Master Project SS21-WS22

Analysis for Criteria for Evaluation of Space Missions

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in cooperation with the department of System Analysis Space Segment of DLR.

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This master's project is our original work and has not been submitted elsewhere in fulfillment of the requirements of this or any other award. Under academic referencing conventions, due acknowledgment has been given to the work of others.

[18741 words]

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ABSTRACT

The exploration of space plays an important role in understanding our place in the Universe, the history of our Solar System, and our planet Earth. Worldwide space agencies and private space industries all face the same challenges in the planning and execution of their missions. Space missions are often associated with long development times and large costs, and therefore require careful evaluation and planning. For this reason, it is important to determine in advance whether the mission is worthwhile despite the possible cost and time overruns.

The presented work aims to support the department of System Analysis Space Segment of DLR in developing a method for the evaluation of space missions.
For this purpose, the following research question is raised: How can the success rate and importance of space missions be measured, and thereby the selection of future missions be efficiently made?

Before the start of this work, possible criteria were identified which could have an influence on, the success rate of a mission. The defined criteria are:

- Number of collaborations
- Globality of the topic
- Scientific relevance
- Mission renaming
- Spillover effects

To answer the research question, an extensive literature review of space missions was performed. Specifically, various missions of the space agencies NASA, ESA, JAXA, ISRO, ROSCOSMOS and CNSA were identified and analyzed with regard to the previously defined criteria. A calculation of the influence rates of each criterion on the different space agencies was carried out. Results for each space agency are presented in radar graphs, both individually and as a weighted summary.

With the help of the report, a perspective on the determination of future successful space missions can be provided alongside the challenges that may occur due to unpredictable factors. The evaluation shows that a combination of globality, number of collaborations, and spillover effect provides the highest probability of success, with the global factor being the dominant one. The number of name-changes does not play a role in the mission success of the space agencies, except for ESA. Nevertheless, other factors such as funding limitations, reorganization of the space agency, or recommendations of the science community can be unpredictable and represent an unknown risk for the project.

During this investigation, a new subtype in the scientific relevance criterion was found. For future research in this field, a closer look could be taken into developments that were

originally designed for space but have since been used on Earth. This research could clarify, if this new subchapter is worth an own criteria. Further research into other agencies and missions could show additional influences on the mission success rate of space agencies on a global scale.

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LIST OF ABBREVIATIONS

ARTES	Advanced Research in Telecommunications Systems
ATV	Automates Transfer Vehicle
CNES	Centre National d'Études Spatiales
CNSA	China National Space Administration
COS-B	Cosmic Ray Satellite B
DLR	German Aerospace Centre
DPAC	Data Processing and Analysis Consortium
ELDO	European Launcher Development
ESA	European Space Agency
ESOC	European Space Operations Centre
ESRO	European Space Research Organisation
ESTEC	European Space research and Technology Centre
GSTP	General Support Technology Program
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
ISRO	Indian Space Research Administration
ISS	International Space Station
IXV	Intermediate Experiment Vehicle
JAXA	Japan Aerospace Exploration Agency
JIMO	Jupiter Icy Moons Orbiter
JUNO	Jupiter Polar Orbiter
NASA	National Aeronautic Space Administration
OOE	Out-Of-Ecliptic
ROSCOSMOS	Russian Federal Space Agency
SIM	Space Interferometry Mission
SMOS	Soil Moisture and Ocean Salinity
XMM-Newton	X-ray Multi-Mirrors Newton

1. INTRODUCTION

This chapter will give an insight into the search for important criteria and the criteria chosen for this report to evaluate a space mission regarding its feasibility and success.

1.1 MOTIVATION

For more than 60 years, humans have explored space. To this day space exploration and observation helps to address fundamental questions about our place in the Universe, the history of our Solar System, and our planet Earth [1]. Technological knowledge, as well as scientific knowledge, benefit not only scientists but also the public. Worldwide space agencies and private space industries face the same challenges in the planning and execution of their missions. Space projects are often associated with long development times and large costs and therefore require careful evaluation and planning.

For example, the development of the James Webb telescope began in 1996, however, the launch was delayed several times due to budget overruns, testing problems, and political difficulties [2]. The launch was finally planned for March 2021 and was delayed again to October 2021 with the Covid-19 pandemic as the main driver as well as reliability to mission success [3] [4]. For now, the costs total 9.8 billion US-Dollar. Since 2009, the mission's estimated cost has nearly doubled, and its launch date has been pushed back by about seven years [5]. Despite the high time and cost deviations, the project was not canceled, even after the proposal to do so. The high value for astronomers, loss of high-tech jobs, damage to U.S. preeminence in science and technology, and loss of benefits to the public prevented the cancellation.

Therefore, it is important to determine in advance whether the mission is worthwhile despite the possible cost and time overruns. The question that arises is: How can you measure the success rate and importance of space missions and thereby efficiently select future missions? Consequently, it is necessary to select missions based on evaluation concerning for example success rate, scientific relevance, programmatic fit, and further.

The following master's project will have a closer look into selected space missions on prior defined criteria. A special look will be taken on the canceled missions which will help to further evaluate the criteria to prevent missions from failing.

1.2 AIM & OBJECTIVES

This project aims to support the department of System Analysis Space Segment of DLR in the development of a method for evaluation of space mission by investigating the relevance concerning mission success of the following five identified criteria:

- Number of collaborations
- Globality of the topic
- Scientific relevance
- Mission renaming
- Spillover effects

The explained aim will be achieved by the accomplishment of the following objectives:

- Development of a research methodology to collect information from the different available sources regarding the five selected criteria.
- Creating an effective evaluation method that allows discerning if the criteria are relevant to the success of a space mission.
- Examine and discuss the results concluding the relevance or irrelevance of each criterion for the success of the different space missions executed by distinct space agencies.

1.3 REPORT STRUCTURE

The structure and content of the chapters of the project report for this master's project are shown in Figure 1. Each chapter will have a brief introduction about its content and will be labeled as shown in Figure 1.

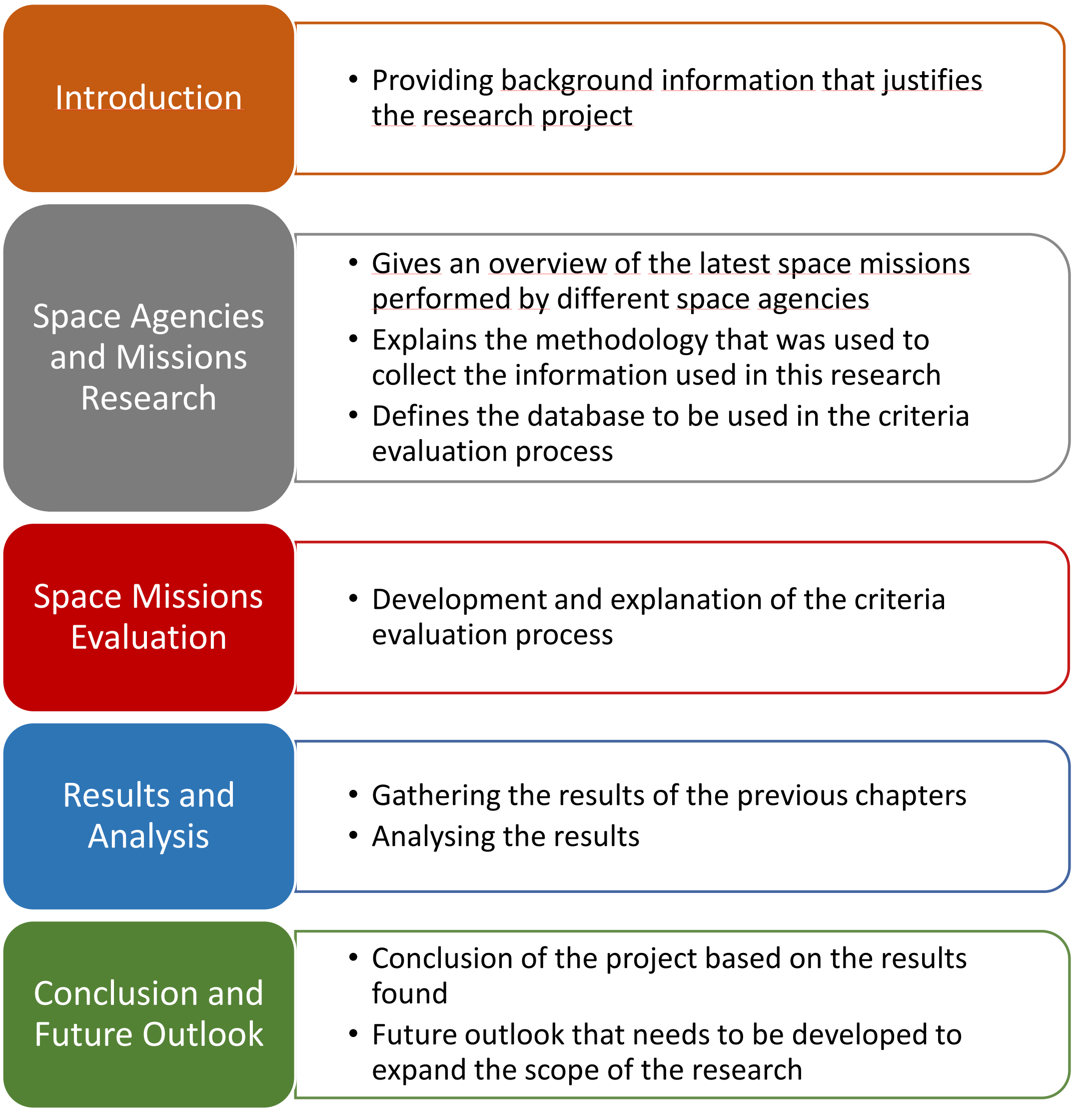

Figure 1 Project Structure and Chapters Content

2. SPACE AGENCIES AND MISSIONS RESEARCH

This chapter provides an introduction to the different space agencies that are covered in this project followed by an overview of the state of the art of space missions. Finally, the research methodology of the data collection is described with the provision of the category and quantity of selected space missions.

2.1 STATE OF ART OF SPACE MISSIONS

The state of art gives an overview of the latest cutting-edge space missions from different space agencies. At the same time, it will focus on the most important successful and failed missions.

2.1.1 NASA

The National Aeronautics and Space Administration (NASA) is America's civil space program and was founded in 1958 in response to early Soviet space achievements. NASA developed from the National Advisory Committee for Aeronautics (NACA) as well as other governmental organizations. NASA's vision is to "reach for new heights and reveal the unknown for the benefit of humankind". With an annual budget of $23.2 billion in 2021, their mission is to drive advances in science, technology, aeronautics, and space exploration. The goal is to enhance knowledge, education, economic vitality, and stewardship on Earth [6] [7]. Currently, 12 missions and programs are operated by NASA.

ARTEMIS

One of the latest is the *Artemis* program, a collaboration with commercial and international partners. The main goal of the program is to use innovative technologies to land astronauts on the moon again, including the first woman and the first person of color. Thereafter, crewed moon landings are to take place annually. The developments shall also benefit future Mars missions [8].

Figure 2 Artemis Mission [137]

MARS 2020

Mars 2020 is an operating NASA mission. The Perseverance rover landed on Mars on the 18th of February. The aim is to collect and cache samples as well as search for signs of ancient microbial life which shall benefit the exploration of past habitability of the planet. Furthermore, the data shall support the preparation of future human missions [9].

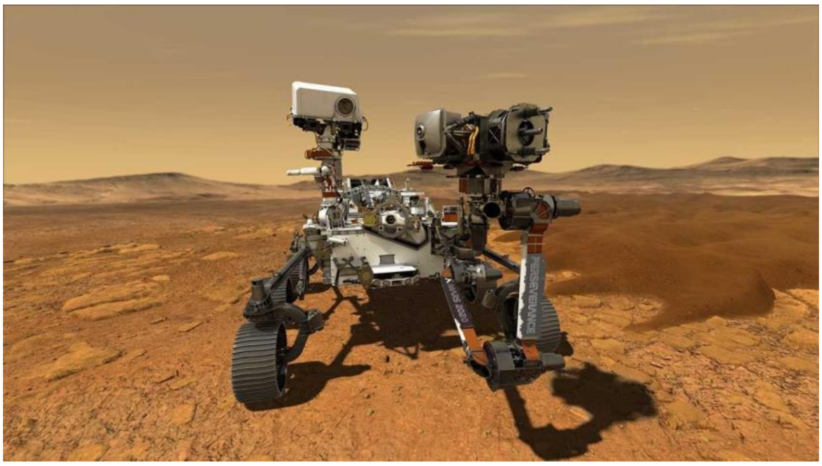

Figure 3 Mars 2020, Perseverance Rover [138]

PARKER SOLAR PROBE

NASA's *Parker Solar Probe* is an operating mission that was launched on the 12th of August 2018. The mission aims to explore the sun, focusing on the solar atmosphere. It is the first-ever mission to "touch" the Sun. To support the science goal, the probe travels directly through the Sun's atmosphere up to a distance of about 6,4 million kilometers from the surface [10].

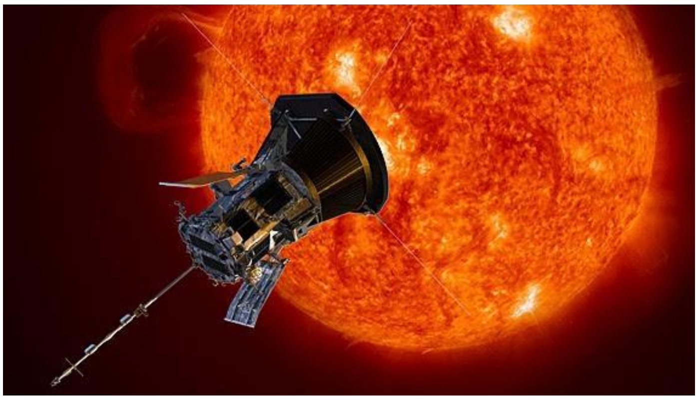

Figure 4 Parker Solar Probe [153]

JUNO

JUNO (Jupiter Polar Orbiter) is after *New Horizons*, the second spacecraft in NASA's New Frontiers program. The spacecraft was launched in 2011 and the mission is still operating [11]. Understanding the origin and evolution of Jupiter, looking for a solid planetary core, mapping magnetic fields, measuring water and ammonia in the deep atmosphere, and observing auroras are the main goals of the mission [12].

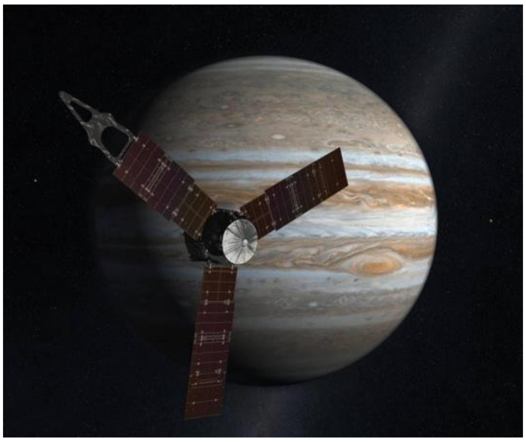

Figure 5 JUNO Spacecraft [139]

NASA does not complete every proposed or planned mission. In some instances, the missions are canceled due to different reasons. For example, budget and time overruns or political redirection. Two of those canceled missions are *Space Interferometry Mission (SIM)* and *Jupiter Icy Moons Orbiter (JIMO)*.

SIM

SIM was a planned space telescope to search for Earth-sized planets orbiting in the habitable zones of nearby stars. *SIM/SIM-Lite* was not recommended for development by the Astro2010 Decadal Survey. This resulted in the discontinuation of the NASA sponsorship in 2010 [13].

