image 11), academic institutions, industry partners, and the general public, to promote the organisation's mission, projects, and accomplishments.
- Coordinating with the Management Team to ensure that the PR efforts are aligned with the project's overall objectives, goals, and schedule, and that the organisation's public image is consistent with its core values.
- Managing the organisation's online presence, including its website, social media accounts, and other digital platforms, to enhance its visibility, engagement, and outreach.
- Organising and executing events and outreach activities to showcase the organisation's projects and attract new members, sponsors, and partners.
- Providing guidance and training to team members on effective communication techniques and media relations.

Image 11 CTU Space Research's spokesperson gives an interview to Česká Televize
Source: Own elaboration

To summarise, the Public Relations (PR) team serves an important part in establishing and preserving the public perception of an organisation, advocating for its objectives and initiatives, and interacting with interested parties to improve its effectiveness and scope.

External Contributors

There are also contributions from an external subject that are not members of CTU Space Research, for example, university professors, academic staff, experts from the aeronautical industry, thesis writers, and volunteers from different universities who do not share a willingness to be part of a team or cannot participate physically at CTU Space Research.

8.1.2 Mission & Vision Statement

A mission and vision statement is cardinal for a rocketry team as it provides focus, alignment, and a shared sense of purpose. The mission statement should communicate the team's objectives, including developing expertise in rocket propulsion, aerodynamics, materials science, and electronics, while emphasising the importance of teamwork, critical thinking, and problem-solving skills. The vision statement should inspire and motivate stakeholders toward a shared goal, such as advancing the field of aerospace engineering or developing new technologies for space exploration. A collaborative and iterative process involving all stakeholders should be used to develop and regularly review and update the statements to ensure they remain relevant and aligned with the team's goals and objectives.

According to CTU Space Research's Mission statement (Marvan 2022) says that:
"The goal of our student rocket team is to inspire the next generation of space explorers by designing, building and launching high-performance rockets using state-of-the-art space technology. Through hands-on learning and collaboration, we want to foster a love of science, technology, engineering, and mathematics (STEM) in young people and provide them with valuable skills and experiences that will prepare them for future careers in the space industry."

In line with CTU Space Research's Vision Statement (Marvan 2022) states that:
"Our vision is to become a leading force in student rocketry and inspire a new generation of space enthusiasts. We strive to be at the forefront of space technology and push the boundaries of what is possible in rocket design and propulsion. We want to provide our team members with the knowledge, skills and experience they need to become leaders in the space industry and significantly contribute to space exploration and exploitation."

8.1.3 Financial Foundations

From internal sources and interviews with members of CTU Space Research (Pavelec, Jurča 2023), the author has observed that the financial resources required for the successful implementation of CTU Space Research projects primarily come from two significant sources within the university: the Rector's Office and the Faculty of Mechanical Engineering.

Based on the analysis of the author, the Rector's Office is a critical subject in providing the necessary funds to support the operations and expansion of CTU Space Research. The Rector's Office, being the supreme governing body of the university, is tasked with the responsibility of distributing financial resources and other essential assets to diverse projects and initiatives within different faculties. CTU Space Research received the highest funding among all the approved projects, which is a surprising outcome. The provision of support by the Rector's Office indicates the acknowledgement of the significance and prospective influence of CTU Space Research, guaranteeing the availability of the requisite financial resources for the project's triumph.

Moreover, the author's research has revealed that the Faculty of Mechanical Engineering is another significant contributor to the funding of CTU Space Research. Being one of the most prominent faculties within the Czech Technical University, the Faculty of Mechanical Engineering is in a solid position to support the development of cutting-edge technologies and research in the student rocketry domain. The financial contributions made by the faculty not only emphasise its dedication to fostering innovation and excellence in space research but also showcase its commitment to nurturing talent and expanding knowledge in this area.

In addition to the Rector's Office and the Faculty of Mechanical Engineering, a portion of the funds for CTU Space Research is allocated from other scientific departments within the Czech Technical University, such as Czech Aerospace Research Centre (VZLÚ). These contributions highlight the collaborative nature of the project and the interdepartmental support required for success.

Furthermore, private companies are essential in supporting CTU Space Research through various means, particularly material donations. Some notable companies contributing to the project include 3M, Linde, Ansys, TechSoft, XTend, UpSideDownVR, and Solík. Their contributions showcase the strong industry-academia collaboration and the mutual benefits that arise from such partnerships. These companies recognize the value of supporting cutting-edge research and development at the university level, as it can lead to advancements in their respective industries while fostering a skilled workforce for the future.

The planned budget for CTU Space Research for the accounting period 2022 was 1 200 000 CZK; however, due to external factors, such as an increase in energy prices that reduced the university's free capital and reduced funding for university projects, the planned budget for the accounting period 2023 has been reduced. On the other side, the team enjoys free access to various academic facilities. The majority of the funding for 2022 has not yet been authorised. Even though the planned budget is slightly lowered to 1 000 000 CZK because most of the equipment and materials purchased for the previous year are still possible to use. The remaining funds would be returned to the University since all money allocated to CTU Space Research for 2022 has already been used. Table 3 displays CTU Space Research's planned budget.

CTU Space Research - Budget		
	2022	2023
Planned	1 200 000 CZK	1 000 000

Table 3 CTU Space Research - Planned Budget
Source: Pavelec, Jurča (2022)

It is challenging to precisely determine the expenditure ratio among various team segments, as some costs are shared across teams. Nevertheless, the propulsion team appears to be the most resource-intensive in terms of budget allocation. A substantial portion of the budget is also dedicated to rocket competition and manufacturing, as indicated in the report (Pavelec, Jurča 2022).

The Rector's Office, the Faculty of Mechanical Engineering, other scientific departments within the university, such as VZL, and material gifts from commercial corporations are only a few sources that support CTU Space Research. The project is able to access a wide variety of resources and skills thanks to the diverse financing structure, which enables it to accomplish its goals and preserve its standing as an innovative project at the Czech Technical University in Prague.

8.1.4 Fundraising

According to Schnurbein (2020, pp. 1–11), Fundraising is the process of soliciting financial contributions from individuals, businesses, or institutions to support a cause or organisation. It involves various activities such as communicating the organisation's mission and values, building relationships with potential donors, managing resources effectively, and ensuring ethical and transparent practices. Although fundraising is often viewed as an operational task, its strategic integration within an organisation is crucial to its long-term success. This involves aligning fundraising efforts with the organisation's overall goals and values and ensuring that the board provides oversight and guidance to mitigate potential risks associated with accepting donations. In general, fundraising plays a vital role in organisational sustainability and growth, and a well-executed fundraising strategy can help an organisation achieve its mission and expand its reach.

Fundraising has a significant impact on student organisations with limited constraints, and this is even more intensified in the case of CTU Space Research due to its technical complexity and operations within the aeronautical and rocket industry. On the other hand, unusuality creates an excellent potential for seeking additional funds through the material and financial sponsorships and partnerships.

8.1.5 External Factors Analysis

The forthcoming chapter will focus on an external evaluation of the business environment within CTU Space Research through the utilisation of the Lo(N)GPESTLE analysis instrument, which is an expanded rendition of the conventional PESTLE model. The methodology integrates factors at the local (Lo), national (N), and global (G) levels.

Lo(N)GPESTLE Analysis

The reason for using the Lo(N)GPESTLE analysis framework for the Czech student rocketry team is to gain a comprehensive understanding of the external factors that may impact the team's operations and success. PESTLE analysis stands for Political, Economic, Sociocultural, Technological, Legal, and Environmental analysis. This framework allows to identify the key factors that may influence the team's performance and to develop appropriate strategies to address them (Lucidity 2023).

For purposes of CTU Space Research's analysis, the national level has been erased due to its similarities to other to levels[7]. The removal of the national level analysis is explained by the fact that this level would only act as a bridge between the local and global levels and, in many cases, would create duplication. The national environment factors are then spread over the remaining two levels. Brief overview is shown in Table 4.

[7] Note: Therefore the author refers to analysis as Lo(N)GPESTLE, not LoNGPESTLE.

Lo(N)GPESTLE Analysis - Overview		
Factors	Local Level	Global Level
Political	Material and financial support from universities and private companies.	A supportive policy towards the development of space exploration.
Economic	Development of space activities within the Czech Republic. Reduced university funds.	Significant development in specific regions of the United States, France and Germany. More or less amount in university funds based on each country.
Sociocultural	The general interest of Czech society in space exploration and rocketry. High potential for interest among the community and sponsors.	Relative potential of interest among the community and sponsors abroad. Advantage of CTU Space Research being the one and only (so far) rocketry team with intensions to participate in international competitions.
Technological	Level of technological advancement in Czechia and especially in Prague, broad access to specialized equipment and facilities.	High Level of technological advancement individually allocated to other European Countries, restricted access to equipment and facilities abroad.
Legal	Prohibited launches of high-powered rockets, missing regulations for rocket tests.	Rocket launches as a more acceptable and definable activity limited to military areas and test zones.
Environmental	Not impacted by natural disasters, weather conditions and environmental regulations.	Minor impact of increased costs related to flight transport due to environment fees (air passenger duty, aviation tax). Not impacted by natural disasters or weather conditions.

Table 4 Lo(N)GPestle Analysis
Source: Own elaboration

In the first part of the analysis, author focuses on the local level and examines the factors that may impact the Czech student rocketry team in the context of Czechia, also known as the Local Level.

Political (local level):

On a local level, the Czech student rocketry team may be impacted by political factors such as government policies and regulations related to space research and rocketry, as well as the availability of funding and grants. CTU Space Research, for example, is supported by funds and material help from universities and private companies to cover expenses such as equipment, materials, and research and development.

However, governmental policies have not yet defined and put rocket launches at a legal level, which could pose a potential challenge to the team's operations and projects. Without clear legal guidelines, the team may face difficulties obtaining necessary permits or encountering legal obstacles during rocket launches.

To address these political factors, the Czech student rocketry team may need to engage with policymakers and other stakeholders to advocate for favourable policies and regulations that define the legal framework for rocket launches. Additionally, the team may need to continue to establish relationships with universities and private companies to secure material and financial support to ensure that it has the necessary resources to pursue its research and projects and achieve success in the field of rocketry. There is also a possibility to gain additional support from ministry departments, e.g., Ministry of Industry and Trade, Ministry of Education, Youth and Sports or Ministry of Defence.

Economic (local level):

On a Local Level, the Czech student rocketry team may be impacted by economic factors such as the development of space activities within the Czech Republic, reduced university funds, and the state of the economy and degree of investment.

The development of space activities within the Czech Republic can affect the team's operations and projects. If there is a lack of investment or support for space research and rocketry within the country, it may limit the team's opportunities for collaboration, funding, and resources. On the other hand, if the government and private sector invest in developing space activities, it may create a supportive environment for the team to excel in its field.

Reduced university funds can also pose a challenge to the team's operations and projects. Without sufficient funding, the team may face difficulties in obtaining the necessary resources and equipment for research and development. It may also limit the team's ability to recruit and retain talented members. The university is the key subject for the existence of CTU Space Research, and therefore, its funds play a crucial role team’s activities and plans.

The expanding space research sector in the Czech Republic has led to a notable increase in the number of companies focused on various aspects of space exploration and technology. For instance, ATC Space (Grygar 2020) has emerged as a key player in the manufacture of the Ariane 6 rocket's mid-section and propulsion panels, contributing significantly to the rocket's overall structural integrity and thrust capabilities.

Similarly, OHB Czechspace has dedicated its efforts towards planetary protection, a field concerned with safeguarding celestial bodies and Earth from harmful biological or physical contamination during space missions. This vital area of research ensures the preservation of extraterrestrial environments and facilitates the accurate study of potentially habitable worlds (Grygar 2020).

Furthermore, SAB Aerospace has established itself as a leading firm in the development of mechanical systems and subsystems for both satellites and launch vehicles. Their expertise in engineering and design has played a crucial role in advancing the reliability and performance of spacecraft and launch systems, paving the way for more ambitious space missions (Grygar 2020).

In addition to these specialized companies, the European Union's Global Navigation Satellite System Agency (GSA) and the EU Space Programme Agency (SPA) have embarked on an ambitious project to construct a state-of-the-art research and development centre in Palmovka, Prague. This expansive facility is expected to accommodate several hundred professionals from the space industry, fostering collaboration, innovation, and the exchange of ideas between experts from various disciplines (Bayer 2023).

Collectively, these developments within the Czech Republic's space research sector not only highlight the nation's growing contributions to the global space industry but also underscore the importance of continued investment in and support for this critical area of scientific enquiry and student rocketry organisations investments.

To address these economic factors, the Czech student rocketry team may need to seek opportunities for collaboration with other organisations within the Czech Republic or internationally. Additionally, the team may need to engage in fundraising efforts and explore alternative funding sources to ensure that it has the necessary resources to carry out its research and projects.

By addressing these economic factors, the team can ensure that it has the resources and support it needs to pursue its goals and continue to excel in the field of rocketry.

Sociocultural (local level):

Sociocultural factors can significantly influence the Czech student rocketry team's success and growth at the local level. One such factor is the general interest of Czech society in space exploration and rocketry. A high level of public interest in these areas can create a supportive environment for the team, fostering enthusiasm for their projects and potentially leading to increased opportunities for funding and collaboration.

Another sociocultural factor to consider is the high potential for interest among the community and sponsors. The team's ability to engage and attract the attention of local stakeholders, including businesses and individuals, can be crucial for securing financial support and resources. By showcasing their projects and achievements, the Czech student rocketry team can raise awareness of their work and inspire potential sponsors to invest in their endeavours.

As another sociocultural factor, the available workforce stands as a critical element for the success of the team. CTU Space Research does not pay salaries to any of its members regularly. Therefore, members are rewarded for representing CTU at events and with a performance award at the end of the year, which is in the lower units of thousands of CZK. Hence, the organisation cannot act as a direct competitor in the search for labour compared to conventional employers and can offer mainly development within the rocket industry.

To capitalize on these sociocultural factors, the team should actively engage with the local community, participate in events, and promote their projects through various channels, such as social media, traditional media, and public presentations. By fostering strong connections with the community and sponsors, the team can create a supportive environment for their work and pave the way for future success in the field of rocketry.

Technological (local level):

Technological factors are a critical component of comprehending the operational environment of businesses and industries within the framework of the LoNG PESTLE analysis. The technological advancement of the Czech Republic and the presence of specialised equipment and facilities throughout the nation make these factors particularly noteworthy. This section centre on the technological environment of Czechia, with a particular focus on Prague and the potential consequences of these factors for various businesses and industries.

The Czech Republic has made remarkable strides in technology, owing to a strong focus on research and development (R&D) and innovation. The government has been actively investing in R&D, leading to an increase in the number of research institutions and universities. As a result, the country boasts a pool of skilled and talented workforce capable of driving technological advancements in various sectors. This has created a conducive environment for businesses to thrive and grow, with a robust support system that includes access to advanced infrastructure and state-of-the-art facilities.

The city of Prague, being the capital and the most populous city in Czechia, is situated at the forefront of the ongoing technological revolution because of the presence of its primary technical institution, the Czech Technical University in Prague. The urban area is host to a prosperous entrepreneurial ecosystem, multiple clusters of technological infrastructure, and centres of innovation that facilitate the advancement and expansion of cutting-edge technologies. In addition, Prague is considered a prominent location for multinational technology corporations due to the city's skilled labour pool, exceptional quality of life, and advantageous commercial conditions. The development mentioned above has contributed to the advancement of technology in both the urban setting and the entire country.

The widespread availability of specialized equipment and facilities across the Czech Republic is another essential aspect of the nation's technological prowess. This access enables businesses to adopt and implement innovative solutions more efficiently and cost-effectively. CTU Space Research can access a wide range of facilities within the university (e.g., Czech Aerospace Research Centre, Workshops of the Faculty of Mechanical Engineering CTU) and outside (e.g., Next Zone and 3M Workshops).

The technological factors in the Czech Republic, especially in Prague, play a vital role in shaping the entrepreneurial landscape, motivating inventors and innovators to share their ideas and interest. The high level of technological advancement and complete access to specialised equipment and facilities provide fertile ground for innovation and growth. This, in turn, offers businesses and industries a competitive edge in the global market. As part of the Lo(N)GPESTLE analysis, understanding these technological factors is essential to identify opportunities and potential challenges that may arise in the future.

Legal (local level):

When conducting a Lo(N)G PESTLE analysis for CTU Space Research, it is imperative to take into account diverse legal factors that could potentially affect the operations of the team. A pertinent aspect pertains to the legal and regulatory framework that oversees the utilisation of airspace and launch facilities within the Czech Republic. The existing regulatory framework exhibits certain uncertainties that could potentially impede the acquisition of the necessary authorisations for missile launches and manufacturing. This holds particular significance in light of the increasing global focus on space exploration and associated endeavours. Consequently, the team must remain up-to-date with any modifications in the legal terrain to guarantee adherence to all pertinent statutes and mandates.

An additional legal aspect that merits contemplation pertains to the intellectual property (IP) regulations associated with the team's research and development endeavours. While CTU Space Research has not prioritised patenting thus far, and any patents acquired were done so through other business entities, it is imperative to contemplate the possibility of future patenting endeavours. This could potentially become a pertinent matter as the team's research advances and potentially culminates in commercially viable innovations or technologies.

It is vital to acknowledge the legal responsibilities that come with conducting academic research as a university-affiliated team. These obligations encompass ethical deliberations and safeguarding confidential data. Adhering to the expectations of the academic community and complying with pertinent laws and regulations can guarantee that the research activities of the team are conducted appropriately.

The team ought to take into account the influence of European Union (EU) regulations on their operations in conjunction with the pertinent Czech laws. CTU Space Research's operations may be subject to additional requirements or restrictions due to the Czech Republic's membership in the European Union and its compliance with various EU directives and regulations. The aforementioned encompasses the possible aftermath of regulations applicable throughout the European Union regarding domains such as data protection, environmental protection, and export controls, among other areas.

In light of the dynamic and progressive nature of the space sector, it is imperative for CTU Space Research to remain vigilant in observing any alterations in the legal landscape, both domestically and across the European Union. The task at hand may necessitate active involvement with policymakers and regulators to gain a deeper understanding of the potential consequences of nascent laws and regulations and to champion the interests of the team and the broader community of space exploration researchers. CTU Space Research can enhance the efficacy of its undertakings by keeping itself abreast of the legal aspects that impact its operations, enabling it to manoeuvre through the complex regulatory environment adeptly.

Environmental (local level):

At the local level, environmental factors can also play a role in shaping the activities of CTU Space Research. A key consideration is a growing motivation for adopting wasteless solutions. As a reaction to the motivation, CTU Space Research has developed, for example, 3D-printed fuel made of recyclate. This trend can provide the team with opportunities to develop more sustainable technologies, reduce their environmental footprint, and potentially attract interest from environmentally conscious stakeholders.

The Czech Republic's low risk of natural disasters and stable weather conditions can be advantageous for CTU Space Research. These factors may allow the team to conduct operations without significant disruptions, reducing the need for contingency plans and ensuring the smooth progress of their projects.

While there are no significant local environmental regulations currently impacting CTU Space Research, it is essential to remain vigilant about potential changes in this area. The team should stay informed about any emerging regulations or policies related to environmental protection, both locally and within the EU, to proactively adapt their practices and maintain compliance.

In the second part of the analysis, we will shift our focus to the global level and explore the factors that may impact the Czech student rocketry team in the context of the broader international landscape, also known as the Global Level.

Political (global Level):

At the global level, the Czech student rocketry team may encounter different political factors that impact their operations and projects. Similar to the local context, EU membership creates a shared legal and regulatory environment across the continent, including countries like Czechia. While there have been positive developments in this area, financial support for rocketry and space research varies significantly among countries and universities.

In comparison, countries such as the United States and Australia have more lenient conditions and regulations for space research and rocketry. It is based not only on their geographical opportunities (vast uninhabited areas). Especially the USA has a more established space industry that helps student rocketry teams in the activities. For instance, The University of Southern California's Rocket Propulsion Laboratory Team USCRPL (USCRPL 2019) has reached the first student rocketry team Kármán line with its boundary of 100 kilometres. The team managed this success during Spaceport America Cup 2019 in the Jornada del Muerto desert, New Mexico. In contrast, the altitude aim for rockets launched European Rocketry Competition (EuRoC 2023b) is set to 10 kilometres.

The Czech student rocketry team should be aware of these international political factors, as they might affect collaboration opportunities or influence the development of space policies and regulations in Czechia and the EU.

Economic (global Level):

On a global level, economic factors impacting the Czech student rocketry team may include the growth of the international space industry, funding disparities, and limited opportunities for collaboration with foreign partners. The global expansion of space activities can create both opportunities and challenges for the team in terms of competition and access to resources.

Limited opportunities for collaboration with foreign partners may reduce the overall familiarity of CTU Space Research overseas. By establishing connections and partnerships with international organisations, the team can gain access to new perspectives, resources, and opportunities for growth. However, they may face greater competition from well-funded teams in Western Europe, the USA, and Australia.

