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PROCEEDINGS

of SEE Universe Space Conference 2020

Belgrade, Serbia

30 September – 2 October 2020

Edited by Milan Mijović and Milan Stojanović

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SOUTH EAST EUROPE SPACE CONFERENCE 2020
BELGRADE SERBIA

Organised by SERBSPACE

SERBSPACE

Serbian Office for Space Sciences Research and Development | Канцеларија Србије за свемирске науке, истраживања и развој

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PREFACE

Starting on 30 September and lasting until 2 October 2020, in the form of a virtual event, the first South East Europe Space conference - SEE Universe 2020 was held. This multidisciplinary conference was organized by the Serbian Office for Space Science, Research and Development (SERBSPACE), a non-governmental organization founded in Belgrade in 2016. Originally scheduled for 2 and 3 April 2020, the Conference was planned to be held in the Science Technology Park Belgrade but was postponed due to the COVID-19 virus pandemic. By changing the format, the Conference was held online and was divided into three parts, i.e., three days. The first day was reserved for representatives of the academia and science, the second day for speakers from industry, and the third day for presentations from the societies sector. The conference brought together 50 speakers from over 20 countries. The participants of the Conference had the opportunity to attend the presentation of the keynote speaker of the Conference, Dr. Andreas Mogensen, an astronaut of the European Space Agency.

The conference was opened by Milan Mijović, President and Founder of the Office, who presented the history and projects of SERBSPACE as well as the Conference program. Dr. Saša Lazović, Assistant Minister for Technological Development, Technology Transfer and Innovation System of the Ministry of Education, Science and Technological Development addressed the attendees, followed by Dr. Christian Feichtinger, Executive Director of the International Astronautical Federation, who shared the news that SERBSPACE has become the new and only member from Serbia in this organization, which since 1951 brings together all leading space agencies, universities, companies and organizations from over 70 countries. The opening ceremony continued with a presentation by a representative of the United Nations Office for Outer Space Affairs, Mr. Luc St-Pierre and their projects, and ended with an address by H. E. Ruth Stewart, Ambassador of Australia in Belgrade and H. E. Susanne Shine, Ambassador of Denmark in Belgrade. The conference was also led by Dr. Milan Stojanović from the Belgrade Astronomical Observatory and Jacqueline Myrrhe from the magazine GoTaikonauts!

Elaborating about the multidisciplinary nature of Space sciences, the first day of the Conference continued with presentations of scientific papers by domestic and foreign speakers, including topics in space law and politics, astrophysics, medicine, materials and structures, GIS Systems, meteorology, and solar sailing. Also, the first Panel of the Conference was held, where participants exchanged their views on the potentials of space sciences and projects. The Panel was led by Dr. Milan Stojanović from the Belgrade Astronomical Observatory, who discussed the importance and possibilities of space sciences with the Panel participants from the point of view of the non-governmental sector, scientific institutions, and faculties. The discussion showed that many projects are already being implemented in Serbia, but there are still opportunities in the form of international scientific cooperation.

Living in the technology and innovation driven world, the second day of the Conference was reserved for representatives of industry and economy. Participants were able to hear lectures on entrepreneurship, the space industry, ways of financing, start-up companies and already successful companies engaged in the production of satellite equipment. This was followed by Panel Industry 4.0, moderated by Prof. Dr. Radivoje Mitrović, Dean of the Faculty of Mechanical Engineering, University of Belgrade. The aim of the panel was to discuss Industry 4.0 and its application in academia and industry.

Looking and listening to the firsthand Space experience, a special part of the Conference was dedicated to Dr. Andreas Mogensen, an active astronaut of the European Space Agency, who in his one-hour presentation spoke about his mission on the International Space Station and the experiments in which he participated.

At last, the final day of the Conference was marked by many lectures and presentations in the field of social and humanistic segment. Opening the third day of the Conference, a representative of the United Nations Office for Outer Space Affairs gave an overview of the Office's activities and projects, focusing on the main idea: that space activities are available to all countries, organizations, and individuals. Other presentations included presentations of space activities in Australia, Germany and China, presentations of Mars analogue locations and Horizon Europe projects. This was followed by a Panel that brought together the non-governmental sector in Serbia, where participants could exchange their ideas but also suggest steps for the future. The conference ended with a Poster session when participants from six countries were able to present their scientific research.

Taking into the account the significant number of speakers and a large number of listeners, the Conference gave a concrete picture of Serbia's capacity in the space sector, and connected domestic and foreign participants, all with the aim of improving knowledge, international cooperation, industry development and innovation and general positioning of Serbia in the global space arena. SERBSPACE highly appreciates the recognition of the SEE Universe 2020 Conference by domestic and foreign stakeholders, the United Nations, and the International Astronautical Federation.

Internationally and nationally, the conference was supported by, iter alia, the Ministry of Education, Science and Technological Development, Astronomical Observatory Belgrade, GoTaikonauts! magazine, Raumfahrt Concret magazine, the International Astronautical Federation, the European Space Agency, the embassies of Australia, Denmark, Israel, Spain, and Switzerland, as well as by many scientific institutions and companies. The Office plans to make the SEE Universe Space Conference a regular event and with the aim of creating a national, regional, and international platform that will enable the exchange of knowledge and experience of representatives of the space sector. Also, SERBSPACE believes that this Conference will become an important part of the space strategy in Serbia that the Office is developing.

Milan Mijović
President of SERBSPACE

Invited Reviews

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FROM SPACE LAW TO SPACE OFFICE

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Abstract: In this Paper, the Author will provide the overview of his activities regarding his Space law research and the history and work of Serbian Office for Space Sciences, Research and Development. Divided in three parts, the first part of the Paper will focus on the Author's research regarding establishment of property rights in Outer space and arguments for introduction of same. The second part will show the history of SERBSPACE, its activities and projects, including the SEE Universe 2020 Space conference. Finally, the third part will reflect the Author's opinion on the current aspects of scientific research and society in general.

Keywords: Space law, ownership, SERBSPACE, SEE Universe 2020, society

1. TO OWN OR NOT TO OWN – A LEGAL STANDSTILL IN SPACE

They say that Space is the final frontier, but a deeper analysis of this sentence brings us to a demotivating standpoint. From one point of view, space can be considered as a final frontier, felt in a sense that crossing it is a final step for mankind's prosperity. On the other hand, we can consider such a frontier as the line which we cannot cross over, a unique boundary for humanity. The latter interpretation, which is more pessimistic, should be considered metaphorically. Needless to say, humanity has extended its presence to outer space and continues to do so each and every day, however, have we conquered space in legal terms (see Mijovic 2017), that is, have we, except for a physical presence, established a suitable legal framework and a sustainable economic system, which in 2021 are an obligation for a sustainable and civilized life?

Although Article 2 of Outer Space Treaty (OST) clearly forbids "appropriation" by stating that "Outer Space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any means", other provisions of OST, especially, Article 1 stipulates that "Outer Space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies".

Legally observed, I do not see why outer space is considered and emphasized to be so much different than Earth. First, one should raise a question regarding private ownership of humans on Earth. This right is without question attributable to humans, i.e., we are entitled to Earth. We can obtain property, sell, lease etc. Without any intention of entering a theological or political debate – the question must be raised: ***does the Earth belong to humans per se***? Is our understanding of Earth appropriation based on the facts that humans are the only intelligent species on Earth? From a legal perspective, what is our *modus aquuirendi* and *iustus titulus* of Earth? Why are we so confident that it is ours? This question is of vital importance, because it represents and adds to the argument that the appropriation of outer space is possible and would represent double standards if we would allow private ownership on Earth and forbid it outside it. Are the ownership rights, i.e., human rights limited to Earth? Of course, current technology does not allow us to deepen the concrete system of ownership rights applicable to Outer space, but this must not prevent us from thinking in advance. We cannot and must not keep dividing Earth and the rest of the universe.

Being one of my first papers on this topic, I have written a paper entitled "Problems of regulation of Property rights in Space, Moon and other celestial bodies" (see Mijović 2015) in 2015 for which I have received an IAF Emerging Space Leader grant which allowed me to attend and present at 66th International Astronautical Congress which took place in Israel in 2015. Throughout the years I have further researched mentioned topic and published several papers: "Outer Space Treaty 1967 vs. 2017, A lex specialis or Derogation from Human Rights?" (see Mijovic 2017) and "Taxation of outer space: a next step for space exploration?" (see Mijovic 2018).

2. ABOUT SERBSPACE

Abovementioned event from 2015 propelled me further in pursuing activities not only related to Space law, but to Space in general, including all benefits stemming from its research and development. Inspired by many foreign and international space entities, faced with the fact that similar organization or the governmental body in Serbia does not exist, I have founded the Serbian Office for Space sciences, Research and Development (SERBSPACE) in August 2016 as a non-governmental organization based in Belgrade with the general aim of developing the Space sector in Serbia through Academia, Industry and Societies as three main pillars of the wider Space ecosystem. Being the president since and having graduated from Faculty of Law in Belgrade, Serbia, continuing my Academic studies and research relating to Space law, and following several years of Space law research and practice, an active role within Space Generation Advisory Council as a National point of contact for Serbia and member of Space law working group, an appointment as Advisor for Serbian team for Manfred

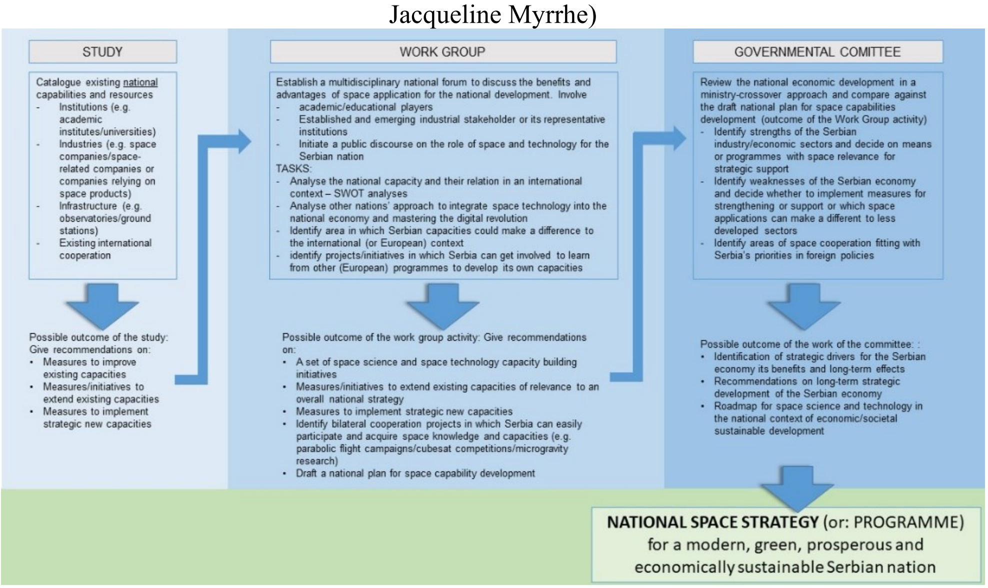
Lachs Space law Moot competitions, participation as a speaker at International Astronautical Congress 2015 (Jerusalem, Israel), 2016 (Guadalajara, Mexico), 2017 (Adelaide, Australia), 2018 (Bremen, Germany) and United Nations conferences in 2016 (Guadalajara, Mexico), 2017 (Samara, Russian Federation), 2018 (Islamabad, Pakistan), 2019 (Changsha, China) and key speaker including Near Space Conference 2019 (Torun, Poland) and CCAF 2019 (Wuhan, China), I have become a strong advocate for introduction of Space related activities in Serbia and positioned myself and SERBSPACE as recognized stakeholders in national and international community. All this previous work was reflected in the paramount achievement – the organization of the First South East Europe Space conference SEE Universe 2020, which blazed the way for new space activities, research, development, and cooperation in Serbia.