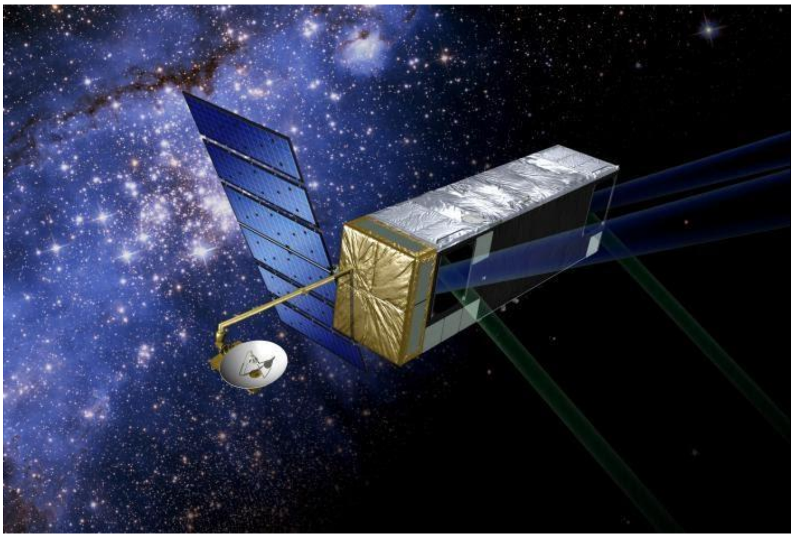

Figure 6 SIM Spacecraft [140]

JIMO

The *Jupiter Icy Moons Orbiter (JIMO)* was a proposed mission by NASA to explore the icy moons of Jupiter. The target of the spacecraft was to orbit Callisto, Ganymede, and then Europa. With the launch date around 2015, *JIMO* should feature innovative technologies [14]. The project lost funding in 2005, due to a shift in priorities at NASA [15].

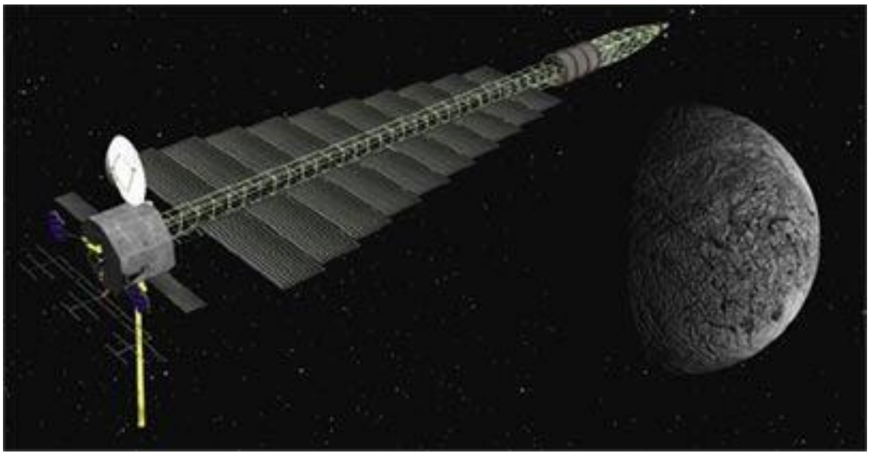

Figure 7 JIMO Spacecraft [141]

APOLLO

As a final point, an important program that shaped NASA's history was the *Apollo* program. Starting in 1961 the main goal of landing Americans on the moon and the safe return to Earth was driven by the Space Race, a competition with the Soviet Union. In 1969, with *Apollo 11*, the first successful moon landing was achieved. Other goals by NASA included the establishment of technology, achieving dominance in space, and the scientific exploration of the moon. The program was terminated completely in 1972 [16].

Figure 8 Apollo Mission Logo and Moon Landing [142] [154]

2.1.2 ESA

Today's European Space Agency was founded on the 30th of May 1975 and arose from the former European Launcher Development Organization (ELDO) and European Space Research Organization (ESRO) which were already established in 1962 [17].
ESA represents an international organization that consists of 22 member states. Their goal is to explore the universe while developing the fundamental base and capabilities to do so. Additionally, their progress shall be an advantage for all mankind. ESA’s future vision is to make space safer, to keep climate change under surveillance, to investigate the Solar System, and to further develop space design and technologies [18] [19].
The agency’s activities can be split into mandatory and optional programs. Plans which are financed by the General Budget and Space Science program fall into the mandatory category. This contains “[...] studies on future projects, technology research, shared technical investments, information systems and training programmes”. The optional program however refers to “[...] Earth observation, telecommunications, satellite navigation, and space transportation”. Each member state subsidizes these two programs dependent on its gross national product [20].
Two important programs of the ESA are the Science and the Cosmic Vision programs. The first one aims to keep up in the European space business and commits to sustainable infrastructures and capabilities [21]. The second one represents the planning cycle of missions that ESA will launch during 2015 and 2025 [22].

<u>EXOMARS</u>

A recent program in the science and exploration sector is called *ExoMars* and consists of two missions which are in cooperation with ROSCOSMOS. The first one is called the *Trace Gas Orbiter (TGO)* and the second one consists of a rover and a surface platform. The former was already successfully launched in 2016 while the latter is planned to be launched in 2022 [23]. The first mission had the objective to gain more knowledge about atmospheric gases such as methane. The reason for that search is to find evidence for biological or geological activities on Mars [24]. The current mission will clarify the existence of life on Mars. Additionally, to this aim, the rover will look for water deposits beneath the Martian surface [25].

Figure 9 ExoMars Orbiter (left) and Rover (right) [156]

SOLAR ORBITER

Another recent mission in the science and exploration sector and part of the M-class mission in the Cosmic Vision program of ESA is the *Solar Orbiter* mission which was launched on the 10th of February 2020 [26]. Originally, this idea was proposed in the report "A Crossroads For European Solar and Heliospheric Physics" with the two ideas of firstly launching a mission to the Sun to take pictures in the visible as well as in the ultraviolet regime and secondly to travel closer to the Sun as before. Although this mission is solely found by ESA it still strongly cooperates internationally, for example, NASA is providing the launcher [27]. The objective of the current mission is therefore to perform a close-up observation of the Sun and inner heliosphere with the onboard telescope. Its goal is to gain knowledge about the Sun's behavior to be able to forecast solar storms before they will reach the Earth [27].

Figure 10 Solar Orbiter Spacecraft [27]

CHEOPS

CHEOPS, the *Characterising Exoplanet Satellite*, was built in cooperation with Switzerland and is part of the S-class mission in the science program of ESA [28]. Furthermore, it was successfully launched on the 18th of December 2019 along with the objective to investigate bright, nearby stars. However, only stars that host exoplanets will be observed with the telescope since the size of the star can be determined through the transition of itself in front of its host star [29]. When combining the mass and radius of the star it is possible to make a statement about the star's density which helps to classify exoplanets in the future [30].

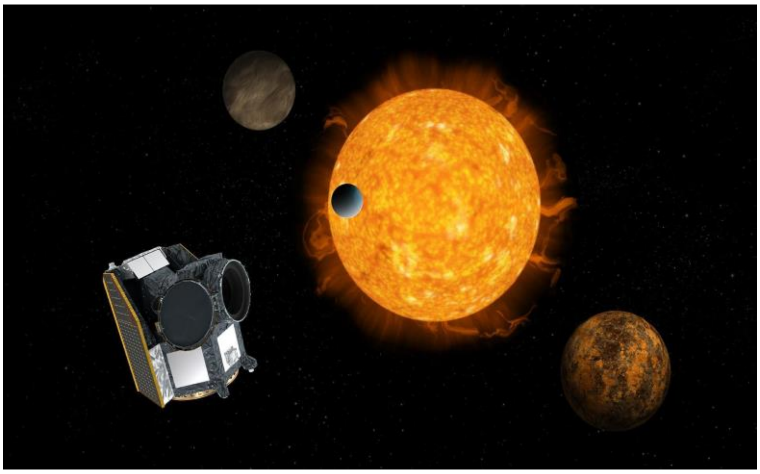

Figure 11 CHEOPS Space Telescope [30]

COLUMBUS MODULE

An important mission to mention is the *Columbus Module* of ESA. It was launched on the 07th of February 2008 and was later on attached to the *ISS Harmony Module*. The *Columbus Module* has the objective to offer a place for long-term experiments in weightlessness. The reason is that it is not possible to build such an environment on Earth due to gravity [31]. This vast mission clearly demonstrates that a global collaboration between different partners and cultures is possible as well as practical [32]. This collaboration includes astronauts working together inside the *Columbus Module* as well as the ground support on Earth.

Figure 12 Columbus Module [157]

DON QUIJOTE AND AIDA

On the contrary, it is important to have a look at not realized missions. One of such a kind is the mission *Don Quijote*, which was thought of as an asteroid-deflection mission. It was planned to consist of two missions, one as the impactor and the other one as the observer to study the impact and momentum transfer [33]. However, this concept idea was then further developed into the *Asteroid Impact and Deflection Assessment (AIDA)* consisting of NASA's *DART (Double Asteroid Redirection Test)* and ESA's *Hera* mission. As a result, *AIDA* lowered the costs due to ground-based observatories. *AIDA's* target object was the moon of the Didymos binary asteroid system in order to change its orbit [34]. The *DART* mission was already successfully launched on the 24th of November 2021 [35] and the launch of *Hera* is planned to start in 2024 [36].

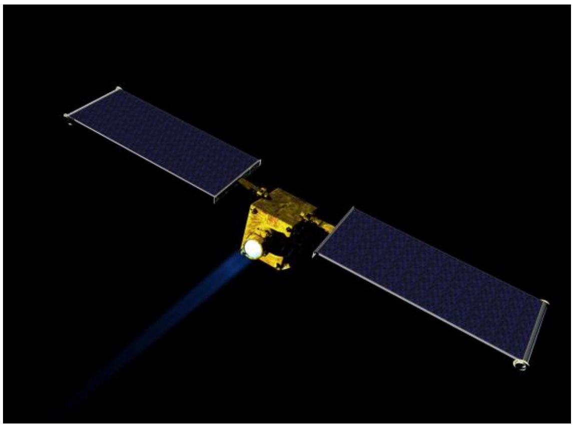

Figure 14 DART Spacecraft [34]

Figure 13 Hera Spacecraft at Didymos [34]

EDDINGTON

Another mission that is worth mentioning is the ESA mission *Eddington*. Its mission objective was to study the size and composition of chemical components of stars. Furthermore, it should look for Earth-sized planets which might host extraterrestrial life [37]. Sadly, this mission was canceled, and the reason, therefore, was budget overruns with other missions. *Rosetta* for example was one of those missions which led to *Eddington's* canceling [38].

Figure 15 Eddington Spacecraft [38]

2.1.3 JAPAN AEROSPACE EXPLORATION AGENCY (JAXA)

In October 2003, the Japanese government established an Independent Administrative Agency, the Japan Aerospace Exploration Agency (JAXA), merging three aerospace organizations, the Institute of Space and Astronautical Science, the National Aerospace Laboratory, and the National Space Development Agency of Japan. JAXA was designated as a core performance agency to support the Japanese government's overall aerospace development and utilization. This space agency can conduct integrated operations from basic research and development to utilization [39].

HAYABUSA2

The *Hayabusa2* is the successor of the first sample return mission *Hayabusa* (2004-2010) by JAXA. *Hayabusa* took surface particles from S-type near-Earth asteroid (25143) Itokawa. After *Hayabusa's* successful return to Earth, JAXA planned another asteroid mission *Hayabusa2* to visit a carbonaceous-type (C-type) near-Earth asteroid and return surface samples of the asteroid to Earth. The science goals of *Hayabusa2* aim at understanding the origin and evolution of materials in the early solar nebula and the asteroid parent body, as well as to constrain the physical properties of planetesimals during the planetary accretion processes [40].

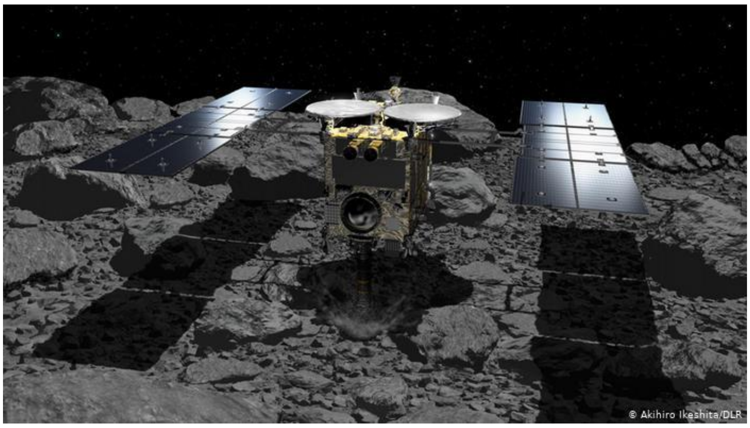

Figure 16 Hayabusa2 Taking a Sample from Its Asteroid Target (CGI) [41]

MIO/BEPICOLOMBO

MIO/BepiColombo is an international space mission to explore Mercury led by cooperation between JAXA and ESA. The challenge of this large-scale international cooperative mission is to simultaneously send two spacecraft to orbit Mercury – the *Mercury Planetary Orbiter (MPO)* and the *Mercury Magnetospheric Orbiter (MIO)* – to conduct a comprehensive study of Mercury. The main objectives of the mission are to understand the surrounding environment of Mercury, its geographical features, and its magnetic field [41].

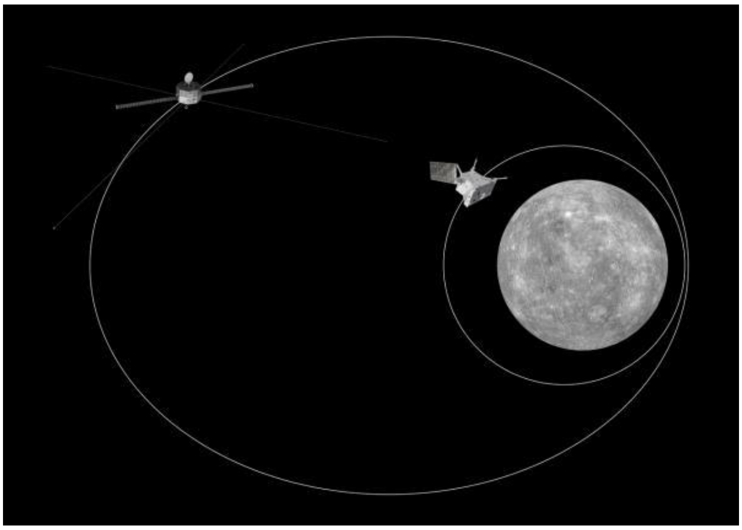

Figure 17 MIO/Bepicolombo Satellites Orbiting Mercury (CGI) [43]

HTV2

The *HTV2* space mission includes the design and launch of the *H-ll Transfer Vehicle (HTV)* which is an uncrewed cargo transfer spacecraft that delivers supplies to the *International Space Station (ISS)*. The *HTV* vehicle made its first flight to the *ISS* in September 2009. The main goals of the mission are cargo delivery and trash loading [42].

Figure 18 H-ll Transfer Vehicle (HTV) [44]

2.1.4 INDIAN SPACE RESEARCH ORGANIZATION (ISRO)

The space research activities in India were initiated during the early 60s when applications using satellites were in experimental stages. In 1969 the Indian Research Organization (ISRO) was founded under the Department of Atomic Energy [43]. Since that date, ISRO performs commercial and governmental activities related to space like the design and development of launch vehicles and satellites [44].

MOM

The *Mars Orbiter Mission (MOM)* was ISRO’s first interplanetary mission to planet Mars with an orbiter spacecraft designed to orbit the planet in an elliptical orbit. The mission has been configurated to carry out observations of the physical features of Mars and carry out a limited study of the Martian atmosphere with five payloads onboard. The main goal of the mission is the exploration of Mars’s surface, studying the constituents of the Martian atmosphere, and studying the dynamics of the upper atmosphere of Mars (effects of solar winds, radiation, and escape of volatiles to space). The mission provides multiple opportunities to observe the Mars moon Phobos [45].