The financial capabilities of foreign teams can also pose challenges for the Czech student rocketry team. With more extensive resources, these teams may have a competitive advantage in research, development, and technology. To address these global economic factors, the CTU Space Research team may need to explore opportunities for international collaboration, engage in fundraising efforts, and seek alternative funding sources.

By considering these global economic factors and adapting their strategies accordingly, the Czech student rocketry team can better position itself for success in the competitive international space industry.

Sociocultural (global Level):

As international enthusiasm for space-related activities continues to rise, the team may find opportunities to collaborate with international partners, participate in global competitions, and exchange knowledge and resources with other teams from around the world.

However, another sociocultural factor to consider is the team's relatively low reputation and image on a global scale. This lack of recognition can make it more challenging for the Czech student rocketry team to establish connections with international organisations, secure funding, and engage in collaborative projects with well-known teams from other countries.

To address these global sociocultural factors, the team should enhance their international visibility and reputation. This can be achieved through active participation in global events, competitions, and conferences, as well as by showcasing their projects and achievements on various international platforms. Building a solid online presence, engaging with the international space and rocketry community, and collaborating with global partners can help the team raise their profile and gain recognition in the competitive international arena.

By acknowledging these global sociocultural factors and proactively working to improve their international reputation, the Czech student rocketry team can create new opportunities for growth and success in the global space exploration and rocketry landscape.

Technological (global Level):
Technological factors at the Global Level are crucial in understanding the broader environment in which businesses and industries operate. The level of technological advancement in other countries can impact the competitiveness of the Czech student rocketry team, as international advancements may affect the global landscape and the team's ability to keep pace with cutting-edge developments.

Access to international research and development opportunities is another important aspect to consider. By collaborating with international researchers and participating in global projects, the team can benefit from a diverse range of perspectives, resources, and expertise. This can help foster innovation, drive technological growth, and enhance the team's position in the global arena.

Environmental (global Level):
At the Global Level, environmental factors can also influence the CTU Space Research team's activities. One such factor is the potential increase in costs related to flight transport due to environmental fees, such as air passenger duty or aviation tax. While the impact of these fees may be relatively minor, the team needs to be aware of it and plan for any additional expenses in their budget.

The team's operations are generally not affected by natural disasters or extreme weather conditions, as the Czech Republic's geographic location offers a relatively stable environment. However, it is essential to consider the potential impact of global climate change on the broader context of their activities, as shifting weather patterns and increasing environmental concerns could lead to changes in regulations or industry practices that may affect the team's work.

8.1.6 Internal Factors Analysis

For purposes of the Internal Factors analysis, the Resource-Based View (RBV) and VRIO analysis serve as a foundational approach for examining a firm's distinct resources and capabilities, enabling the identification of its internal strengths and weaknesses. Another critical instrument employed for this internal analysis is the VRIO framework, which encompasses four key questions to assess a resource or capability's competitive potential. These questions pertain to the aspects of Value, Rarity, Imitability, and Organisation. By utilizing the RBV and VRIO framework, it becomes feasible to systematically evaluate a firm's various resources and capabilities and gauge its potential to generate competitive advantages in the market (Barney, Hesterly 2018, pp. 67–70).

VRIO Framework/Analysis

As stated by Barney & Hesterly (2018, p. 91): "The VRIO framework can be used to identify the competitive implications of a firm's resources and capabilities—whether they are a source of competitive disadvantage, competitive parity, temporary competitive advantage, or sustained competitive advantage and the extent to which these resources and capabilities are strengths or weaknesses."

Consequently, organisations can effectively leverage their unique resources and capabilities to optimize their market position and maintain a competitive edge in an ever-evolving business landscape. By continuously assessing and adapting their resources and capabilities using the VRIO framework, firms can identify new opportunities and address emerging challenges, ensuring their long-term success. This proactive approach to resource management fosters innovation, enhances operational efficiency, and promotes organisational resilience, enabling businesses to stay ahead of the competition, capitalize on market trends, and create lasting value for their stakeholders.

CTU Space Research stands by these metrics as follows:

Valuable:

The CTU Space Research programme is seen as valuable due to its ability to foster the development of key skills among its participants, including but not limited to teamwork, problem-solving, and engineering expertise. Furthermore, participation in rocketry competitions facilitates the acquisition of recognition and networking prospects among students in the aerospace and rocketry sector.

Rare:

The presence of CTU Space Research among student clubs and organisations is relatively rare. Although a considerable number of universities offer engineering programmes, it is not commonplace to practise for them to have specialised teams focused on rocketry. The requisite proficiency and aptitude demanded by such teams are not commonly prevalent, thereby rendering them more selective.

Inimitable:

The success of a student rocketry team can be challenging to imitate due to several factors. The team's knowledge and expertise come from a unique combination of students, faculty advisors, and resources available at a particular university. Additionally, the team's experience, culture, and accumulated know-how also contribute to its uniqueness, which might be hard to replicate by others. Despite the potential difficulty in replicating the group, the team is not inimitable due to several reasons based on limited financial constraints and a lack of knowledge and experience. Therefore, Inimitable is defined as "NO" for CTU Space Research.

Organised:

Although the assertion that organisation is critical for CTU Space Research to excel in competitions holds true in many instances, it is essential to recognise the unique context surrounding a newly formed team. In the nascent stages, the team is still exploring its potential and attempting to understand its capabilities. Consequently, it may not have developed a comprehensive decision-making structure, efficient communication channels, or effective resource allocation mechanisms. As the team evolves and matures, these organisational elements may be refined and optimised; however, one must acknowledge that they may not be fully operational at the team's inception.

Conclusion:

In the context of the VRIO analysis, CTU Space Research has achieved a temporary competitive advantage (see
Table 5). This suggests that the team possesses valuable and rare resources, such as more or less skilled members, specialised knowledge, and access to unique facilities, which gives them an advantage over their competitors. However, the temporary nature of this advantage implies that team resources might not be entirely inimitable or organised at the moment. As a result, competitors could quickly neutralise CTU Space Research's advantage in the future. To maintain and improve its competitive position within Czechia, the team should focus on continuously improving its resources, safeguarding its unique capabilities, and improving its organisational structure. By addressing these areas, CTU Space Research can work towards transforming its temporary competitive advantage into a sustainable one, ensuring its long-term success in space research and related competitions.

Valuable?	Rare?	Inimitable?	Organised?	Competitive implication
No				Competitive disadvantage
Yes	No			Competitive parity
Yes	Yes	No		Temporary competitive advantage
Yes	Yes	Yes	No	Unexploited competitive advantage
Yes	Yes	Yes	Yes	Sustained competitive advantage

Table 5 VRIO analysis of CTU Space Research
Source: Own elaboration

Resource-Based View (RBV)

According to Barney & Hesterly (2018, p. 90): "The RBV is an economic theory that suggests that firm performance is a function of the types of resources and capabilities controlled by firms. Resources are the tangible and intangible assets a firm uses to conceive and implement its strategies. Capabilities are a subset of resources that enable a firm to take advantage of its other resources. Resources and capabilities can be categorized into financial, physical, human, and organisational resources categories." The whole relationship is described in Image 12 and based on Lubis (2022, p. 592), comprises many streams of thought about the Resource Based View approach.

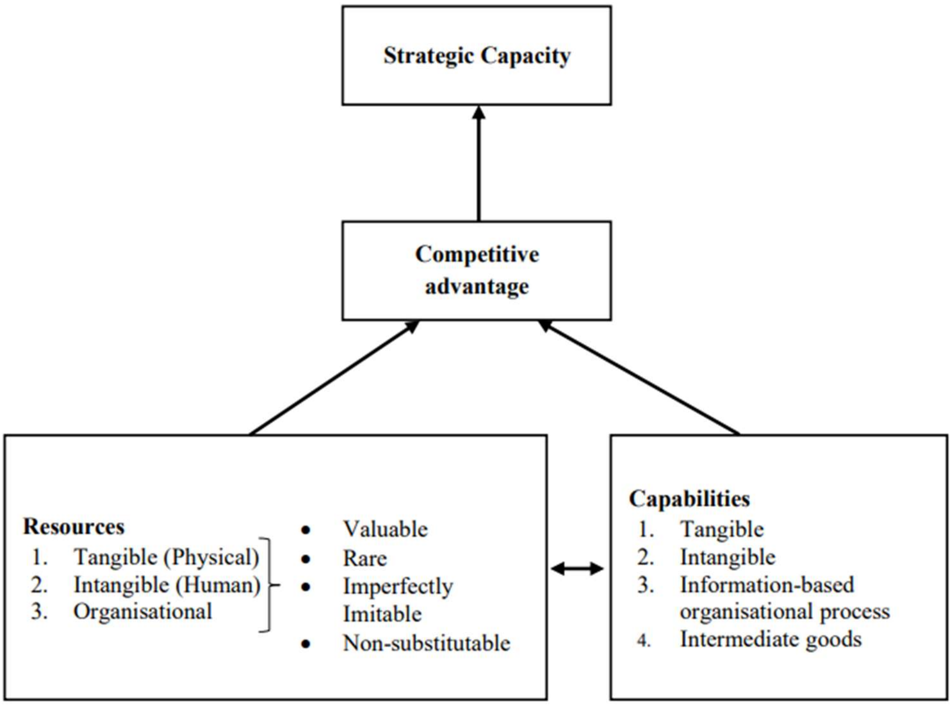

Image 12 Resource Based View
Source: Lubis (2022, p. 592)

Competitive success in the market requires organisations to have extensive knowledge of the various categories of resources and capabilities. This understanding enables firms to allocate resources optimally, leveraging their distinctive capabilities towards creating value for their product. By thoroughly evaluating financial, physical, human and organisational elements across the organisation's framework, businesses can successfully devise strategic plans enabling higher performance levels, thereby obtaining a significant edge within the industry.

It is necessary to recognize and assess the team's resources and competencies, which can be broadly divided into tangible and intangible assets, to study a chosen organisation from an RBV perspective.

Tangible resources:

- Financial: Relatively sensitive team budget and access to funding (e.g., sponsorships and university grants) determine the resources allocatable to projects, competitions, and other activities. Financial resources vary significantly and are analysed in Chapter 8.1.3, Financial Foundations.
- Physical: Positive team access to facilities (e.g., workshops, labs, or testing grounds) and equipment (e.g., tools, computers, or software) influences the team's ability to design, build, and test rockets.
- Human: The technical skills, knowledge, and experience of the team members, as well as the faculty advisors, are crucial for the team's success. Human (tangible) resources in CTU Space Research are strongly impacted by its organisation as a student rocketry team.

Intangible resources:

- Organisational culture: A strong culture that promotes teamwork, innovation, and continuous learning enhances the team's performance and cohesion.
- Reputation: A positive reputation within the university and aerospace community helps the team to attract talented members, secure funding via sponsorships, and create networking opportunities.

A resource-based view (RBV) of the CTU Space Research student rocketry team highlights the significance of both material and intangible resources in ensuring the team's success. To build a sustained competitive edge in the field of rocketry projects and competitions, CTU Space Research must be aware of and make use of both its tangible and intangible resources.

8.1.7 SOAR Analysis

SOAR analysis is used by organisations to optimise their existing strengths instead of focusing on mitigating external or internal threats. See the comparison in Table 6. This approach is grounded in the principle of appreciation enquiry or AI. In the context of organisations, AI highlights the importance of initiating the assessment process by identifying what the organisation is already excelling at.

SWOT	SOAR
Strengths	Strengths
Weaknesses	Opportunities
Opportunities	Aspirations
Threats	Results

Table 6 SWOT and SOAR Analysis
Source: Own elaboration

By focusing on the identification and enhancement of an organisation's core competencies, SOAR analysis fosters a proactive and solution-oriented mindset. The four key elements of the SOAR analysis framework are as follows:

Strengths:

This element of the study encourages businesses to acknowledge and assess their exceptional skills, resources, and core competencies. Organisations can capitalize on these assets and strategically position themselves for success by identifying them. Strengths for CTU Space Research include the following:

- Talented and motivated student members with diverse academic backgrounds and skill sets.
- Access to university resources, facilities, and expertise in aerospace engineering and related fields.
- Strong collaboration and teamwork, fostering a supportive and innovative learning environment.
- A track record of successful rocket launches and participation in national and international competitions.
- The uniqueness of the student rocketry organisation in Czechia.

Opportunities:

In this phase, organisations are encouraged to explore potential growth areas, emerging market trends, and untapped resources. By identifying and seizing these opportunities, organisations can establish a competitive edge and create a roadmap for sustainable growth. The following opportunities exist for CTU Space Research:

- Potential partnerships with industry leaders, government agencies, or research institutions for knowledge exchange, funding, and advanced technology access.
- Expansion into new areas of space research, such as satellite design, advanced propulsion systems (e.g., second stage or a rocket, liquid fuel engine), or payload development.
- Increased engagement with local schools and communities to promote STEM education and inspire future aerospace professionals.
- Utilization of digital platforms and social media to raise awareness, attract new members, and share achievements with a broader audience.

Aspirations:

This framework component focuses on the organisation's vision, goals, and desired future state. By articulating their aspirations, organisations can align their efforts and resources to achieve a shared understanding of success and foster a culture of continuous improvement. Aspirations for CTU Space Research encompass foregoing:

- To become a leading student rocketry team nationally and internationally recognised for innovation, technical prowess, and a commitment to advancing space research.
- To develop advanced, sustainable, and cost-effective rocket technologies that contribute to the broader aerospace community.
- To foster a diverse and inclusive team culture that supports the professional growth and development of all members.
- To inspire and educate future generations of aerospace engineers and space enthusiasts.

Results:

The final element of the SOAR analysis emphasizes the significance of defining concrete, quantifiable outcomes that show progress towards the organisation's aspirations, enable continuous improvement, and lead to achieving strategic goals. The following are the results of CTU Space Research:

- Measurable increases in team membership and diversity, reflecting the team's efforts to attract and retain a wide range of talented individuals with varying expertise.
- Documented progress in research and development initiatives, such as mentions in publications in reputable academic journals and conference presentations.
- Successful partnerships and collaborations with industry, government, and academic institutions, as evidenced by joint projects, funding, and technology transfers.
- Enhanced outreach and engagement initiatives, leading to increased participation in STEM-related programs within local schools and communities, as well as a growing online presence and social media following.
- Tangible contributions to the field of aerospace engineering and space research, including the development of new technologies, methodologies, or tools that are adopted by other organisations or incorporated into commercial applications.
- A robust alumni network, with former team members securing positions in leading aerospace companies, research institutions, or government agencies, underscoring the value of the team's training and mentorship programmes.

The SOAR analysis conducted for CTU Space Research culminates by emphasising the team's numerous strengths and areas for enhancement in the domains of student rocketry and space research. The team can achieve their objectives and deliver exceptional outcomes by utilising its existing competencies and capitalising on novel prospects. Furthermore, this strategic framework places significant emphasis on cultivating a diverse and inclusive team culture, engaging with the broader community, and promoting the progress of aerospace engineering. Suppose CTU Space Research remains dedicated to its objectives and consistently evaluates its progress through measurable outcomes. In that case, they have the potential to establish themselves as a prominent entity within the student rocketry community and serve as a model for upcoming generations of aerospace professionals.

8.1.8 Analysis of the competitive environment

The competitive environment within the student rocketry team is measured through teams that participated in the chosen competition with an international character.

The competitive landscape in the realm of student rocketry is both collaborative and inspiring, with various teams from across Europe participating in the European Rocketry Challenge (EuRoC) in Chapter 8.2.1European Rocketry Challenge (EuRoC). Although it is not a direct competition to gain a competitive advantage, the event serves as a platform for teams to learn from each other, share ideas, and foster innovation in the field of space research. In this context, CTU Space Research acknowledges the importance of understanding the practises and strategies employed by other participating teams that use this knowledge to enhance their capabilities and collaborative potential.

This chapter will focus on a competitive analysis of CTU Space Research concerning other EuRoC participants, explicitly examining the software and tools used for project management, communication, and cloud solutions. By gaining insight into the approaches and technologies adopted by successful and established teams, CTU Space Research can identify areas for improvement and integrate best practises to streamline their processes and enhance collaboration. It is important to note that the scope of this analysis is limited to EuRoC participants, as these teams tend to share similar values and objectives with CTU Space Research, making their strategies and methods particularly relevant for comparison and learning. The analysed teams are in Table A1 (Appendix A).

Numerous teams, particularly those with prior participation in at least one EuRoC competition, have received communication requesting them to articulate the mechanisms employed within their team to manage time constraints and effectively construct a rocket. The majority of the teams provided a detailed email response and expounded upon their internal procedures. The responses were analysed in different sections:

Project Management Software

The software that is frequently used to oversee project management activities within teams is ClickUp. ClickUp is a widely adopted software solution that offers multilevel planning tools, including Gantt charts, kanban charts, and finance controlling, which are used by teams across various domains. As expected, major rocketry teams utilise the software.

Moreover, Trello is a frequently utilised software that offers teams numerous kanban boards and is available for free to non-profit organisations, such as rocketry teams.

The Notion is software that exhibits several resemblances with ClickUp in terms of its user experience and user interface. The author's research identified Asana, Discord, and Jira as additional software utilised.

The DanSTAR team has reported that their primary method for task management involves the utilisation of a whiteboard located within their office, which functions as a Kanban board. The sole offline tool cited in the author's research was the tool mentioned above.

Communication Channel

Various communication tools have emerged in research, including Slack, Discord, Microsoft Teams, Trello, Messenger, and Telegram. The variance among the declared communication channels is minimal as they offer comparable functionalities. The official communication channel utilised by CTU Space Research involves using MS Teams with university access.

Cloud Solution

The Google Cloud Platform is a prevalent cloud computing solution that is used by numerous teams. On the other hand, the use of Microsoft SharePoint/OneDrive by teams is attributed to its accessibility within the university, the provision of unlimited storage space, and the safeguarding of data by the university.

Standards

A limited number of teams have declared their utilisation of any standards. The sole explicitly mentioned criteria were the ECSS, established by the European Space Agency, and the NTSS, implemented by the National Aeronautics and Space Administration. The ECSS framework is used primarily for project planning, while the NTSS framework is used predominantly for technical requirement purposes. In every instance, student rocketry teams have observed a restricted utilisation of standards because of the limited resources available to them. Individuals who have not yet affirmed any established criteria have utilised the regulations of the EuRoC competition and the Spaceport America Cup as primary guidelines to adhere to.

Through this competitive analysis, CTU Space Research aims to foster a spirit of continuous growth and learning, embracing the collaborative nature of the EuRoC event while striving to achieve its goals in the ever-evolving world of space research and exploration. None of the contacted teams has confirmed task management only on an ad-hoc basis which proves the complexity and importance of obtaining of any planning tools.

8.1.9 Projects

CTU Space Research focuses on the development and execution of various projects, which serve as the primary outcomes reflecting the team's progress and achievements. Since its inception, the team has undergone significant evolution in terms of project focus and complexity.

Multiple Project of Rockets for Czech Rocket Challenge (CRC)

Initially, the team concentrated on multiple small student rocket projects that participated in the Czech Rocket Challenge (CRC). These projects provided a solid foundation for the team's development and growth (see Image 13 for better imagination). However, they have since evolved and are now primarily serving as a source of knowledge acquisition and fostering social contributions in Czechia. Currently, CTU Space Research aspires to advance further, exploring more complex and cutting-edge projects that can compete on a global scale.

Image 13 One of the teams of CTU Space Research at CRC
Source: Own elaboration

Project Illustria

In recent years, CTU Space Research has been diligently working towards the development of innovative technologies in order to establish itself as a formidable contender within the global space research community. One such initiative is Project Illustria (in accordance with Image 14), a sophisticated modular rocket specifically engineered for participation in the European Rocketry Challenge (EuRoC). This project demonstrates CTU Space Research's commitment to advancing aerospace technology while simultaneously showcasing its competitive prowess on an international platform. Project Illustria's unique design is centred around modular segments, which enable the rocket to be adjusted and customised to participate in multiple categories. This adaptability ensures that it can cater to a variety of mission requirements, giving it a competitive edge in the fast-evolving space research landscape. With an impressive height of 4 metres, the rocket boasts a commanding presence and demonstrates the potential for scalability in future designs.

Image 14 Rocket Illustria render
Source: Grygerek (2021)

Furthermore, the manufacturing process of Project Illustria incorporates advanced 3D printing techniques, resulting in components that are lightweight, precise, and cost-effective. This cutting-edge approach not only accelerates the production timeline but also promotes sustainability, as it reduces waste and streamlines the supply chain. Overall, CTU Space Research's Project Illustria exemplifies the future of aerospace engineering, highlighting the importance of flexibility, innovation, and efficient manufacturing in the quest to conquer new frontiers in space. The projected timeline is visualised in
Table 7.