As my research led to the thesis that private ownership rights should be allowed in Outer space, advocating this idea since my early days of Space law research, I have provided arguments for these rights and published several papers (see Mijović 2012, Mijović 2015, Mijovic 2017 and Mijovic 2018) on this matter introducing this idea to the international community, believing that, with proper governance system, private ownership must be allowed in Outer space, in order to provide development and sustainable space exploration.

During the years, I have received several prestigious Space law awards and acknowledgements and became a member of the International Institute of Space law and The Hague Space Resources Governance Working Group, with several Space law papers published in national and international publications, whereas SERBSPACE has become a member of the International Astronautical Federation (IAF), being the only member organization from Serbia.

Realizing that Serbia should join the global Space community, as an equal Stakeholder, I have continued with expanding my Space career through Serbian Office for Space sciences, Research and Development (SERBSPACE). The scope of my work includes Space sciences and industries, improvement of research and development relating to Space, cooperation with national and international universities, associations, Governments, United Nations, space agencies and companies, participation in and organization of events, congresses, workshops and other space related activities and events, development of Space strategies, road maps, applications, and other Space related projects. The Office is developed as an umbrella organization that would include all relevant individuals, organizations, academic institutions, business entities and county representatives from the field of space sector in Serbia. The scope of the work of the Office covers several areas, both nationally and internationally. On the national level, the Office conducts a permanent capacity building project in the field of space science, technology, and research, which includes the involvement of the abovementioned entities in the projects of the Office and the creation of a network of experts in this field, all with the aim of developing space activities in Serbia and strengthening the position of Serbia internationally.

Table 1: Recommendation for Serbian Space strategy (developed by Milan Mijović and Jacqueline Myrrhe)



Regarding the international aspect, supported by the United Nations and the UN Office for Outer Space Affairs (UNOOSA), the Office was officially presented at the International Astronautical Congress in Guadalajara, Mexico in September 2016, and was acknowledged by the international space community. In this sense, SERBSPACE presented the Reasons for establishing Serbian Space Agency project to the United Nations and Serbian government, and since then has been implementing various activities aimed at involving Serbia on the international scene. The office is a permanent representative of Serbia in all important international events, and among the most important are the International Astronautical Congresses and UN Conferences, at which the scientific work of our members was presented, new partnerships established and the talks on the accession of Serbia to various international organizations continued.

In October of 2017, SERBSPACE was invited to participate in a UN conference in Russia aimed at implementing and coordinating international programs related to space science, with the goal of sustainable development of countries. At that time, SERBSPACE presented its model for the development of the space sector in Serbia before the international auditorium but emphasized the importance of regional cooperation and international cooperation.

It is especially important to point out that at the end of February 2018, SERBSPACE presented a project relating to the application of satellite technologies in the field of protection against natural disasters at a UN conference in Pakistan. This project was developed in cooperation with the Water Directorate of the Ministry of Agriculture, Forestry and Water Management and represents one of the steps towards improving the overall application of space technologies in Serbia, in this case to improve the use of watercourses, but also to prevent accidents and natural disasters. In this regard, the UN has offered cooperation on this issue, which is reflected in the possibility of obtaining free satellite imagery to better manage and contribute to early warning systems relating to natural disasters, as well as to participate in numerous international programs of this type.

In March 2018, Yuri's Night, a global event marking the anniversary of sending the first man to space, Yuri Gagarin, was organized for the first time in Belgrade on 12 April. A networking event was organized in Belgrade aimed at improving domestic capacities in the field of space, which was supported by the Russian House - Russian Center of Science and Culture in Belgrade.

In May 2018, following several UN Conferences and in accordance with respective recommendations, SERBSPACE has initiated creation of a Space Working group within Serbian government and submitted a report to Serbian government detailing further steps towards utilization of Space applications and technologies, including steps towards joining United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and cooperation with European Space Agency, as one of the tasks of the Group.

In October 2018, SERBSPACE was represented by at the 26th UN/IAF Workshop on Space Technology for Socio-Economic Benefits: “Industry, Innovation and Infrastructure for Development” which took place in Bremen, Germany in conjunction with 69th International Astronautical Congress. The Workshop discussed space science, technologies, and applications in support of economic, social, and environmental development with a focus on the role of industries as key player to offer innovation and infrastructure needed for sustainable development.

On behalf of SERBSPACE, I have presented a report relating to projects and activities taken by our Office throughout the years, which are an integral part of the Reasons for establishing the Serbian Space Agency project, communicated to the Serbian government in 2016. Mentioned report covered possible industrial cooperation, investment opportunities and the benefits of start-ups in Serbia which could enable more jobs and further education. In addition to this, report presented development of space sector in Serbia and the role of SERBSPACE in creation of national space framework and international cooperation, being a facilitator between Serbian government and various opportunities. Further on, the presentation provided SERBSPACE’s projects and activities and its positive impact on academic, scientific, and societal segments in Serbia, its role among international space community, as well as ongoing projects such as Serbian Space Agency and Emerging Countries Space Office projects. During the conference, I had a series of B2B meetings with several aerospace companies, which expressed their interest in investments and future cooperation.

For the second time in a row, on 12 April 2019, the Office organized Yuri's Night, this year at the Nikola Tesla Museum.

Following the invitation of the United Nations and the Chinese National Space Agency (CNSA), I participated at the United Nations/China Forum on Space Solutions held in Changsha, China, from 24 to 27 April 2019. The aim of the conference was to develop space technologies and cooperation, with the aim of achieving the sustainable development goals as defined by the United Nations Agenda 2030. SERBSPACE presented the SEE Universe Conference project as the first of its kind in this part of Europe. The Conference project has received strong support from the international community and the United Nations. During the conference, I had a series of meetings with representatives of the academic community and Chinese industry sector, who expressed a great desire for further cooperation.

Supported by *Raumfahrt Concret* and *GoTaikonauts!* the SEE Universe 2020 Conference was announced at the 53rd Paris Air Show in June 2019, reaching the European and World Aerospace community. The advertisement for the Conference was displayed on numerous booths of European space industry and space institutions.

During the celebration of the 50th anniversary of IFR in Bremen in September 2019, I have visited Airbus and OHB in Bremen, presenting the SEE Universe 2020 Space conference and work and the activities of SERBSPACE.

In October 2019, SERBSPACE participated at the Near Space Conference 2019 Above and Beyond in Torun, Poland as one of the Partners. The main goal was to show the broad range of recipients that the space exploration generally and near space exploration particularly is accessible virtually for everyone and it has a growing impact on our daily life. Other Partners from several European countries were invited to SEE Universe 2020 Space conference, as it was presented during the event.

SEE Universe 2020 Space conference and SERBSPACE were presented at the Fifth China International Commercial Aerospace Forum in Wuhan by myself, president of SERBSPACE, which took place on 19 and 20 November 2019. The forum aims to gather elites and quality resources in the field of commercial aerospace to discuss technological achievements and innovative ideas, explore development paths and boost industrial resources integration and rapid development of the commercial aerospace industry.

As the March of 2020 slowly but surely arrived, preparations for the SEE Universe 2020 Space conference reached its peak, as the Conference was scheduled for 2-3 April of 2020. Just two weeks before the event in April, the COVID 19 virus pandemics was officially declared, and the State of emergency was introduced in Serbia putting everything and everyone on hold until further notice. As the situation improved, SERBSPACE decided to go ahead and to organize an online event which finally took place from 30 September to 2 October 2020.

3. CONCLUSION

Planet (of the) Lost

There is no person, no resident of the "modern" world, who did not expect flying cars, a cure for all diseases, and the colonization of outer space by the end of the 20th century. All that, today, leaves a bitter taste in our mouth, a taste of collective failure which, and to make matters worse, <u>we refuse to admit</u>, but rather act like the eternal student and an even more eternal professor who deliberately keeps on failing us on the exam because we are protagonists in a strict conspiracy named “The professor must hate me”. That failure towards the general better, even degradation in numerous spheres, including not only the technological and scientific aspect, but also the societal and humanistic, is the fault of all of us, culminating under the shout “I can't change anything here”. From the mantra to the everyday anthem, fueled by the irrelevance of the individual, scraping around the developed and highly sophisticated dystopian consumer system of the 21st century, the human has found himself in a new existential crisis, but this time it could not be justified by flying on the wings of modernism which the 20th century dictated, but rather disguised by various television channels and social networks, all in accordance with the good old proven recipe *panem et circenses*. It was hard to believe that from the first lyrical works that had the theme of a car accident at that time, as something unseen until the beginning of the 20th century, in just a few decades (and two world wars later) man would fly at supersonic speed on commercial flights and blaze among the stars, relentlessly leaving the brave Wright brothers in the dust of an unstoppable technological revolution. This incredible 20th century, at least in terms of the fastest and most comprehensive technological development ever, tragically stagnated as early as the 1990s, leaving a human accustomed to an exciting tomorrow in a grey confusion of preparation for the 21st century. This downfall, reflected in the recycling and slight improvements (used for wrong intentions many times) of already existing technology, has pushed humanity into perhaps the only novelty of the 21st century, and that is a constant feeling of collective incompetence, hypocrisy and finally ultimate failure. And that collective decline and the incidental consequences of neglecting science will soon resonate with probably every person on the planet, as early as in early 2020, when less than two months after the outbreak, the new Corona virus brought the entire human world to its knees, especially the “modern” parts of the world, threatening to take us all back to the Stone age: politically, economically, socially, and most of all morally and ethically.