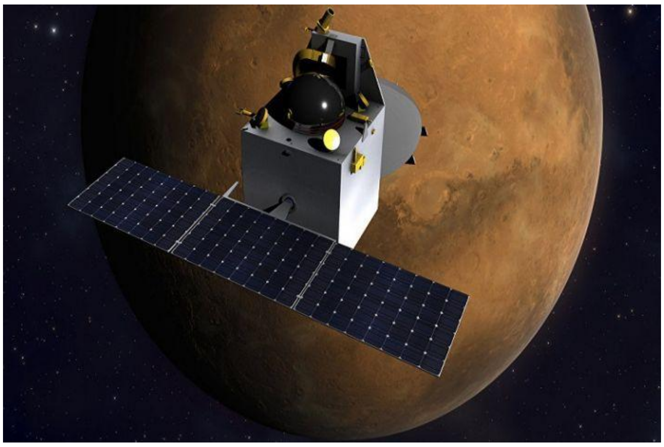

Figure 19 MOM in Orbit (CGI) [48]

PSLV-C51/AMAZONIA-1

Amazonia-1 is an optical Earth observation satellite of the Brazilian National Institute for Space Research (INPE) in collaboration with ISRO. The satellite was launched using India's C51 Polar Satellite Launch Vehicle (PSLV-C51) as the primary satellite of the mission. This is the first commercial mission of PSLV of the governmental company New Space India Limited (NSIL). The main objectives of the mission are to provide remote sensing data to users to monitor deforestation in the Amazon region and analyze diversified agriculture throughout the Brazilian territory [46].

Figure 20 Amazonia-1 Satellite (CGI) [50]

PSLV-C50/CMS-01

CMS-01 is a communication satellite intended to provide services in the extended C-band of the frequency spectrum. This band covers the Indian mainland, Andaman-Nicobar, and Lakshadweep Island. The satellite was launched using India's C50 Polar Satellite Launch Vehicle (PSLV-C50) as the primary satellite [47].

2.1.5 RUSSIAN FEDERAL SPACE AGENCY (ROSCOSMOS)

Established in 2015, the Russian Space Agency (ROSCOSMOS) is a state corporation of the Russian government to oversee and implement a comprehensive reform of the Russian space industry. The main task of ROSCOSMOS is to ensure the implementation of the Russian government's space program and the development of the manufacture and supply of space equipment and space structures [48].

OREL

Orel is a spacecraft that will be used to attempt to send a crewed flight around the Moon in 2029. The first flight test is scheduled for 2023, followed by an uncrewed flight to the *ISS* in 2024 and a crewed flight in 2025. The objective of this mission is to test rocket technology, crew life support modules, communications, and navigation systems [49].

Figure 21 Orel Spacecraft (CGI) [54]

LUNA-GLOB

The Russian *Luna-Glob* project is a space probe mission that has been conceived to understand the origin of the Earth-Moon system. The objective and the main feature of the *Luna-Glob* mission will be the main study of the internal structure of the Moon by seismic instruments. The results of this mission will help in the validation of the recently developed model of the formation of the Earth and Moon from a common cloud of particles of primitive (chondritic) composition [50].

Figure 22 Luna-Glob Spacecraft (CGI) [56]

PHOBOS-GRUNT

Phobos-Grunt was a Russian space probe mission with the goal of traveling to Phobos, a moon of Mars, and back to Earth with a piece of material from a relatively easy accessible small body of the Solar System. The mission failed because the spacecraft failed to fire the engine to put it on the correct path to the red planet [51]. The main objectives of the mission were the investigation of ancient matter pertinent to asteroid class bodies with remote sensing, in situ techniques, achieving the most challenging goal of delivering samples to Earth for laboratory studies, and studying the Martian environment at the Phobos orbit [52].

Figure 23 Phobos-Grunt Spacecraft [59]

2.1.6 CHINA NATIONAL SPACE ADMINISTRATION (CNSA)

Founded in 1993, the China National Space Administration (CNSA) is a government organization responsible for managing space activities for non-military purposes, regulating international space cooperation between China and other countries, and performing the corresponding governmental functions [53].

TIANWEN-1

Tianwen-1 is China's space probe mission, which includes an orbiter and a rover, that follows the failed *Phobos-Grunt* flight including the *Yinghuo-1* craft that was to be China's first Mars orbiter. The main objectives of the mission are: The search for evidence of current or past life; produce Martian surface maps; examine the Martian atmosphere; characterize Martian soil composition and water ice distribution [54].

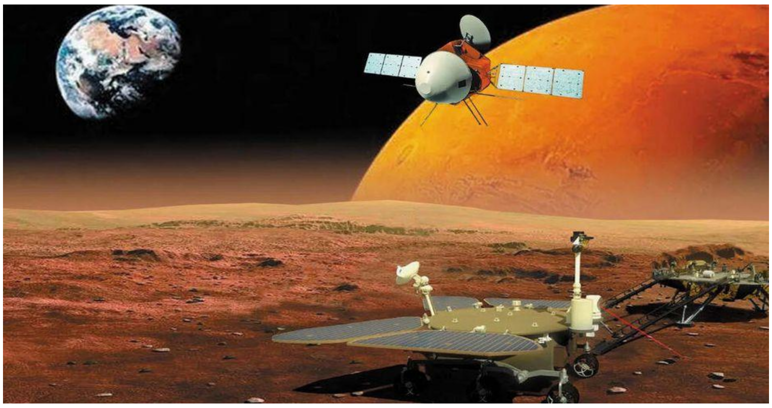

Figure 24 Tianwen-1 Orbiter and Rover (CGI) [61]

CHANG'E

Since the beginning of the 21st century, the interest of CNSA regarding lunar exploration was increased, with more than a dozen probes having undertaken the scientific exploration of the Moon. Prominent among these have been the robotic *Chang'e* missions of the China Lunar Exploration Program (CLEP). The goals of CLEP are to develop a global and comprehensive understanding of the Moon through orbital spacecraft exploration; to conduct exploration and surveying of the lunar surface, through Earth-based monitoring, sky mapping, and lunar soft landing with landers and rovers; and to develop a more in-depth understanding of the Moon and its history through the sampling of lunar rocks and soils, and returning them to Earth [55].

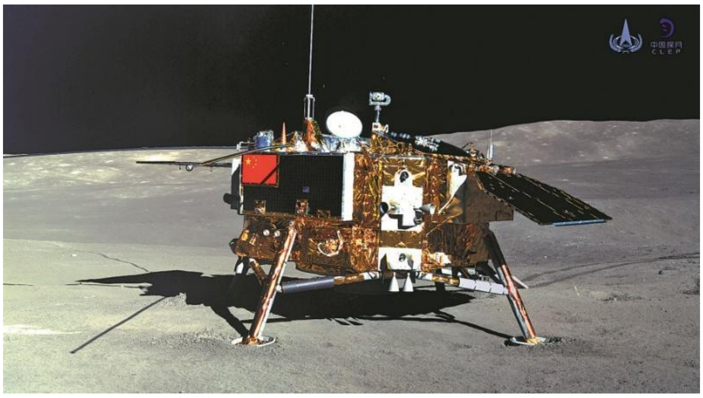

Figure 25 Lander Chang'e 4 Probe [63]

YINGHUO-1

Yinghuo-1 mission was a Chinese Martian space environment exploration orbiter mission that was launched together with Russian spacecraft, *Phobos-Grunt*, to orbit Mars. The main objectives of the *Yinghuo-1* mission were to investigate the magnetosphere and ionosphere in the Mars magnetosheath; to investigate the loss mechanism of water on Mars, and to carry out comparative studies of planets and understand how the space environment of Earth-like planets evolve [56]. The mission failed due to a failure in the *Phobos-Grunt* spacecraft carrying the Chinese microsatellite [57].

Figure 26 Yinghuo-1 Microsatellite (CGI) [66]

2.2 METHODOLOGY FOR DATA COLLECTION

The model that was used for structuring this work is called the *Saunder's Research Onion Model*. It consists of the following parts: Research Philosophy, Research Approach, Research Strategy, Choices, Time Horizon, and Data Collection [58]. This model helps to understand and choose a suitable research methodology for the present research project.

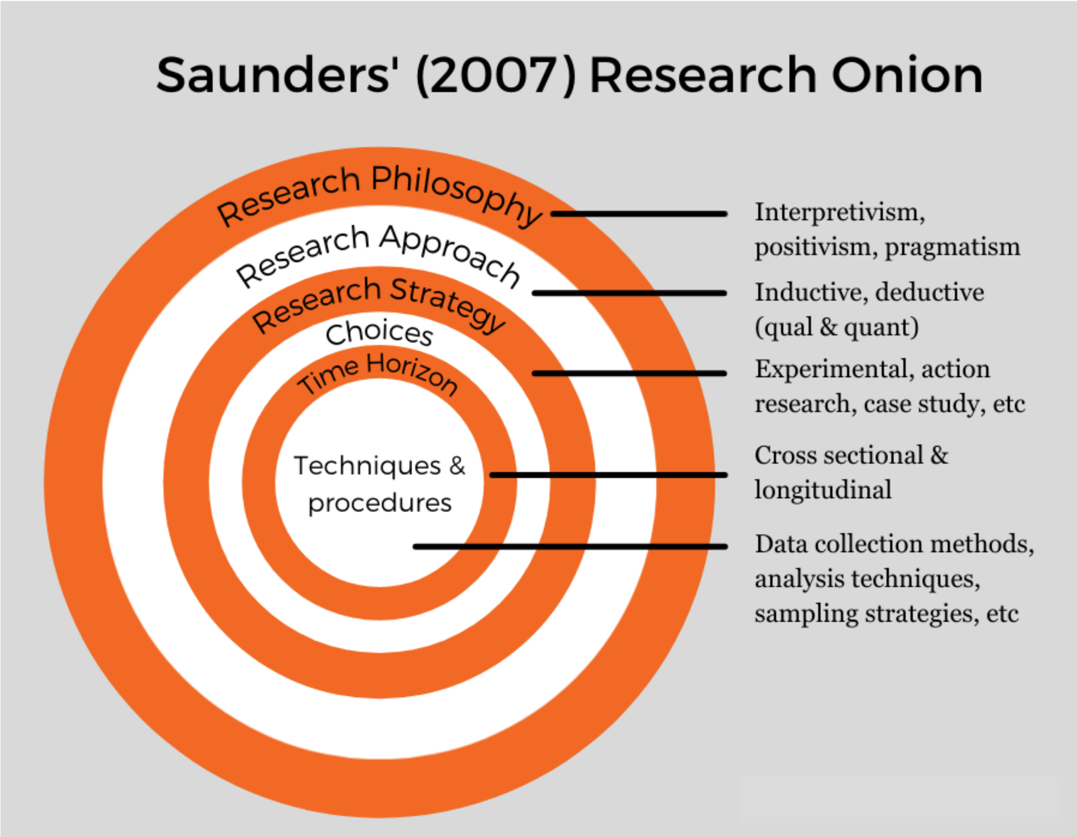

Figure 27 Saunder's Research Onion Model [67]

2.2.1 RESEARCH PHILOSOPHY

The philosophy of research is based on opinions on which this analysis is conducted. It can be further split into ontological and epistemological viewpoints. The former refers to how deeply one can grasp and interpret the information whereas the latter describes the way of gaining this information and how well it can be discerned.

For this project, one out of three main research philosophies is chosen namely the pragmatism research methodology because of the fact, that it will try to use the best possible sources of information for the development of a practical process. Due to the high confidentiality level inside the space industry, our development process will be focused on the amount of available information to select a space mission.

2.2.2 RESEARCH APPROACH

The research approach is inductive because a theory must be developed that relates the defined criteria and the success of space missions based on previous research.

2.2.3 RESEARCH STRATEGY

A research strategy details how, based on the aims of the study, research can be conducted. There are several strategies, but in this case, an approach called grounded theory is best for the defined purpose. This research strategy informs using the data about developing a new theory, model, or framework. It is very useful for a completely new research like the investigated relationship between criteria and success of a space mission.

2.2.4 CHOICES

This layer of the “Saunder’s Research Onion” model is about deciding how many types of data will be used in the research. Since our sources are diverse (involving the use of books, scientific articles, interviews, and many other types of references), the choice of a multi-method, in which different types of sources can be used to collect data, will meet our research requirement. This method allows us to use different quantitative and qualitative approaches to analyze the founded data.

2.2.5 TIME HORIZON

This part of the model describes the time horizon used from which the data was collected. Two options exist -the cross-sectional and longitudinal time horizon. Since this research requires data collection based on multiple points in time (maybe over a few months, years, or even decades) the longitudinal approach is preferred over the cross-sectional time horizon, which allows to used information about a certain point in time.

2.2.6 TECHNIQUES AND PROCEDURES

In the following chapters, all the data that has been previously analyzed in this work is collected and summarized, as well as the data generated from the information extracted from the official publications of space agencies and their partners. Some data was also collected from well-known scientific articles, books, and web pages related to different space missions analyzed by this master's project.

2.3 SPACE MISSIONS CATEGORIZATION

Chapter 2 gives a first impression of the research variety of the different space agencies that were considered in this report. To achieve the goal of this research project, 127 space missions from different types performed by different space agencies were taken into account. The complete list of space missions, on which the report is based on, can be found in APPENDIX A. List of NASA Missions to APPENDIX F. List of CNSA Missions.

The selected space missions were classified into two main groups:

- Uncrewed Missions
- Crewed Missions

Each of these main groups has four subgroups:

- Sub-Orbital Missions: sounding rockets that reach the Kármán line or some kilometers above, but do not complete one orbital revolution
- Orbital Missions: missions to Earth orbits
- Interplanetary Missions: missions going to another planet in the Solar System
- Interstellar Missions: missions that left the Solar System and entered the interstellar Space

Figure 28 Space Missions' Classification by Their Mission Type shows the distribution of the different space missions classified by their mission type. It is important to note that there are no crewed interstellar missions so far.

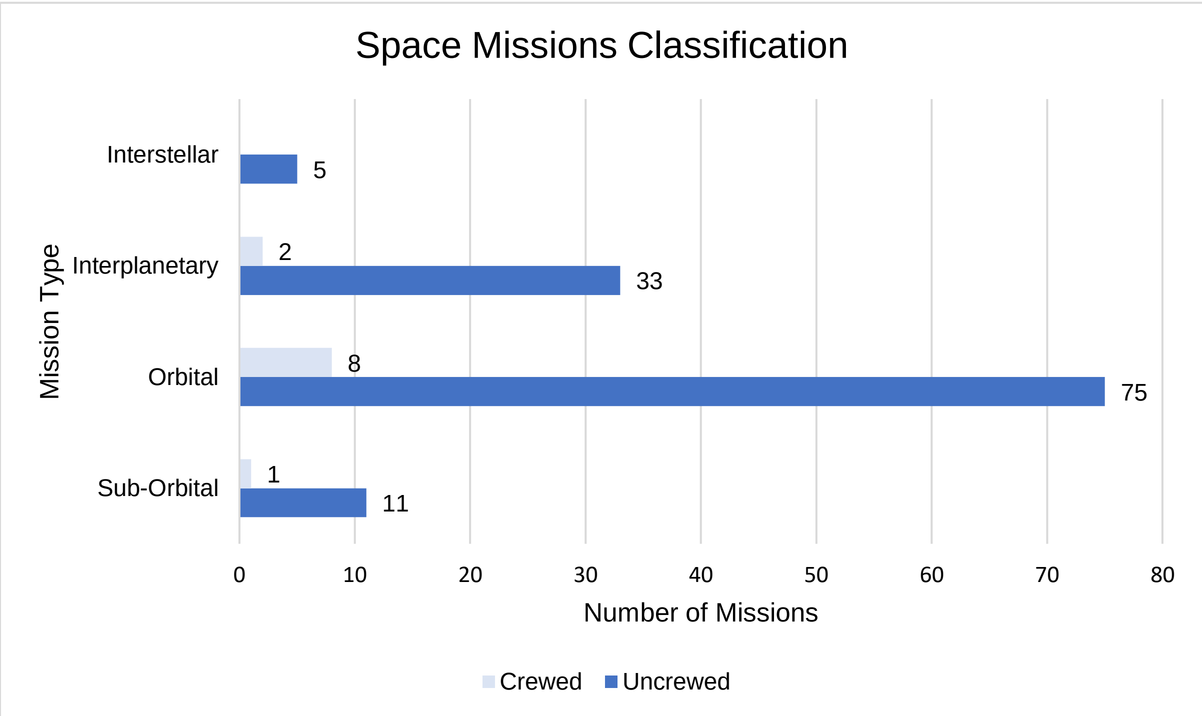

Figure 28 Space Missions' Classification by Their Mission Type

Figure 29 Space Missions' Classification by Involved Space Agencies shows the distribution of the space missions categorized by the involved space agency or the collaboration between them. Space mission classification by their mission type.