Illustria Project Timeline 22/23	
Month	Milestones
October 2022	- Recruitment of 15 new engineering students - Participation at EuRoC 2022 as observers
November - December 2022	- EuRoC 2022 review - Illustria design review - Test stand design
January - February 2023	- Exam period - Test stand manufacturing
March 2023	- Test stand finished - Recovery system design - Next version of Flight Computer - Cold flow, Igniter test, Hot fire - Airframe design (nosecone, fins)
April 2023	- Testing flight software and communication with ground station - UnIO system completion - Recovery system manufacturing - Rocket's segments design - Oxidiser Tank (Flight version) Pressure test
May 2023	- Engine adjustments - Flight software and Ground station test - Rocket's segments manufacturing - Next version of flight computer Cimrman - Recovery system manufacturing
June 2023	- Flight software test - Ground station finished - Rocket's segments manufacturing - Next version of flight computer Cimrman - Recovery system manufacturing
July 2023	- Final manufacturing - Implementation of sensors - Second revision of Flight Computer - Rocket's segments manufacturing and testing
August 2023	- Connect all subsystems to network - Avionics hardware testing - Assembly check
September 2023	- Flight tests - Bugs repairing
October 2023	- 10-16/10 EuRoC 2023

Table 7 Project Ilustria Timeline 2022/2023
Source: Illustria Timeline 22/23 (Jurča 2023)

Project CubeSat

Along with Project Illustria, the CTU Space Research team is also working on the CubeSat project led by Lukáš Mičan (2023). This project aims to capture air samples at different altitudes using advanced electronic components and is a unique opportunity for the Avionics team to acquire hands-on experience with aerospace technology. The CubeSat project is considered a crucial aspect of the team's overall growth and development strategy, even though there are no immediate intentions to submit it for international competitions. Initial Project CubeSat is shown in Image 15.

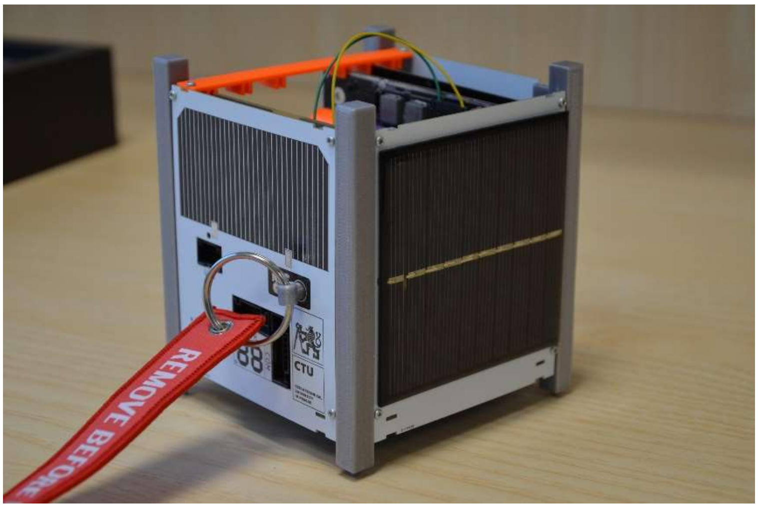

Image 15 Initial CubeSat
Source: Own elaboration

The team, consisting of students from various fields of study, including mechanical engineering, electrical engineering, and chemistry, will launch a rocket equipped with a specially designed device to collect air samples at 1000, 2000, and 3000 metres. The device is equipped with solenoids that will open and close at predetermined altitudes to collect air samples, and an Arduino flight computer will control the timing of the solenoids and the collection of the samples. These features are mounted in the second generation of the CubeSat that is entirely in development by CTU Space Research. Project CubeSat's initial prototype is displayed in Image 16.

Image 16 Both versions of CubeSat (second generation in the background)
Source: Own elaboration

The captured air samples will be analysed in the laboratory to understand better atmospheric conditions and how they vary at different altitudes. Even though these data might not have shocking results for the research community, it is important to understand the project is in the early stage and may have the same value as the rocket itself.

Through the CubeSat project, the Avionics team is helping to promote scientific understanding and shape the future of space exploration. By fostering internal advancement, CTU Space Research is better placed to make a significant result within this specialisation. The project showcases the team's expertise and passion for space exploration and is an exciting opportunity for the team to gain hands-on experience with aerospace technology and electronic components.

Project StratoSat

Lastly, the StratoSat project, established by Ondřej Marvan, serves as an initial training platform for avionics and project planning. This project plays a crucial role in equipping team members with the necessary skills to excel in their respective fields and contribute to the overall success of CTU Space Research. Furthermore, Project StratoSat is developed in collaboration with the Czech Hydrometeorological Institute (CHMI). CTU Space Research's StratoSat will fly on the side of CHMI's satellite to measure ozone, as demonstrated in Image 17. This partnership provides the team with valuable resources, such as access to CHMI's balloons, launch windows, and, most importantly, their extensive knowledge and expertise in the field.

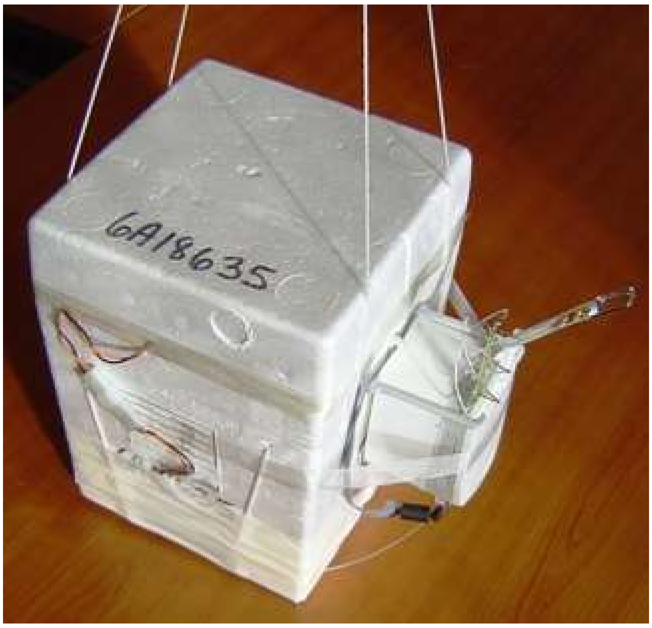

Image 17 Box with ozone sensor and radiosonde (on side)
Source: CHMI (2011)

Although the satellite's sensors and measures may not be ground-breaking, they serve to test the team's internally developed avionics systems and manufacturing techniques. For instance, the team utilised milling of polystyrene to attain greater precision in production and enhance its compatibility with the hardware integrated into the StratoSat (refer to Image 18). Polystyrene is formed into the desired shape through the process of milling. The hardware components, such as sensors, cameras, battery sources, and motherboards, will be situated in designated locations without requiring additional fastening. This approach improves hardware safety and provides the benefit of improved isolation.

Image 18 StratoSat's outer protective casing made of Extruded polystyrene
Source: Tomáš Lapeš (2023)

8.1.10 Project Management

In the early stages of CTU Space Research's existence, project management was primarily driven by an operative approach, with tasks allocated on an ad hoc basis. Each team lead had its preferred method of collecting and maintaining tasks, ranging from traditional paper-based systems to digital solutions like Microsoft Excel spreadsheets and to-do list apps. Although this approach allowed for some degree of flexibility and autonomy for individual team leads, it soon became apparent that it was insufficient to manage the increasing complexity of the team's projects.

As CTU Space Research's projects grew in scale and intricacy, the need for a more cohesive and unified project management system became evident. The disparate and decentralised nature of the initial project management approach made it difficult to track progress, coordinate efforts between different teams, and efficiently allocate resources. Recognising these challenges, the team began exploring alternative project management solutions that could better support their evolving needs and drive the successful completion of their ambitious projects.

8.1.11 Innovation Analysis

The CTU Space Research student rocketry team is dedicated to exploring cutting-edge technologies and innovative approaches in the field of space exploration. By leveraging the latest advancements in additive manufacturing, alternative fuel sources, and wireless charging, the team aims to push the boundaries of what is possible in rocketry while maintaining a strong focus on sustainability and efficiency. This chapter delves into the innovative aspects of CTU Space Research, providing an in-depth analysis of their adoption of additive manufacturing, utilisation of 3D printed fuel for hybrid propulsion engines, and the implementation of wireless charging technology for their rockets. Through this examination, we will gain a better understanding of the team's innovative efforts and their potential impact on the future of space exploration.

Additive manufacturing

Additive manufacturing, or so-called 3D printing, has become a widely used technology for the CTU Space Research student rocketry team, providing an affordable and versatile solution for creating various rocket components. From intricate small items and gear wheels to the entire rocket structure, this innovative approach enables the team to optimise designs for weight, strength, and performance while working within their limited financial budget.

The cost-effectiveness of additive manufacturing allows the team to produce components in-house, significantly reducing production costs and eliminating the need for expensive tooling and outsourcing. This resource-saving aspect enables the team to allocate more time and effort to research, development, testing, and analysis. Moreover, 3D printing offers the flexibility to rapidly iterate designs and make adjustments as needed, ensuring that the team rockets consistently push the boundaries of innovation.

Long story short, the CTU Space Research student rocketry team leverages additive manufacturing to create high-quality, lightweight, and cost-effective components for their rockets and related projects. By embracing this technology, the team can continue to advance the field of space exploration and develop efficient, reliable rocket designs within the constraints of their limited resources.

3D Printed fuel to Hybrid Rocket Propulsion

Hybrid rocket propulsion is an advanced propulsion system that combines elements of liquid and solid rocket technologies. It consists of a solid fuel grain and a separate liquid or gaseous oxidiser mixed and combusted in the combustion chamber to generate thrust. Hybrid rocket engines offer several advantages over traditional solid and liquid propulsion systems, such as improved safety, better performance, and reduced environmental impact (ZARM 2023).

CTU Space Research's current team leader, Viktor Hais (2021, pp. 11–56), has proposed an innovative approach to enhance the performance of hybrid rocket engines by leveraging the potential of 3D printing technology. This ground-breaking idea aims to optimise fuel grain design and composition by utilising the flexibility and precision provided by 3D printing techniques. Hybrid rocket propulsion is shown in Image 19.

Image 19 Hybrid rocket propulsion (prototype)
Source: Own elaboration

A greener plan involves crushing old pallets into an emulsion, which will then be printed on a 3D printer according to the design and thrust required by the rocket.

3D printing offers several benefits for the development of hybrid rocket propulsion systems, particularly in the context of student research projects, according to the Centre of Applied Space Technology And Microgravity (ZARM 2023):

- Customised Fuel Grain Design: 3D printing allows for the creation of fuel grains with unique and intricate geometries that can be tailored to optimise the engine's performance. This level of customization is difficult, if not impossible, to achieve using traditional manufacturing methods.

- Rapid prototyping: 3D printing in the development process enables rapid prototyping and iteration of fuel grain designs. This accelerates the design cycle and allows for swift evaluation and engine performance optimisation.

- Material Flexibility: 3D printing technologies can work with a wide variety of materials, enabling the possibility of experimenting with different fuel compositions and additives to enhance performance or achieve specific combustion characteristics.

- Cost Efficiency: The ability to produce complex fuel grain geometries without the need for expensive tooling makes 3D printing a cost-effective option for small-scale hybrid rocket engine development, particularly for student research projects with limited budgets.

Wireless charger

Keeping an optimal battery charge in rocket avionics is crucial for successful launches, particularly when waiting for favourable flight windows. Conventional charging methods often require opening the rocket and directly connecting a cable, which can be time-consuming and potentially risky. Aleš Pešek, an external member of the CTU Space Research student rocketry team, has devised an innovative solution to address this challenge and improve the charging process for rocket avionics.

Pešek's Wireless Charging System [in progress] (2023) eliminates the need to access the rocket's internals physically, streamlining the charging process and reducing the risk of damage or human error. This innovative approach allows the rocket to be charged efficiently and safely for extended periods, ensuring that the avionics remain at optimal power levels until the moment of launch. As a result, the wireless charging system enhances the reliability of the rocket and contributes to the overall safety of the launch operations.

Currently, Aleš Pešek (2023) is working on his diploma thesis, which delves deeper into the development and application of this wireless charging technology. Although the details of his work have not yet been published officially, the preliminary results are promising and demonstrate the potential impact of his contribution to the CTU Space Research team. Once completed, Pešek's work will undoubtedly pave the way for further advancements in rocket charging systems, improving the efficiency and safety of space exploration projects for the team and beyond.

The CTU Space Research student rocketry team is successfully integrating cutting-edge technologies and approaches to drive innovation in the rocket industry. Through additive manufacturing, 3D printed fuel for hybrid rocket propulsion engines, and wireless charging systems, the team has optimised its designs, maximised its limited resources, and made significant advancements towards its upcoming participation in an international competition. These innovative efforts have the potential to impact the future of the inexpensive rocket industry and propel the team toward more successful missions.

8.2 Participation in competition as project validation

For student rocketry teams, participation in competitions serves as a vital avenue to validate their designs and test their rockets in a controlled and supportive environment. While launching rockets independently may be an appealing prospect for these teams, they often need help with numerous challenges, such as prohibitive legislation, restrictive logistics costs, limited support of experts and safety concerns. This section of the thesis aims to demonstrate the importance of student rocketry teams' involvement in competitions, highlighting the unique opportunities for validation, testing, and overcoming the challenges associated with independent rocket launches. The reasons above impede their ability to proceed with individual launches, especially in the case of newly established teams with almost limited budget, knowledge, time and unfamiliarity with a government.

There are several rocketry competitions around the world that challenge university and high school students to design, build, and launch rockets to specific altitudes or with scientific payloads. Examples include the International Rocketry Competition (IRC), NASA Student Launch, Spaceport America Cup, Australian Youth Aerospace Forum (AYAF) Rocketry Competition, and the Global Space Balloon Challenge. However, for CTU Space Research and the author's thesis research, the European Rocketry Challenge is the main competition to focus on. It challenges university and college students from across Europe to design, build, and launch rockets in a Portuguese military area right in the middle of a desert. The second analysis is aimed at the Czech Rocket Challenge as the only currently available rocketry competition in Czech Rocketry.

8.2.1 European Rocketry Challenge (EuRoC)

The European Rocketry Challenge, also known as EuRoC, is a prestigious annual competition that brings together student teams from all over Europe with the aim of promoting the development of aerospace engineering skills among young people. This competition serves as a platform to foster innovation, team building, and technical problem-solving in areas such as rocket propulsion, aerodynamics, materials science, and electronics (*EuRoC* 2023b).

EuRoC is designed to challenge and encourage undergraduate and graduate students to showcase their knowledge and expertise in rocketry by designing, building, and launching rockets that meet specific criteria for altitude, payload, and innovation. This competition provides a unique opportunity for students to gain practical experience in rocketry and network with other students and industry professionals.

The competition takes place over several days and includes technical inspections, presentations, and rocket launches. During this time, students work collaboratively to troubleshoot any technical challenges that may arise, allowing them to develop critical thinking and problem-solving skills in a high-pressure, real-world environment.

Regulations

Regulations for participating and launching a rocket in the EuRoC competition are stated in several documents (EuRoC 2023a, pp. 3–10):

- The EuRoC Rules & Requirements Document provides essential guidelines for participating teams, outlining the competition's objectives, structure, and safety protocols. Adherence to these rules is crucial to a successful and fair contest.

- The EuRoC Design, Test & Evaluation Guide offers a comprehensive overview of the competition's design phase, testing procedures, and evaluation criteria. It helps teams ensure that their rocket designs comply with technical requirements and safety standards.

- The EuRoC Launch Operations Guide covers the operational procedures and protocols for the launch day, including safety measures, launch pad setup, and launch control communication. This guide assists teams in preparing for a smooth and efficient launch process.

- The EuRoC Motors List contains information about the approved rocket motors that teams can use in the competition. It is essential for participants to select motors that meet the competition's requirements and safety standards.

- The EuRoC COTS Motors Acquisition Guide provides details on acquiring commercial off-the-shelf (COTS) motors, including the procurement process, licensing, and transportation. This guide ensures teams can legally and safely obtain the necessary components for their rockets.

- The EuRoC Technical Questionnaire, available in the Teams' Reserved Area, is a form that must be completed by participants to provide detailed information about their rocket design, propulsion system, and safety features. This document is crucial for the competition's evaluation process.

- The EuRoC Waiver and Release of Liability Form, also found in the Teams' Reserved Area, is a legal document that must be signed by all team members to acknowledge the inherent risks associated with rocketry and release the organisers from liability for any damages or injuries.

- The EuRoC Flight Card and Postflight Record, accessible in the Teams' Reserved Area, is a document that teams must submit after their rocket flight. It records essential information about the flight, including rocket performance, any anomalies, and lessons learnt. This record helps the organisers assess each team's performance and contributes to the continuous improvement of the competition. The EuRoC organisers demonstrate their strong understanding and expertise in compliance related to the European Rocketry Challenge.

8.2.2 Czech Rocket Challenge

The Czech Rocket Challenge (CRC 2023), hosted by the Czech Rocket Society (CRS), is an innovative and ambitious initiative aimed at driving the growth of the amateur rocketry sector within the Czech Republic. Established in 2021, the competition offers a unique opportunity for students and young engineers to engage in hands-on rocket design and development, providing them with invaluable experience and exposure to the world of aerospace engineering. Launch of the project rocket is shown in Image 20.

Image 20 Rocket launch at the Czech Rocket Challenge (CRC)
Source: Own elaboration

The competition is divided into two main categories: Beginners and Advanced (see Image 21). The beginner category is designed for students and younger participants mostly from high schools and grammar schools. This category allows participants to gain practical experience with cutting-edge manufacturing techniques, while also encouraging creative and cost-effective rocket designs. To reduce the complexity of the project, parts of the rocket are provided to each team.

The Advanced category is tailored for more experienced enthusiasts and university students, who are tasked with designing, building, and launching a rocket that reaches an altitude of around 1000 metres. In both categories, participants are judged based on various criteria, including the quality of their design documentation, the functionality of their rockets, and their adherence to safety regulations. The Advanced category presents a broader scope of opportunities to address payload criteria, such as the development of a cansat or a satellite equipped with supplementary avionic systems capable of functioning as a sensor station and maintaining communication with ground stations.

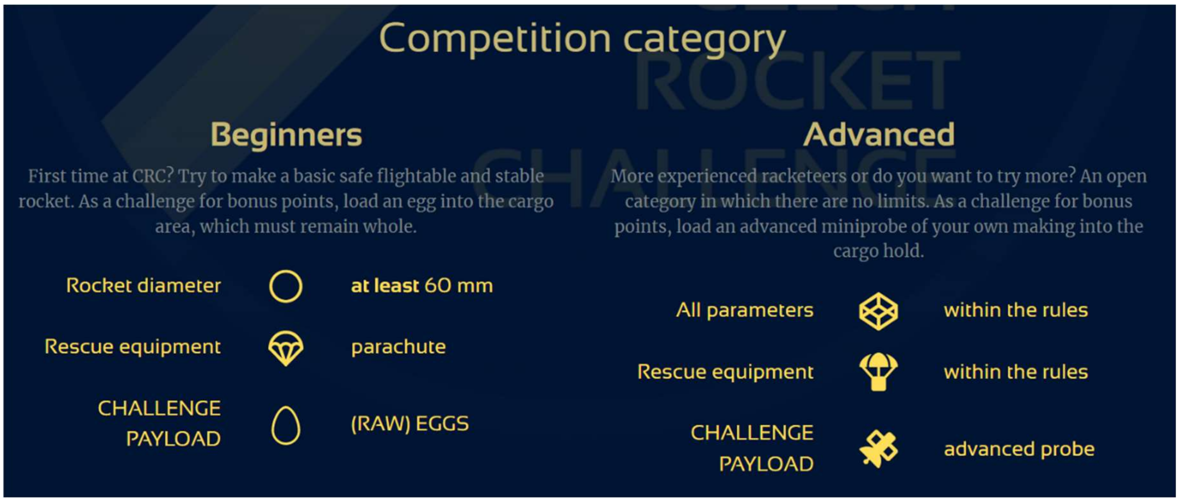

Image 21 Czech Rocket Challenge (CRC) Categories for the year 2023
Source: Czech Rocket Challenge (2023)

The Czech Rocket Challenge has been instrumental in fostering a thriving amateur rocketry community in the Czech Republic. By offering a platform for students and young engineers to showcase their skills and engage with industry professionals, the competition has significantly contributed to the development of a strong talent pool in the field of aerospace engineering. Furthermore, the Czech Rocket Challenge has successfully established strategic partnerships with key stakeholders in the industry, such as universities and research institutions, which has further bolstered its role as a catalyst for growth within the student rocketry sector (CRC 2023).

9 Standardisation and Standards Analysis

The present chapter is centred on the analysis of diverse standardisations and standards that are pertinent to the research subject. Drawing on the theoretical framework, the author evaluates the suitability, efficacy, and potential influence of these standards on the topic at hand.

The author conducts an evaluation of various standards in order to identify the primary factors that contribute to their successful or unsuccessful implementation. The purpose of this analysis is to establish a connection between theoretical concepts and practical applications, thereby enhancing the overall comprehension of the research topic's practical implications.