Yes, the 21st century, so furiously anticipated and filled with unlimited human imagination towards the glorious tomorrow, seems to get lost somewhere, and in the process lost its touch with knowledge, education, science and above all with human mind, leaving us waiting for some brighter future in years or centuries that might follow or be followed.

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SPACE SCIENCES

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Abstract: Panel "Space Sciences" was attended by moderator and 4 speakers who represented all segments covered by the conference: Academia, Industry and Societies. Various topics were discussed, such as: Space Science in Serbia and in the region, Experiences in international projects and examples of cooperation, Connection between science, industry and society and the future of Space Sciences in Serbia.

Keywords: space exploration, space law and policies, remote sensing, earth observation, mechanics and engineering, satellite applications

1. INTRODUCTION

During the first day of the conference, a Space Sciences panel was held. The panel was attended by moderator and 4 speakers (the authors of this report) who represented all segments covered by the conference: Academia, Industry and Societies. The main idea of this panel was to acquaint the conference participants with the current state of Space Sciences in mentioned segments in Serbia, as well as opportunities for cooperation, developed projects, experiences and more. This report will be divided into several sections according to the questions answered and discussed by the panel participants.

2. AVAILABILITY OF SPACE RELATED ACTIVITIES IN SERBIA

Majority of people here in Serbia, but also in other space developing countries, consider space science and space related activities as something that is unreachable to an everyday man. Lot of people think about this is all connected to Moon missions, Mars missions, rocket science and other very expensive endeavours, but today it is not just that, it is much more. Today the emphasis has changed from these large-scale missions to smaller missions and Near-Earth Objects (NEO) utilization. Pre-condition tool to understand space segment today is that today everything “revolves” about satellites and usage of satellite data for various purposes. In this light, we all are slowly starting to get acquainted with benefits of this programme especially of some of them that are free for use such as Copernicus or UN Charter programme and all the benefits we can get from them. Today, at the NGO sector, academic institution, and small and medium enterprises we are witnessing introduction and utilization of such programmes. In other words, this is our own battle we need to fight and research and develop different tools for using and exploiting the data that today is mostly easily accessible on internet and free for use.

3. EXPERIENCES REGARDING THE IMPLEMENTATION OF INTERNATIONAL PROJECTS IN SERBIA IN THE AREA OF SPACE R&D

Space Sciences, as they are defined, cover extremely wide field of science and there are many reasons why people come to it or are motivated by it. We can list just a few examples for space research and development (R&D). First one, simply, curiosity driven research like: why is the Universe the way it is, what are the laws or fate of it, how do planetary systems form, what are the conditions for life etc. This is mostly covered by sciences like physics, astronomy, and astrophysics. The second motivation can be exploration, since there are always people who are driven by the wish to explore new frontiers in space. So, we have manned space mission, and now maybe even more then before unmanned space missions and additionally very long unmanned space voyages, where there must be incorporated many different areas of science like artificial intelligence, engineering etc. Third reason could be monitoring Earth’s environment, for example space telescopes could be focused outside or inwards and in the case of the latter we can research and look at the things like radiation belts, ionosphere, ozone layer, understanding climate change etc. Then, the fourth one could be something completely different like the direct economic benefit that can be very interesting to certain people and/or organizations. Today we are quite aware of satellite and communication evolution, we know how important global positioning systems are and in very near future we will have mining of various materials from space objects. Then there are the long-term technological challenges like solar sails, ion drives, space elevators and limited terraforming, depending how far you are looking to the future. These kinds of challenges can spur similar effect, that, for example, we had going to the Moon fifty years ago. The next reason that we want to mention here as motivation for space R&D is managing existential risks. That means as first step classifying existential risks and the next one would be classifying the responses that civilization can take to mitigate those risks. In addition, one could mention a few more important areas of research, such as modifying terrestrial life for extra-terrestrial conditions, search for extra-terrestrial life, and various military applications.

When we look at Space Science, we should look at it through at least these 8 prisms. If we try to visualize this approach, we could arrange them on a graph where these motivations for space R&D are on x-axis and time is on y-axis in the sense of how far that is in the future for countries like Serbia and others in the region. First layer would be to use the things that have already been implemented in these countries and this means that we can "start small". Curiosity driven research, monitoring Earth's environment and even managing existential risks are among those that have already been developed here in Serbia, but certainly need to be expanded upon in the future. Next layer are the areas where we could contribute but still, we are not part of them. They are of importance for our country, and similarly for some other countries in our region, because there is dichotomy between research and industry and this layer could be very important in bringing these two sides together. For example, here we can talk about long term challenges. Huge projects such as solar sails or space elevators can incorporate small partners and slowly bring in commercial sector in those countries. We have necessary expertise and now we have to create multidisciplinary teams, and hopefully cross-border teams in our region, for tackling this problem in certain ways. The next layer are the projects where organization or company or country need to be partners in very large collaborations in order to contribute and for that more mature hi-tech sectors are needed, and motivations for space R&D of that type are, for example, exploration and direct economic benefits. The fourth and last layer is something that could be used in defence or military applications. Taken through these x and y axes we can look at various types of problems or ideas for research. First type, such as those curiosity driven problems, or more theoretical research, or analysis of data that is available, have already been introduced in Serbia and we are already participating in this kind of R&D. Things like measuring the ionosphere, looking at the changes in the ozone layer and in the radiation belt and better understanding of climate changes are among those that are being researched at on the Institute of Physics in Belgrade, while astrophysics and cosmology and some other of the curiosity driven research are developed at the Astronomical Observatory in Belgrade. In all these things we are making the first steps, but there are some problems like for instance that Serbia is not a member of European Space Agency (ESA) and currently we are working on solving this problem. For now, we are partners in many Horizon projects, and we are sure that membership in ESA will significantly raise the number of successful space segment projects in Serbia. Next step is that we start thinking about technological challenges and to bring researchers, engineers and financial experts involved around certain well-defined and very ambitions international technological challenges. In this way we can substantially increase the number of international projects and collaborations in the field of Space Science.

4. THE FUTURE OF SCIENCE IN THE SPACE SEGMENT IN SERBIA AND IN THE REGION

To better understand the situation we are currently in, we can add another dimension or the third axis to the previously mentioned two-axes visualization of Space Science. The third axis could be dubbed created value. We know that different items, ideas, or projects on different timescales have different capacity for creating values. When we talk about space in general, and Space Science and technology, we need to think about all the relevant scales: temporal scales, spatial scales, and the resource scale, and we need to see how any activity can scale up to larger amount of space and further in time. In that sense, we fully endorse the mentioned key topic which is networking. Big "space" projects are not supported by single country, but it is always some sort of collaboration on different levels, both in terms of vision and investment. This happens in the space segment, as well as in other fields of human endeavour in general, including economics, quality of life, ecology, etc. Among other ideas, we need to think about local and regional integration into wider networks, first on European level and then at the global level as well. Many of those motivations and incentives that were mentioned previously are something which is, by definition, of global character. For example, investigating and possibly mitigating climate change is a priori global problem which cannot be resolved locally. Additionally, this problem can be extended by the lack of public understanding and deepened further by the lack of understanding of the problem in circles of people who are decision makers, fundraisers, and those who do not have sufficient knowledge and understanding of the problems involved. Therefore, we encounter many difficulties, like simply correctly measuring and reporting concentration of anthropogenic greenhouse gases. Networking and integrating in wider networks, in both organizational and commercial ways, is a necessary way to go.

We don't need to emphasize too much how the international collaboration is crucial for science itself, but also for engaging in projects which go well beyond the science; and not just into industry, but toward some sort of very big problems that are transgenerational. We should not discount problems, like climate change, in a way that it will be resolved by future generations, instead we need to work together to challenge and change this atmosphere of endless delays. This means a more future oriented view in research, in education and in public outreach is needed. This will immediately lead to understanding how the future of all humanity, lies in *space*. As Tsiolkovsky said: "The Earth is the cradle of mind, but one cannot live in a cradle forever." So, when we scale up all these problems, but also opportunities and benefits, to truly cosmic scales, we can expect to create maximum value which is obviously our goal in both cognitive and ethical terms.

As soon as we understand the nature of the problems and the nature of opportunities, we are on the way of helping global and transgenerational enterprise which is building sustainable human future. This in general is in space, but it does not necessarily mean beyond Earth. Quite to the contrary, probably the only way to build ecologically sustainable Earth environment is to transfer some of the Earth's industry, and problems which we created, into space by utilizing cosmic resources. In a long term, meaning 10 generations from now, that people will be completely puzzled and surprised that we could ever not think that space is our priority.

5. EXAMPLES OF INTERNATIONAL COOPERATION WHICH OFFER THE GREATEST BENEFITS AND PERSPECTIVES IN SERBIA AND SEE REGION

When we talk about the examples, we can single out those that have the most practical applications in space technologies, such as utilization of space monitoring, Earth observation programs like Copernicus, and global positioning systems like Galileo. These applications are essentially becoming part of everyday life of all citizens, whether they are aware or not, as space technologies are used for agriculture, smart transportation systems, weather forecast, meteorology, and so on. Global cooperation in the field of exchange of data from weather stations and global network of meteorological satellites and combining them with Earth observation, produces huge savings in purely financial terms just by having more accurate weather forecast.