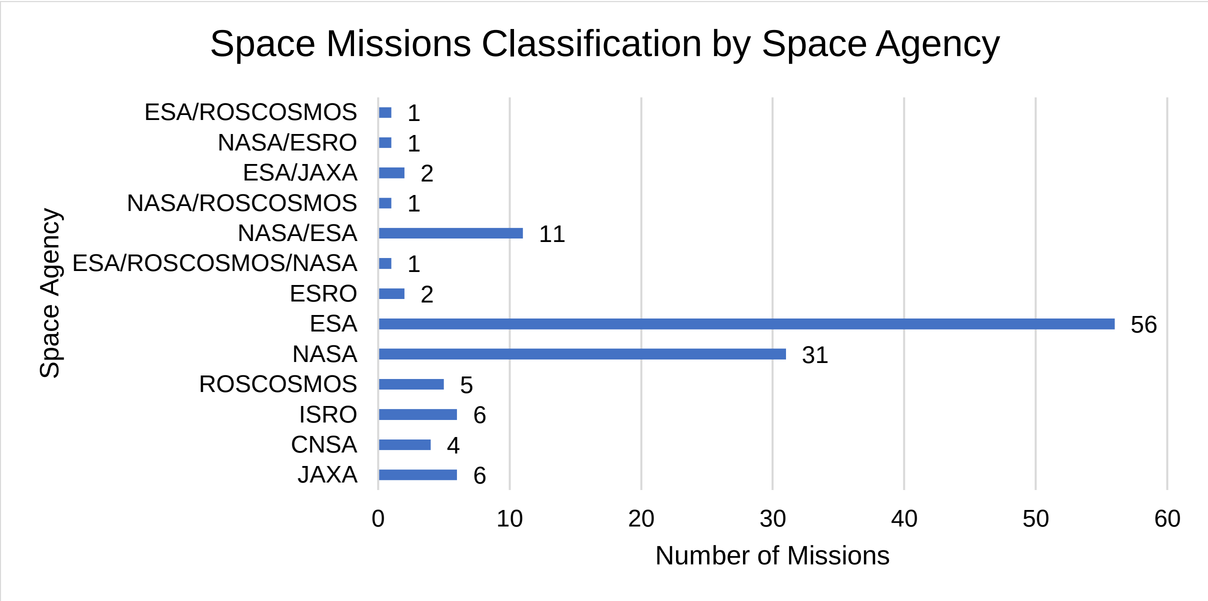

Figure 29 Space Missions' Classification by Involved Space Agencies

3. SPACE MISSIONS EVALUATION

This chapter describes the different evaluated criteria, and it is followed by the explanation of the evaluation methodology that was applied to the analyzed space missions.

3.1 CRITERIA DESCRIPTION

The selected criteria used for this research are the following:

- NUMBER OF COLLABORATIONS
  The cooperation of different space agencies, industry partners, and research institutes in a global context is covered within this aspect. To investigate the impacts of various team sizes on project success is the main goal of this criterion.

- GLOBALITY OF THE TOPIC
  This criterion deals with the question of whether the topic is of global interest or just a single-point initiative.

- SCIENTIFIC RELEVANCE
  It considers the number of publications and scientific papers. Additionally, it provides support for other scientists in their field of research.

- MISSION RENAMING
  This criterion addresses the number of changes in the mission's name. In detail, this means if a name-change does indicate less or more probability of implementation.

- SPILLOVER EFFECT
  A spillover effect refers to the impact of the mission's success on other events. Effects on society, education, and economy on project implementation are covered in this term.

3.2 EVALUATION METHODOLOGY

The following subchapter explains the evaluation methodology that will define if one of the five selected criteria is critically related to the success of a space mission. Since each space agency is located in a different social, political and economic context, one cannot expect the same rates of influence of the diverse. In addition, the evaluation method will be based on evidence provided by the data collected.

The explained criteria will be listed to streamline and ease the evaluation method as follows:

- Number of Collaborations → Criterion 1
- Globality of the Topic → Criterion 2
- Scientific Relevance → Criterion 3
- Mission Renaming → Criterion 4
- Spillover Effects → Criterion 5

It is necessary to recognize the influence of the selected criteria in each space mission to apply the designed evaluation methodology. This information will be organized in charts, which can be found in the appendix, for each criterion in the context of the different space agencies. The influence charts, which justify the following paragraphs, can be found from APPENDIX G. Influence Chart of NASA Missions to APPENDIX L. Influence Chart of CNSA MissionsAPPENDIX I. Influence Chart of JAXA Missions

In the following lines, a non-real example is presented to illustrate the computation to the reader.
There is bibliographic evidence that in 20 of the 49 space missions carried out by NASA, the scientific relevance criterion influenced their success.

$$Influence\ rate\ in\ \% = \frac{Number\ of\ NASA\ missions\ influenced\ by\ this\ criterion}{Total\ number\ of\ evaluated\ NASA\ missions} x100$$

In this case, the influence rate will be calculated numerically as follows:

$$Influence\ rate\ in\ \% = \frac{20}{49} \cdot 100 = 41\%$$

4. RESULTS AND ANALYSIS

This section summarizes the findings from this research. Furthermore, the results are analyzed and put into context.

The calculation of the influence rates is completed. The results are shown using radar charts to give a quick overview to the reader of how the selected criteria influence the success of a space mission in the general and individual context of each space agency.

A radar chart is a two-dimensional chart type designed to plot a series of values over a multiple quantitative value. Each variable (criteria in this case) has its axis that joins in the center of the figure. These charts were selected for this research work because they allow an easy comprehension and comparison of the results [59].

4.1 NASA

4.1.1 RESULTS

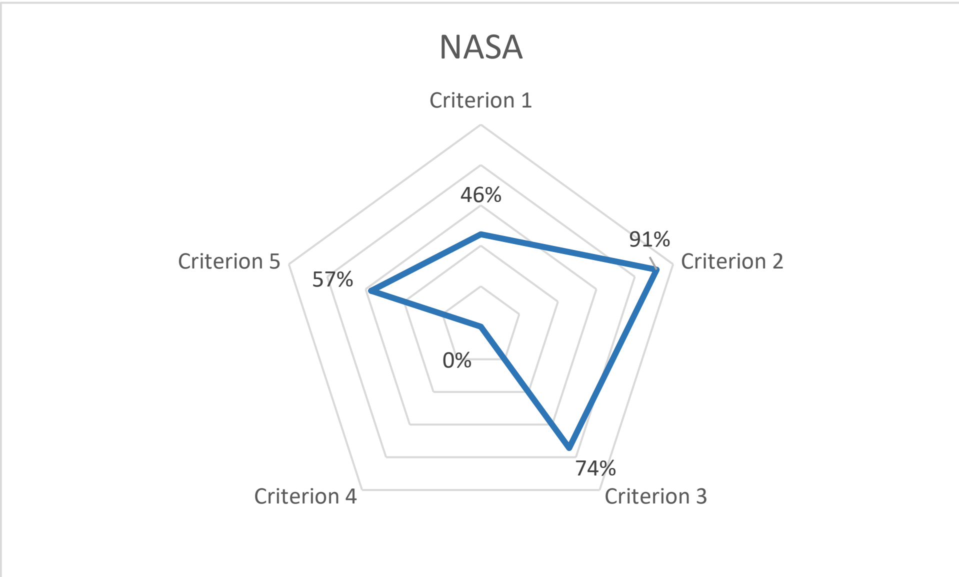

Figure 30 Radar Chart: NASA

The radar chart of NASA (see Figure 30 Radar Chart: NASA) shows a strong tendency to criterion 2 (91%) and criterion 3 (74%). Criteria 1 and 5 have a positive influence on the mission success of about 50%. For criterion 4 no influence rate was calculated. The analysis of the selected NASA mission showed no indicator for a higher success rate for multiple name-changes as stated before in Figure 30 Radar Chart: NASA.

4.1.2 ANALYSIS

- Number of Collaborations

NASA is particularly interested in access to technology and highly skilled personnel and therefore shows a strong interest in collaborating with international partners. NASA not only sees value in the collaboration with space agencies and commercial partners but also in the involvement of universities as well as engineers and scientists worldwide.

In the early years of NASA, the space programs and their missions were an all-American collaboration. At its peak, the *Apollo* program employed 400.000 people and required the support of industrial firms and universities all over the country [60]. This has to be taken into account for the following influence rate. After the end of the "Space Race", the collaboration with other space agencies started. For instance, in 1975 NASA collaborated with Russia on the *Apollo-Soyuz* mission [61]. With this in mind, the foundations for future collaborations were set.

That is why the influence rate could look differently if the study only focuses on the analysis of recent or upcoming missions. The number of collaborations has gained more significance in recent years, hence the 46%.

The *Hubble Space Telescope* is an international collaboration between NASA, ESA, and institutional partners. It was conceived, built, and assembled by a diverse group of thousands of scientists, engineers, and technicians around the world. Furthermore, it has been operated and managed throughout its lifetime by the many partners that make up the *Hubble* team [62]. In addition, *Hubble* observing is open to the worldwide astronomical community. By submitting their scientific proposals, the scientists can win time on the telescope for research purposes [63].

The *Artemis program* is one of NASA's large-scale collaborations with commercial companies, including Blue Origin, SpaceX, and Boeing as well as many European suppliers [64]. Commercial companies will play an increasing role in the space industry [65].

For example, SpaceX has the advantage of the speed and freedom to innovate; NASA provides experience and technical expertise. This results in mutual benefits for both NASA and SpaceX. SpaceX developed knowledge in the course of several NASA programs, and they got access to NASA's testing facilities. In addition, NASA can learn from SpaceX's work practices and knowledge to apply to current and future programs. Andrew Chambers and Dan Rasky state that "Although the agency will never operate like a small, entrepreneurial firm, its own innovative work could benefit from a version of SpaceX's sparse matrix engineering and rapid prototyping." [66] The speed and freedom to innovation from collaboration partners could lead to budget and time savings, which could be a crucial factor for the stakeholders and therefore the realization of a mission.

This could be crucial for NASA's goal to continue being a global leader in scientific discovery, fostering opportunities to turn new knowledge into technologies that improve life on Earth [73].

- Globality of the Topic

NASA missions represent a goal of global importance which have a great influence on the decisions of the space agency. NASA aims to maintain its position of preeminence in the field of space exploration [67]. Thus, missions that can achieve a goal on a global scale of importance like scientific "firsts" and key discoveries are usually run successfully and are supported by the space agency. 91% of the evaluated missions are of global interest.

A chief aim for NASA is to land the first woman and next man on the lunar surface [68].
The *Artemis* mission covers the global issue of equality and will not only benefit NASA but may also influence politics on a larger scale.
Many scientific “firsts” and key discoveries were fulfilled by the *GALILEO* mission and therefore it is stated as one of the most impressive feats of exploration of the 20th century. The mission added to the understanding of the Jovian system and our entire Solar System. Moreover, the mission was a triumph of teamwork and innovation under difficult conditions [69].
Despite the great mission success rate of NASA, it has to be taken into account, that 6 of the 32 missions were canceled during development due to a shift in priorities or funding limitations [70].
However, some of the missions stay of global importance, such as the *LISA* mission, which ESA continues to execute [71].

- Scientific Relevance

The scientific relevance of a mission and how its discoveries can support other scientific areas is a key factor in NASA's decisions. They aim to drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth [72].
The relevance for science, and therefore for the mission success of NASA, is measured by published papers and the contribution to science itself. This is clearly shown in the *Hubble* mission, a space telescope, that produced its 10.000th published paper in 2019 [73]. Among other findings, *Hubble* contributed to the measurement of the Hubble constant, which is used to determine the age of the universe [74].
However, for some missions, no data was available for public use. This shows an effect on the influence rate of criterion 3. In addition, missions that were canceled in the development phase cannot contribute to the fulfillment of this criterion. Considering this, the percentage is likely to be close to the 100% mark. In conclusion, NASA does not execute a mission without the scientific relevance for this research.

- Mission Renaming

Looking at the analyzed missions from NASA in this report, it is clear to state, that the number of name-changes does not have an impact on the overall mission success.
None of the missions had more than one name-change throughout their implementation. Most of them either did not have a name-change at all, or no data on this subject is available for research. Therefore, the influence rate of criterion 4 is 0%, as given in the radar chart.
The following section documents aspects which were noticeable during the evaluation but do not indicate a significance of the defined criterion 4.
The literature related to NASA’s space programs, such as the *Apollo* program, shows, that, after the successful completion of the initial mission, further missions are planned and that the official name gets updated [75].

NASA's most prominent missions are often renamed after a person who contributed to science or the space agency itself. For example, the *Hubble* telescope was named after Edwin Hubble, an American astronomer. This can be an indicator for a successful mission but is not to be linked with the number of name-changes [76].
A mission worth mentioning is *the James Webb Space Telescope*. It was originally called the "Next Generation Space Telescope" before it was renamed after James Webb, the second-appointed administrator of NASA from 1961 to 1968. In 2021, scientists requested a renaming of the telescope due to ant-LGBT+ claim against Webb, however, the request was denied by NASA. With the launch of the telescope, this public allegation will show if it affects the success and global importance of the mission [77] [78].

- Spillover Effects

Finding accessible information on the spillover effect of the selected NASA missions was difficult, due to the number and confidentiality of data.
However, the literature indicates three main spillover effects with regard to NASA missions:

Economy

The commercial and economic spillover effect results in the creation of job opportunities in the development of new technologies and materials in various fields, such as medicine, clothing, telecommunication, and micro-technology [79]. Another point within the scientific relevance is the development of technologies originally developed for space but later used on Earth. An example of this is space blankest, also known as emergency blankets, which are made from insulation and developed by NASA in 1964 [80].
The analysis shows that economy is the strongest driver for space missions. To give an illustration, NASA's economic impact report suggests that the agency generated nearly $65 billion in economic impact during the fiscal year 2019 [81].
With the *Mars 2020* mission, space mining could become another economic benefit that could influence NASA's mission selection [82].

Public Outreach and Education

One of NASA's goals is the inspiration of the youth, to interest and engage them in science, technology, engineering, and mathematics (STEM) and to educate them on global factors such as the student dust counter on the *New Horizons* mission [83]. Furthermore, with the *Curiosity* mission, the Education and Public Outreach division of NASA provided connections between citizens, scientists, and engineers. In real-life opportunities such as "Send your name to Mars" and the use of the internet, social media, and mobile devices the public can be engaged in missions [84] [85]. The public outreach and education are focusing on building a future diverse STEM workforce, which could profit the United States' economy in the long term. However, it cannot be seen as an indicator of the success rate of NASA missions.

International Relationships
Additional effects for NASA are the improvement of international relationships and access to knowledge and technology. The *Apollo-Soyuz* mission laid the foundations for the collaboration between the United States and Russia after the Cold War [69].