This chapter presents a comprehensive analysis of the relevant standards and their impact on the research issue.

9.1 Standards for the Field of Project Management at CTU Space Research

It helps to assess different criteria, including relevance to the space industry, accessibility, comprehensiveness, and adaptability to the specific requirements of the organisation, in order to choose the standards that are most appropriate for the field of project management at CTU Space Research. For the purpose of facilitating an informed decision-making process, this section aims to provide an overview of the leading standards in the field of project management and their applicability to CTU Space Research.

Considering the distinct demands of CTU Space Research and the exceptional requisites of the space sector, ECSS may present itself as the optimal option for fulfilling the organisation's project management requirements. The ECSS standards offer a comprehensive and consistent set of guidelines specifically designed for space projects. Additionally, their broad acceptance and implementation within the space sector promote a sense of cohesion and cooperation among various organisations. The implementation of ECSS standards by CTU Space Research can establish a robust basis for project management and technical procedures, while simultaneously conforming to the most effective practises within the industry.

9.2 Availability of Each Standards

Availability is a significantly measured aspect that limits several Standardisation Systems to be used within CTU Space Research. Availability is related to financial affordability of each standard systems, as well as publicity of these standards, language, and up-to-dateness. Those metrics are analysed in
Table 8.

Financial Affordability metric means if the set of standards is available both, free or paid.

Standards	Accessible	Financial Affordability	Limits
AIAA	Yes (paid)	Paid access	Reginal applicability, financial constraints
CNSA	No, restricted public access	N/A	Language of standards (Chinese)
EASA	Yes	Free access, some standards require subscription	Aviation oriented mostly
ECSS	Yes	Requires registration, then free access	Complexity unabling to use all standards
FAA	Yes	Free access, some standards require subscription	Aviation oriented mostly
IAF	Yes	Paid access	Standards as a minor business area
INCOSE	Yes	Access requires paid subscription	System Engineering oriented
ISO	Yes	Paid access	Expenses related to obtaining specific standards and fulfil its requirements
ITU	Yes	Paid access	Limited applicability
JAXA	Yes, limited public access	N/A	Irrelevant for European operated student rocketry team
NASA	Yes	Free access, some standards require subscription	Older Standards issue date

Table 8 Summary of the findings on each standard.
Source: Own elaboration based on AIAA (2020), CNSA (2023), EASA (2023), ECSS (2023), FAA (2023), IAF (IAF 2023), INCOSE (2023), ISO (2023), ITU (2023), JAXA (2023), NASA (2023a)

9.3 Suitability Ranking for Chosen Organisation

In the current study, the objective is to evaluate and rank the standards analysed using a well-established method, the Likert scale (as shown in Table 9), which ranges from 1 to 7. This psychometric instrument facilitates the systematic assessment of respondents' opinions and attitudes towards the identified standards, with 1 representing the lowest level of agreement or importance and 7 indicating the highest level. By employing the Likert scale, a comprehensive and rigorous approach is provided to examine the relative significance of each standard, thus contributing to a more nuanced understanding of their implications within academic and professional contexts.

Likert Scale	Description
1	Strongly Disagree: Completely disagrees with the statement or considers the standard to be of minimal importance.
2	Disagree: Mostly disagrees with the statement or considers the standard to be of low importance.
3	Somewhat Disagree: Somewhat disagrees with the statement or considers the standard to be of moderate-low importance.
4	Neutral: Neither agrees nor disagrees with the statement or considers the standard to be of neutral importance.
5	Somewhat Agree: Somewhat agrees with the statement or considers the standard to be of moderate-high importance.
6	Agree: Mostly agrees with the statement or considers the standard to be of high importance.
7	Strongly Agree: Completely agrees with the statement or considers the standard to be of utmost importance.

Table 9 Likert scale description
Source: Own Elaboration

Ranking of standards is following (see Table 10):

Standards	Suitable
AIAA	4
CNSA	1
EASA	4
ECSS	7
FAA	3
IAF	3
INCOSE	4
ISO	5
ITU	2
JAXA	1
NASA	6

Table 10 Standards ranking
Source: Own elaboration

The table presents a ranking of various standards based on their suitability, assessed using the Likert scale from 1 to 7. A closer examination of the results reveals that ECSS emerges as the standard with the highest performance, having achieved the highest rating of 7, indicating the utmost importance or strong agreement with the statement. This is followed by NASA, which secures a ranking of 6, signifying high importance or agreement. Finally, ISO is positioned as the third ranking standard, with a score of 5, which represents moderate-high importance or somewhat agreement with the statement.

In conclusion, the finalists in this assessment are ECSS, NASA, and ISO, with rankings of 7, 6, and 5, respectively. These standards demonstrate a higher level of suitability compared to the other listed standards, implying their greater relevance and potential for application in the given context.

9.4 The Financial Dimension of Project Management

Calculating financial metrics to determine the value of each type of standard can be challenging, given their varying objectives and structures. As a non-profit organisation, the success of these standards does not directly result in financial profits or revenues for the team or its members. The primary aim is to develop a competitive product for rocket competitions while minimising losses associated with project failures rather than generating profits.

Consequently, the focus of this chapter is not on precisely determining the Rate of Return (ROI) or the Internal Rate of Return (IRR). Instead, the objective is to identify the standardisation that best achieves a balance between project success and cost effectiveness, ensuring both optimal results and resource efficiency.

9.4.1 ECSS

The European Cooperation for Space Standardisation (ECSS) stands out as the premier choice among the various industry standards for several reasons, mainly because of its accessibility and widespread use. Unlike other standards that may require payment or limited access, the ECSS provides full and free access to its resources. This is a significant advantage for organisations, especially for student rocketry teams, which may have budget constraints or limited resources.

Another strong reason to choose the ECSS standards is their prevalence and adoption across the space industry, including among student rocketry teams. This widespread acceptance is a testament to the quality and relevance of the ECSS standards. By choosing to follow these standards, the team would align itself with numerous other organisations that have already adopted the same practises. This creates a sense of unity and collaboration within the industry and makes it easier for teams to share experiences and learn from one another.

In addition, the ECSS standards provide a comprehensive framework for all aspects of space projects, from project management to engineering, product assurance, and environmental testing. This means that by adopting ECSS standards, a student rocketry team can ensure that they are following a consistent and well-established set of guidelines throughout the entire project lifecycle. This will not only contribute to a more streamlined and efficient project management process, but it will also help reduce the risk of errors or inconsistencies that could lead to project failure.

In conclusion, ECSS standards are a highly recommended choice for student rocketry teams because of their free accessibility, widespread use, and comprehensive coverage of various aspects of space projects. Adopting these standards will provide a solid foundation for project management and technical processes while fostering a sense of unity and collaboration within the space industry community.

9.4.2 ISO

The International Organisation for Standardisation (ISO) is well-known for its extensive range of standards that are applicable to various industries, not just the space sector. These standards, developed through a consensus-driven process involving international experts, are designed to help organisations ensure quality, safety, and efficiency across a broad spectrum of activities.

One such example is ISO 21500:2021 - Project, programme and portfolio management — Context and Concepts (ISO 2021a). This standard provides guidance on project management principles and concepts that can be applied to various industries and types of projects. By providing a universal framework for project management, ISO 21500:2021 aims to improve the effectiveness and efficiency of project management practises, regardless of the field or sector in which they are implemented.

As another example, ISO 56002:2019 - Innovation Management System can be considered, which provides guidelines for organisations seeking to create, implement, maintain, and constantly enhance an effective innovation management system. This thorough framework makes it easier to manage innovation processes in a disciplined way, assisting organisations in finding new opportunities, creating creative solutions, and maintaining competitiveness in their specific markets. Organisations may guarantee that their innovation efforts are in line with strategic objectives, allocate resources efficiently, and promote continuous improvement and learning across the innovation lifecycle by implementing ISO 56002:2019 (2019).

However, it is essential to recognise that ISO standards are not specifically tailored to the student rocketry team as primary standards, which could mean that certain nuances or specialised requirements of aerospace projects might not be covered. While ISO standards can provide a solid foundation for general project management, organisations in the space sector might benefit more from standards that are directly focused on the unique challenges and needs of this industry, such as the ECSS or NTSS.

Another critical consideration is the cost associated with accessing and implementing ISO standards. Gaining access to these standards can be expensive and the certification process can require a significant financial investment from the team. In the case of a student rocketry team, these costs could amount to tens of thousands of Czech Koruna, which may be prohibitive given budget constraints and limited resources. For instance, the access to ISO 21500:2021, 12 paged document costs 61 CHF, that is approximately 1440 CZK (ISO 2021a). Furthermore, access to ISO 56002:2019 costs 124 CHF, that is approximately 3000 CZK (ISO 2021b).

In summary, while ISO standards provide a diverse range of recommendations for broad implementation across various sectors, their relevance to the space industry may be constrained by their lack of specialisation. In addition, the fiscal responsibility associated with obtaining and validating adherence to ISO regulations may present a hurdle for collegiate rocketry organisations. Organisations functioning in the space industry may discover that the ECSS or NTSS standards are more pertinent and economical alternatives for fulfilling their project management requirements. Consequently, the ISO Standards have been excluded from any subsequent analyses.

9.4.3 NTSS

The NASA Technical Standards System (NTSS) is another prominent standard within the space industry, coming in as a close second to the ECSS standards. Although the NTSS is primarily focused on technical aspects, it shares some similarities with the ECSS in terms of its comprehensive coverage and attention to detail. All standards suitable for CTU Space Research were available at the time of the analysis.

NASA has long been a leading force in the aerospace industry and is particularly renowned for publishing detailed propulsion and structural plans for their rockets. This wealth of information and experience has contributed to the development of the NTSS, which has become an invaluable resource for organisations seeking guidance on various technical segments, such as avionics, structures, and propulsion systems. These standards ensure that projects adhere to high levels of quality and safety, which are critical factors for success in the space industry.

However, it is important to note that some of the NTSS standards may not be readily available, and certain standards might be inactive or cancelled. This could potentially present challenges for organisations aiming to fully comply with the NTSS, as they may need to invest additional time and effort in identifying and sourcing the relevant standards. Nonetheless, the NTSS still remains a highly valuable resource for those seeking technical guidance in the aerospace domain.

In contrast to the ECSS, the NTSS is more focused on technical areas rather than project management. While this emphasis on technical expertise is undoubtedly beneficial, organisations seeking a more comprehensive and integrated approach to project management might find the ECSS standards to be a better fit for their needs.

In summary, the NASA Technical Standards System is a highly respected and valuable resource within the space industry, particularly for technical segments such as avionics, structures, and propulsion. However, due to the inaccessibility, inactivity, or cancellation of some standards, and the limited focus on project management, organisations may find the ECSS standards to be a more suitable choice for their overall project management needs.

9.5 In-Depth Analysis of the Chosen Standardisation

In this chapter, an in-depth analysis of the chosen standardisation for the CTU Space Research team will be conducted, with a focus on the European Cooperation for Space Standardisation (ECSS) and its application in project management and system engineering. Through this analysis, the essential ECSS standards relevant to project management and system engineering will be examined, their value and impact on space projects will be assessed, and their applicability to the needs and objectives of the CTU Space Research team will be explored.

9.5.1 ECSS

The European Cooperation for Space Standardisation (ECSS) is a cooperative effort by the European Space Agency (ESA), national space agencies, and European industry associations to develop and maintain a comprehensive and consistent set of standards for space projects. ECSS standards are specifically tailored to the space industry, covering a wide range of disciplines such as project management, system engineering, and product assurance, among others.

For project management and system engineering, ECSS offers several dedicated standards that provide guidance and best practices to ensure the success of space projects. The following is an in-depth analysis of these standards:

ECSS-M-ST-10C: Project Planning and Implementation
This standard defines the requirements for project management, including planning, organisation, execution, and control. It covers aspects such as project objectives, risk management, budgeting, scheduling, and reporting (ECSS 2009a). This standard is a valuable resource for project managers, providing a structured approach to managing space projects.

ECSS-M-ST-80C: Risk Management
This standard provides a comprehensive framework for managing risks in space projects, ensuring that potential threats are identified, assessed, and mitigated. It covers risk identification, analysis, evaluation, treatment, and monitoring, which are essential components of any project management process (ECSS 2008).

ECSS-E-ST-10C: System Engineering General Requirements
This standard outlines the general requirements for system engineering in space projects, including system requirements, design, and verification processes. It provides a structured approach to developing, integrating, and validating systems, ensuring that they meet the project objectives and requirements (ECSS 2009b).

By adopting ECSS standards for project management and system engineering, organisations in the space industry can benefit from a comprehensive and consistent framework that is specifically tailored to their unique needs and challenges. ECSS standards provide a solid foundation for effectively managing space projects, ensuring that they are completed on time, within budget, and meeting all technical and performance requirements.

These standards are available for download on the ECSS website (https://ecss.nl/), allowing organisations to access and implement the guidelines in their projects. By summing up the gained knowledge and experience captured within the ECSS standards, project managers and system engineers can enhance the success of their space projects and contribute to the overall advancement of the space industry.

9.5.2 NTSS

The NASA Technical Standards System, abbreviated as NTSS (Bailey 2023a) is a collection of standards, guidelines, and best practises developed by NASA to ensure the success of its space projects. These standards are the result of NASA's extensive experience in the space industry, addressing various aspects of space projects such as project management, system engineering, safety, and reliability. The following is an in-depth analysis of NTSS standards relevant to project management and system engineering:

NASA Procedural Requirements (NPR) 7120.5: NASA Space Flight Program and Project Management Requirements
This document establishes the requirements for managing NASA space flight programmes and projects. It covers the entire project lifecycle, from formulation to implementation, and addresses aspects such as project planning, organisation, budgeting, scheduling, and performance management (NASA 2014). This document consists of 486 pages and stands as a more complex alternative to ECSS standards.

NASA Procedural Requirements (NPR) 7123.1: NASA Systems Engineering Processes and Requirements
This standard defines the system engineering processes and requirements applicable to NASA programmes and projects. It covers system engineering activities such as requirements definition, design, integration, verification, and validation, ensuring that systems are developed and operated in accordance with the project objectives and requirements (NASA 2013).

The NTSS standards provide a robust and comprehensive framework for project management and system engineering in the space industry. By adopting these standards, organisations can benefit from NASA's vast experience and knowledge, predominantly orientated to technical standards that are not a subject of this analysis. These standards are not as uniform and easily accessible as those made by ESA.

Both standards stand out from the others in terms of their characteristics, as well as their staffing and financial requirements. Also, the use of these standards is the closest match to the needs of the analysed organisation.

9.6 SWOT Analysis of Chosen Standards

Despite the previous analyses, at least a fundamental SWOT analysis should be used to identify characteristics in a team environment such as CTU Space Research. Brief overview to SWOT Analysis is shown in Table 11.

SWOT Analysis	
Strengths	Weaknesses
- Access to advanced technology - Expertise and knowledge gain	- Limited financial budget - Limited human resources
Opportunities	Threats
- Quality improvement - Attracting sponsors - Improving results in competitions	- Adaptation challenges - Costs associated with standard compliance - Technological obsolescence

Table 11 SWOT Analysis of ECSS (ESA) and NTSS (NASA)
Source: own elaboration

Strengths:

- Access to advanced technology: Collaborating with established space agencies like ESA and NASA will provide the student team with access to advanced technologies and systems such as ECTSS and NTSS. These systems will enhance the team's ability to design and develop more sophisticated and efficient rockets.
- Expertise and knowledge gain: Working with ESA and NASA standards will enable students to learn from experienced resources in the field of space research and rocket science. This knowledge transfer will improve the team's technical skills and help them make better decisions throughout the development process.
- Enhancing the team's reputation: Association with reputable space organisations will enhance the credibility and reputation of the CTU Space Research Student Rocketry Team. This could lead to greater interest from sponsors and other stakeholders.

Weaknesses:

- Limited financial budget: The student rocketry team operates with a limited budget, which might make it challenging to take advantage of the ECTSS and NTSS systems fully. There may be a need to prioritize certain aspects of the collaboration based on the available funds.
- Limited human resources: The limited human resources of the team may restrict the ability to utilise the advanced ECTSS and NTSS systems effectively. Students may need to invest additional time and effort to fully understand and utilise these complex systems, which may be challenging given their other academic commitments.

- Difficulties related to time consumed by working with standards: Team resources are also limited by time. Each member has limited time that can you to contribute on specific project. Time spend on analysing, following and editing standards could be allocated to other activities within or outer of CTU Space Research. Then, we are talking about opportunity costs that are individual for each member.

Opportunities:

- Quality improvement: The integration of ECTSS and NTSS systems into the student rocketry team's projects can lead to significant improvements in the quality of the rockets they produce. This can result in more successful launches, as well as enhanced safety and reliability.
- Attracting sponsors: Collaboration with ESA and NASA, and the resulting improvements in rocket quality, could attract more sponsors and investors. This could lead to increased funding for the team's projects, enabling them to expand their capabilities and resources further.
- Improving results in competitions: Correctly handled standards can contribute and improve the team's result in competition and prove that it is not just a random walk, but well organised set of activities and processes that makes together complex project.

Threats:

- Adaptation challenges: Adopting ESA's ECTSS and NASA's NTSS standards might pose challenges for the student rocketry team, especially considering their limited human resources. The team may need to invest substantial time and effort in understanding and implementing these standards, which could impact their progress in other areas of their projects.
- Costs associated with standard compliance: Ensuring compliance with ECTSS and NTSS standards may require additional investments in terms of equipment, materials, or software. These costs could be a significant burden on the team, considering their limited financial budget. Fortunately, the early stage of

implementation of a few standards is not expecting significant expenditures related to it.

- Technological obsolescence: Space technology is constantly evolving, and standards like ECTSS and NTSS may become outdated or replaced by newer standards over time. The student rocketry team may need to constantly update their knowledge and adapt their projects to remain in line with the latest industry standards, which can be resource intensive.

Therefore, for working with standards, it is inevitable for CTU Space Research to seek specialists orientated mainly toward project management and standards handling. Further, carefully analyse and discuss standards related costs, and find an equilibrium in advantages related to using standards and time consumed by the process of working with standards.

DESIGN PART

10 Adaptation of Standards at CTU Space Research:

As the CTU Space Research team goes into the frontier of cutting-edge rocket technology, it is becoming progressively crucial to conform and execute a sturdy set of protocols. The implementation of these standards is expected to enhance the efficacy and triumph of the team's actions, while simultaneously cultivating an environment of perpetual advancement. This chapter will undertake an analysis of the standards that have been adopted by the CTU Space Research team and also consider prospective standards that may be incorporated in the future.

10.1 Standardisation Equilibrium

Standardisation Equilibrium refers to the balance achieved between the use of standardised processes, methods, or components and the need for customisation and innovation within an organisation or industry. In the context of project innovation management, it is essential to strike the right balance between these two factors to ensure efficiency, cost savings, and adaptability while promoting creativity and innovation.

In the case of CTU Space Research, Standardisation Equilibrium would mean adapting a limited number of standards chosen according to analyses in previous chapters. The team should aim to achieve standards with higher added value to the team and its goals. Furthermore, the team may aim to develop standards that solve higher risk for those activities that may fail or lie on a critical path.

Based on depth analyses of standards within the aeronautical industry, the two central and key standards to follow were chosen to achieve defined objectives related to participation at the student rocketry competition.

10.1.1 ECSS-M-ST-10C Rev.1 – Project Planning and implementation

For CTU Space Research, choosing the ECSS-M-ST-10C-Rev.1 standard can provide considerable advantages in terms of project management and general effectiveness. This standard emphasises project planning and execution, and a rocketry team will find it to be of great value. The following are some key points supporting the idea of implementing this standard:

- Comprehensive project management: Detailed and systematic approach to managing space projects by the standard that addresses a number of topics, including planning, structuring, scheduling, and risk management. The student rocketry team may make sure that their projects are managed successfully and in accordance with industry best practises by adhering to this standard.
- Resource allocation and optimisation: The ECSS-M-ST-10C-Rev.1 standard provides instructions on the effective distribution and use of resources, such as personnel, equipment, and money. The student rocketry team may maximise project results and make the best use of their limited resources by adhering to this guideline.
- Stakeholder communication and engagement: The standard highlights the need for effective communication and stakeholder participation in space projects. The student rocketry team can develop stronger relationship with stakeholders, such as sponsors, academic institutions, and industry partners, by using this strategy, which may result in more support and collaboration.

10.1.2 ECSS-E-ST-10C Rev.1 – System Engineering General Requirements

Selecting the ECSS-E-ST-10C-Rev.1 standard for CTU Space Research, a student rocketry team, can provide numerous benefits and help the team achieve its goals in a structured and efficient manner. The European Cooperation for Space Standardisation (ECSS) has developed this standard specifically for space projects, making it an ideal choice for a rocketry team. Here are some reasons why adopting this standard is beneficial:

- Industry relevance: The ECSS-E-ST-10C-Rev.1 standard addresses the unique challenges and requirements faced by CTU Space Research operating in this field. By using this standard, the student rocketry team can ensure that their processes and systems are aligned with industry best practices.