The first and the simplest way to work on space applications is to raise to a next level what we currently have. We need to have region wide partnerships for building a critical mass related to monitoring Earth's environment. For now, each country, or in some cases institutions, in our region has ongoing efforts to do this, so we need to follow examples of other European regions and build partnerships in order to bring better quality of research and economic benefits for our region. The second level of examples of international cooperation should be connected to the potential responses to existential threats. A lot has been done at the level of strategies on what should be done and identifying the risks, so the next step that is completely feasible in our region is to start looking into the roadmaps on how to mitigate these potential threats. We need to work on and make these roadmaps together and that would be a fantastic contribution to a problem that certainly is transgenerational. Directed evolution is one of the most promising ideas on how to deal with future threats of that kind and this means to create or modify existing microorganisms for use in environments outside the Earth. This includes huge series of multidisciplinary questions including ethical issues. Our region has already shown competence at global level in working toward those ideas. We have witnessed a computer revolution a few decades ago, but the new genomic revolution is not necessarily going to happen in large institutions but instead in small collectives in various places, and we have already seen a lot of success done in our region, mostly from some companies in Slovenia. When we talk about space elevators, mentioned before in the text, we are talking about a great technological challenge that led to lot of scientific and technological discoveries, and it has wonderful results in motivating young people to turn to science, which is something we lack in our country, but we are confident that we and everyone else will overcome this problem. Finally, we can talk about things like long term travel, where probably the best way to do this is to build unmanned probes with incorporated artificial intelligence that would have proper decision making in order to work in space in prolonged time, even when there is no, or little, contact with Earth. The region we are in is competent in development of artificial intelligence in comparison to global arena, and Space Science offers great opportunities in connecting people from different disciplines to further develop some new concepts that will ultimately lead to some technological breakthrough like long term space travel. Things like this have some components where our region can make immediate contribution, which will be good for the global effort and beneficial for our region for building self-confidence, cooperation, and growth of the high-tech sector.

When we talk about projects of this magnitude, like space travel, we have to think about a few very challenging issues, which are the human resources and infrastructure that exists here or somewhere else. We need good scenarios how to connect people from different areas of interest and how to properly and effectively use the infrastructure together. The great results cannot be achieved in one leap, but the first step is to make good approach to this problem, assemble good team and define goals that need to be done. There are already good role-models and examples of such attempts in the European Union from which we can learn much. It is important to stress that we have human resources and necessary infrastructure so the next goal should be integrating larger number of institutions and different infrastructures to pursue the same goal. That’s why we need to emphasize, one more time, the importance of networking, team building and collaborations in order to achieve this.

There is another perspective from which we should look at the mentioned ideas about at least some of the big technological breakthroughs and that is space law. If we take as an example asteroid mining and legal status of excavating materials from outer space, international community agrees that this is in the so-called gray zone, and that there are lot of things that need to be done. To add another argument to this there are already several nations who have issued national legislation which allows them to have full ownership rights on anything “they excavate outside of Earth”. So, in this light we can probably expect the all the nations will join the next space race at least in the space law perspective. The international community is currently working on the changes and modifications of the Outer Space Treaty, which entered into force in 1967. The new changes should reflect on the new technologies we have today and those that will be available in near future, like private space missions, asteroid mining, modifications of other planets and natural satellites in Solar system etc.

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INDUSTRY 4.0 - INNOVATION & INVESTMENTS

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Abstract: Industry 4.0 - Innovation & Investments panel was attended by moderator and 4 speakers who represented all segments covered by the conference: Academia, Industry and Societies. Various topics were discussed, such as: education and research in the context of Industry 4.0, readiness of Serbian industry for the application of Industry 4.0, Industry 4.0 and industrial policy, digitization in large organizations in Serbia and platform Industry 4.0 for Serbia.

Keywords: Industry 4.0, education, industrial policy, national platform

1. PANEL: INDUSTRY 4.0 – INNOVATION AND ECONOMIC GROWTH

Moderator: Prof. Dr. Radivoje Mitrović, Dean, Faculty of Mechanical Engineering, Belgrade discussed about activities of the Faculty of Mechanical Engineering in education and research in the context of Industry 4.0. In the introduction, Mitrović explained the basic concept of Industry 4.0 and listed the activities of the Faculty of Mechanical Engineering in the field of engineer education, research, and development of Industry 4.0. On October 1, 2020, the Faculty of Mechanical Engineering introduced Industry 4.0 Master Studies, whereas there are several subjects in this field at undergraduate, master's and doctoral studies. There are also several projects regarding Industry 4.0 that the Faculty of Mechanical Engineering is working on.

Participants: Prof. Dr. Vidosav Majstorović, Faculty of Mechanical Engineering, Belgrade discussed about readiness of Serbian industry for the application of Industry 4.0. Majstorović presented research on this topic, which included 49 SME production organizations from Serbia. A developed model with ten criteria was presented, which showed that organizations are most ready / interested in the application of this model in production, then in procurement, sales, product, and technology design, etc. Strategy Criterion was the lowest ranked, which means that the awareness of the importance of Industry 4.0 for the organization is not acceptable to the top management of the same.

Prof. Dr. Dragan Đuričin, Faculty of Economics, Belgrade discussed about Industry 4.0 and industrial policy. Đuričin talked about the model of national industrial policy in the conditions of the Covid 19 pandemic for the application of Industry 4.0. He especially emphasized the importance of the so-called "Double we" model for managing economic growth of the country's economy, which is based on supporting the growth and development of the ICT-based sector, which includes Industry 4.0 with the application of this concept and in production with new added value.

Vojin Vukadinović, Director of IT Sector, Company Metalac, Gornji Milanovac discussed about digitization in large organizations in Serbia. Vukadinović presented the Digitalization Project of Metalac. It has the following modules: CAD / CAM, PLM, SCM, CRM, ERP, MES, finance and bookkeeping. These modules make up the Industry 4.0 model infrastructure for this organization. Work is now underway to develop and implement IoT for work order management.

Vidosava Džagić, PKS-PKB, Belgrade discussed about platform Industry 4.0 for Serbia. Džagić presented the framework and elements of the National Platform for Industry 4.0, which was adopted at the AMP Conference in 2019, on Industry 4.0 organized by Faculty of Mechanical Engineering in Belgrade.

2. INDUSTRY 4.0 - HISTORY OF DEVELOPMENT IN SERBIA

Industry 4.0 has become a global international project today, and it all started in 2011, when the Program of Scientific and Technological Development of German Industry called *Industie 4.0* was presented at CEBIT in Hanover.

Today, in March 2021, 37 most industrialized countries in the world have their national programs: Europe (21), America (5), Africa (1), Asia (8) and Oceania (2).

The Faculty of Mechanical Engineering in Belgrade has initiated and held five Conferences since 2016 - International Conference on the Industry 4.0 model for Advanced Manufacturing - AMP I4.0. Proceedings were published by Springer[1].

Serbia adopted its national Program for Industry 4.0 on June 6, 2019, at the 4th International Conference on the Industry 4.0 model for Advanced Manufacturing - AMP I4.0 2019, entitled: Digital Platform for Industry 4.0 in Serbia.

So far, the Faculty of Mechanical Engineering in Belgrade with its partners (Ministry of Education, Science and Technological Development, Ministry of Economy, Ministry of Defence, PKS, PKS-PKB, Faculty of Technical Sciences in Novi Sad, Faculty of Mechanical Engineering in Nis, Science and Technology Park from Belgrade, Faculty of Mechanical Engineering and Civil Engineering from

[1] https://link.springer.com/book/10.1007/978-3-030-46212-3

Kraljevo, Faculty of Engineering, Kragujevac, Faculty of Economics in Belgrade, Institute “Mihajlo Pupin”, Institute “Vinča”, and others) held 29 Panels on Industry 4.0 (see Table 1 and 2).

Table 1: Overview of the number of participants in the Panels by venue.

No.	*Name and venue*	*Number of panels*	*Date*	*Number of participants*
1.	Faculty of Mechanical Engineering, Belgrade	6	2015 – 2019	215
2.	The International Conference on the Industry 4.0 model for Advanced Manufacturing - AMP I4.0, Belgrade	5	2016 – 2020	190
3.	Faculty of Mechanical Engineering, Niš	1	December 2017	35
4.	Science and Technology Park, Belgrade	1	June 2018	45
5.	International Conference IRMES, Trebinje	1	February 2018	60
6.	Faculty of Technical Sciences, Novi Sad	1	March 2018	50
7.	International Conference IEEP, Zlatibor	1	June 2018	95
8.	Company “Metalac”, Gornji Milanovac	2	April 2018, October 2019	120
9.	Company “Sloboda”, Čačak	1	February 2019	85
10.	International Conference Danube Strategy, Novi Sad	1	September 2019	55
11.	Kopaonik Business Forum	2	March 2019, March 2020	190
12.	Faculty of Mechanical Engineering and Civil Engineering, Kraljevo	1	November 2019	65
13.	Faculty of Engineering, Kragujevac	1	December 2019	40
14.	Technical Faculty, “Mihajlo Pupin”, Zrenjanin	1	January 2020	65
15.	Regional Chamber of Commerce of Rasina Administrative District, Kruševac	1	February 2020	70
16.	International Conference "SEE Universe 2020" Belgrade (online)	1	October 2020	65
17.	Company “Inmold”, Požega (on site + online)	1	October 2020	95[2]
18.	Faculty of Technical Sciences, Science and Technology Park, Čačak (online)	1	November 2020	55[3]
19.	Technical Faculty, Bor (online)	1	April 2021	61
	Total	**29**		**1656 + 686**[2,3]

[2] Additionally, 189 views on YouTube until 28.11.2020.
[3] Additionally, 497 views on YouTube until 28.11.2020.

Topics discussed at the Panels were:
- Industry 4.0 - basics and models,
- Industry 4.0 and new industrial policies in the world - an overview,
- New Industrial Policy of Serbia,
- Industry 4.0 and intelligent products,
- Industry 4.0 and the Internet of Things,
- Industry 4.0 and large data set analysis,
- Industry 4.0 for SMEs,
- Industry 4.0 and engineer education,
- Industry 4.0 and the rapid growth of the industry,
- National programs for Industry 4.0,
- Digital platform for Industry 4.0 in Serbia,
- Digitization in Serbian industry - examples,
- The path from idea to finished products through the process of digitization,
- Industry 4.0 in the process industry,
- Education for Industry 4.0,
- Industry 4.0 and accelerated economic development of Serbia,
- Industry 4.0 and Space exploration,
- Industry 4.0 - an example of best practice Inmold, Požega,
- Industry 4.0 - examples of best practice from the economy of Čačak,
- Industry 4.0 - examples of research at TF Bor, application in mining, medicine and dentistry.