- Additional Information

For NASA, the ranking in the Decadal Survey on Astronomy and Astrophysics has a major impact on the selection process and the continuation of missions. If the scientists do not find the mission significant enough for the community, then it is not named in the next decadal ranking [86]. Therefore, NASA will often cancel the mission during development. This was done for instance with the *TPF and SIM* missions, which are both space telescopes. *TPF* was not mentioned in the 2010 astronomy and astrophysics Decadal Survey, an influential review compiled by the National Research Council that recommends missions for space science over the next ten years [87].
Marcy said that part of the blame for the current lack of large exoplanet missions should be placed on the scientific community, which did not advocate more strongly for *TPF*. Not too long ago, *TPF* was considered the most important and exciting mission for exoplanet science [88].
In the same way, *SIM/SIM-Lite* was not recommended for development by the Astro2010 Decadal Survey. Consequently, NASA's sponsorship of the project was discontinued as well [89].

4.1.3 SUMMARY

The effect of this is that the NASA budget and mission success are strongly influenced by this survey, even if other factors may favor a continuation of this work. With this in mind, the different criteria of this report do show an influence but only to a certain extent. The analysis made clear, that the number of name-changes is unrelated to the success of NASA missions.
Other criteria like the spillover effect and the Number of Collaborations tend to have more influence on the execution of missions, although the chart shows a smaller value for the influence rate in percent. This is because the economy of the United States benefits from NASA to a high extent. NASA benefits from the international partners through access to knowledge, expertise, and the share of costs. The analysis has shown that the Globality of the Topic is the most valuable criterion for NASA. Looking back at the motivation of this report, *James Webb Space Telescope* is mentioned to be a mission that has schedule and budget overruns and continues to be supported by NASA and the international partners. This is because NASA strives to stay the global leader in space exploration. The high-cost missions like *James Webb Space Telescope* and *Artemis* are prestige projects for NASA and the US government. In addition, they want to influence the scientific community by being the provider of the necessary instruments.

4.2 ESA

4.2.1 RESULTS

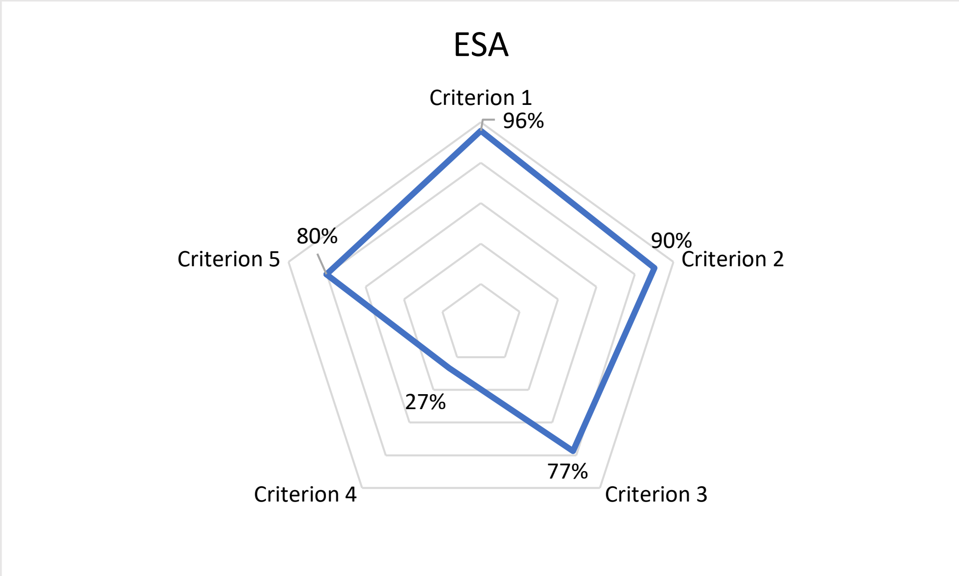

Figure 31 Radar Chart: ESA

The radar chart of ESA (see Figure 31 Radar Chart: ESA) shows a strong tendency to four of the 5 criteria. Criteria 1 and 2 reached over 90% of positive influence on the mission success of ESA. Followed by criterion 5, with an influence rate of 80%. Criterion 4 has with 27% the lowest influence rate on ESA's mission success.

4.2.2 ANALYSIS

- Number of Collaborations

By evaluating 71 ESA missions it became clear that ESA puts the most focus on a wide range of collaboration partners. The vast majority of the projects have multiple European industry partners with additional cooperation with some of the bigger agencies like NASA, JAXA, CNES, or ROSCOSMOS. The collaboration partners are representing either a prime contractor or a supplier who develops and produces parts of the spacecraft, payload or who provides the launch capacities.

This strong tendency to pass into collaborations is reasonable due to the 22 member states of ESA. By that ESA is able to finance its programs which one single European country would not be able to undertake on its own, because the funding is contributed from all member states [18]. This combined financing makes it clear that criterion 1 has a high status for ESA regarding its number of collaborations.

The previously mentioned observation can be proven based on the *Solar Orbiter*, which was an ESA-led mission including high participation from NASA [90]. An additional team out of seven European countries was created [91], which again shows the wide spreading of expertise to successfully develop and launch that mission. The collaboration made it possible for the *Solar Orbiter* mission to split its tasks into smaller parts. To mention some distributed tasks, ESTEC in the Netherlands managed the development effort, the spacecraft design was

done by Airbus, the ESOC center is operating the *Solar Orbiter* and the launch vehicle was provided by the United Launch Alliance of Centennial [92]. A collaboration of this kind is useful for any participant because it allows working with agencies and companies which are experts in their specific field, so the responsible mission leader does not have to do every task on their own. The wide spreading of tasks that lead to collaborations with many companies is represented in 96% of the evaluated missions.
In contrast to the *Solar Orbiter* mission, the *Eddington* project was a purely European mission. However, it cannot be concluded that this mission failed due to the lack of international partners but more because of budget overruns of other missions like *Rosetta* which were running in parallel [38].

- Globality of the Topic

For ESA the decision to accept or decline a project strongly depends on the programs run by ESA itself. The goal of those programs is to support ESA by defining future technology and to be able to reach the defined goals. Both will ensure ESA's competitiveness and the global rise in commercial products and services [93]. An indication for successful projects is the long-term planning within such programs. These cover the scientific research of global interest in which multiple institutes and universities can participate to support the mission goal. In the following, a few ESA programs are listed and shortly explained concerning their globality effect:

- Cosmic Vision 2015-2025 program:
  Dedicated to gaining more knowledge about the universe [94].
  Since the European space science community was part of every decision, such as selecting themes and possible mission candidates, the global interests are integrated into each mission [22].
- ARTES (Advanced Research in Telecommunication Systems) program:
  Assistance in the development of satellite telecommunication systems and services [93].
  More than half of the income in the space industry comes from satellite communications which is why the European and Canadian industries endeavor to stay leaders in the global market. It is conjoined with the creation of new jobs and businesses in different sectors [95].
- Human and Robotic Exploration Strategy program (earlier: Aurora Exploration):
  Creation of a European long-term plan for human exploration with regard to life on another planet [96].
  The program's goal is to guarantee Europe's position within global space exploration and to be a contribution to society and future generations [97].

- Horizon 2000 Science program:
  Exploration of the Universe [98].
  The science programs of ESA, starting with the Horizon 2000 program, have the objective to provide tools for the scientific community and to constantly develop European space capabilities and infrastructure further to keep up with the space competence [21].
- GSTP (General Support Technology Program):
  Evolution of already proven innovations to space suitable hardware [93].
  This program is a joint work between ESA, participating states, and industry to develop products usable for space resulting in jobs that are created and the competitiveness of Europe on the market [99].

- Scientific Relevance

The scientific relevance of a mission and how its findings can support other areas in this field is a key factor in ESA's decisions. This criterion is measured on the relevance of published papers and the contribution of the science aspect itself. This statement is supported by having a look at the mission *INTEGRAL*, which has in total 1913 refereed publications [100], 3901 refereed and non-refereed publications [101], 114 completed theses [102], 15 ongoing theses [102], 70 references [103] and is part of ESA's *Horizon 2000* Science Program. One example of its scientific contribution is the detection of radiation bursts from a dead star within a collaboration of different telescopes [104].
It is clear that the academic part plays an important role as well. Through that, young educate get the chance to be involved in scientific missions by adding their knowledge and help within the research. Furthermore, ESA runs its ESA Academy for ESA Member States students. In this specific program, students get the chance to participate in a space mission with the help and interaction of professionals. This enriches their academic skills and introduces them to the space sector as early as possible to prepare them well for their entry into the labor market. Further programs such as the Training and Learning Program boost the academic education of students in different fields such as space engineering, mission planning, or space medicine [105]. Each mentioned academic contribution becomes more clear to the reader with the mission *XMM-Newton*, which had around 405 Ph.D. theses related to this topic and shows clear involvement of universities with academic recruits [106].

- Mission Renaming

Looking at the analyzed missions of ESA, it gets through that mission renaming represents the merest impact on the overall mission success with namely 27%. Although there has been mission renaming, this did not endanger a mission's success. Playing a part in that small number of name-changes is the lack of data during this research.
Mission renaming occurred because of different reasons. One motive was the recognition of a famous scientist as in the case of the mission *XMM-Newton*. This mission was originally called the *High Throughput X-ray Spectroscopy* mission based on the satellite's great capacity

of detecting X-rays. The renaming later occurred in honor of Sir Isaac Newton who invented spectroscopy [107]. Another reason for a name-change was due to drawbacks in the budget of one major agency. The former mission *OOE (Out-Of-Ecliptic)* was a collaboration of ESA and NASA. During the development, NASA had to drop out of this mission which was caused by financial cutbacks of the in parallel developed Space Shuttle. As a result, ESA was left alone with the mission and renamed it to *Ulysses* because its mission goals also had changed [108]. However, during the research, a different kind of renaming occurred, which will be described in the following. Namely in the two missions, the *Automated Transfer Vehicle (ATV)* and *Cluster*. The former had individual name-changes between the different *ATVs*. Therefore*, ATV-1* was called "Jules Verne" and *ATV-2* "Johannes Kepler" [109]. The latter had also individual names for the *Cluster* satellites such as Rumba, Salsa, Samba, and Tango [110]. Those name-changes of individual satellites cannot be directly linked to a mission renaming but is a subpart of a mission name-change.

- Spillover Effects

The research for spillover effects with regard to ESA missions turned out to be difficult. However, the literature indicates six main spillover effects, on which will be looked closer in the following:

<u>Universities</u>

The spillover effect of universities results in unique hands-on experiences for students accomplished by the participation in projects or conducting of master or Ph.D. theses. This benefits with the first intention the younger generation but immediately results in the growth of society. Given that these academic trainees represent the future workforce, they drive space exploration further. That is why it is of such importance for ESA to offer educational programs to prepare young adults for any challenges which might occur to be able to make responsible decisions in any kind of field [111]. To underline this statement, the mission *Gaia* had opened a post-doctoral position offering to work within the *Gaia* DPAC (Data Processing and Analysis Consortium) [112]. Furthermore, the mission *TEAMSAT* proposed a hands-on involvement of young trainee engineers at the facility of ESTEC in the Netherlands [113].

<u>Education and Public Outreach</u>

A second spillover effect is upon the youth of the society. Therefore, ESA has a section for kids in which they try to bring science and especially space flight closer to them. For the mission *BepiColombo,* there is a website to educate children playfully with little games, visualizations, and drawing contests [114].

On top of this, public outreach plays an important role as well. In this category, the scientific community gets the chance to participate in the mission by getting observation time. The aforementioned one is conducted via a proposal selection process carried out by ESA [115]. The non-science public was also involved through a name proposal contest for a mission name like it was conducted for the *Solar Orbiter* mission [116].

Weather Forecast and Climate Change

Weather forecast and climate change are global hot topics which is why they can also be counted for the globality criterion.

The results of the mission *Biomass* for example have a high impact on monitoring the climate system and predicting the future weather. Furthermore, it reveals details about Earth's vegetation concerning the change of the climate [117]. The data of the mission *SMOS* will also contribute to better forecasting of weather and extreme-event climates [118]. Moreover, *SMOS* data will be implemented in a storm awareness which is used for an early prediction of hurricanes and cyclones for those who need accurate predictions at sea or who live close to the coast [119].

New Technologies and Cost-Effective Approaches

The development of new technologies manifests the position of Europe in the global market and brings developments to other scientific fields. Therefore, the technologies developed for the mission *IXV* can be transferred into the commercial arena such as ultra-lightweight honeycomb structures, avionic components, and advanced braking systems [120].

Another spillover effect are cost-effective approaches as it was the case for the *Neosat* mission. Its developments brought a reduction of satellite costs through the introduction of innovation and optimization by using electric propulsion [121].

Contribution for Further Missions (Mars Express)

Some missions or programs had paved the way for future projects such as the ESRO program. This operation is the pioneer for missions like *COS-B, Exosat, Giotto,* or *Rosetta* for which the experiences from the ESRO program were used [122]. To mention some other missions which have led to a contribution of further missions, the retrieval of the *Eureca* mission had given ESA the rare opportunity to study the spacecraft surfaces which were damaged by meteoroids and space debris. The observations were then later implemented in impact population studies and contributed to models of space debris and meteoroid environments [123]. The quick and low-cost approach of the *Mars Express* mission had a spillover effect on the *Venus Express* mission, for which the experiences gained on the *Mars Express* mission were used [124].

4.2.3 SUMMARY

To conclude this analysis of ESA missions, it became clear that the number of collaborations and the globality of the topic are the most important criteria for this agency. As extensively analyzed in the previous chapter, ESA prefers to work with other agencies and companies to be able to successfully execute a mission. This is done by distributing individual tasks among the collaboration partner, who are each experts in specific fields. Of equally importance is the globality of the mission topic, subdivided into different programs run by ESA. This ensures well-structured long-term planning of future tasks and keeps ESA up to date in the race on the global market.

Besides these two main criteria, the scientific relevance and the spillover effect are playing a non-negligible factor in the success rate of ESA. Although their percentage is less than the

former two mentioned criteria, it can still be seen that ESA puts its focus on the youth by supporting them in different programs with the assistance of professionals. This will help young educates to be well prepared for their future academic path as well as to be able to make responsible decisions for future society.
Finally, name-changes have happened in 19 of the overall 71 missions. However, only one out of the 19 missions was canceled, namely *Don Quijote*. The reason was not the mission renaming but more the splitting of the mission into two with further development of ESA and NASA.

4.3 JAXA

4.3.1 RESULTS

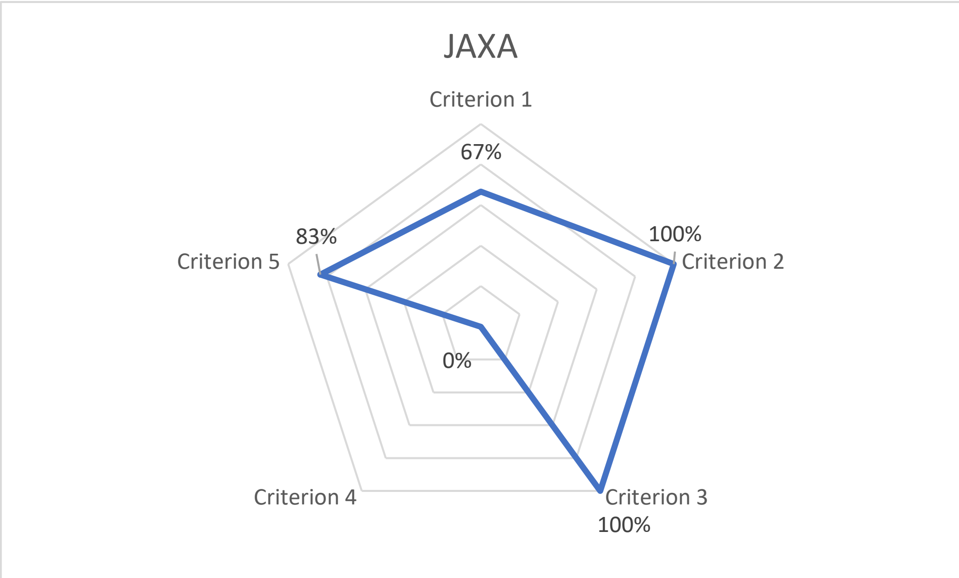

Figure 32 Radar Chart: JAXA

The radar chart of JAXA (see Figure 32 Radar Chart: JAXA) shows a strong tendency towards criteria 2, 3, and 5. Criteria 2 and 3 even reached a value of 100%. Criterion 1 has a positive influence on the mission success for more than half of the evaluated missions in this report. Criterion 4, the number of name-changes, has 0% influence on the mission success rate of JAXA.