- Quality Management Needs: The implementation of the ECSS-E-ST-10C-Rev.1 standard is tailored to the quality management requirements of the student rocketry team by providing a complete structure for quality assurance and control. The standard places significant emphasis on the systematic approach to quality management, which guarantees that all phases of the project, from design to implementation, adhere to elevated quality standards. Enhancing the likelihood of prosperous launches and augmenting their standing for superiority are both outcomes of this approach. By fulfilling the requirements of quality management, the team can sustain a superior level of performance.

- Improved communication and collaboration: Improved communication and collaboration: Adopting a well-established standard helps facilitate better communication and collaboration among team members and external partners. This is because everyone involved can refer to the same guidelines, terminology, and processes, reducing the chances of miscommunication and misunderstandings.

- Enhanced safety and reliability: The ECSS-E-ST-10C-Rev.1 standard places a strong emphasis on reliability and safety in managing rocket projects. The student rocketry team may ensure that their projects meet strict safety and reliability standards by adhering to this standard, lowering the risks involved in the development and launch of rockets.

10.2 Future Standard Opportunities

There are several standards that are out of the scope of CTU Space Research to fulfil for the current academic year and its goals related to competition. Even though, it does not mean the team cannot think about further standards to develop across team segments in upcoming seasons. Standards for future opportunities are following.

10.2.1 ISO 56002:2019 - Innovation management system

Investigating potential future team opportunities in ISO 56002:2019 Innovation Management System can be very beneficial in preserving a structured and efficient approach to innovation while remaining competitive in the rapidly developing space industry. The team can ensure they maximise the potential of their inventive abilities and maintain their position at the forefront of technological breakthroughs by taking ISO 56002:2019 into consideration.

- Systematic innovation approach: The complete framework provided by ISO 56002:2019 can help organisations establish, implement, and continuously improve their innovation management procedures. This standard will enable the student rocketry team to manage and foster innovation in a consistent and well-organised manner.

- Aligning innovation with strategic objectives: The standard supports organisations in fusing their innovation management system with their overarching strategic goals. The team's inventive efforts are guaranteed to immediately advance its purpose and vision in the area of rocket development and space research because of this connection.

10.2.2 NASA Technical Standards

Further technical NTSS can be implemented in CTU Space Research on a team-segment basis. These standards may be rather more technical orientated and used in the case CTU Space Research tries to participate in Spaceport America Cup, which is more influenced by its rules by NTSS and by NASA, as a key stakeholder in rocketry in the USA.

10.3 Process of Adapting Chosen Standards

The process of adapting chosen standards within CTU Space Research on various levels includes several steps to follow by management and team leaders to complete the initial stage successfully. On the other hand, the process of adapting chosen standards cannot be complicated due to limited human resources and the potential disappointment of members with the standards adaptation process.

The process of adapting includes several steps that may be done in a specific period to maintain the following of chosen and most suitable standards in the long run. Adaptation of standards may include the following:

- Evaluate the existing methods employed in CTU Space Research. Undertake a thorough evaluation of extant standards, appraise their merits and demerits, and pinpoint opportunities for enhancement.

- Identify appropriate project management standards: Conduct a thorough analysis and evaluation of different standards. Subsequently, select a standard that is in congruence with the organisational objectives, goals, and culture of CTU Space Research.

- The process of customising a chosen standard involves tailoring it to the specific needs and context of CTU Space Research. This can be achieved by developing a customised project framework, processes, and templates or editing already created frameworks, processes, and templates in previous terms.

- The objective is to evaluate the training requirements of the project management personnel and create and implement a comprehensive training initiative to enhance their proficiency and expertise in the modified standards.

- Execute the modified criteria in practise. The objective is to incorporate bespoke project management standards into the operational procedures and workflows of CTU Space Research while implementing a change management approach to ensure a seamless transition.

- Establish a set of KPIs to assess the effectiveness of the modified standards. Additionally, a monitoring and evaluation framework should be implemented to monitor the advancement of the project. It is also advised to conduct periodic reviews and audits to ensure adherence to the established standards.

11 Project Management Tools

The following handbooks related to project management and the chosen standards have been established to facilitate a more simplistic understanding of their implementation. These handbooks can serve as valuable resources throughout the entire lifecycle of the standards. However, it is essential to note that updates and edits may be required based on the evolving needs of the team segments.

By creating these handbooks, CTU Space Research demonstrates its commitment to utilising established standards and fostering a transparent approach to compliance. Handbooks not only improve understanding, but also serve as accessible tools for ensuring adherence to standards across all team segments. As a result, they contribute to more efficient and effective project management, ultimately supporting the successful completion of the team's objectives.

11.1 Establishment of Handbooks

To maintain a straightforward understanding of chosen standards – ECSS-M-ST-10C Rev.1 - Project Planning and implementation and ECSS-E-ST-10C Rev.1 – System Engineering General Requirements got its handbook created by the author of this thesis. Furthermore, CTU Space Research has published a handbook for project managers and a handbook for team members in the context of Project Management aimed at enhancing comprehension. Handbooks will be used in the initial part of the training given to chosen members, primarily management and team segment leaders.

11.1.1 Project Management - Student Rocketry Team Handbook

The Project Management - Student Rocketry Team Handbook (see Appendix [C] Project Management Handbook) is a comprehensive guide designed to help project management teams navigate the complex world of student rocketry projects. It covers the fundamental components of project management, such as objectives, milestones, project monitoring, adjustments, communication, collaboration, and leveraging ClickUp for project management. The handbook promotes a transparent, efficient, and supportive work environment that fosters teamwork and a solid commitment to project success. By following the principles and practises outlined in this guide, project management teams can ensure the successful completion of their rocketry projects while simultaneously nurturing a positive and collaborative environment within the team.

11.1.2 Team Segments Project Management - Student Rocketry Team Handbook

The Team Segments Project Management - Student Rocketry Team Handbook (see Appendix [D] Project Management Handbook for Team Segments) serves as a guide for unifying and streamlining the efforts of all segments within the student rocketry organisation, such as Avionics, Propulsion, Structures, and PR. It covers critical aspects of project management, including objectives, milestones, project monitoring, adjustments, communication, collaboration, and leveraging project management tools for segment efficiency. By providing a clear framework for each segment, the handbook aims to facilitate better collaboration and organisation across the team. Following the principles and practices outlined in this handbook will help each segment contribute to the overall success of the Student Rocketry Team, ensuring that projects are completed on time, within budget, and with the highest quality standards. The handbook emphasises the importance of a supportive, transparent, and efficient work environment for the benefit of all segments of the organisation.

11.1.3 ECSS-M-ST-10C Project Management Handbook

The Extended Project Management Handbook for CTU Space Research (see Appendix [E] ECSS-M-ST-10C Project Management Handbook) is based on the ECSS-M-ST-10C standard and aims to provide comprehensive guidance for project management within the organisation. The handbook is divided into ten main sections: Project Management Philosophy, Project Organisation and Responsibilities, Project Planning and Control, Risk Management, Configuration Management, Quality Assurance and Product Assurance, Project Documentation and Reviews, Resource Management, Stakeholder Management, and Lessons Learnt and Continuous Improvement. By following the principles and practices outlined in this handbook, CTU Space Research can foster a collaborative, efficient, and supportive project management environment, ultimately achieving its mission and elevating the organisation to new heights.

11.1.4 ECSS-E-ST-10C-Rev.1 System Engineering Handbook

The System Engineering Handbook, based on ECSS-E-ST-10C-Rev.1 (see Appendix [F] ECSS-E-ST-10C Rev.1 System Engineering General Requirements Handbook), serves as a comprehensive guide for professionals working on space projects. It covers key processes in system engineering, including requirements engineering, technical solutions, technical risk management, configuration management, and technical information management. The handbook also provides guidance on project management, quality management, and the development of a System Engineering Management Plan (SEMP).

By following the processes and principles outlined in the handbook, engineers can optimize system performance, reduce risk, manage costs, and improve overall project efficiency. However, it is essential to note that this handbook is not an official ECSS document and should be used as a supplementary resource to the ECSS-E-ST-10C-Rev.1 standard.

With its extensive coverage of system engineering topics, the System Engineering Handbook is a valuable resource for professionals in the space industry looking to better understand and apply the ECSS-E-ST-10C-Rev.1 standards in their work.

11.2 Road Map

Table 12 presents a roadmap for project management at CTU Space Research, outlining a list of recommendations across three stages. This roadmap aims to facilitate effective project management and ensure the successful execution of the project's objectives.

Stage	Stage 1	Stage 2	Stage 3
Timeframe	Month 1 – Month 2	Month 3 – Month 5	Month 6 – Month 8
Objectives	- Set up ClickUp for a project. - Define project goals and scope. - Assign tasks and resources.	- Monitor and track project progress. - Utilize ClickUp features for collaboration and communication.	- Review and optimise - Implement improvements - Close project and evaluate
ClickUp Features	- Create project structure. - Set up custom fields and views. - Allocate resources.	- Use task dependencies. - Implement automations. - Track time and resources.	- Generate reports and analytics. - Use custom views to evaluate. - Archive project.
Human Resources	- 1 project manager.	- 3 project managers, scrum masters.	- 5 project managers, full assistance to the management.
Possible activities	- Framework establishment. - ClickUp Support. - Project Management Compliance.	- Finance controlling. - Scrum mastering. - Team leaders' assistants. - Advanced Gantt Charts.	- Internal audit. - Establishment of further ECSS and NASA Standards.
Costs	- 0 EUR / 0 CZK	- 8x Click License for $5 = $40 - Approx. 37 EUR per month or 900 CZK/ month	- 8x Click License for $5 = $40 - Approx. 37 EUR per month or 900 CZK/ month

Table 12 Road Map of Project Management Framework Establishment
Source: Own elaboration

The roadmap is divided into three stages, each with specific objectives, ClickUp features, human resources, and possible activities. The first stage focuses on setting up ClickUp for the project, defining project goals and scope, and assigning tasks and resources. The second stage emphasises monitoring and tracking project progress and utilising ClickUp features for collaboration and communication. The final stage involves reviewing and optimising the project, implementing improvements, and closing and evaluating the project. Throughout these stages, various ClickUp features and human resources will be utilised to ensure the project success and compliance with the appropriate standards.

11.3 Project Management Software Analysis

In the realm of project management, it is important to maintain a comprehensive understanding of the project's progress, including tracking tasks, timelines, resources, and other essential aspects. This holistic approach ensures that project managers can make informed decisions, identify potential bottlenecks or challenges, and implement corrective actions as needed to keep the project on track and aligned with its objectives.

Effective project tracking involves continuous monitoring and evaluation of various project components. This includes keeping an eye on individual tasks and ensuring that they are completed according to schedule and within the established budget. By regularly reviewing the progress of the task, project managers and other team members can identify any deviations from the original plan and take appropriate action to address them.

Furthermore, tracking timelines is of paramount importance, as this enables project managers to assess the overall progress of the project and ensure that milestones are met in a timely manner. A well-maintained timeline provides a clear visual representation of the project's trajectory, allowing project managers to foresee potential risks or delays and proactively manage them.

In summary, a comprehensive and diligent approach to project tracking is vital for successful project management. By closely monitoring tasks, timelines, resources, and stakeholder communication, project managers can maintain a clear understanding of the project's progress and make informed decisions to ensure its successful completion. This proactive and systematic approach to project tracking ultimately contributes to the achievement of project objectives and the overall advancement of the organisation's goals.

The CTU Space Research, a student rocketry team, has recognised the importance of effective project management and has considered implementing software tools to facilitate the management of their projects. After careful consideration, the team has identified three potential project management software options that could meet their needs.

11.3.1 MS Project

Microsoft Project is a popular and robust project management software that is used by organisations worldwide. It provides comprehensive tools for project planning, scheduling, resource management, and progress tracking. With its powerful functionality and integration with other Microsoft products, MS Project offers a reliable and familiar platform for managing complex projects in a professional setting. The MS Project stands as the most expensive and the most advanced software of all analysed.

Its use has been considered as too complex, expensive and time demanding. It would be required to have at least eight licenses – for all project managers, management and team leads, other users could use free versions instead. Anyway, the price starts on $10 per user per month and can get up to $55 per user per month that is unlocking all cloud solutions, according to Morpus (2022). For better understanding, the price model is demonstrated in
Table 13.

Plan and its tools	Price
Plan 1 – team access, task status updates, kanban boards, export projects	$10/user/month
Plan 3 – all previous features and desktop application, Gantt charts, finances, resource management, timesheets, project and road mapping, advanced task allocation	$30/user/month
Project 5 – all previous features and project analytics, portfolio reports	$55/user/month

Table 13 Price Model of MS Project
Source: Morpus (2022)

11.3.2 Project Libre

Project Libre is an open-source alternative to Microsoft Project that offers similar functionality for project management tasks. It supports Gantt charts, resource allocation, and task tracking, among other features. As a free and open-source solution, Project Libre is an attractive option for budget-conscious teams looking for an accessible and user-friendly project management tool.

Project Libre is, on individual basis, free alternative to MS Project that share similarities in an environment and tools with MS Project as well. Project Libre uses the same file formats. Unfortunately, this software is in early access and consists of minor bugs that can decrease the user experience. Furthermore, Project Libre launched pricing model for business during testing the environment by CTU Space Research. According to an online meeting with Project Libre Founder & CEO Marc O'Brien (2022), the pricing for the cloud solution will start at $5 per user per month.

11.3.3 ClickUp

ClickUp is a cloud-based project management software that offers features to help teams plan, organise, and manage their tasks and projects. With its user-friendly interface and customisable views, ClickUp allows for seamless collaboration among team members, ensuring that everyone stays informed and engaged throughout the project lifecycle.

ClickUp stands out as an advantageous project management software due to its extensive variety of user-friendly tools and an intuitive interface, catering to diverse project types and scopes. Its ease of use minimises the learning curve, allowing team members to focus on tasks and project objectives. The platform fosters a transparent and cohesive working environment through seamless collaboration capabilities, enabling efficient communication and teamwork. Customisable views and dashboards provide a personalised experience for each user, ensuring effective utilisation of the platform by all team members. In general, ClickUp's emphasis on adaptability, collaboration, and customisation streamlines project management processes, leading to improved project outcomes and organisational success.

ClickUp offers a free version of its software, paid versions start at $5 per user per month and go up to $19 per user per month for business plus versions, according to the official website (ClickUp™ 2023). The price list with features is shared in Image 22. The software was successfully analysed by the author and team management on its free access. This access was considered as an optimal version for the early stage of project management.

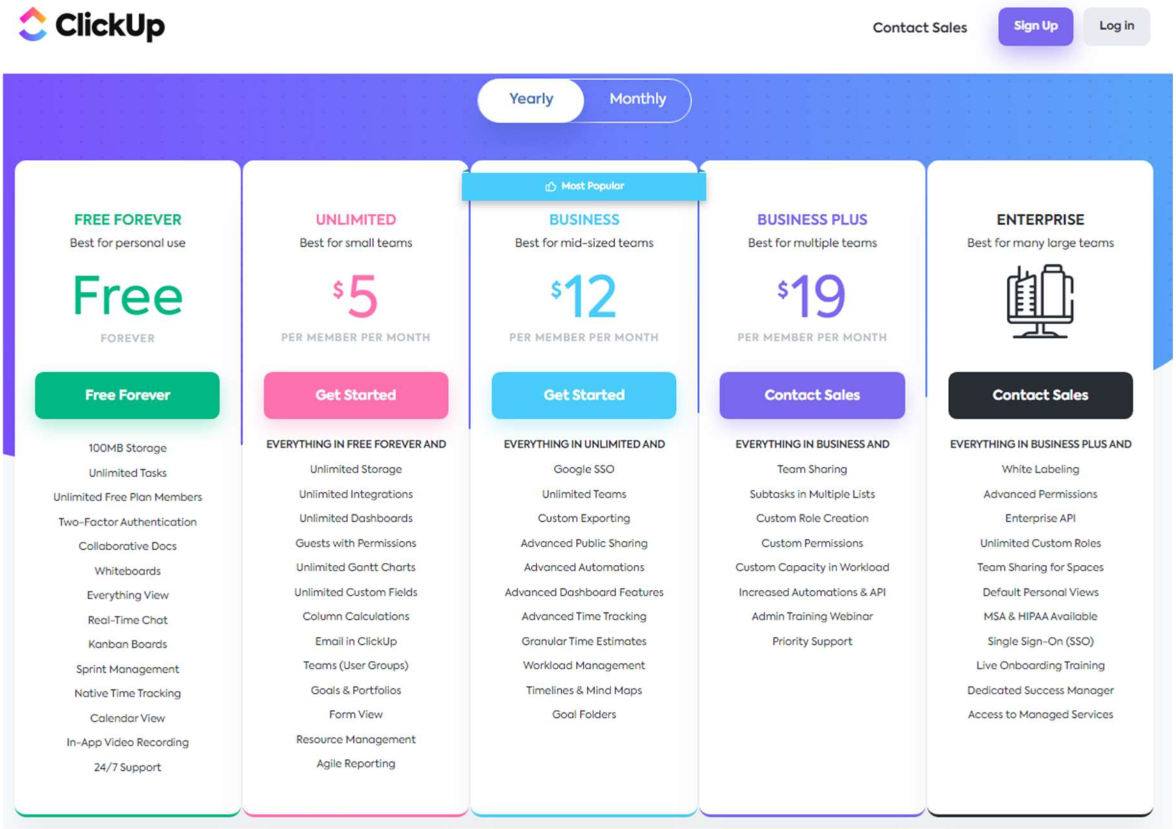

Image 22 ClickUp pricing
Source: ClickUpTM (2023)

11.4 Establishment of Project Management Software (ClickUp)

The CTU Space Research student rocketry team has successfully established a ClickUp software environment to streamline project management and enhance team collaboration. Through the utilisation of ClickUp's comprehensive functionalities, the team can effectively arrange, strategise, and carry out diverse undertakings linked to their ambitious space exploration initiatives.

The ClickUp platform for CTU Space Research is organised into distinct channels (as shown in Image 23), including Avionics, Propulsion, Structures, Payload, Public Relations, Management, and EuRoC. Each channel is designed to address a distinct aspect of the project, enabling team members to concentrate on their individual responsibilities without being burdened by extraneous duties. For initial testing space was used Project StratoSat described in Chapter 8.1.9.

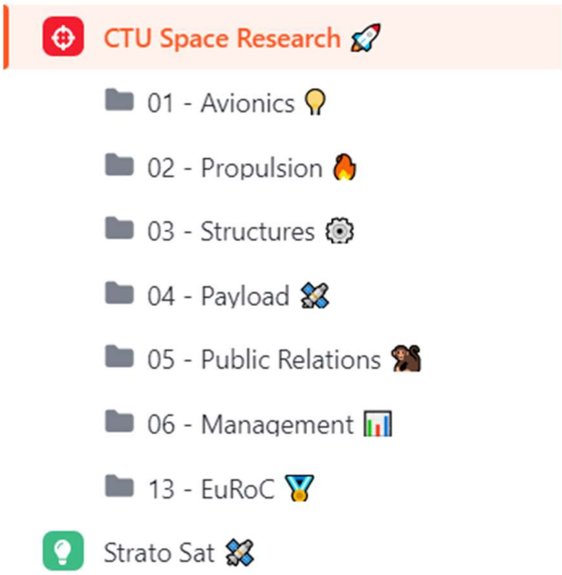

Image 23 ClickUp Space Management of CTU Space Research
Source: Own elaboration

Each channel is comprised of three discrete sections, namely Main, Tasks, and Reports. The Main section presents a comprehensive outline of the channel's goals and significant details, whereas the Tasks section enumerates discrete tasks that can be further structured utilising the Gantt Chart Model. The graphical representation of the project timeline facilitates the monitoring of progress and the effective distribution of resources among team members. The Reports section functions as a medium for the presentation of project updates, discoveries, and evaluations.

ClickUp offers a variety of customisable features for each task, including assignees, priority levels, start and due dates, dependencies, comments, subtasks, tags, and attachments. The aforementioned characteristics guarantee that the members of the team possess a lucid comprehension of their obligations and time constraints, promoting responsibility and facilitating efficient correspondence among team members. Task features are represented in Image 24.