Table 2: Overview of the number of participants in the Panels according to stakeholders

No	*Panel - Stakeholder*	*Number of Participants*	*Percentage*
1.	Academia (Faculties, Institutes), Educational institutions, NGOs	455	28 %
2.	Decision makers (Government, Ministries, Chamber of Commerce)	185	10 %
3.	Economic sector	1031	62 %
	Total	1671	100 %

Today we can proudly say - INDUSTRY 4.0 LIVES IN SERBIA!
Next panels to be held:

1. 30. online Panel I4.0 – FEFA faculty, Belgrade – 20th April 2021.[4]
2. 31. online Panel I4.0 – Kopaonik Business Forum – 25th May 2021.[5]
3. Planned Industry 4.0 Panels are: Bilateral Panel Serbia - Slovakia, Bilateral Panel Serbia - Germany, Bilateral Panel Serbia - Slovenia, University of Novi Pazar; Faculty of Dental Medicine in Belgrade, and others.

Welcome to Industry 4.0 in Serbia - more information at
www.mefics.org or www.mas.bg.ac.rs.

[4] https://www.fefa.edu.rs
[5] https://www.kopaonikbusinessforum.rs/speakers

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ACCESS TO SPACE FOR ALL: AN INITIATIVE OF THE UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS

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Abstract: The Office for Outer Space Affairs manages and implements the program on the peaceful uses of outer space, which is aimed at strengthening international cooperation in space activities and in the use of space science and technology for achieving sustainable development, and represents the United Nations in promoting international cooperation in the exploration and peaceful uses of outer space for economic, social and scientific development, in particular for the benefit of developing countries. The Office discharges these responsibilities by, among other duties, implementing the Program on Space Applications, which has been created in 1971. The program was created to increase awareness about the benefits to be derived from the applications of space technology and today provides capacity-building in the form of conferences, training courses, advisory services, fellowships, and hands-on opportunities.

The Office for Outer Space Affairs launched the Access to Space for All Initiative in 2018 providing research and orbital opportunities for United Nations Member States to Access Space. Under the Initiative, the Office for Outer Space Affairs has been collaborating with spacefaring governmental, intergovernmental, and private sector entities to open ground- and space-based facilities to all Member States of the United Nations for micro- and hypergravity experiments, space missions, and human spaceflight-related activities.

This report presents the objective of the Initiative and the specific achievements of its different opportunities as of end of 2020. Lessons learnt also guide the development of new actions for future cycles and new partnerships.

Keywords: Smallsat, microgravity, hypergravity, exploration, United Nations

1. ACCESS TO SPACE FOR ALL INITIATIVE

The goal of the Access to Space for All Initiative is to provide research and orbital opportunities for United Nations Member States to access space and to ensure that the benefits of space, for sustainable development, are truly accessible to all. To fulfil this goal, the opportunities have been organized in three different tracks which enable progressive capacity development:

- Hypergravity and Microgravity Track,
- Satellite Development Track, and
- Exploration Track.

As opposed to individual opportunities, The Tracks have been created to deliver progressive sustainable and responsible hands-on capacity on space technology development from start to the end, by grouping existing opportunities and identifying gaps that the Office is striving to close.

Partnership is a distinctive feature of the Initiative. The Access to Space for All Initiative is only possible owing to the partnerships with various public and private actors, who are contributing to the Initiative in various manners. New contributions to the Initiative are possible and encouraged.

The number of opportunities is different from track to track. The Hypergravity and Microgravity Track currently has the highest number of opportunities available, with five programmes. The requirements for applicants vary from opportunity to opportunity, although, in general terms, the Initiative is mainly addressed to developing countries, rendering accessible opportunities that otherwise would be difficult to access or too costly and to provide the building blocks to start building capacity towards more complex experimentations in a structured manner. To that effect, the Hypergravity and Microgravity Track has been designed to provide a full range of facilities, from ground to orbit, to help acquiring the skills and knowledge to develop experiments in orbit, while the Satellite Development Track currently provides two opportunities which require a different degree of expertise and enable the deployment of different sizes of CubeSats. The Office has also identified the Exploration Track to provide hands-on opportunities for space technology development related to space exploration. Currently there are no opportunities under the Exploration Track, but the Office is already discussing with some potential partners to fill this gap.

The Office for Outer Space Affairs strives to support the monitoring and achievement of the 17 Sustainable Development Goals (SDGs), part of the 2030 Agenda for Sustainable Development and requires that applicants make the link between what they try to achieve and the SDGs. In the years that the Initiative has been active, the Office has received applications relevant to all the targets of the SDGs, including developments for improving the communications in areas subject to disasters using CubeSats, cancer prevention and treatment, or the development of high efficiency solar cells. Therefore, the importance of the Access to Space for All Initiative transcends the development of space capabilities, as the skills that are acquired through the participation in the opportunities are multi-purpose and can be used in a wide range of other fields.

2. AREAS OF RESEARCH CONDUCTED UNDER THE INITIATIVE

The Office has offered opportunities since 2010, however, it is only in 2018 when the Access to Space for All Initiative was launched. Considering the opportunities provided under programs that are still active and now under the Initiative, there have been winners from 28 different countries, and of one organization that groups 8 countries.

The areas of interest are varied, covering many different aspects of space science and technology, such as:

- Three projects in biology, microbiology, biotechnology, and biophysics have direct or indirect application in food supply for space exploration, agriculture and food security on Earth, medicine, epidemiology, and public health.
- Eight projects are innovative in physics and chemistry studies, including in material science, fluid dynamics, thermodynamics, or nuclear physics.
- Ten engineering and technology experiments have applications in space exploration, satellite development and operations such as Earth observation and telecommunication, 3D printing in space and others.
- Two projects in astronomy and five with applications to monitor climate change impacts and other indicators of development.

Many of the winning projects are cross-sectoral and can deliver results of interests in other areas of applications.

Scientific selection committees of each opportunity approved projects from high schools, colleges and universities, national and regional research and development institutes and agencies, space agencies, societies, and research councils in all three Tracks.

The following sections provide an overview of the highlights for each Track during 2020 and associated opportunities during 2020.

3. HYPERGRAVITY AND MICROGRAVITY TRACK

The objective of this Track is the development of hands-on capacity to develop experiments under different gravity conditions.

Hypergravity is when the acceleration force is larger than the gravitational force equivalent of 1g, while microgravity is when the acceleration forces are of the order of 1 millionths of the Earth gravity (mg). Experiments under varying gravity can help to prove theories, reveal unexplained phenomena, and develop new technology.

Through the opportunities offered in the Hypergravity and Microgravity Track, in partnership with different entities, teams from all over the world have been able to run experiments on engineering, such as the development of mechanisms to dump oscillations of tethers in satellites or understanding the behavior of a reduced-scale robotic arm manipulator. There have also been experiments in material science, such as the analysis of the mechanical features of nitinol alloy, a biocompatible material, super elastic, and intelligent material with “shape-memory”, and experiments related to medicine and microbiology, such as the one on a method to develop increased antimicrobial activity in medicine droplets. To complement the experiments, the Office provides theoretical knowledge to ease access for countries with no capacity related to hypergravity/microgravity experimentation.

3.1. DROPTES[1]

3.1.1. PROJECT OUTLINE

The Drop Tower Experiment Series (DropTES) program is done in partnership with the Centre of Applied Space Technology and Microgravity (ZARM) and the German Aerospace Centre (DLR). DropTES allows student teams from non-spacefaring countries to learn and study microgravity science first-hand by performing experiments at the Bremen Drop Tower in Germany. This drop tower is a ground-based laboratory with a drop tube of a height of 146 meters, which can enable short microgravity experiments to be performed in various scientific fields, such as fluid physics, combustion, thermodynamics, and material science. Each experiment consists of four drops or catapult launches within a one-week period. The entire program is aimed at contributing to the promotion of space education and research in microgravity.

3.1.2. IMPLEMENTATION

Six rounds have been successfully implemented and the winning teams between 2013 and 2019 were from Jordan, Bolivia, Costa Rica, Poland, Romania, and Italy. The experiments conducted range from technology demonstration to medical science and material science. The seventh-round winning team selected in April 2020 is from Universidad Católica de Bolivia, with an experiment to analyze the feasibility of a new 3D printing extruding technique in microgravity. The series of experiments has been postponed to 2022 due to the COVID-19 pandemic.

3.2. CHINA SPACE STATION[2]

3.2.1. PROJECT OUTLINE

The Cooperation on the Utilization of the China Space Station (CSS) is done in partnership with the China Manned Space Agency (CMSA). This program provides scientists from around the world with an opportunity to conduct their own

1 United Nations Office for Outer Space Affairs, Fellowship Programme for "Drop Tower Experiment Series" (DropTES), https://www.unoosa.org/oosa/en/ourwork/psa/hsti/capacity-building/droptes.html

2 United Nations Office for Outer Space Affairs, The United Nations/China Cooperation on the Utilization of the China Space Station (CSS), https://www.unoosa.org/oosa/en/ourwork/psa/hsti/chinaspacestation/ao_main.html

experiments on board CSS. There are three ways to conduct experiments in this program; the first is conducting experiments inside the CSS by utilizing experiment payloads to be designed and developed by the selected applicants, the second is conducting experiments inside the CSS by utilizing experiment payloads already provided by CSS, and finally, conducting exposed experiments outside the CSS by utilizing exposed experiment payloads. It is an innovative and future-focused program to open up space exploration to all nations and to create a new paradigm in building capabilities in space science and technology.

3.2.2. IMPLEMENTATION

A total of forty-two applications from organizations in twenty-seven countries were received and nine experiment projects were selected in the first round in June 2019. This program was innovative in a way that many projects were submitted by multi-national teams. The Office for Outer Space Affairs and CMSA are working together to organize a second round for this opportunity.

3.3. HYPERGES[3]

3.3.1. PROJECT OUTLINE

The Fellowship Program on the Large Diameter Centrifuge Hypergravity Experiment Series (HyperGES) is done in partnership with the European Space Agency (ESA). The fellowship program aims at providing opportunities for scientists and researchers with a team of students from Member States of the United Nations, with particular attention to developing countries, to conduct their own hypergravity experiment series at the large diameter centrifuge facility located at the European Space Research and Technology Centre (ESTEC) of ESA in Noordwijk, the Netherlands. The entire program is aimed at contributing to the promotion of space education and research to understand and describe the influence of gravity systems.