4.3.2 ANALYSIS

- Number of Collaborations

It is stated in the *H-ll Transfer Vehicle "KOUNOTORI" (HTV)* mission press kit report [42] that the number of international collaborations with other space agencies was important to the success of the mission. This is because ESA's *Automated Transfer Vehicle 2 (ATV-2)*, named "Johannes Kepler", was released a few days before *KOUNOTORI*. Both transfer vehicles were berthed on the ISS for a short period and without international cooperation between the two agencies problems could have occurred. For example, both transfer vehicles could have been in orbit at the same time or there could have been a launch delay which would have implied high cost. It is also important to mention that the *KOUNOTORI* mission used a mission control center at NASA's Johnson Space Center and carried NASA's two orbital replacement units (ORUs). Overall, the collaboration with other space agencies provides JAXA prestige and access to the ISS, where ROSCOSMOS, ESA, and NASA are the main shareholders.

- Globality of the Topic

For JAXA, the fact that the purpose of its missions represents a goal of global importance has a great influence on its decisions. Thus, missions that can achieve a global goal are usually successful and are supported by the space agency. For example, one of the biggest problems facing the ISS is the potable water transport to the station. *H-ll Transfer Vehicle "KOUNOTORI" (HTV)* delivered approximately 80kg of water and, in the future, is expected to deliver up to 600kg of potable water to the ISS [42]. Another mission that justifies the statement could be the *BepiColombo* mission that was strongly supported by JAXA for the reason that no other space agency sent an orbiter around Mercury. This planet closely resembles the Moon in appearance, but with a very harsh environment that could help humanity to understand deeply some of Earth's natural processes [41].

- Scientific Relevance

The scientific relevance of a mission and how its discoveries can support other scientific areas is a key factor in JAXA's decisions. This is clearly shown in the *ARASE (ERG)* mission which investigates the particle acceleration processes in the inner magnetosphere helping scientists to understand ultra-low-frequency waves, ion-cyclotron waves and collecting new magnetic field data that can be used for further studies [125].

- Mission Renaming

As can be seen in the JAXA’s influence chart, there is no concrete evidence that the mission renaming affects their success. No name-change occurred during the development of a mission performed by JAXA. The literature related to one of their main missions, called *H-ll Transfer Vehicle "KOUNOTORI" (HTV)*, shows that the mission was updated and re-launched nine times until now, and it was always successful [126].

- Spillover Effects

JAXA is always looking for challenging missions that help them to develop cutting-edge technology based on the mission requirements. This can be seen in one of the more complex missions realized by JAXA, called *Hayabusa2*. In this mission, sampling surface material of the target asteroid represents the most important and challenging task and will leave a technological legacy for the space agency [40].

4.3.3 SUMMARY

In conclusion, it is to say that the globality of the topic and the scientific relevance are the key criteria of influence for JAXA. As expressed before, JAXA has a high collaboration rate in its missions. They value working with bigger international space agencies like ESA and NASA to sustain the success of their missions. In addition, JAXA is involved in complex missions due to the prestige that the space agency can gain. Lastly, it is clear to state that the number of name-changes does not influence the mission success rate of JAXA's missions.

4.4 ISRO

4.4.1 RESULTS

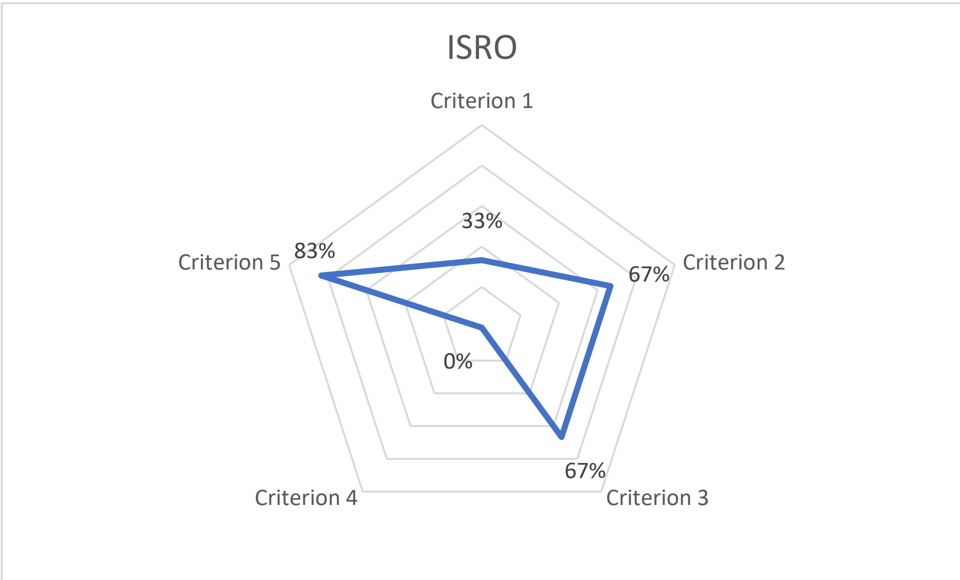

Figure 33 Radar Chart: ISRO

The radar chart of ISRO (see Figure 33 Radar Chart: ISRO) shows a strong tendency to criterion 5, with 83% of the missions being positively influenced by it. Criteria 2 and 3 are both having an impact of 67%. One-third of all the analyzed ISRO missions in this report have an influence on the mission's success. Criterion 4, the number of name-changes, has 0% influence on the success rate of ISRO's missions.

4.4.2 ANALYSIS

- Number of Collaborations

Most of the selected ISRO missions have no cooperation with other space agencies and were executed and launched by India's space agency itself. This is the case for the *Mars Orbiter Mission (MOM)*, *LVM3-X (CARE)*, *AstroSat,* and *PSLV-C50/CMS-01* mission. However, missions like *PSLV-C51/Amazonia-1* [46] and *PSLV-C49/EOS-01* [47], in which ISRO has commercial participation, were highly influenced by the number of collaborations for their success. This is because in these missions ISRO provides the launch vehicle and smaller space agencies give them the payloads, that they want to send to space. For example, the *Amazonia-I* satellite was produced by the Brazilian space agency, but it was launched by ISRO using a PSL V-51 launch vehicle.

- Globality of the Topic

Missions like the *Mars Orbiter Mission (MOM)* and *PSLV-C50/CMS-01* show that the main research fields of the space agency are influenced by the globality of the topic. On the first, it is said that the technologies that were developed for a mission to Mars play a significantly important role in determining the deterrence potential of a state. Hence, the country's policies for investments into missions like the Mars mission need to be viewed at the backdrop of the relevance of space technologies in the overall global order [45]. In the second case, international news show that the implementation of the C-band is a relevant topic in countries who are also participants in the space race [127].

- Scientific Relevance

Most of the time, ISRO based its mission selection criteria on the scientific relevance that the success of the space mission can achieve. For instance, the mission called *LVM3-X (CARE)* was used for testing the re-entry technologies envisaged for the crew module including the validation of the parachute-based deceleration system [128]. Also, the *Mars Orbiter Mission (MOM)* has technological objectives like the design and realization of a Mars orbiter with a capability to survive and perform Earth bound maneuvers, cruise phase of 300 days travel, Mars orbit insertion/capture, and on-orbit phase around Mars [129].

- Mission Renaming

There is no data in the collected literature for the ISRO missions that relate their name-change to their success rate.

- Spillover Effects

Most of the successful missions that are strongly supported by ISRO have spillover effects on society. For example, the mission success of PSLV-*C51/Amazonia-1* meant that for the first time a satellite will monitor the deforestation in the Amazon region and will also analyze the diversified agriculture in this important area of Earth [46]. Another example could be the *PSLV-C50/CMS-01* mission that will provide a cheaper bandwidth for India [47] [130].

4.4.3 SUMMARY

In summary, it is clear to state that the number of name-changes does not have an influence on the mission success rate of ISRO's missions. The agency is involved in complex missions due to the prestige that the space agency can gain. As expressed before the influence of scientific relevance on the success of ISRO's missions is an important factor. Thus, ISRO does not put much value on collaboration with international partners. They execute most of their mission on their own. As indicated by the information presented, the scientific relevance and the spillover effects are the key criteria of influence for IRSO.

4.5 ROSCOSMOS

4.5.1 RESULTS

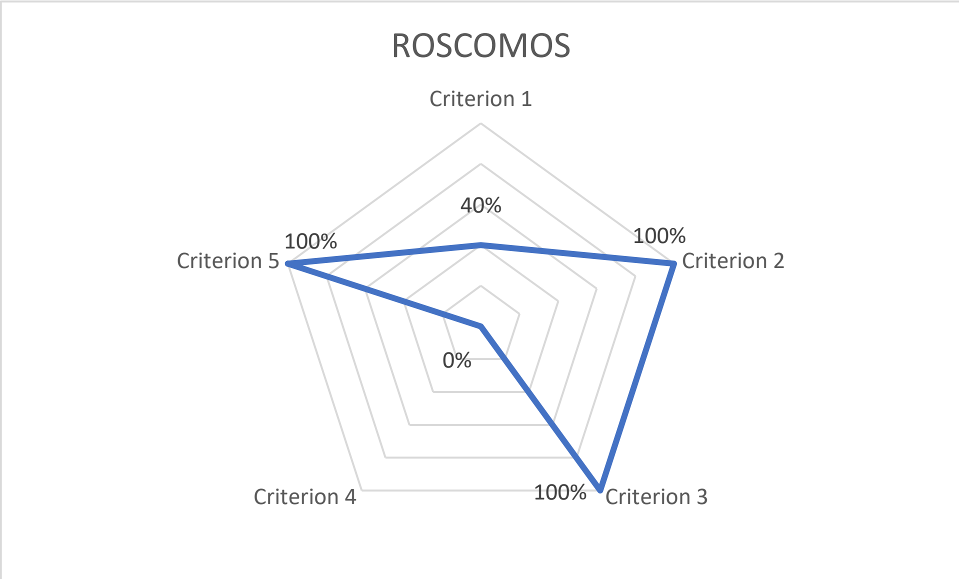

Figure 34 Radar Chart: ROSCOSMOS

The radar chart of ROSCOSMOS (see Figure 34 Radar Chart: ROSCOSMOS) shows a strong tendency towards criteria 2, 3, and 5. All reaching the 100%-mark in this chart. Followed by criterion 4 with a 40% influence rate on the mission success of ROSCOSMOS. Criterion 4, the number of name-changes, has 0% influence on the success rate of ROSCOSMO's missions.

4.5.2 ANALYSIS

- Number of Collaborations

Based on the collected literature related to the ROSCOSMOS missions, it is clear to state that it is not a space agency that depends on international cooperation for the success of its space missions. This statement can be supported by the words of its press service chief Vladimir Ustimenko, when asked about cooperation with the United States for the Venera-D mission "we did not say anything about refusing to cooperate with the USA on the Venera-D project. We are not refusing international cooperation. We simply talked about not involving wide international cooperation" [131].

- Globality of the Topic

The solution of global issues, like the Moon's origin or the nature of Martian satellites, are usually the main motivators for ROSCOMOS when they get involved in a space mission. These topics of global importance was the main reason for space missions like *Luna-Glob* [50] and *Phobos-Grunt* [52], respectively.

- Scientific Relevance

How the results of a successful space mission will support other scientific fields of research is also an important criterion for ROSCOSMOS. For instance, the successfully realization of the project *Venera-D* will allow solving scientific problems of comparative planetology and understanding why Venus and Earth are similar in many aspects [132]. Another project like the development of *Orel's* spacecraft will bring future cosmonauts to the Moon's surface and eventually to Russia's lunar base [133].

- Mission Renaming

In the literature related to the selected ROSCOSMOS missions, there is no evidence linking the mission renaming to their success.

- Spillover Effects

There are implicit spillover effects in ROSCOSMOS missions. The collected literature shows that there is a strong relationship between the success of a space mission and Russia's economy. That is why the impact of the results of a space mission is major in the mission selection process. At a general meeting of the Russian Academy of Sciences, ROSCOSMOS director Dmitry Rogozin said: "Are you sure that we will have sufficient funds for all the four missions, including *Venera-D* and then three national missions? I am not sure of that. If you have to choose among these missions, you have to choose precisely those that will yield a huge synergy effect." [134]

4.5.3 SUMMARY

In conclusion, it is clear to state that the number of name-changes does not have an influence on the mission success rate of ROSCOSMOS's missions. In general, the agency is a very independent space agency. They rarely collaborate with international partners on space missions and are often in competition with NASA. Nevertheless, from the beginning, they collaborated with CNSA. ROSCOSMOS is involved in complex missions due to the prestige that the space agency can gain. As indicated by the information presented, the scientific relevance and the globality of the topic are the key criteria of influence for ROSCOSMOS.

4.6 CNSA

4.6.1 RESULTS

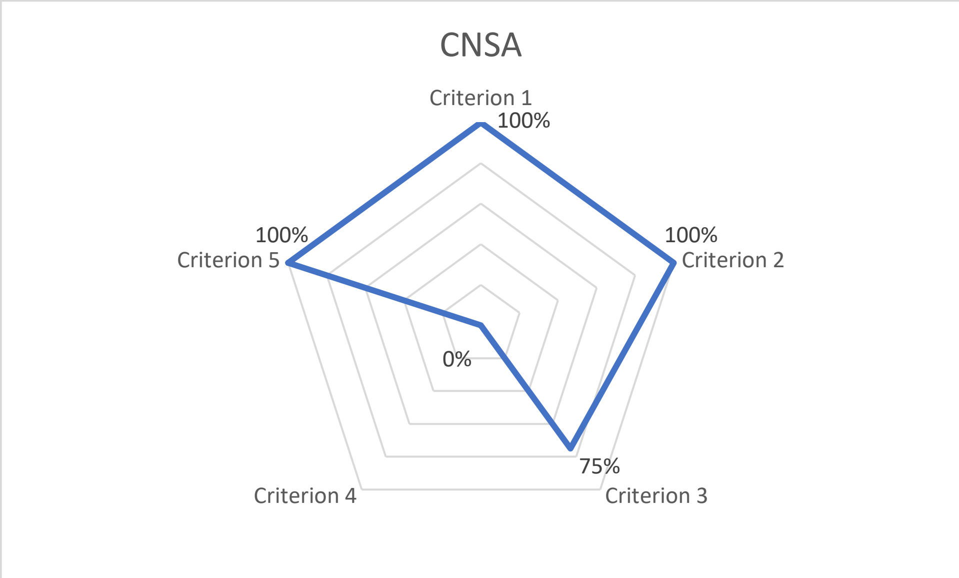

Figure 35 Radar Chart: CNSA

The radar chart of CNSA (see Figure 35 Radar Chart: CNSA) shows a strong tendency to the criteria 1, 2, and 5. All of them reached the 100%-mark. Followed by criterion 3 with a 75% influence rate on the mission success of CNSA. Criterion 4, the number of name-changes, has 0% influence on the success rate of CNSA's missions.