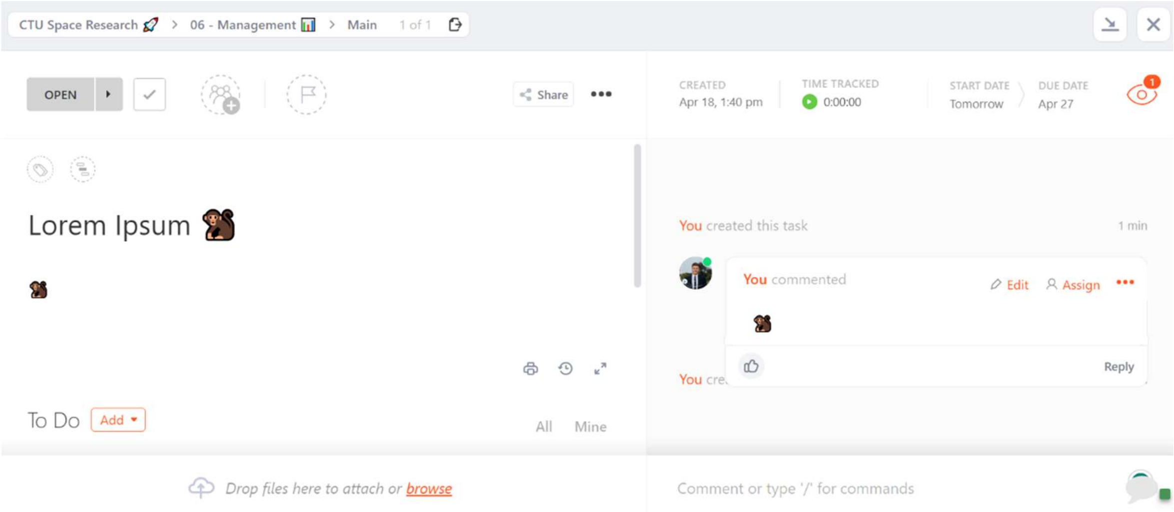

Image 24 ClickUp task management
Source: Own Elaboration

The CTU Space Research student rocketry team has established an efficient and transparent project management system by integrating the ClickUp Software environment. This system fosters productivity, facilitates collaboration, and ultimately enhances the success of the team in advancing aerospace technology. The main dashboard is visible in Image 25. For better insight, the ClickUp dashboard is placed in Appendix [B] ClickUp Dashboard of Management Channel, as well.

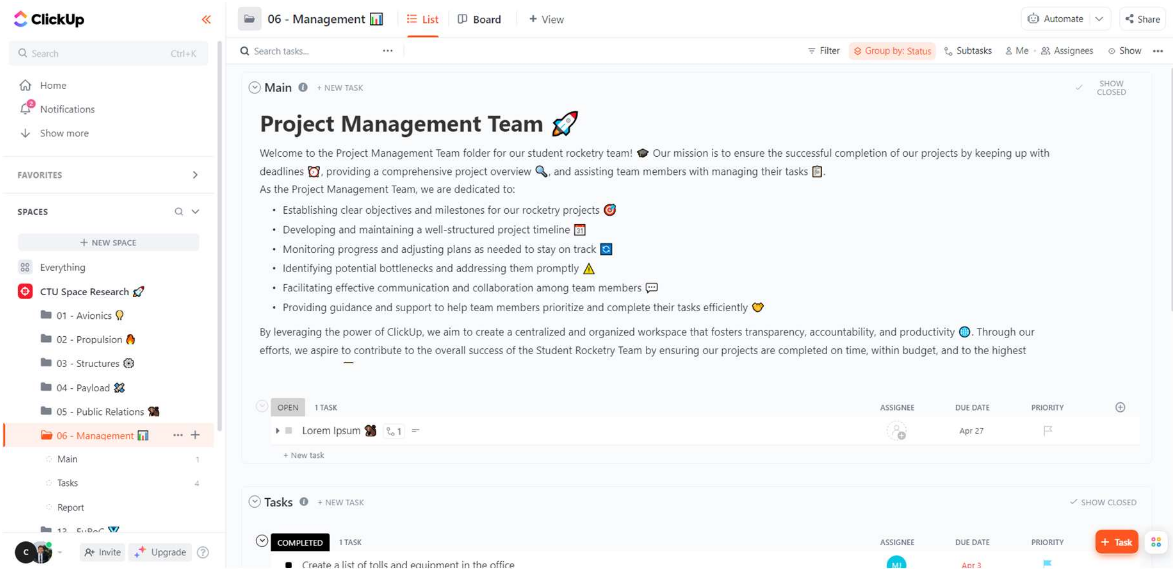

Image 25 ClickUp dashboard
Source: Own elaboration

11.5 System Engineering Software/Database

For the purpose of implementing a System Engineering Interface for CTU Space Research and its project management, team member Tomáš Lapeš has developed a comprehensive Application Programming Interface (API) using the app Appsmith. The user interface has been designed to adhere to the ECSS-E-ST-10C-Rev.1 standard and is constructed based on Viktor Hais' database.

The System Engineering Interface comprises various fundamental entities in the project hierarchy, which include:

- Objective (e.g., establish a rocket and ground station)
- System (e.g., the rocket, ground station, and test stand)
- Subsystem (e.g., Propulsion Unit, Electrical Power Subsystem)
- Unit (e.g., Hybrid Engine, Battery Pack)
- Component/part (e.g., Nozzle, Battery Cell, Screws, Connector)

Furthermore, the interface integrates fundamental project management functionalities, including the evaluation of risk magnitude. This assessment is established by considering the severity and likelihood scales, which range from 1 to 5 (see Table 14). The interface facilitates requirement verification techniques to ensure comprehensive validation of all project aspects and compliance with superior quality benchmarks. It is good to add that every value in likehood and severenity has clearly defined characteristics of probability and cost increase and delay.

		Severity				
	x	1	2	3	4	5
Likelihood	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Table 14 Risk magnitude
Source: Hais (2022)

The System Engineering Interface is dependent on pre-existing databases, such as the product tree and a roster of team members. The integration of these resources into a unified platform facilitates project management and promotes collaboration among team members.

CTU Space Research has successfully established a project management system that is both efficient and robust through the implementation of the System Engineering Interface. This system adheres to industry standards and enables seamless communication and coordination among team members, thereby contributing to the success of their aerospace research projects. For better illustration, see Image 26.

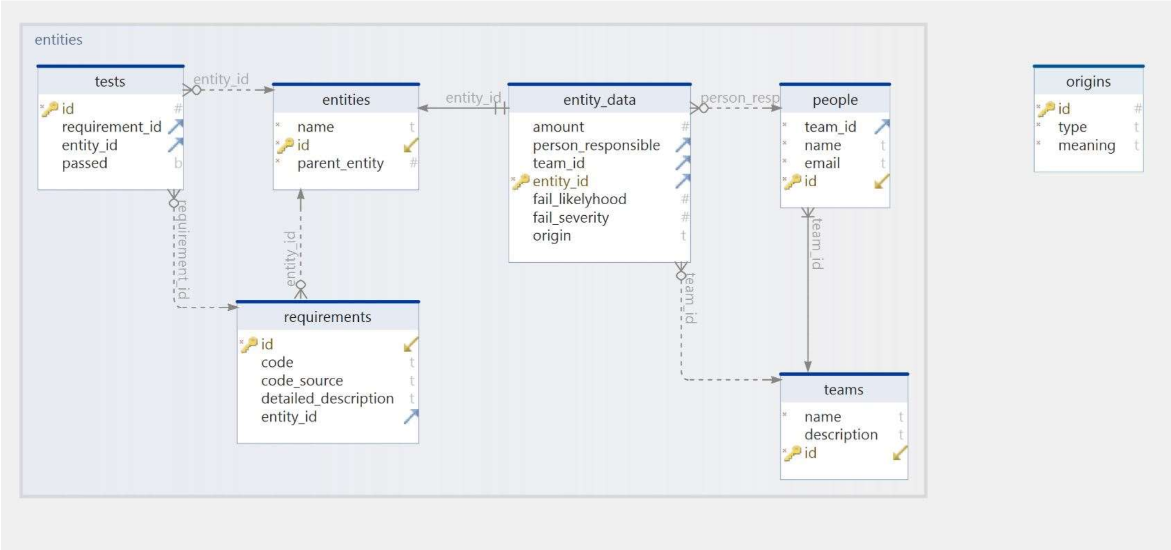

Image 26 Entity-Relationship Diagram of System Engineering
Source: Lapeš (2023)

11.6 Innovation Project Management Framework

Subsequent sections of the text introduce and elaborate on the Innovation Master Plan and Innovation Portfolio Management Framework, with the aim of transferring the concept to team management and team leaders.

11.6.1 Innovation Master Plan

The CTU Space Research team enthusiastically focuses on the exploration of novel frontiers in rocket technology and endeavours to cultivate a culture of innovation among its members, particularly those involved in rocketry. The objective of this plan is to provide direction to the team's innovative attempts, with the aim of maintaining their concentration on their objectives, promoting cooperation, and efficiently utilising resources. The subsequent sections will present a detailed Innovation Master Plan customised for the CTU Space Research student rocketry team. This plan will cover essential enquiries and offer strategic direction to foster innovation and, we hope, success. The Innovation Master Plan, was taken up by answering the five essential questions:

Why innovate?

- The primary objective of CTU Space Research's student rocketry team is to introduce students to practical challenges in rocket design, construction, and launch, thereby enriching their learning experience. The team endeavours to achieve this goal through innovation.
- Research and innovate novel technologies and methodologies with the potential to fundamentally transform the domain of rocket science.
- Facilitate the dissemination of knowledge, discoveries, and technological progress to the wider scientific community.
- Enhance the team's competitive edge in both national and international rocketry competitions.

What to innovate?

The team dedicated to rocketry among the students will prioritise the subsequent domains of novelty:

- This study aims to investigate novel and improved propulsion systems to achieve higher efficiency and greater power in the launch of rockets.
- The aim is to create and evaluate materials that possess both lightweight and well-built characteristics, with the goal of enhancing the rocket's overall performance and safety.
- The development of avionics and telemetry systems is aimed at improving the performance of onboard electronics, guidance, navigation, and control systems, with the ultimate goal of enhancing the stability and accuracy of rockets during flight.
- The development of reliable, effective, and sustainable recovery systems is imperative to ensure the secure retrieval of the rocket and its payload back to the Earth's surface.
- The objective is to explore and execute strategies aimed at reducing the ecological footprint associated with rocket launches.

How to innovate?

In order to promote innovation among the student rocketry team, the subsequent measures will be implemented:

- The proposal is to create a specialised research and development (R&D) unit within the student rocketry team with the aim of investigating and analysing novel solutions.
- Promote a culture of inclusivity and cooperation that fosters the exchange of thoughts and encourages active participation in group ideation sessions.
- Establish collaborative relations with industry professionals and academic organisations to facilitate the sharing of knowledge, skills, and resources.
- Attend national and international conferences, workshops, and competitions to remain up-to-date with the latest developments and trends in the field of rocketry.

Who innovates?

The composition of the student rocketry team shall comprise individuals who will undertake the following responsibilities:

- The individuals who will establish the direction, objectives, and standards for the innovation endeavours of the team are the innovation leaders, comprising faculty members and senior students.
- Innovation geniuses refer to students from diverse academic backgrounds who leverage their distinct expertise, understanding, and ingenuity to conceive and implement novel concepts.
- Innovation champions are individuals who are tasked with the responsibility of orchestrating and managing the innovation process, facilitating assistance to their colleagues, and guaranteeing the efficient allocation of resources.

Where to innovate?

In order to facilitate the innovation process within the student rocketry team, a set of infrastructure and tools will be made available:

- The provision of a specialised workshop and laboratory area, furnished with essential tools and equipment, for the purpose of designing, building, and evaluating rockets.
- The utilisation of digital tools, such as computer-aided design (CAD) software, simulation tools, and other pertinent technologies, is imperative in facilitating the development and examination of pioneering rocket systems.
- Funding: It is advisable to explore various avenues of financial support such as grants, sponsorships, and other funding sources in order to secure the necessary resources for the team to undertake novel projects.
- The establishment of external collaborations can be utilised to leverage partnerships with industry experts, other academic institutions, and space agencies, thereby providing access to specialised knowledge and resources.

11.6.2 Innovation Portfolio Management for CTU Space Research

Innovation Portfolio management stands in contrast with Innovation Master Plan in Chapter 11.6.1 and creates slight duplicity in analysed areas and a given outcome. Even though the Innovation Portfolio analysis is use, to ensure a diverse and balanced innovation portfolio, CTU Space Research should consider the following steps to create and manage its innovation portfolio:

Define the overall innovation objectives:

- The objective is to create advanced rocket technologies and launch systems.
- Encourage the development of a work environment that prioritises innovation, continuous learning, and effective collaboration between all members of the team.
- The objective is to bolster the standing of CTU Space Research among the aerospace and academic circles.

Identify innovation project categories:

- The objective of rocket propulsion systems is to enhance the efficiency and performance of existing systems and to create innovative propulsion technologies.
- The development of unique launch mechanisms and infrastructure is crucial for accommodating a wide range of rocket models and mission specifications.
- This pertains to the development of sophisticated control systems, navigation, and communication solutions for diverse rocket applications within the field of avionics.
- The task at hand involves the development of systems and processes that integrate scientific, commercial, or educational payloads into rocket missions.
- The objective is to identify and develop materials and processes that are environmentally sustainable in order to reduce the ecological impact of rocketry activities.

Develop an innovation project pipeline:

- Generate a catalogue of feasible ideas for innovation corresponding to the aforementioned classifications.
- Evaluate the technical feasibility, potential impact, necessary resources, and congruence with the team's goals for every project.
- It is recommended to prioritise projects by taking into account their strategic significance, technical complexities, and potential advantages for CTU Space Research and the wider aerospace sector.

Allocate resources and monitor progress:

- Allocate team members across each team segment to every ranked innovation initiative, guaranteeing a heterogeneous blend of competencies and knowledge.
- Assign resources such as time, funding, equipment, and facilities to facilitate the effective implementation of every project.
- It is recommended to consistently oversee the progress of each project, making the necessary modifications to resource allocation and priorities to maintain a well-balanced innovation portfolio.

Encourage collaboration and knowledge sharing:

- Create an enjoyable and cooperative environment that encourages project teams to exchange concepts, obstacles, and gained knowledge.
- Interact with industry stakeholders, educational establishments, and fellow student rocketry organisations to share expertise and investigate possible ways for cooperation.
- Attend academic conferences, workshops, and competitions to exhibit the innovative projects and accomplishments of CTU Space Research.

Evaluate outcomes and iterate:

- Establish KPIs and success criteria to assess the results of each innovation project.
- It is recommended to perform periodic evaluations of the project outcomes, assessing accomplishments, shortcomings, and opportunities for enhancement.
- Use feedback and insights to enhance the innovation portfolio and guide subsequent project selection and prioritisation.

Through the adoption of an innovation portfolio management strategy, CTU Space Research can ensure the inclusion of a wide range of projects that are in line with its goals and bolster its standing as a pioneering and accomplished student rocketry organisation. The aforementioned procedure is anticipated to cultivate an environment that prioritises education, cooperation, and ongoing enhancement, thereby enabling the team to remain at the vanguard of aerospace advancements.

The present outline, which describes a series of steps and examples for the establishment and administration of an innovation portfolio, has been custom-designed to suit the requirements of CTU Space Research. It is advisable to present this framework to the management and team leaders of CTU Space Research in an upcoming meeting or workshop. This will enable the team to deliberate, enhance, and modify the suggested methodology to more closely correspond with their distinct objectives, assets, and limitations. Adopting and implementing the innovation portfolio management framework can enable CTU Space Research to sustain its reputation as a prominent student rocketry team, while promoting innovation and collaboration.

11.7 Quality Management Framework

A brief quality management framework has been developed to provide CTU Space Research with a prompt and effective approach to a wide range of tasks encountered by the entire team. This framework aims to address quality management comprehensively, not only limited to the handling of space technologies and rocket systems. The framework aims to provide an approach that is quick in time-orientated and based on established quality management principles. Its purpose is to ensure that the team maintains high-performance standards across different project domains consistently.

The framework is based on ISO9001 described in Chapter 5 Quality Management and is located in:

Step	Description
Customer Focus	▪ Prioritize stakeholder satisfaction. ▪ Collect feedback for continuous improvement.
Leadership	▪ Establish clear quality management objectives. ▪ Foster a culture of quality from the top down.
Engagement of People	▪ Involve team members at all levels. ▪ Encourage open communication and skill development.
Process Approach	▪ Manage resources and activities through processes. ▪ Understand the connections between various activities.
Improvement	▪ Evaluate performance periodically. ▪ Develop a culture of continuous improvement.
Evidence-based Decision-making	▪ Collect and analyse data for informed decisions. ▪ Improve strategic planning and risk management.
Relations Management	▪ Build strong relations with stakeholders. ▪ Collaborate for win-win outcomes and innovation.

Table 15 Brief Quality Management Framework for CTU Space Research
Source: Own elaboration

11.8 Project Management Team Recruitment

To successfully follow and maintain establishments created in this thesis, it is vital to obtain new members specialised in project management and further activities related to the existence of CTU Space Research, such as marketing, fundraising, human resources or more technical roles related to Avionics, Propulsion, and Structures teams. A well-rounded recruitment strategy is essential to attract new students to join the Project Management Team at Czech Technical University. Both online and offline methods can be used to ensure maximum outreach and engagement.

Online recruitment can be conducted through the team's social media platforms, such as Instagram, Facebook, and LinkedIn. By creating engaging content on Instagram that highlights the benefits of joining the Project Management Team, the team can attract interested students (design sample shown in Image 27). Sharing stories of current members and collaborating with popular CTU accounts can further enhance the reach of recruitment posts. On Facebook, creating a dedicated event for a virtual information session or recruitment fair can encourage students to learn more about the opportunities available within the team. By sharing updates, testimonials, and success stories on the official CTU Facebook page and engaging students through relevant Facebook groups, the awareness of the team can be increased. Utilising targeted Facebook ads can also help reach a wider audience. On LinkedIn, articles and updates about the benefits and skills gained from joining the team can be shared on the official CTU website. Current team members and alumni can endorse the team on their personal profiles, and connections with student groups, professional organisations, and industry leaders can be established to expand reach and credibility.

Image 27 Online Recruitment of CTU Space Research (cosist of two swipeable images)
Source: Procházková (2023)

Offline recruitment can involve the strategic use of posters (inspect Image 28) and on-campus events. Eye-catching posters can be designed to showcase the benefits of joining the Project Management Team and displayed in high-traffic areas and notice boards at specific CTU faculties relevant to project management. Incorporating QR codes on posters can direct students to online resources or registration forms. On-campus information sessions and recruitment fairs can be organised to engage potential recruits and provide them with essential information. Inviting current team members and alumni to share their experiences can offer valuable insight into the advantages of joining the team. Additionally, the distribution of informational materials such as brochures or flyers at these events can further promote the team and its benefits.

Image 28 The newest recruitment poster of CTU Space Research
Source: Tomášková (2023)

By implementing this comprehensive recruitment strategy that combines both online and offline methods, the Project Management Team can effectively reach and engage with potential new members, ultimately expanding and strengthening the team at Czech Technical University.

Discussion

I acknowledge that delving into the technical standards is beyond the scope of my major, and my knowledge in this area is limited.

The following statements offer insights into the management perspectives of CTU Space Research, as shared by various team leaders. These reflections emphasize the importance of effective project management, systems engineering, and adherence to industry standards in order to achieve successful outcomes in the field of space research. By examining the experiences and opinions of these leaders, we can better understand the crucial role that organisational and technical expertise plays in the development of rocketry team within the academic sphere.

"Like my colleague Ondřej Marvan, I have dedicated myself to improving the project management of CTU Space Research. We are responsible for two projects: the Illustria rocket and StratoSat.

Previously, the project management system used was not dynamic, leading to a lack of knowledge about the current status of projects. Therefore, I positively evaluate the implementation of ClickUp, which can be used across the Avionics, Structures, Propulsion, PR, and Management teams. As a result, all innovative proposals from our talented colleagues can be consolidated in one place, and we can stay informed about their progress.

This system allows us to manage numerous administrative tasks required for component production and testing more efficiently. I believe that our projects have become more flexible and easier to execute.

Our standardisation and drawing documentation now meet the requirements demanded in the field of mechanical engineering."

- Jiří Beran, Former member & External Contributor CTU Space Research

"The project management tool is set to become one of the most crucial and beneficial tools for our team. My anticipation is that it will assist our team in maintaining a timely schedule. It should also help other members remain focused on their respective tasks. For me personally, as the Deputy Lead of the team, this tool will be immensely helpful. At times, I lose track of time and tasks; the project management tool (in this case, ClickUp) ought to aid me in staying organised and heighten my awareness of the team's activities. Naturally, it will require a significant amount of effort to ensure the system operates effectively."

- Michael Jurča, Deputy Team Lead CTU Space Reseach

“From my perspective, the next and inevitable stage for the CTU SR student team is the process of development towards systems engineering and the management project. Where it is already appropriate to implement new tools to manage and get an overview of such a large project, such as in situations where larger groups need to be managed. The use of ClickUp software is one of the many new approaches that has been implemented. This software has been used in the public relations industry, and it has assisted in making project management within the group clearer and more formal.

In the future, I believe that the implementation of the strategies mentioned above will bring the level of simplicity and clarity that the team has been looking for. And that is a path that is never a bad choice to go in the direction of.”