3.3.2. IMPLEMENTATION

The first cycle for HyperGES opened in the second half of 2019 with the selection of the winner taking place in the beginning of 2020. The winner of this cycle is a team from the Faculty of Science of the Mahidol University, Thailand, with a proposal to study the effect of hypergravity on wolfilia, commonly known as watermeal or duckweed, a type of aquatic plant, with the aim at using it as a source of food and oxygen for space exploration. The experiment has been postponed to 2022 due to the COVID-19 pandemic.

[3] United Nations Office for Outer Space Affairs, United Nations/European Space Agency (ESA) Fellowship Programme on the Large Diameter Centrifuge Hypergravity Experiment Series (HyperGES), https://www.unoosa.org/oosa/en/ourwork/psa/hsti/ldc_hyperges/ao_main.html

3.4. BARTOLOMEO[4]

3.4.1. PROJECT OUTLINE

The opportunity to accommodate a payload on the Airbus Bartolomeo external platform aboard the International Space Station (ISS) and to have the All-in-One Mission Service is opened in partnership with Airbus Defence and Space GmbH. Bartolomeo is an external platform on the ISS European module. It allows the hosting of small and medium size payloads, with different viewing conditions, offering hosting that can point to Earth or to space. It provides the highest data downlink rate on the ISS and the payloads can be controlled and data retrieved through the Airbus Cloud.

3.4.2. IMPLEMENTATION

The opportunity opened in 2019 and was closed in April 2020 with the reception of proposals from eighteen countries and twenty-nine institutions. The selection process is ongoing at the date of the drafting of this report. The winner of the first round will be selected among the three higher-ranked proposals and will be announced in the last quarter of 2020.

3.5. DREAM CHASER[5]

3.5.1. PROJECT OUTLINE

The opportunity to participate in an orbital space mission utilizing the Dream Chaser® space vehicle of Sierra Nevada Corporation (SNC) is under preparation. The Dream Chaser is the only runway landing space vehicle actively in development is designed to launch on a variety of launch vehicles. It can carry experiments, payloads, or satellites provided by institutions in the participating countries.

3.5.2. IMPLEMENTATION

In 2017, a call for interest was launched to assess the feasibility of a free-flight mission and have a preliminary understanding of the types of payloads to plan for. The results exceeded the expectations with one hundred fifty responses from seventy-five countries. At the International Astronautical Congress of 2019 in Washington D.C., the United States of America, a call for interest for landing sites was launched. The call was open until the end of April 2020. Applications from seven countries have been received. This marks a milestone in the effort of the

[4] United Nations Office for Outer Space Affairs, Accessing Space with the ISS Bartolomeo Platform, https://www.unoosa.org/oosa/en/ourwork/psa/hsti/orbitalmission/bartolomeo/index.html
[5] United Nations Office for Outer Space Affairs, Orbital Space Mission, https://www.unoosa.org/oosa/en/ourwork/psa/hsti/FreeFlyer_Orbital_Mission.html

Office for Outer Space Affairs and SNC towards the opening the announcement of opportunity for the utilization of the Dream Chaser.

4. SATELLITE DEVELOPMENT TRACK

The objective of this Track is the development of hands-on capacity for satellite development.

Despite being as small as 10 cm x 10 cm x 10 cm, CubeSats have a large variety of uses. They can capture images of Earth; they can be used as testbeds for new technologies or help us understand the space environment, among many other applications. They may also allow and encourage a country to establish the essential mechanisms for a larger space program in compliance with international law and regulations and develop engineering and human capacity and getting acquainted with the space systems engineering processes and necessary tools within the development cycle.

As many of their components are readily available, CubeSats are affordable to develop, therefore a very accessible entry point. In this line, the Committee on Space Research (COSPAR) has identified several recommendations concerning small satellites, noting that scientific communities from small countries may benefit from investing their budgets in small satellites.

To complement the experiments, the Office provides theoretical knowledge to ease access for countries with no capacity related to developing CubeSats through webinars, symposiums, and fellowship programs. In 2018, the Office co-organized with the Government of Brazil to hold the "United Nations/Brazil Symposium on Basic Space Technology: Creating Novel Opportunities with Small Satellite Space Missions" which reviewed the status of capacity building for small satellites, examined issues relevant to the implementation of small satellite programs, and elaborated on regulatory and legal issues on the space technology development programs. Currently, the Office and the Government of Japan in cooperation with the Kyushu Institute of Technology (Kyutech) have established a United Nations/Japan Long-term Fellowship Program on Nano-Satellite Technologies for nationals of developing countries or non-spacefaring nations. The Program provides extensive research opportunities in nano-satellite systems using the nano-satellite development and testing facilities available at Kyutech.

The following section provides a list of the opportunities available under this track and the progress in 2020.

4.1. KIBOCUBE[6]

4.1.1. PROJECT OUTLINE

The Cooperation Program on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE" is offered in partnership with the Japan Aerospace Exploration Agency (JAXA). KiboCUBE provides educational and research institutions from developing countries with the opportunity to develop a CubeSat and have it deployed from the Japanese module “Kibo” of the International Space Station. Thanks to the lower vibration and more benign environment during launch, KiboCUBE lowers the threshold for countries to enter space activities and contributes to national capacity development in spacecraft engineering, design and construction, inspiring new generations of scientists and engineers.

4.1.2. IMPLEMENTATION

The Central American Integration System (SICA) was selected as the winner of the fifth round, with a proposal of a communications satellite for emergency situations. Besides SICA, there are three CubeSats, from Indonesia, Mauritius and Moldova respectively, that are currently in development. In April 2020, the second-round winner Guatemala deployed Quetzal-1, the first satellite of the country into orbit. The deployment ceremony was conducted online on 28 April due to the COVID-19 pandemic and was covered by national and international media. It is also worth noting that the first satellite deployed thanks to KiboCUBE, from Kenya, 1KUNS-PF, re-entered the atmosphere in June 2020 after having successfully completed more than ten thousand orbits. It produced many beautiful images and temperature/ velocity data from the on-board components.

4.2. VEGA C[7]

4.2.1. PROJECT OUTLINE

The Cooperation Program on Access to Space by utilization of the Vega C launcher is offered in partnership with Avio S.p.A. This opportunity will put into orbit a CubeSat or aggregates of CubeSats of maximum 3U developed at educational or research institutions from developing countries which are United Nations Member States.

[6] United Nations Office for Outer Space Affairs, The United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE", https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

[7] United Nations Office for Outer Space Affairs, Accessing Space with VEGA-C, https://www.unoosa.org/oosa/en/ourwork/psa/hsti/vegac.html

4.2.2. IMPLEMENTATION

The Office and Avio S.p.A conducted a webinar in July 2020 to raise awareness of the opportunity and another webinar in October 2020 to announce the opening of the Announcement of Opportunity. To ease the process of partnership development, the Office made available an innovative matchmaking tool so interested institutions can advertise their interest in partnering and the type of partner they look for in the context of this opportunity.

5. EXPLORATION TRACK

The Office is interested in developing capacity related to exploration missions, both on ground through opening access to analogue facilities, and in exploration missions beyond the geostationary orbit with the objective of developing hands-on capacity in these areas. The Office is in initial discussion with potential partners.

6. GAPS

It is worth noting that the Tracks, in addition to provide a structured learning path, also allow to identify areas where the Initiative should expand in order to offer a gradual learning curve:

- Hyper and Microgravity Track: As an intermediate step to acquire experience in orbit experimentation, the Office is interested in developing capacity in parabolic and suborbital experimentation, to increase the experience of applicants before applying to an opportunity for developing an in-orbit experiment, as well as, in increasing access to facilities in ground.
- Satellite Development Track: The Office would like to develop capabilities related to CanSats as a starting point that will enable countries to advance their capabilities in space systems engineering. In addition, facilitating access to test facilities on ground, would be beneficial for participants.
- Exploration Track: The Office is interested in developing capacity related to exploration missions, both on ground through opening access to analogue facilities, and in exploration missions beyond the geostationary orbit.

7. CONCLUSION AND LESSONS LEARNT

The opportunities under the Access to Space for All Initiative continue to attract the interest of institutions from all over the world. This year new applications on a wide number of topics have been received. It is worth noting that, although the pandemic situation has created delays for the development of some of the activities, due to the difficulty in importing components or due to the impact on the winning teams such as their access to their respective research facilities or because of travel restrictions, the different opportunities continue to move forward.

In 2020, through the Initiative, the Office achieved the following:

- selected a winner for the seventh-round for DropTES;
- deployed the second-round KiboCUBE winner Guatemala's first satellite into space and opened an announcement of opportunity for another round in December;
- opened an announcement of opportunity for the first-round for Avio;
- the Office also plans to announce the first-round winner for Bartolomeo in the last quarter of the year.

The Office for Outer Space Affairs complements the opportunities with other learning activities such as webinars. A series of webinars were offered to further the work on the Access to Space for All Initiative and continue to offer space-related opportunities as a source of inspiration and to attract students and professionals from different areas, fostering science, technology and innovation and preparing them for the jobs of the future. A total of ten webinars related to Access to Space for All have been organized during 2020 and two sessions of the same webinar were organized to accommodate different time zones.

The Office for Outer Space Affairs continues to work with partners to maintain and enhance the Access to Space for All Initiative, providing opportunities for universities and research institutions, and promoting international cooperation in the peaceful uses of outer space. Member States, private and public entities are encouraged to join the Access to Space for All Initiative.

Invited Lectures

Publ. Astron. Obs. Belgrade No. 101 (2021), 45 *Invited Lecture*

TECHNOLOGY, POLITICS AND WARFARE: LEGAL AND FUTURE CHALLENGES FOR HUMANITY

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Abstract: The development of space-related technology since the dawn of the 'space age' in 1957 has given rise to many new and exciting possibilities. Humankind is now seeking to embark on a broad range of space activities and the utilization of this technology forms an integral element of the global society, such that the world is dependent upon constant and unimpeded 'access' to space. Yet, the existing international legal and governance framework, largely developed in a very different era of space activities (1960s-1980s), is now under strain to provide the necessary certainty, standards, and protections to appropriately address specific uses of space that have emerged due to recently evolving space technologies. This gives rise to several significant challenges for the future global governance of the exploration and use of outer space and, in particular, humankind's interaction with, and dependency on space-related technology. Important questions arise as to how to address these challenges in a way that will enable humankind to continue to use space for peaceful purposes and to garner significant benefits through such use for the benefit of the global society. This talk highlights some of the major challenges that arise and outlines important factors that must be considered in developing appropriate legal, regulatory and policy frameworks for future space activities, so as best to serve the interests of current and future generations.