4.6.2 ANALYSIS

- Number of Collaborations

The collected data shows that there is a substantive influence on the cooperation between CNSA and other space agencies, especially ROSCOSMOS, in the success of the Chinese spatial missions. In the failed mission *Yinghuo-1*, cooperation between CNSA and ROSCOSMOS determined the mission's failure because of the failed fire of the *Phobos-Grunt* spacecraft engine [57]. Nevertheless, Russia and China signed a memorandum of understanding on cooperation in the construction of an international lunar research station [135].

- Globality of the Topic

For missions like *Tianwen-1*, the globality of the topic has played an important role in the development of the mission, because since the former Soviet Union launched the first *Mars-1* probe in November 1962, many international research institutions, including the former Soviet Union, the United States, Europe, and Japan have carried out more than 30 Mars Exploration Programs. But so far, we have not been able to rule out the possibility of past and present life on Mars. Therefore, the search for the existence of life and water on Mars has become one of the biggest dreams and challenges of many scientists all over the world [54].

In addition, the *Chang'e* program was founded because lunar exploration is a big leap in aerospace science and technology development for humanity [55].

- Scientific Relevance

The scientific relevance of a space mission's success developed by CNSA is a major one for this space agency. This was evidenced in the *Yinghuo-1* mission, which tried to provide important clues for understanding the origin and history of the Earth, the Solar System, and the Universe. Besides, the mission tried to investigate the reasons that changed the Martian climate, which has a great significance for protecting the Earth's climate [56]. Another example could be the fact that the implementation of China's Lunar Exploration Program *(Chang'e)* will improve knowledge of the Moon, improving the ability to utilize lunar resources. Lunar exploration may also promote the innovation and development of a series of basic and applied science [55].

- Mission Renaming

As described in the CNSA influence table, there are no related effects between a mission name-change and the mission success. Nevertheless, the Chinese Lunar Exploration Program, also known as the *Chang'e Project*, had more than one version and the official name gets updated to its current version at every launch [136].

- Spillover Effects

The researched missions show that the spillover effects due to the success of the CNSA missions are always the main motivator for this space agency. For example, the *Tianwen-1* will bring a prestigious position to China since this space mission is the most comprehensive mission to investigate the Martian morphology, geology, mineralogy, space environment, and soil and water-ice distribution [54]. Besides that, the lunar exploration, carried out by *Chang'e*, is a nowadays popular topic for spaceflight in the world, and also represents an important reflection of a country's comprehensive national strength, science, and technology level. It may strengthen China's international influence and national cohesion [55].

4.6.3 SUMMARY

To conclude, it is clear to state that the number of name-changes does not have an influence on the mission success rate of CNSA's missions. In general, CNSA is a space agency independent of the decisions of NASA and ESA. Nevertheless, the space agency collaborates with ROSCOSMOS, with whom they have a good relationship. Cutting-edge topics like Mars exploration are of interest to CNSA nowadays due to the economic development of China. As indicated by the information presented, the number of collaborations, the scientific relevance, and the globality of the topic are the key criteria of influence for CNSA.

4.6 Criteria Influence

4.6.1 RESULTS

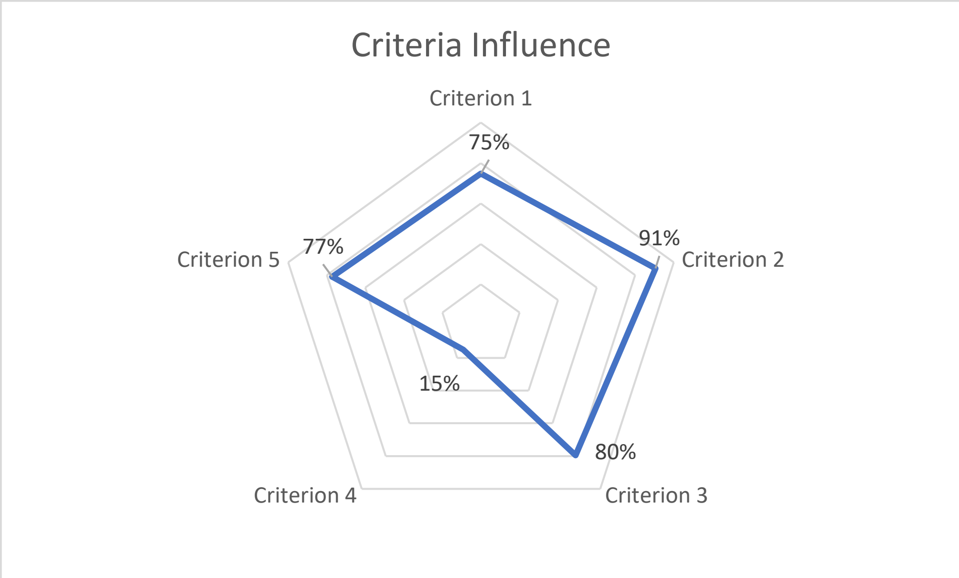

Figure 36 Radar Chart: Criteria Influence

The Criteria Influence radar chart (see Figure 36 Radar Chart: Criteria Influence) combines the radar charts of the individual space agencies. In doing so, the number of missions per space agency is weighted accordingly and taken into account in the calculation. The results depending on the different mission types can be found in APPENDIX M. Radar Charts Depending on the Mission Type and are not included in this chapter.
The chart shows the strongest tendency towards criterion 2, the global factor. Closely followed by the criteria 1, 3, and 5, which reach an influence rate of around 80%. Criterion 4, the number of name-changes, has with 15% the lowest influence rate of this report.

With the results of this report, it is necessary to consider that the values of the criteria could have been more or less of an influence if other or more missions would have been taken into account. The results are based only on the missions listed in the APPENDIX A. List of NASA Missions to APPENDIX F. List of CNSA Missions of this report. It should also be noted that not all information are accessible and confidential information cannot be considered.

The mission selection is closely related to the necessities of the countries or the development stage of their space technology. That is why differences between the space agencies are recognizable during the analysis of the missions. However, these differences are rather small for most of the criteria, as can be seen in the individual radar charts.
The difference between ESA and the other space agencies is, that ESA is a European collaboration with currently 22 member states. The focus is on representing the interests of all parties involved.

The global factor is the most important one for the space agencies which is reasonable since each mission shall bring the society of the corresponding mission nation forward and add to

an increase in knowledge and technological advancement. However, this is not the case for ISRO. They are focusing on the scientific relevance and spillover effects.
It can be seen that the scientific relevance is reflected in the number of published papers to indicate how important a mission internationally is. Additionally, it is a measurement of the importance of a mission for a nation and if this action will bring the nation more prestige and wealth. The spillover effect represents the interest of the agencies in working together with universities and integrating young educates via master theses and Ph.D. positions.
NASA strives to stay the global leader in space exploration and to keep influence on the science community. In close collaboration with the US government, they tend to set their focus on prestige projects like *Artemis* or the *James Webb Space Telescope*. Nowadays the number of collaborations is of the same importance, due to the gain of knowledge and the distribution of tasks. The same is true for ESA. They value globality and the collaboration with international partners, to keep up to date in the race on the global market. The international support is facilitated due to the close cooperation and exchange between the member states. In addition, the aim pursued by JAXA, ROSCOSMOS, and CNSA is to gain prestige on a global scale.

All space agencies considered, except for ROSCOSMOS and ISRO, value international cooperation and draw a benefit from it. The analysis of current missions shows a tendency for international relations to become even more important in the future. This is due to the common goal of further Mars exploration and the future of Mars inhabitation. Working together could speed up the development process and it could provide the expertise as well as the leading technology.

The number of name-changes only occurs within ESA missions. This becomes clear when a collaboration with another space agency is dissolved and ESA continues the mission on its own. For instance, the collaboration on the *JIMO* mission was canceled by NASA during the development phase and ESA reboots the mission under the name *JUICE*. This concludes that ESA is making use of a name-change to indicate a change in partnerships and does not harm the mission's success. To NASA the name-change does not specifically indicate an influence on the mission's success. However, the renaming of missions for famous science contributors like Hubble or James Webb could indicate more public recognition and support. For the other space agencies, the number of name-changes does not influence the mission's success at all. They do not rename their missions but rather update current missions in a program to a newer version.

For NASA the Decadal Survey on Astronomy and Astrophysics is an important factor in the selection process of space missions. Considering the fact, that it is an American survey, it does not influence the decision process of the other space agencies. They are only directly affected if the mission, that is cancelled, is an international collaboration. Despite the cancellation, they continue without NASA's support, if the mission fits the space agency's roadmap.

ESA divides most of its future missions into programs, which are similar to NASA's Decadal Survey on Astronomy and Astrophysics. With these programs, ESA can reach the defined goals by having a previously defined long-term planning within these programs. ESA's programs, such as the Cosmic Vision 2015-2025 program, covers fields such as the scientific research of global interest in which multiple institutes and universities can take part to support the mission goal.

Having taken all these factors into account, a combination of globality, number of collaborations, and spillover effect provides the highest chance of success. The global factor is the most dominant one. This is due to the fact, that all the investigated space agencies strive for prestige and pre-eminence in the world. The success of space agencies cannot be separated from governmental influence. The government is an important stakeholder for the space agency. ESA, on the other hand, represents the interest on a European scale. Prestige is an important factor, but, looking at the number of collaborations, the strengthening of international relationships is the key factor. Established international relationships are of interest to politics. With that in mind, the more criteria fulfilled by the mission the higher the success rate, however, this is not the case for criterion 4 regarding the name-changes. Nevertheless, other factors like funding limitations, reorganization of the space agency, or recommendations of the science community can be unpredictable and represent an unknown risk.

5. CONCLUSION AND FUTURE OUTLOOK

In order to be able to judge a mission for its successful course in its early phases, it is important to check it utilizing various evaluation criteria. Therefore, an extensive analysis based on different space agencies was made which led to the following results.

Out of the five observed criteria, the globality of the topic represented the most important factor. This outcome is reasonable because each mission should bring the society and economy of the corresponding mission nation forward and add to increased knowledge and technology. However, this is not the case for every agency, namely ISRO lays its main attention more on scientific relevance and spillover effects.

The globality criterion is closely followed by the number of cooperation, spillover effects, and scientific relevance. The reason for the first one is the appreciated collaborations with other agencies and companies to stay competitive in the space race. There is also a clear tendency that collaborations play a more important role today than in past missions. The second criterion shows the interest in working together with universities and integrating young educates via master theses and Ph.D. positions. The last criterion is best reflected in the number of published papers to indicate how important a mission is internationally.

The least important criterion is the name-changes, which is only relevant for ESA. Most changes occurred during a dissolution of mission collaborations, so ESA had to conduct the mission further on its own under a new name. However, name-changes can also be found at NASA although they are not contributing to a mission’s success or failure but more to appreciate a famous scientist.

Overall, it is important to mention that the resulting criteria can vary in magnitude and importance due to the lack and non-existence of information. Additionally, not every mission was taken into account but rather missions with a high amount of information available.

Finally, further research into other criteria, agencies, and missions could show additional influences on the mission success rate of space agencies on a global scale.

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APPENDIX A. List of NASA Missions

List of NASA Missions				
Mission name	Uncrewed			
	Sub-Orbital	Orbital	Interplanetary	Interstellar
James Webb Space Telescope		X		
Mars 2020			X	
SWOT		X		
Parker Solar Probe			X	
JUNO			X	
Pioneer			X	X
Mariner			X	
Voyager			X	X
Dawn			X	
Galileo			X	
Hubble		X		
New Horizons			X	X
ACE			X	
ACRIMSAT		X		
ATS		X		
Aqua		X		
Aquarius		X		
Aura		X		
AIM		X		
Mars Exploration Rover (Spirit and Opportunity)			X	

GEMS (cancelled)			X	X
IXO (cancelled)		X		
JIMO (cancelled)			X	
LISA (cancelled)			X	X
MTO (cancelled)			X	
SIM (cancelled)		X		
TPF (cancelled)		X		
Curiosity			X	

Mission name	Crewed		
	Sub-Orbital	Orbital	Interplanetary
Artemis			X
Apollo			X
Mercury		X	
Apollo-Soyuz		X	
ISS		X	
Orion Spacecraft	X		
Lunar Gateway			X

APPENDIX B. List of ESA Missions

List of ESA Missions			
Mission name	Uncrewed		
	Sub-Orbital	Orbital	Interplanetary
Aeolus		X	
Alphasat		X	
Arctic Weather Satellite		X	
ARD	X		
Ariane	X		
ARIEL		X	
ATHENA		X	
ATV		X	
BepiColombo			X
Biomass		X	
CHEOPS		X	
Cluster		X	
Cos-B		X	
CryoSat		X	
Darwin		X	
Don Quijote		X	X
EarthCARE		X	
Eddington		X	
EDRS		X	
Electra		X	
Envisat		X	
ERS		X	
ESRO		X	
Euclid		X	
Eureca		X	
ERA		X	
ExoMars (rover,surface platform)			X
Exosat		X	
FLEX		X	
FORUM		X	
Gaia		X	

GEOS		X	
Giotto			X
GOCE		X	
HEOS-1, -2		X	
Herschel		X	
Hipparcos		X	
Huygens			X
Hylas		X	
INTEGRAL		X	
ISEE-1, -2, -3		X	
ISO		X	
IUE		X	
IXV	X	X	
JUICE			X
LISA		X	
LISA Pathfinder		X	
Mars Express			X
Neosat		X	
Olympus		X	
OTS-1, -2		X	
Planck		X	
PLATO		X	
Proba series		X	
Rosetta			X
SMART-1		X	
SMOS		X	
SOHO		X	
Solar Orbiter		X	
Space Rider		X	
Swarm		X	
TD-1		X	
TEAMSAT		X	
Ulysses		X	
Vega	X	X	
Venus Express			X
XMM-Newton		X	
Φ-sat		X	

Mission name	**Crewed**
	Orbital
Columbus	X
Hermes	X
Spacelab	X

APPENDIX C. List of JAXA Missions

List of JAXA Missions			
Mission name	Uncrewed		
	Sub-Orbital	Orbital	Interplanetary
H-ll Transfer Vehicle "KOUNOTORI" (HTV)	X		
H3 Launch Vehicle	X		
Epsilon Launch Vehicle	X		
MIO/BepiColombo			X
ARASE (ERG)		X	
Asteroid Explorer HAYABUSA2			X

APPENDIX D. List of ISRO Missions

List of ISRO Missions			
Mission name	Uncrewed		
	Sub-Orbital	Orbital	Interplanetary
Mars Orbiter Mission (MOM)			X
LVM3-X (CARE)	X		
AstroSat	X		
PSLV-C51/Amazonia-1		X	
PSLV-C50/CMS-01		X	
PSLV-C49/EOS-01		X	

APPENDIX E. List of ROSCOSMOS Missions

List of ROSCOMOS Missions			
Mission name	Uncrewed		
	Sub-Orbital	Orbital	Interplanetary
Luna-Glob	X		
Venera-D			X
Fobos-Grunt			X
MARS 96			X
Mission name	Crewed		
	Orbital		
Orel	X		

APPENDIX F. List of CNSA Missions

List of CNSA Missions			
Mission name	Uncrewed		
	Sub-Orbital	Orbital	Interplanetary
Tianwen-1			X
Yinghuo-1			X
Chinese Lunar Exploration Program - Chang'e	X		
Mission name	Crewed		
	Orbital		
Shuguang One - Project 714	X		

APPENDIX G. Influence Chart of NASA Missions

Mission name	Criterion				
	1	2	3	4	5
Artemis	X	X	X		X
James Webb Space Telescope	X	X	X		X
Mars 2020	X	X	X		X
SWOT	X	X	X		X
Parker Solar Probe		X	X		X
JUNO		X	X		X
Pioneer		X	X		
Apollo		X	X		X
Mercury		X			X
Mariner		X	X		
Voyager		X	X		X
Dawn	X	X	X		X
Galileo	X	X	X		
Hubble	X	X	X		X
New Horizons	X	X	X		X
ACE			X		
ACRIMSAT		X	X		
AIM		X	X		
Apollo-Soyuz	X	X			X
ATS		X	X		X
Aqua	X	X	X		
Aquarius		X	X		X
Aura			X		X
ISS	X	X	X		X
Mars Exploration Rovers (Spirit and Opportunity)		X	X		
Orion Spacecraft	X	X			X
Lunar Gateway	X	X	X		X
Curiosity	X	X	X		X
GEMS (cancelled)					
IXO (cancelled)	X	X			
JIMO (cancelled)		X			
LISA (cancelled)	X	X	X		
MTO (cancelled)		X			
SIM (cancelled)		X			
TPF (cancelled)		X			