- Jakub Malínek, PR Lead CTU Space Research

“The implementation of project management, system engineering, and space standards within CTU Space Research may undoubtedly pave the way for a brighter future for our team, elevating our professionalism and increasing the potential for fruitful partnerships in the field of space research. Only time will tell how successful the chosen implementation has been.”

- Ondřej Marvan, Project Manager & PR Deputy CTU Space Research

“The integration of project management, system engineering, and industrial practices within CTU Space Research is anticipated to significantly enhance the team's organisation, bringing a higher level of clarity to leadership roles. This streamlined approach will minimize confusion and misunderstandings, such as the common "I thought another group was handling that" issue, ultimately leading to a more efficient, productive, and stress-free environment for our team members. By adopting standard industry processes, we aim to better equip individuals with the necessary knowledge and understanding for future endeavours in the field of space research.”

-

- Marek Dominik Pavelec, Former Team Lead & Co-Founder CTU Space Research

“With the introduction of project management, I expect a significant increase in efficiency, particularly in adhering to the timeline leading up to the competition, which is generally a challenge for engineering students with physical work results, given the educational system's focus on theoretical design phases of projects without actual production. Throughout their university experience, students must meet deadlines but often do not rely on others and are unaccustomed to delays caused by external factors.

By implementing system engineering, I foresee the perfect fulfilment of competition rules and, consequently, achieving a good placement for the entire team. I also feel the need to establish rules for cooperation among team groups and oversee the interfaces between components of different groups, such as the attachment of the onboard computer, which requires attachment points on both the computer (the responsibility of the avionics group) and the rocket's supporting structure (the responsibility of the structures group).

To maximize the practical experience of students in the space industry and to simplify the rocket design process, I view the implementation of ECSS standards and handbooks positively. These guidelines also make it easier for supervising instructors and competition judges to assess the safety of our design - if a component is designed according to the standard, there is no doubt about the calculation or design methodology.”

- Viktor Hais, Team Lead & Former Propulsion Lead CTU Space Research

Conclusion

In a broader sense, this diploma thesis, titled "Establishing Framework Conditions for Project Innovation Management in Rocket Industry through Standardisation in Organisation with Limited Financial Resources," aimed to address the need for efficient processes and management strategies in organisations operating in the rocket industry, particularly those with limited financial resources. To enable organisations to compete successfully in the rapidly expanding market, the objective was to analyse the most recent trends in the sector, introduce standardisation and evaluate its impact on the innovation process.

Throughout the course of this thesis, a comprehensive review of the history and development of standardisation and its impact on performance and quality was conducted. The characteristics, history, innovations, and inventions of the aerospace and rocket industry were also explored, as well as an analysis of various standards and organisations involved in this sector. Project management methodologies, quality management, and innovation project management, among other crucial elements of a successful project innovation management framework, were thoroughly discussed.

The research focused on student organisations operating under the auspices of academic institutions, as these entities often have limited financial resources. It was examined how CTU Space Research, a student organisation with limited funding, used participation in competitions to validate its projects in a case study that was presented. A "Standardisation Equilibrium" was created to balance the constrained human and financial resources of student rocketry teams after various standards and standardisations' suitability, availability, and financial dimensions were examined. This equilibrium was reached after a thorough examination of the standardisation that CTU Space Research had decided to use.

The final portion of the thesis was dedicated to the adaptation of standards at CTU Space Research, including the establishment of handbooks, roadmaps, project management tools, and the innovation project management framework. The use of handbooks helped people understand standardisation processes and made it easier to put them into practice. Despite its limited financial resources, the organisation was able to manage projects within the rocket industry thanks to this comprehensive approach.

The results of this thesis provide useful information for companies working in the rocket industry, especially those with limited funds. The proposed framework requirements, when combined with a practical case study, offer a solid framework for these organisations to implement project innovation management successfully.

The results of this thesis can be expanded upon by future research by concentrating on particular areas within the standardisation and team segment. The effects of various standardisation levels on project outcomes, the role of communication and collaboration tools in standardisation implementation, and the potential advantages and disadvantages of adopting various standards based on market trends and advancements are a few possible research topics.

Future research opportunities may also examine how project management, systems engineering, and standardisation procedures could be further improved using IT, database, and software-orientated solutions. This can involve investigating the development of custom software tools, the integration of existing software solutions, or the creation of comprehensive database systems to better manage project information, track progress, and streamline communication among team members. Other possible areas of exploration include the impact of various standardisation levels on project outcomes, the role of communication and collaboration tools in standardisation implementation, and the potential benefits and drawbacks of adopting different standards based on industry trends and advancements.

In conclusion, by offering a thorough analysis of standardisation and its impact on organisations with limited financial resources, this diploma thesis has significantly advanced the field of project innovation management in the student rocket field. This work has laid the foundation for future research and innovation in this rapidly changing industry through the creation of the "Standardisation Equilibrium" and the successful adaptation of standards at CTU Space Research.

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List of Used Images

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List of Appendices

Appendices

See below

Appendix [A] EuRoC competitive analysis of teams

Competitive Analysis

Software & Standards

ID	Team	Country	PM Software	Communication Channel	Cloud Solution	Standards	Note
1	ASTG	Austria	Trello	Telegram	Discord	-	
2	BME Aerospace	Hungary	ClickUp	-	-	NTSS	
3	CTU Space Research	CZ	-	MS Teams	Microsoft Sharepoint/OneDrive	-	
4	DanSTAR	Denmark	White board (kanban chart)	Slack, Discord	OneDrive	NTSS	Test Standards followed
5	Endeveavor	UK	-	Discord	Google Drive	-	
6	EPFL Rocket Team	Switzerland	Notion	Slack	Google Drive	ECSS	Structure sub-system standards
7	Fenix Rocket Team	Portugal	ClickUp	-	-	NTSS	
8	ICLR (Imperial College London Rocketry)	UK	Trello	Trello	Github	-	
9	PoliWrocket	Poland	Discord	Discord, Messenger	Podio	ECSS and NTSS	Standards are held on team level
10	Portal Space	Norway	Asana	Slack	Google Drive	Self created regulations	
11	RED	Portugal	ClickUp	MS Teams	Microsoft Sharepoint/OneDrive	ECSS	
12	Skyward	Italy	ClickUp	Slack	Google Drive	-	
13	TU Wien Space	Austria	JIRA, Trello	-	-	-	JIRA for satellite projects, Trello for rocket projects

Newbies at EuRoC

Table A1 EuRoC Competitive analysis of rocketry teams
Source: Own elaboration

Appendix [B] ClickUp Dashboard of Management Channel

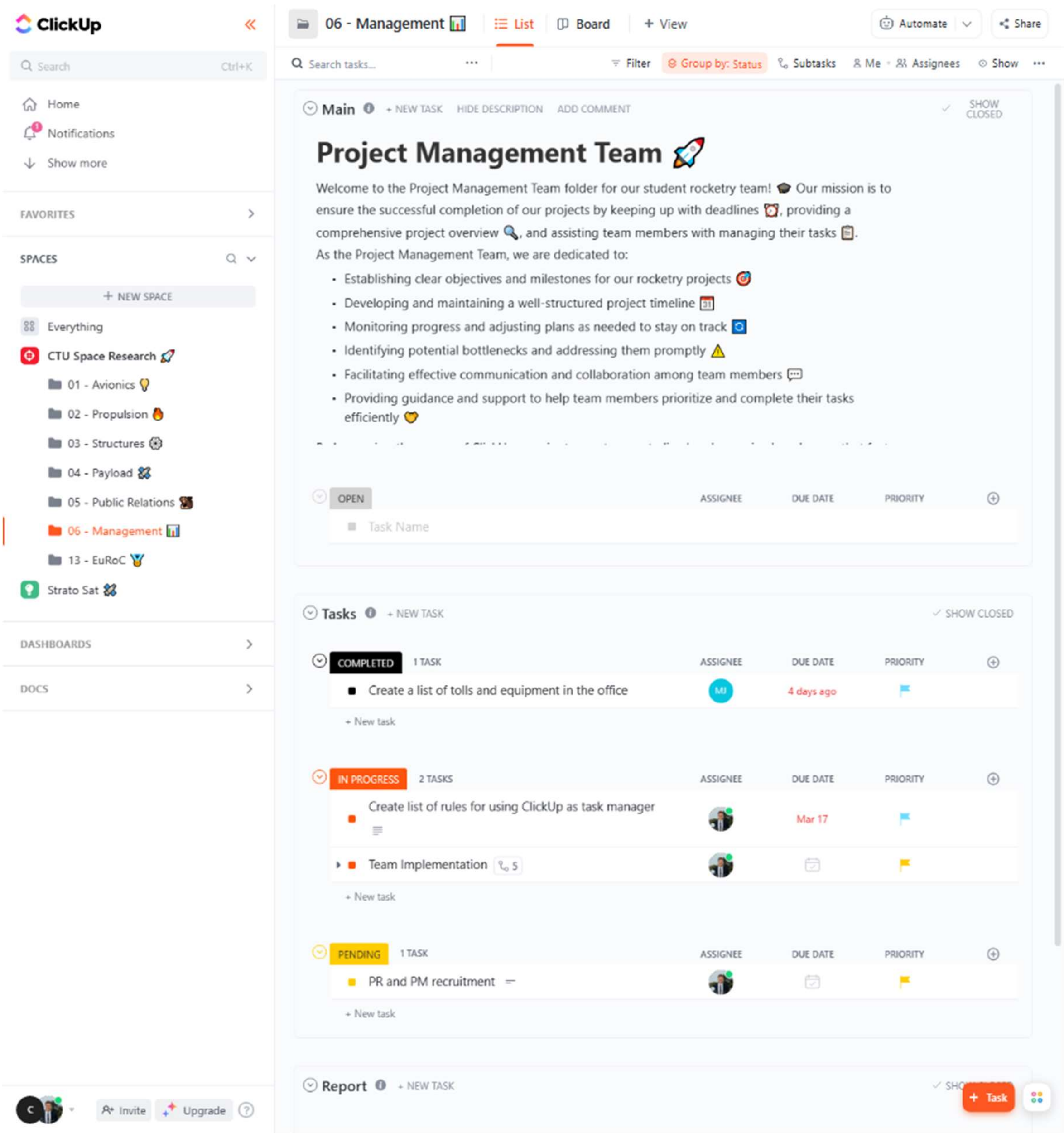

Table B1 ClickUp dashboard of the Management Segment
Source: Own elaboration

Appendix [C] Project Management Handbook

CTU Space Research

Project Management – Student Rocketry Team Handbook

Introduction

Welcome to the Project Management Team folder for our student rocketry team! Our mission is to ensure the successful completion of our projects by complying with deadlines, providing a comprehensive project overview, and helping team members with managing their tasks. As the backbone of the Student Rocketry Team, we are dedicated to delivering results and fostering a collaborative and organised work environment.

In this guide, you will find detailed information on our goals, processes, tools, and best practises to help us achieve our mission. Please take the time to familiarise yourself with this information and apply it to your work within the team.

1

Image C1 Project Management Handbook, page 1
Source: Own elaboration

Contents

Image C2 Project Management Handbook, page 2
Source: Own elaboration

1. Objectives and Milestones

As the Project Management Team, we are responsible for the following:

1.1 Establishing clear objectives and milestones for our rocketry projects
- Define the project's scope, requirements, and deliverables.
- Set specific, measurable, achievable, relevant, and time-bound (SMART) goals.
- Break down the project into smaller tasks and assign them to the appropriate team members.
- Collaborate with team leads to develop Key Performance Indicators (KPIs) to measure the project's success.

1.2 Developing and maintaining a well-structured project timeline
- Create a detailed project schedule, including deadlines for each task and milestone.
- Update the timeline regularly to reflect any changes in the project's scope or priorities.
- Communicate project updates and changes in a timely manner to all team members.
- Establish contingency plans for potential risks or unforeseen obstacles.

Image C3 Project Management Handbook, page 3
Source: Own elaboration

CTU Space Research

2. Project Monitoring and Adjustments

2.1 Monitoring progress and adjusting plans as needed to stay on track

- Conduct regular progress meetings to review the status of each task and identify any issues or delays.
- Adjust project plans, resources, or deadlines as needed to address any obstacles or setbacks.
- Develop a risk management plan to identify, assess, and address potential risks throughout the project lifecycle.
- Implement a change management process to handle any necessary alterations to project scope, objectives, or resources.

2.2 Identifying potential bottlenecks and addressing them promptly

- Keep a close eye on the critical path, ensuring that all dependencies are met and that no tasks cause unnecessary delays.
- Collaborate with team members to find solutions to any bottlenecks or resource limitations.
- Conduct regular bottleneck analyses to identify areas where improvements can be made.
- Develop strategies to prevent bottlenecks from occurring in future projects.

4

Image C4 Project Management Handbook, page 4
Source: Own elaboration

CTU Space Research

3. Communication and Collaboration

3.1 Facilitating effective communication and collaboration among team members

- Establish clear communication channels for team members to share information and ask questions.
- Encourage open and honest communication, promoting a culture of trust and teamwork.
- Implement a regular schedule of team meetings, workshops, and brainstorming sessions to foster collaboration and innovation.
- Use online collaboration tools to facilitate real-time communication and document sharing.

3.2 Providing guidance and support to help team members prioritise and complete their tasks efficiently

- Offer assistance and resources to team members who are struggling with their tasks or facing challenges.
- Help team members prioritise their workloads by identifying the most critical tasks and deadlines.
- Develop a mentorship programme to provide support and guidance to less experienced team members.
- Conduct regular performance reviews to recognise achievements and address areas for improvement.

5

Image C5 Project Management Handbook, page 5
Source: Own elaboration

4. Leveraging ClickUp for Project Management

4.1 Creating a centralised and organised workspace

- Utilise ClickUp's features to create a comprehensive and user-friendly workspace for the entire team.
- Keep all project-related information, including documents, files, and discussions, in one accessible location.
- Customise ClickUp's views and dashboards to provide relevant information to team members based on their roles and responsibilities.
- Integrate ClickUp with other tools and platforms used by the team to streamline communication and collaboration.

4.2 Fostering transparency, accountability, and productivity

- Use ClickUp's reporting features to track team members' progress and hold them accountable for their tasks.
- Implement time tracking to monitor productivity and ensure that team members stay on schedule.
- Set up automated reminders and notifications to keep team members informed about upcoming deadlines and pending tasks.
- Use ClickUp's goal tracking feature to align individual tasks with project objectives and milestones.

4.3 Optimising ClickUp for efficient project management

- Conduct regular training sessions to ensure that all team members are familiar with ClickUp's features and best practises.
- Encourage team members to provide feedback on ClickUp's functionality, usability, and effectiveness in managing projects.
- Continuously evaluate and improve the team's ClickUp workspace to accommodate the evolving needs of the Student Rocketry Team.
- Stay up-to-date with ClickUp's updates and new features, incorporating them into the team's processes as necessary.

6

Image C6 Project Management Handbook, page 6
Source: Own elaboration

Conclusion

Through our efforts, we aim to contribute to the overall success of the Student Rocketry Team by ensuring that our projects are completed on time, within budget and to the highest quality standards. By adhering to the principles and practises outlined in this comprehensive guide, we can work together to achieve our mission and propel our team to new heights. As we continue to grow and learn, let remain committed to fostering a supportive, transparent, and efficient project management environment for the benefit of our entire team.

7

Image C7 Project Management Handbook, page 7
Source: Own elaboration

Appendix [D] Project Management Handbook for Team Segments

CTU Space Research

Team Segments Project Management - Student Rocketry Team Handbook

Introduction

Welcome to the Team Segments - Student Rocketry Team Handbook! This handbook is designed to provide a unified framework for all segments within the organisation, including Avionics, Propulsion, Structures, and PR. Our mission is to ensure the successful completion of our projects by fostering a collaborative and organised work environment across all segments.

In this handbook, you will find detailed information on the objectives, processes, tools, and best practises that will help each segment achieve its mission. Please take the time to familiarise yourself with this information and apply it to your work within your respective segment.

1

Image D1 Project Management Handbook for Team Segments, page 1

Contents

Image D2 Project Management Handbook for Team Segments, page 2

1 Objectives and Milestones

As members of the Student Rocketry Team, we are responsible for the following:

1.1 Establishing clear objectives and milestones for our projects

- Define the project's scope, requirements, and deliverables.
- Set specific, measurable, achievable, relevant, and time-bound (SMART) goals.
- Break the project into smaller tasks and assign them to the appropriate segment members.
- Collaborate with other segments to develop Key Performance Indicators (KPIs) to measure the project's success.

1.2 Developing and maintaining a well-structured project timeline

- Create a detailed project schedule, including deadlines for each task and milestone.
- Update the timeline regularly to reflect changes in the project's scope or priorities.
- Communicate updates and changes to the project in a timely manner to all segment members and relevant stakeholders.
- Establish contingency plans for potential risks or unforeseen obstacles.

3

Image D3 Project Management Handbook for Team Segments, page 3

2 Project Monitoring and Adjustments

2.1 Monitoring progress and adjusting plans as needed to stay on track

- Conduct regular progress meetings to review the status of each task and identify any issues or delays.
- Adjust project plans, resources, or deadlines to address obstacles or setbacks.
- Develop a risk management plan to identify, assess, and address potential risks throughout the project lifecycle.
- Implement a change management process to handle any necessary alterations to the scope, objectives, or resources of the project.

2.2 Identifying potential bottlenecks and addressing them promptly

- Keep a close eye on the critical path, ensuring that all dependencies are met and that no tasks cause unnecessary delays.
- Collaborate with segment members and other segments to find solutions to any bottlenecks or resource constraints.
- Conduct regular bottleneck analyses to identify areas where improvements can be made.
- Develop strategies to prevent bottlenecks from occurring in future projects.

Image D4 Project Management Handbook for Team Segments, page 4

3 Communication and Collaboration

3.1 Facilitating effective communication and collaboration among segment members and across segments

- Establish clear communication channels for segment members to share information, ask questions, and collaborate with other segments.
- Encourage open and honest communication, promoting a culture of trust and teamwork.
- Implement a regular schedule of segment meetings, workshops, and brainstorming sessions to foster collaboration and innovation.
- Use online collaboration tools to facilitate real-time communication and document sharing.

3.2 Providing guidance and support to help segment members prioritise and complete their tasks efficiently.

- Offer assistance and resources to segment members who are struggling with their tasks or facing challenges.
- Help segment members prioritise their workloads by identifying the most critical tasks and deadlines.
- Develop a mentorship programme to provide support and guidance to less experienced segment members.
- Conduct regular performance reviews to recognise achievements and address areas for improvement.

Image D5 Project Management Handbook for Team Segments, page 5

CTU Space Research

4 Leveraging Project Management Tools for Segment Efficiency

4.1 Creating a centralised and organised workspace

- Use project management tools to create a comprehensive and user-friendly workspace for the entire segment.
- Keep all project-related information, including documents, files, and discussions, in one accessible location.
- Customise views and dashboards to provide relevant information to segment members based on their roles and responsibilities.
- Integrate project management tools with other tools and platforms used by the segment to streamline communication and collaboration.

4.2 Fostering transparency, accountability, and productivity

- Use project management tools' reporting features to track segment members' progress and hold them accountable for their tasks.
- Implement time tracking to monitor productivity and ensure that segment members are on time.
- Set up automated reminders and notifications to keep segment members informed about upcoming deadlines and pending tasks.
- Use goal tracking features to align individual tasks with project objectives and milestones.

4.3 Optimising project management tools for efficient segment collaboration

- Conduct regular training sessions to ensure that all segment members are familiar with the features and best practises of project management tools.
- Encourage segment members to provide feedback on the functionality, usability, and effectiveness of the tools in managing projects.
- Continuously evaluate and improve the segment's project management workspace to accommodate the evolving needs of the Student Rocketry Team.
- Stay up-to-date with project management tools' updates and new features, incorporating them into the segment's processes as necessary.

6

Image D6 Project Management Handbook for Team Segments, page 6

Conclusion

Through our collective efforts, we aspire to contribute to the overall success of the Student Rocketry Team by ensuring our projects are completed on time, within budget, and to the highest quality standards. By adhering to the principles and practises outlined in this comprehensive handbook, we can work together to achieve our mission and propel our organisation to new heights. As we continue to grow and learn, let remain committed to fostering a supportive, transparent, and efficient work environment for the benefit of all segments within the Student Rocketry Team.

Image D7 Project Management Handbook for Team Segments, page 7

Appendix [E] ECSS-M-ST-10C Project Management Handbook

CTU Space Research

ECSS-M-ST-10C Project Management Handbook

Introduction

This Project Management Handbook is a continuation of the previous handbook, providing further elaboration on the principles and practises outlined in the European Cooperation for Space Standardisation (ECSS) ECSS-M-ST-10C Rev. 16 March 2009. This handbook aims to enhance the guidance for project management within the CTU Space Research organisation by delving deeper into the critical areas of project management and incorporating additional best practises and recommendations. This comprehensive handbook serves as a valuable resource for project managers and team members in all functional areas, fostering a culture of collaboration, continuous improvement, and project management excellence.