Presentation link: https://www.youtube.com/watch?v=YrUrpBy0e6A

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TRAJECTORY CHALLENGES AND CONSIDERATIONS FOR NASA'S DART MISSION

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Abstract: This paper describes recent trajectory design results for the NASA Double Asteroid Redirection Test (DART) mission. DART will launch in 2021 and impact the binary target Didymos in September or October of 2022. Prior to the impact, DART will demonstrate new technologies including NASA's Evolutionary Xenon Thruster (NEXT-C).

Keywords: trajectory design, asteroid, electric propulsion.

1. INTRODUCTION

Planetary defence is comprised of the methods to detect, characterize, and mitigate asteroids that may threaten Earth. The principal mitigation options that researchers have studied are civil defence, gravity tractor, kinetic impact, and nuclear explosive devices (National Research Council 2010). The kinetic impact option involves a spacecraft or set of spacecrafts impacting the hazardous asteroid and imparting a small change in the asteroid's velocity. Given sufficient time, this change can result in the asteroid missing Earth at a future conjunction. Despite seeming to be a simple approach, this method still presents challenges and uncertainties. One example is the effect of ejected material from the asteroid's surface, which also imparts a change in velocity to the asteroid (Syal et al. 2016). This, and other challenges, cannot be easily characterized in simulation or laboratory environments. To help us understand this method, NASA is launching the Double Asteroid Redirection Test (DART) Mission as the first asteroid kinetic impact experiment (Reed et al. 2019). The DART spacecraft will impact the smaller member, Dimorphos, of the Didymos binary asteroid system. In doing so, DART will demonstrate the guidance, navigation, and control to target and impact a 163 meter diameter object at the target relative hypersonic velocity of 6.5 km/s. At approximately 600 kg, we expect DART to impart on the order of 3 mm/s to Dimorpos's velocity. If measured relative to the Sun, this 3 mm/s is only one part in ten-million relative to Dimorphos's velocity (on the order of 30 km/s). However, measured relative to Didymos, this change is one part in fifty relative to Dimorphos's velocity (on the order of 15 cm/s). This makes the small change much more detectable and measurable. In fact, the change can be measured from Earth as a change in period in light-curve observations. The scale of the system is illustrated in Figure 1 relative to familiar terrestrial objects, including sites in Serbia and the United Arab Emirates.

The DART Mission Level 1 Requirements are:

(1) DART shall intercept the secondary member of the binary asteroid (65803) Didymos as a kinetic impactor spacecraft during its September to October 2022 close approach to Earth.

(2) The DART impact on the secondary member of the Didymos system shall cause at least a 73-second change in the binary orbital period.

(3) The DART project shall characterize the binary orbit with sufficient accuracy by obtaining ground-based observations of the Didymos system before and after spacecraft impact to measure the change in the binary orbital period to within 7.3 seconds (1-σ confidence).

(4A) The DART project shall use the velocity change imparted to the target to obtain a measure of the momentum transfer enhancement parameter referred to as “Beta” (β) using the best available estimate of the mass of Didymos B.

(4B) The DART project shall obtain data, in collaboration with ground-based observations and data from another spacecraft (if available), to constrain the location and surface characteristics of the spacecraft impact site and to allow the estimation of the dynamical changes in the Didymos system resulting from the DART impact and the coupling between the body rotation and the orbit.

The spacecraft also includes new technologies that it will demonstrate prior-to or as part of the kinetic impact, including:

- Roll Out Solar Arrays – These solar arrays provide a high power-to-mass ratio. They stow compactly prior to deployment and unroll to approximately 8 m x 2 m once in space.
- Radial Line Slot Array Antenna – This flat disk-shaped antenna produces a high gain narrow pattern, similar to traditional parabolic dish antennas, but with a reduced volume.
- SMall body Autonomous Real-Time Navigation – The SMARTNav algorithms (Chen et al. 2018) are responsible for autonomously identifying and guiding to the asteroid target. This includes image processing capabilities operating at roughly 1 Hz.
- NASA Evolutionary Xenon Thruster – The NEXT-C electric propulsion thruster (Patterson et al. 2002) can operate over a wide range of power levels while providing high efficiency thrust for trajectory changes.

Approximately 10 days prior to impact, DART will deploy the Light Italian CubeSat for Imaging Asteroids (LICIACube) (Simonetti et al.2019). LICIACube will execute two manoeuvres to position itself behind DART at the time of impact. It will safely pass the Didymos system while imaging the ejecta from the impact.

As a follow-up characterization mission, the ESA Hera concept is being developed (Michel et al. 2017). The Hera spacecraft will launch in 2024 and rendezvous with the system in 2026. Hera's detailed observations of Didymos and Dimorphos will provide thorough context for the full impact experiment, including measurements of the system's bulk density and DART's crater size.

This paper describes the DART trajectory design, which has evolved over the mission's development life in response to competing objectives.

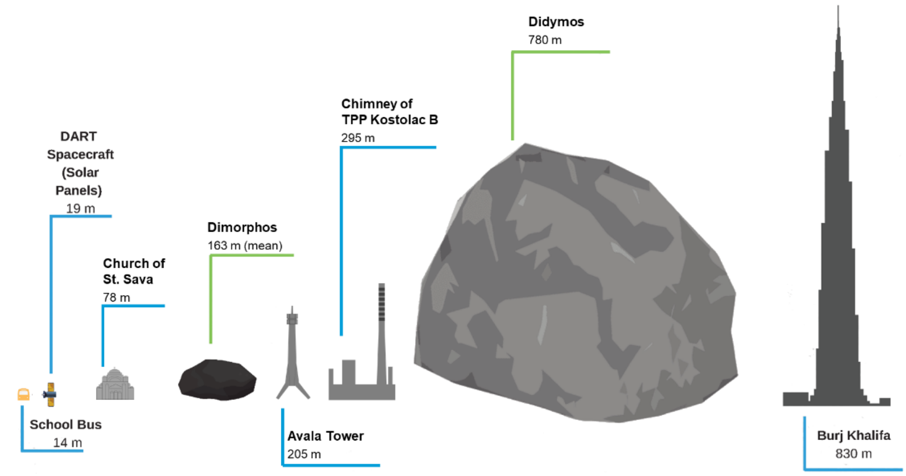

Figure 1: The scale of the Didymos and Dimorphos system relative to familiar terrestrial objects.

2. TRAJECTORY DESIGN

2.1. TRAJECTORY CONTEXT

The objective of DART's trajectory design process is to find a trajectory that departs Earth and intersects Dimorphos, while minimizing total ΔV, and subject to the following constraints:

- The launch declination must be compatible with United States launch sites
- The approach for the impact must have favourable lighting, quantified as a solar phase angle less than 60 degrees.
- The impact must occur within 30 degrees of the binary system's orbit plane (the orbit of Dimorphos relative to Didymos).
- The impact must occur at a time in Dimorphos's orbit when the imparted change in velocity will primarily change Dimorphos's orbit period (orbit energy, as opposed to orbit plane or eccentricity).

The arrival geometry constraints are illustrated to scale in Figure 2.

Finally, the trajectory must also incorporate a demonstration of NEXT-C, which cannot interfere with the impact experiment. Since the trajectory cannot exploit the on-board capabilities of NEXT-C and must minimize ΔV, we vary the arrival date to adjust the trajectory arrival conditions. This removes the need for post-launch manoeuvres. This simplifies the trajectory design process to essentially solving Lambert's problem for a series of launch and arrival dates. There are some subtleties with reconverging the two-body trajectories in the full-fidelity model (N-Body and solar radiation pressure) (Atchison et al. 2016). The primary perturbation is Earth's gravity, because DART remains in an Earth-like orbit from launch to impact.

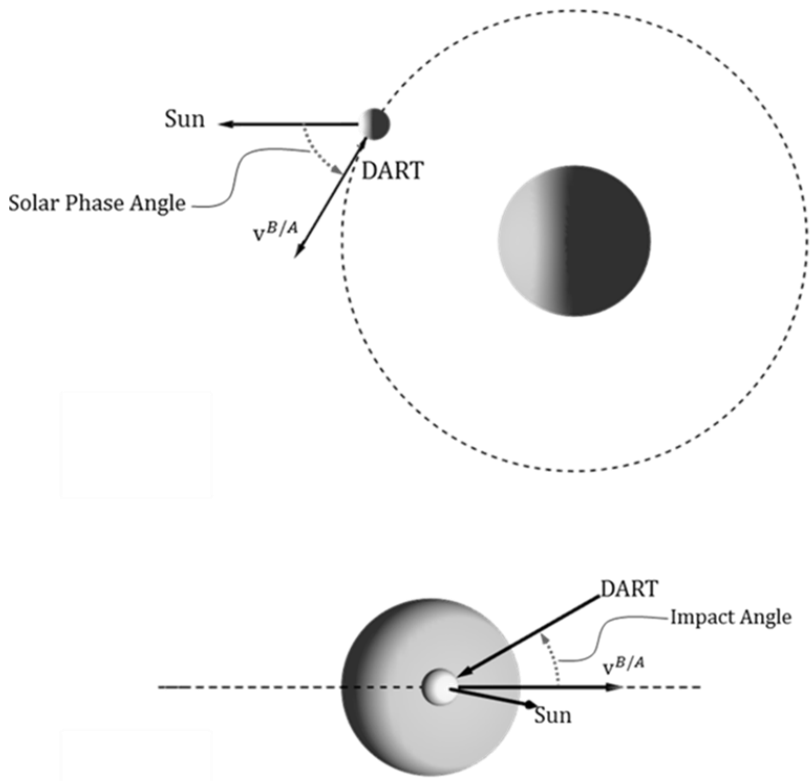

Figure 2: Dimorphos arrival geometry constraints.

2.2. PREVIOUS TRAJECTORY ITERATIONS

At one point, DART had the requirement to launch as a ride-share from a geostationary-transfer orbit, from which it would use NEXT-C to escape Earth (Atchison et al. 2018). This represented a means of saving cost by sharing the cost of a launch vehicle. DART was previously also required to execute a small body flyby prior to the impact (Atchison et al. 2016, Atchison & Ozimek 2019). This flyby would have provided the mission with a rehearsal of the terminal activities prior to Dimorphos.