APPENDIX H. Influence Chart of ESA Missions

Mission name	Criterion				
	1	2	3	4	5
Aeolus	X	X	X		X
Alphasat	X		X		X
Arctic Weather Satellite	X	X			X
ARD	X	X			X
Ariane	X	X	X		X
ARIEL	X	X	X		X
ATHENA	X	X	X	X	X
ATV	X	X	X		X
BepiColombo	X	X	X		X
Biomass	X	X	X		X
CHEOPS	X	X	X		X
Cluster	X	X	X		X
Columbus	X	X	X	X	X
Cos-B	X	X	X		X
CryoSat	X	X	X		X
Darwin (cancelled)	X	X			
Don Quijote (cancelled)	X	X		X	
EarthCARE	X	X	X		X
Eddington (cancelled)		X			
EDRS	X		X		X
Electra	X	X			
Envisat	X	X	X	X	X
ERS	X	X	X		X
ESRO	X	X	X	X	X
Euclid	X	X	X	X	
Eureca	X	X	X		X
ERA	X	X	X		X
ExoMars (Rover + surface platform)	X	X	X	X	
Exosat	X	X	X		X
FLEX	X	X	X		
FORUM	X	X	X	X	X
Gaia	X	X	X		X
GEOS	X	X	X		X
Giotto	X	X	X		X
GOCE	X	X	X		X
HEOS-1, -2		X			X
Hermes (cancelled)	X				X
Herschel	X	X	X		X

Hipparcos	X	X	X		
Huygens	X	X			X
Hylas	X		X		
INTEGRAL	X	X	X		X
ISEE-1, -2, -3	X	X	X	X	
ISO	X	X	X		
IUE	X	X	X		X
IXV	X		X		X
JUICE	X	X	X	X	
LISA	X	X	X		X
LISA Pathfinder	X	X	X	X	X
Mars Express	X	X	X		X
Neosat	X	X		X	X
Olympus	X	X	X		
OTS-1, -2	X	X			X
Planck	X	X	X	X	X
PLATO	X	X	X		X
Proba Series	X	X	X		X
Rosetta	X	X	X		X
SMART-1	X	X	X		X
SMOS	X	X	X		X
SOHO	X	X	X	X	X
Solar Orbiter	X	X	X	X	X
Space Rider	X				X
Spacelab	X	X	X		X
Swarm	X	X	X	X	X
TD-1	X	X			
TEAMSAT				X	X
Ulysses	X	X	X	X	X
Vega	X	X			X
Venus Express	X	X	X		X
XMM-Newton	X	X	X	X	X
Φ-sat	X	X			X

APPENDIX I. Influence Chart of JAXA Missions

Mission name	Criterion				
	1	2	3	4	5
H-ll Transfer Vehicle "KOUNOTORI" (HTV)	X	X	X		X
H3 Launch Vehicle		X	X		X
Epsilon Launch Vehicle		X	X		X
MIO/BepiColombo	X	X	X		X
ARASE (ERG)	X	X	X		X
Asteroid Explorer HAYABUSA2	X	X	X		X

APPENDIX J. Influence Chart of ISRO Missions

Mission name	Criterion				
	1	2	3	4	5
Mars Orbiter Mission (MOM)		X	X		X
LVM3-X (CARE)			X		X
AstroSat		X	X		X
PSLV-C51/Amazonia-1	X	X			X
PSLV-C50/CMS-01		X			X
PSLV-C49/EOS-01	X		X		

APPENDIX K. Influence Chart of ROSCOSMOS Missions

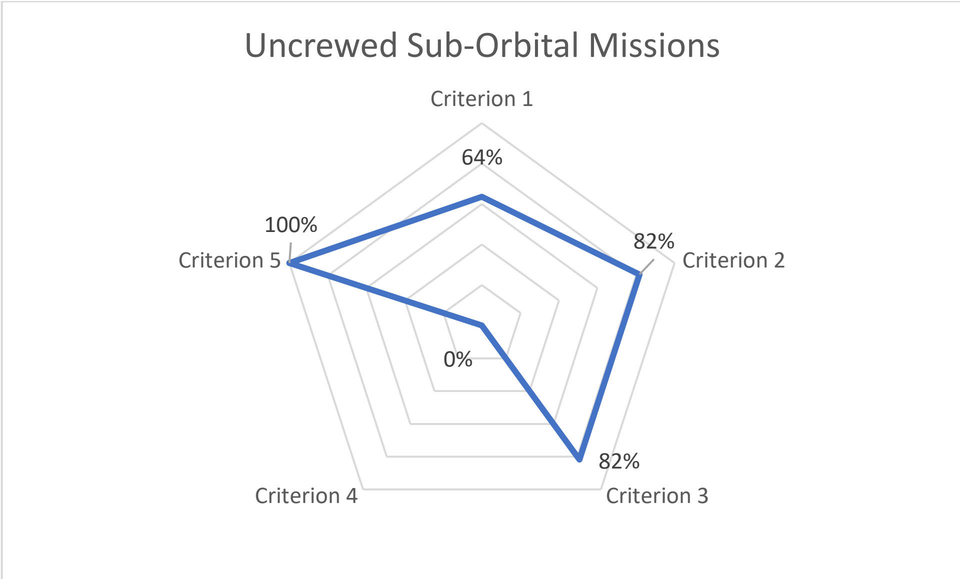
Mission name	Criterion				
	1	2	3	4	5
Luna-Glob	X	X	X		X
Venera-D		X	X		X
Fobos-Grunt		X	X		X
MARS 96	X	X	X		X
Orel		X	X		X

APPENDIX L. Influence Chart of CNSA Missions

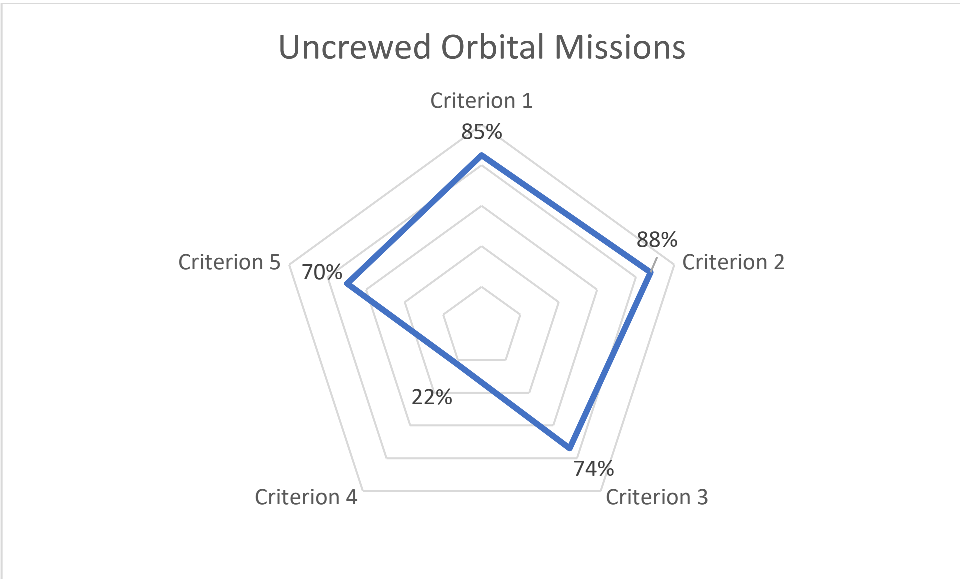
Mission name	Criterion				
	1	2	3	4	5
Tianwen-1	X	X	X		X
Yinghuo-1	X	X	X		X
Chinese Lunar Exploration Program - Chang'e	X	X	X		X
Shuguang One - Project 714	X	X			X

APPENDIX M. Radar Charts Depending on the Mission Type

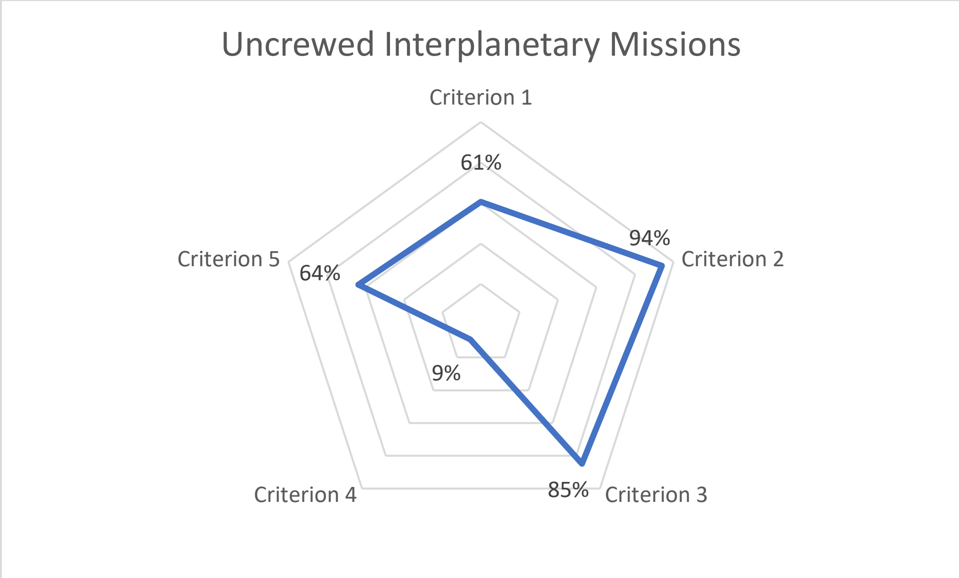
Radar chart: Uncrewed Sub-Orbital Missions (Number of missions used: 11)



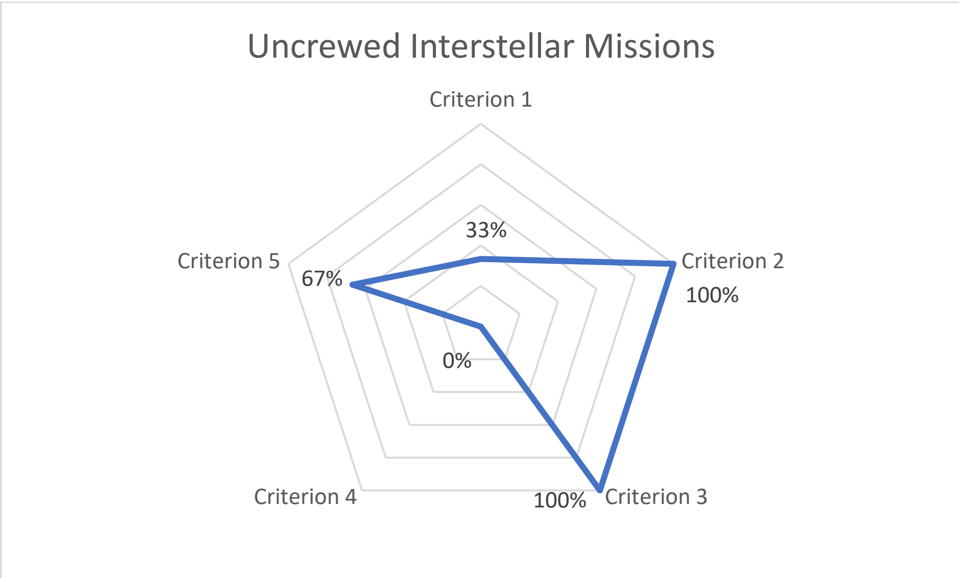
Radar chart: Uncrewed Orbital Missions (Number of missions used: 73)



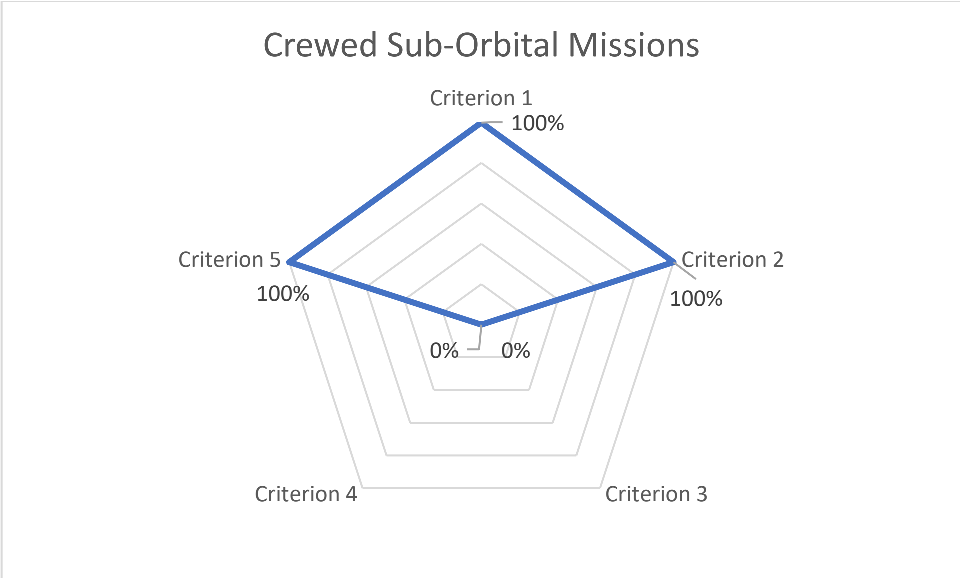
Radar chart: Uncrewed Interplanetary Missions (Number of missions used: 33)



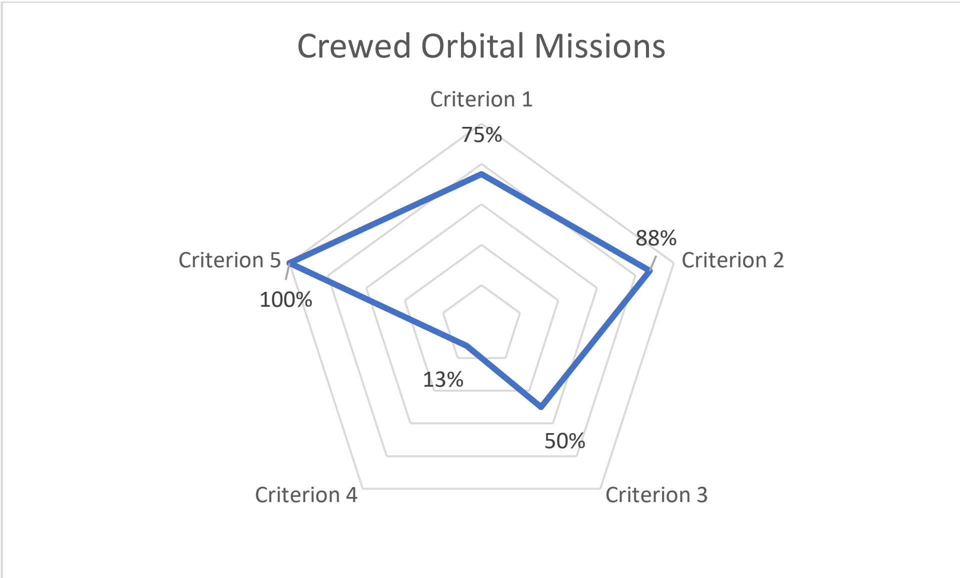
Radar chart: Uncrewed Interstellar Missions (Number of missions used: 3)



Radar chart: Crewed Sub-Orbital Missions (Number of missions used: 1)



Radar chart: Crewed Orbital Missions (Number of missions used: 8)



Radar chart: Crewed Interplanetary Missions (Number of missions used: 3)