1

Image E1 ECSS-M-ST-10C Project Management Handbook, page 1

Contents

Image E2 ECSS-M-ST-10C Project Management Handbook, page 2

1. Project Management Philosophy

1.1 Project Lifecycle

- Follow a structured approach to project management, dividing the project lifecycle into phases: concept, development, production, and operations.
- Implement a phase review process to assess project progress and readiness for the transition to the next phase.
- Employ the ECSS project management process model to ensure consistency between all projects within the organisation.

1.2 Project Management Principles

- Align project management practices with the principles of the ECSS standard, focusing on quality, cost, and schedule.
- Adopt a risk-based approach to project management, identifying and mitigating risks throughout the project lifecycle.
- Emphasise teamwork, collaboration, and effective communication among project stakeholders.

1.3 Stakeholder Involvement

- Involve stakeholders throughout the project lifecycle, ensuring their needs and expectations are considered in project planning and execution.
- Encourage stakeholder participation in project reviews and decision-making processes.

1.4 Continuous Learning and Improvement

- Promote a learning culture within the organization, encouraging team members to expand their knowledge and skills continuously.
- Evaluate and adopt new project management methodologies, tools, and techniques as appropriate to enhance project performance.

Image E3 ECSS-M-ST-10C Project Management Handbook, page 3

2. Project Organization and Responsibilities

2.1 Project Organization

- Establish a clear project organization structure, defining roles and responsibilities for project team members, project management, and other stakeholders.
- Implement a matrix organisation structure to facilitate resource sharing and communication across functional teams.

2.2 Roles and Responsibilities

- Assign responsibilities for project management, technical management, and product assurance to appropriate team members.
- Define the roles and responsibilities of the Project Manager, Technical Manager, Product Assurance Manager, and other key stakeholders in the project.

2.3 Decision-Making Processes

- Establish clear decision-making processes within the project organization, defining the roles and responsibilities of stakeholders in making project decisions.
- Implement a structured approach to decision-making, considering alternatives, risks, and potential impacts.

2.4 Cross-Functional Collaboration

- Foster collaboration and knowledge sharing among functional teams to ensure seamless integration of project components and deliverables.
- Encourage joint problem-solving and innovation across teams to address complex project challenges.

4

Image E4 ECSS-M-ST-10C Project Management Handbook, page 4

CTU Space Research

3. Project Planning and Control

3.1 Project Planning

- Develop a comprehensive project plan incorporating project scope, objectives, requirements, schedule, budget, and risk management.
- Include a Work Breakdown Structure (WBS) to organise and define project tasks and deliverables.
- Establish a Configuration Management (CM) plan to control project documentation, product configuration, and changes.

3.2 Project Control

- Implement a project control process to monitor progress, track performance, and adjust plans as needed.
- Use Earned Value Management (EVM) techniques to assess project performance and identify deviations from the plan.
- Conduct regular progress meetings and reviews to evaluate project status and address any issues or concerns.

3.3 Resource Allocation and Management

- Identify and allocate necessary resources, including personnel, equipment and facilities, to support project objectives and requirements.
- Implement a resource management system to track and optimise resource utilisation throughout the project lifecycle.

3.4 Performance Metrics and Reporting

- Establish performance metrics and Key Performance Indicators (KPIs) to measure project progress and success.
- Provide regular performance reports to project stakeholders, highlighting achievements, challenges, and areas for improvement.

5

Image E5 ECSS-M-ST-10C Project Management Handbook, page 5

CTU Space Research

4. Risk Management

4.1 Risk Identification

- Establish a systematic process for identifying risks throughout the project lifecycle.
- Involve all project stakeholders in the risk identification process to ensure comprehensive coverage.

4.2 Risk Assessment and Mitigation

- Assess identified risks in terms of their probability, impact and timeframe.
- Develop risk mitigation strategies and contingency plans to minimise the potential consequences of risks.
- Monitor risks continuously and update the risk management plan as needed.

4.3 Risk Monitoring and Reporting

- Implement a risk monitoring system to track the status of identified risks and the effectiveness of risk mitigation strategies.
- Provide regular risk reports to project stakeholders, highlighting new or emerging risks and the actions taken to address them.

4.4 Risk Management Culture

- Foster a risk management culture within the organisation, encouraging team members to identify, assess, and address risks proactively.
- Provide training and resources to enhance team members' risk management skills and knowledge.

6

Image E6 ECSS-M-ST-10C Project Management Handbook, page 6

5. Configuration Management

5.1 Configuration Identification

- Define configuration items (CIs) at an appropriate level of granularity for effective control and traceability.
- Assign unique identifiers to CIs and maintain a configuration item list (CIL) for tracking purposes.

5.2 Configuration Control

- Establish a Configuration Control Board (CCB) to review and approve changes to CIs.
- Implement a change control process to ensure changes are correctly documented, assessed, and approved before implementation.

5.3 Configuration Status Accounting

- Maintain records of the status of all changes, deviations, and waivers.
- Provide regular configuration status reports to project stakeholders.

5.4 Configuration Audits

- Conduct regular configuration audits to verify the accuracy and completeness of the configuration records and the proper implementation of the configuration management processes.
- Identify and address any discrepancies or non-conformances identified during configuration audits.

5.5 Configuration Management Training

- Provide training and resources to enhance team members' understanding and application of configuration management principles and practises.
- Encourage continuous improvement and adaptation of configuration management processes based on lessons learnt and industry best practises.

Image E7 ECSS-M-ST-10C Project Management Handbook, page 7

6. Quality Assurance and Product Assurance

6.1 Quality Assurance

- Develop and implement a quality assurance program to ensure project deliverables meet the specified requirements and standards.
- Conduct quality audits and inspections to evaluate project processes and output.
- Establish a non-conformance reporting and corrective action system to address.
- Identify and resolve non-conformances, implementing corrective actions to prevent a recurrence.
- Continuously improve project processes and outputs by analyzing quality performance data and implementing lessons learned.

6.2 Product Assurance

- Implement a product assurance programme to ensure that the final product meets the specified requirements, standards, and safety objectives.
- Integrate reliability, maintainability, and safety (RMS) analyses into the design and development process.
- Monitor and control the supply chain to ensure that subcontractors and suppliers meet quality and product assurance requirements.

6.3 Quality Culture

- Promote a quality-focused culture within the organisation, emphasising the importance of meeting and exceeding customer expectations and requirements.
- Encourage team members to take ownership of quality and continually look for improvement opportunities.

6.4 Supplier and Subcontractor Management

- Establish processes for selecting, managing, and evaluating suppliers and subcontractors to ensure they meet quality and product assurance requirements.
- Conduct regular audits and assessments of supplier and subcontractor performance to identify and address any issues or concerns.

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Image E8 ECSS-M-ST-10C Project Management Handbook, page 8

7. Project Documentation and Reviews

7.1 Project Documentation

- Develop and maintain project documentation according to the Configuration Management plan and the ECSS standards.
- Ensure that all project documents are easily accessible, up-to-date, and properly controlled.
- Establish a document review and approval process to ensure the quality and accuracy of project documentation.

7.2 Project Reviews

- Conduct regular project reviews, including Phase Reviews, Progress Meetings, and Technical Reviews, to assess project status, risks, and readiness for the next phase.
- Involve relevant stakeholders in the review process, including project team members, management, and external experts.
- Use project reviews to identify areas for improvement, address issues, and update project plans as needed.

7.3 Document Retention and Archiving

- Implement a document retention and archiving policy to ensure proper storage and preservation of project records and documentation.
- Ensure that archived documentation is easily accessible and retrievable for the future.

7.4 Lessons Learnt and Sharing of Knowledge

- Incorporate the lessons learnt and best practises identified during project reviews into the organisation's knowledge base.
- Share knowledge and insights gained from project reviews with other teams and stakeholders to promote continuous improvement and learning across the organization.

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Image E9 ECSS-M-ST-10C Project Management Handbook, page 9

8. Resource Management

8.1 Human Resources

- Recruit, train, and retain qualified personnel to support project objectives and requirements.
- Establish clear roles and responsibilities for all team members and provide the necessary training and resources.
- Implement a performance management system to evaluate and reward individual and team performance.

8.2 Financial Resources

- Develop a detailed project budget, including cost estimates for labour, materials, equipment, and other resources.
- Monitor project expenditures and track financial performance against the budget.
- Implement cost control measures to ensure that the project stays within budget constraints.

8.3 Capacity Planning

- Conduct regular capacity planning exercises to assess the organisation's resource needs and availability for current and future projects.
- Develop strategies for addressing resource constraints, including hiring, training, and reallocating resources as needed.

8.4 Procurement and Contract Management

- Implement a robust procurement and contract management process to ensure the timely acquisition of necessary resources and services at competitive prices.
- Establish guidelines for selecting and managing suppliers and contractors, including performance evaluation and risk management.

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Image E10 ECSS-M-ST-10C Project Management Handbook, page 10

9. Stakeholder Management

9.1 Stakeholder Identification and Analysis

- Identify all project stakeholders, including internal and external parties that may influence or be affected by the project.
- Analyse stakeholders' needs, expectations, and potential impact on the project.

9.2 Stakeholder Engagement

- Develop a stakeholder engagement plan that describes communication strategies and methods to address stakeholder concerns and needs.
- Foster open and transparent communication with stakeholders throughout the project lifecycle.
- Regularly update stakeholders on project progress, risks, and any changes to project scope or objectives.

9.3 Stakeholder Satisfaction

- Monitor stakeholder satisfaction throughout the project lifecycle, soliciting feedback, and taking action to address any concerns or issues.
- Establish a process for resolving stakeholder conflicts and disputes in a timely and equitable manner.

9.4 Stakeholder Communication Channels

- Using various communication channels to ensure effective communication with all stakeholders, including meetings, reports, presentations, and digital platforms.
- Tailor communication methods and content to the needs and preferences of individual stakeholder groups, ensuring that information is presented in a clear, concise and accessible manner.

Image E11 ECSS-M-ST-10C Project Management Handbook, page 11

10. Lessons Learned and Continuous Improvement

10.1 Lessons Learned

- Establish a process to capture the lessons learnt throughout the lifecycle of the project.
- Share the lessons learnt with the project team members, the management, and other stakeholders to promote continuous improvement.
- Incorporate lessons learnt from previous projects into current and future projects.

10.2 Continuous Improvement

- Encourage a culture of continuous improvement within the organisation, focussing on identifying and resolving issues and inefficiencies.
- Regular review of project processes, tools, and techniques to identify areas for improvement.
- Implement changes and improvements based on lessons learnt, stakeholder feedback, and performance data.

10.3 Post-Project Reviews

- Conduct post-project reviews to assess the project's overall success and identify lessons learnt and best practises for future projects.
- Involve all project stakeholders in the post-project review process to gather diverse perspectives and insights.

10.4 Benchmarking and Industry Best Practices

- Benchmark the organisation's project management performance against industry best practises and standards, identifying areas for improvement and innovation.
- Stay informed about new developments and trends in project management by incorporating relevant insights and practises into the organisation's project management approach.

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Image E12 ECSS-M-ST-10C Project Management Handbook, page 12

Conclusion

The CTU Space Research Project Management Handbook, based on the ECSS-M-ST-10C standard, provides a comprehensive framework for effective project management within the organisation. By adhering to the principles and practises outlined in this handbook, we can work together to achieve our mission and propel our organisation to new heights. Let remain committed to fostering a supportive, transparent, and efficient project management environment for the benefit of all stakeholders within CTU Space Research.

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Image E13 ECSS-M-ST-10C Project Management Handbook, page 13

Appendix [F] ECSS-E-ST-10C Rev.1 System Engineering General Requirements Handbook

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ECSS-E-ST-10C-Rev.1 System Engineering Handbook

Preface

This handbook provides an overview of the system engineering standards and guidelines of the European Cooperation for Space Standardisation (ECSS). It is designed to help professionals in the field to better understand and apply the ECSS-E-ST-10C-Rev.1 standards in their work.

The handbook covers key processes in system engineering, including requirements engineering, technical solutions, technical risk management, configuration management, and technical information management. It also provides guidance on project management and quality management in the context of system engineering and the development of a System Engineering Management Plan (SEMP). Finally, the handbook discusses various tools and techniques for system engineering and includes appendices with a glossary of terms, acronyms, abbreviations, and reference documents.

It is important to note that this handbook is not an official ECSS document and should be used as a supplementary resource to the ECSS-E-ST-10C-Rev.1 standard. Users are encouraged to refer to the original document for the most accurate and up-to-date information on system engineering standards.

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Image F1 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 1

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Content

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Image F2 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 2

Introduction

Purpose of the Handbook

This handbook aims to provide a comprehensive guide to understanding and implementing the ECSS-E-ST-10C-Rev.1 standard in space projects, focussing on general requirements for system engineering.

Objectives of System Engineering
System engineering plays a critical role in ensuring the successful development and execution of space projects. Its primary objectives include optimising system performance, reducing risk, managing cost, and improving overall project efficiency.

Structure of the Handbook
The handbook is divided into ten sections, each addressing a specific aspect of the ECSS-E-ST-10C-Rev.1 standard. Subheadings within each section offer a more detailed exploration of related topics.

Importance of Standards in Space Projects
Standards play a crucial role in ensuring consistent quality, reducing risks, and facilitating collaboration and communication among stakeholders in rocket projects.

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Image F3 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 3

1. Scope

1.1 Applicability of the Standard
The ECSS-E-ST-10C-Rev.1 standard applies to all space projects, including spacecraft systems, payloads, ground systems, and launch vehicles. It establishes general system engineering requirements applicable to various project phases.

1.2 Covered Space Systems and Projects
The standard covers all types of space systems and projects, from small satellites and scientific payloads to spacecraft and interplanetary missions.

1.3 Exclusions and Limitations
The standard does not apply to specific technical or scientific disciplines with dedicated ECSS standards. Users must consult additional documents for detailed requirements in those areas.

1.4 Tailoring and Adaptation
Tailoring allows organisations to adapt the standard to specific project needs and circumstances, ensuring a fit-for-purpose approach that maintains the standard's objectives.

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Image F4 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 4

2. Normative References

2.1 Relationship between References and the Standard

Normative references are essential for interpreting and implementing the standard. Users must understand the context and relationship between the referenced documents and the ECSS-E-ST-10C-Rev.1 standard.

2.2 Complementary Standards

Users should also be aware of complementary standards that may be relevant to their specific project or discipline, such as ECSS-E-ST-20 for electrical engineering or ECSS-E-ST-30 for mechanical engineering.

Image F5 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 5

3. Terms, Definitions, and Abbreviations

3.1 Glossary of Terms and Definitions

This section provides a glossary of essential terms and definitions related to the standard, such as system engineering, requirements engineering, and functional analysis.

3.2 List of Abbreviations

This section lists common abbreviations used throughout the handbook and the standard, such as ECSS (European Cooperation for Space Standardisation) and V&V (Verification and Validation).

3.3 Terminology Consistency

The consistent use of terminology and abbreviations throughout the project is essential to prevent misunderstandings and ensure clear communication among stakeholders.

Image F6 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 6

4. System Engineering Process

4.1 Overview of the Process
The system engineering process consists of several iterative steps, including requirements engineering, functional analysis, synthesis, and architectural design, and verification and validation.

4.2 Phases of System Engineering
The system engineering phases include concept development, preliminary design, detailed design, manufacturing, integration, testing, operations, and disposal.

4.3 Roles and Responsibilities
System engineers are responsible for managing the overall system development process, coordinating interdisciplinary efforts, and ensuring compliance with applicable standards and requirements.

4.4 Key Process Inputs and Outputs
Inputs to the system engineering process include mission objectives, stakeholder needs, and constraints. Outputs include system requirements, functional allocations, architectural designs, and verification and validation plans.

4.5 Stakeholder Engagement
Engaging stakeholders throughout the system engineering process helps to ensure that their needs and expectations are accurately captured and addressed, promoting project success.

Image F7 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 7

5. Requirements Engineering

5.1 Definition and Importance

Requirements engineering is the process of eliciting, analysing, specifying, and validating the needs of stakeholders for a system. It is essential to ensure that the system meets its intended purpose and satisfies stakeholder expectations.

5.2 Identifying and Defining System Requirements

The system requirements are identified through stakeholder interviews, mission objectives, and other sources. They should be clear, complete, consistent, and traceable throughout the lifecycle of the system.

5.3 Analysing and Documenting Requirements

Requirement analysis ensures that requirements are feasible, verifiable, and necessary. Documenting requirements includes capturing them in a clear, concise, and structured manner, typically using a requirement management tool.

5.4 Requirements Management

Requirements management involves tracking, controlling, and maintaining requirements throughout the system's development. This process includes handling changes, tracking requirements, and ensuring consistency between requirements and design artefacts.

5.5 Traceability

Traceability is essential to track the relationship between requirements and other artefacts of the project, such as design elements, test cases and risk mitigations, to ensure that all aspects of the system are aligned with the intended objectives.

Image F8 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 8

6. Functional Analysis and Allocation

6.1 Role of Functional Analysis in System Engineering
The functional analysis breaks down system functions into smaller sub-functions and allocates them to specific system elements, enabling the development of an efficient and effective system architecture.

6.2 Decomposition of System Functions
Decomposition involves hierarchically breaking down high-level functions into lower level subfunctions, considering functional dependencies, performance, and other design constraints.

6.3 Allocation of Functions to System Elements
Function allocation assigns each subfunction to a specific system element (hardware, software, or personnel), considering the capabilities and limitations of each element to achieve a balanced and efficient system design.

6.4 Evaluation and Selection of Functional Architectures
Multiple functional architectures can be generated by varying function allocations and interfaces. Evaluation and selection involve assessing these alternatives based on performance, cost, risk, and other relevant criteria.

6.5 Monitoring and Control
Monitoring and control activities ensure that the functional analysis and allocation process remains on track, identifying and addressing any deviations or issues that may arise.

Image F9 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 9

7. Synthesis and Architectural Design

7.1 Synthesis and Integration of System Elements
Synthesis involves designing and integrating system elements based on functional analysis and allocation, ensuring that all elements work together to perform the system's functions effectively.

7.2 Principles of Architectural Design
The architectural design defines the overall structure of the system, including the arrangement and interaction of the system elements, interfaces, and data flow.

7.3 Evaluation and Selection of System Architectures
Various system architectures can be created by organising system elements and interfaces in different ways. Evaluation and selection involve evaluating these alternatives based on performance, cost, risk, and other relevant criteria.

7.4 Interface and Integration Management
Interface management ensures compatibility and efficient communication between system elements. Integration management involves planning and executing the integration of system elements to form a coherent system.

7.5 Design Optimisation
Design optimisation involves refining the system architecture to maximise performance, minimise cost, and reduce risk while maintaining compliance with requirements and constraints.

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Image F10 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 10

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8. Verification and Validation

8.1 Definitions and Importance
Verification confirms that the system meets specified requirements, while validation ensures that the system fulfils its intended purpose. Both are critical to ensure that the system meets stakeholder expectations and functions correctly.

8.2 Verification and Validation Methods
Common methods include inspection, analysis, demonstration, and testing. The selection of methods depends on the nature of the requirements, the complexity of the system, and the constraints of the project.

8.3 Verification and Validation Planning
Planning involves defining verification and validation objectives, methods, schedules, resources, and acceptance criteria. A comprehensive plan ensures a systematic and efficient approach to verifying and validating the system.

8.4 Execution of Verification and Validation Activities
Execution includes performing the planned verification and validation activities, documenting results, and tracking any discrepancies or issues that need resolution.

8.5 Continuous Improvement
Lessons learnt from verification and validation activities can be used to identify areas for improvement, enhance the system's performance and reliability, and inform future project developments.

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Image F11 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 11

9. Configuration and Information Management

9.1 Configuration Management in System Engineering
Configuration management ensures the control, traceability, and documentation of changes to the system's configuration throughout its lifecycle.

9.2 Information Management Principles
Information management involves the efficient organisation, storage, retrieval, and sharing of project-related data, ensuring its accuracy, consistency, and accessibility.

9.3 System Documentation Management
Documentation management involves maintaining an organised and up-to-date repository of all system-related documents, including requirements specifications, design documents, test plans, and other relevant artefacts.

9.4 Data Integrity and Control
Ensuring data integrity and control requires implementing processes to maintain data quality, traceability, and security throughout the system lifecycle, protecting against unauthorised access, corruption, or loss.

9.5 Change Management
Change management is a critical aspect of configuration and information management, which involves systematic evaluation, approval, and implementation of changes to the system or project documentation.

Image F12 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 12

Conclusion

This comprehensive ECSS-E-ST-10C-Rev.1 Handbook provides an in-depth guide for understanding and implementing the standard's general requirements for system engineering in space projects. By following the principles and processes described, engineers can ensure the development of efficient, reliable, and successful space systems.

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Image F13 ECSS-E-ST-10C Rev. 1 System Engineering General Req. Handbook, page 13

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