2.3. CURRENT TRAJECTORY

DART launches on a SpaceX Falcon 9 from Vandenberg Air Force Base. The primary launch period originally spanned 22 July 2021 to 24 August 2021. However, in February of 2021, the DART project decided to shift to the secondary launch period, owing to delays related to hardware development and COVID. It is now scheduled for the secondary launch period, which opens on 18 Nov 2021 with 90 opportunities, ending on 15 February 2022. The transfer inclination is roughly 3.5 degrees relative to Earth's orbit. The required launch energy (C3) ranges from 3.6 km^2/s^2 to 7.6 km^2/s^2 over these periods. The impact at Dimorphos occurs on 26 September 2022 to 02 October 2022 depending on the launch date.

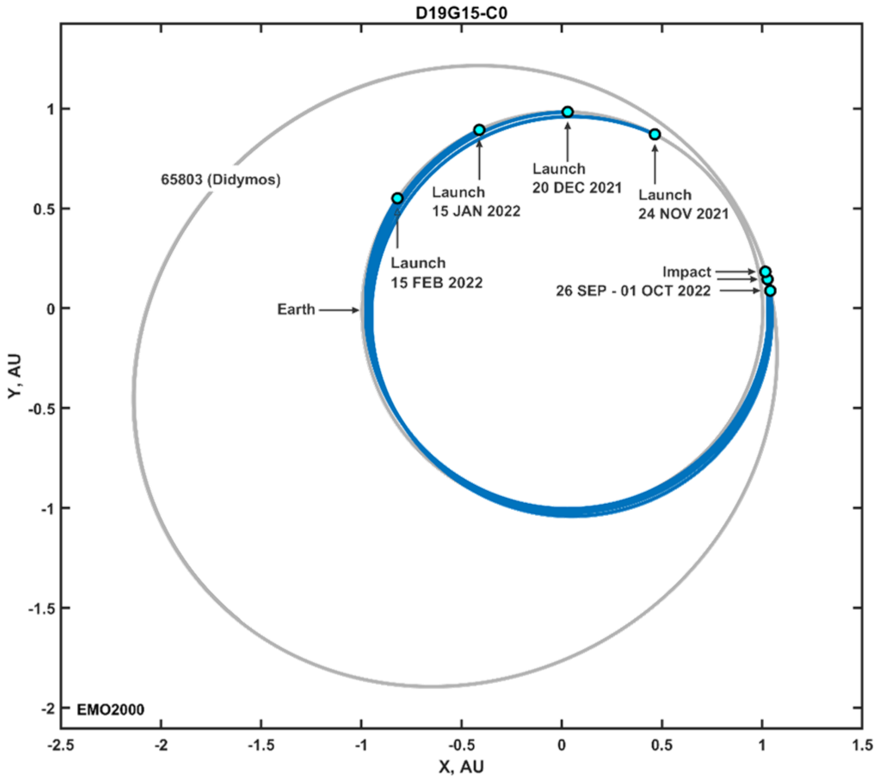

Figure 3: DART's launch period transfer trajectories.

Samples of trajectories are shown in Figure 3 in an inertial frame. Figures 4 and 5 depict the trajectory in a rotating frame. The rotating frame is centred at the Earth and rotates with Earth's annual orbit. The X direction is oriented with +X pointing from the Sun (at left) to the Earth. The Z direction is oriented with Earth's orbit normal direction, and the Y direction completes the right-handed system. In Figure 4, one can observe that DART drifts and impacts "ahead" of Earth. In Figure 5, DART's inclination is observable as motion in the Z direction. The impact occurs "below" Earth's orbit.

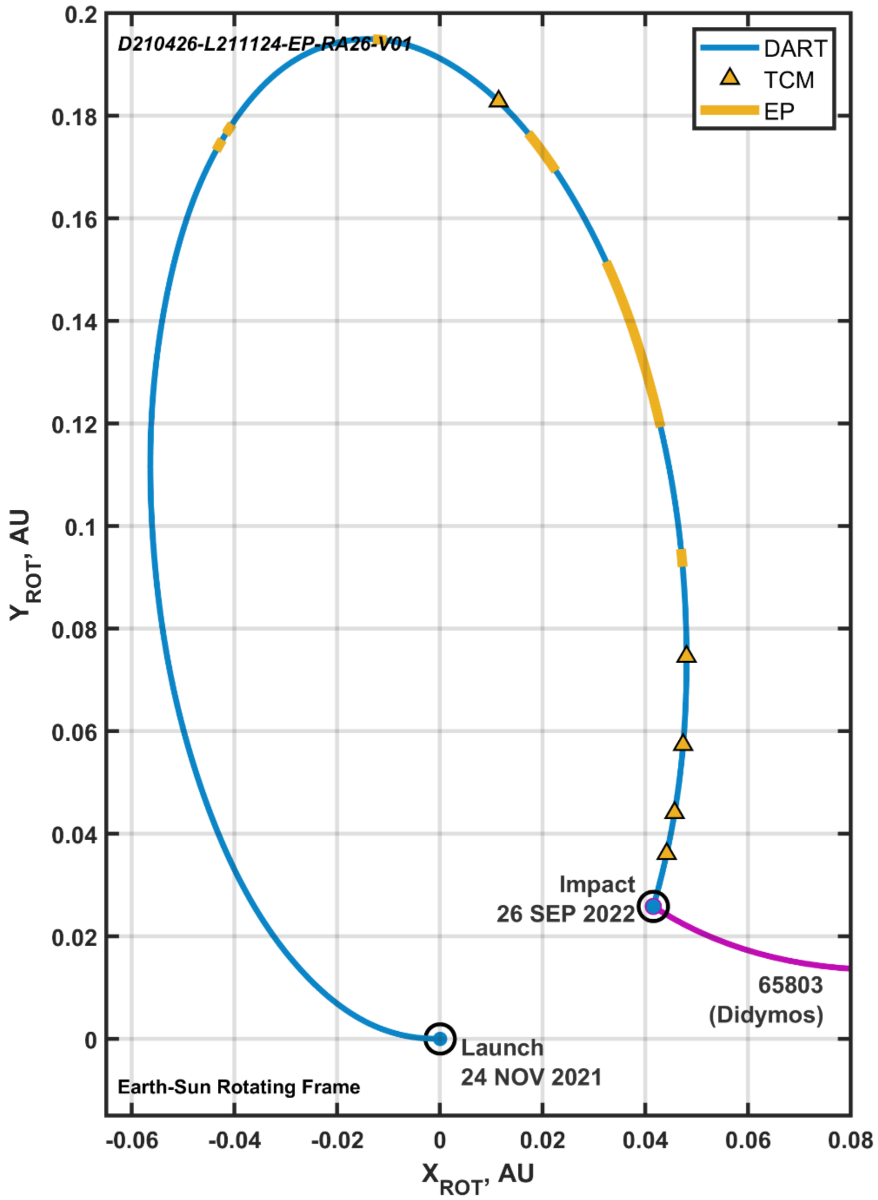

Figure 4: DART's launch period open trajectory, shown in X-Y axes of an Earth-Sun rotating frame.

The figures show trajectory correction manoeuvres as short electric propulsion segments or as red triangles. These manoeuvres keep the spacecraft on its reference trajectory, correcting for errors caused by launch vehicle delivery, model uncertainties (e.g., solar radiation pressure), Didymos and Dimorphos orbit uncertainties, attitude-control thruster misalignments, and manoeuvre execution errors.

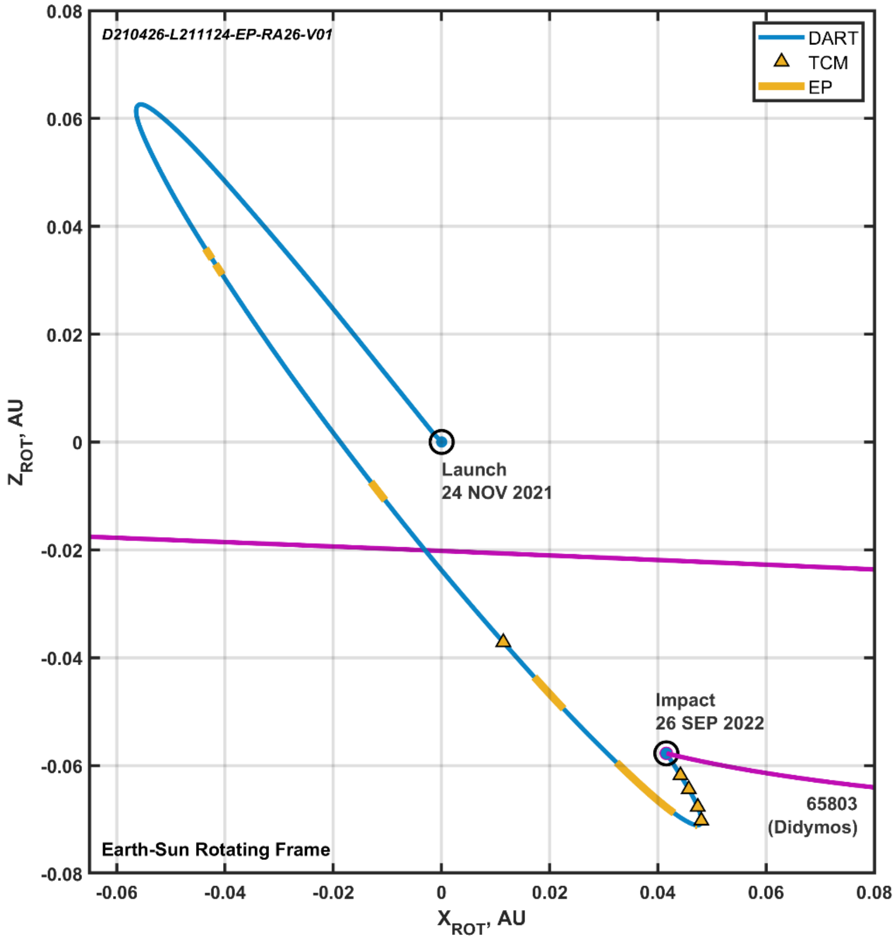

Figure 5: DART's launch period open trajectory, shown in X-Z axes of an Earth-Sun rotating frame.

2.4. ELECTRIC PROPULSION DEMONSTRATION

The NEXT-C thruster must be demonstrated without interfering with DART's impact encounter. This essentially requires us to operate the thruster without changing the trajectory, which is opposite traditional trajectory design. After reviewing many options, the DART team selected a rotating "neutral burn" approach. Here, the spacecraft is oriented relative to the Sun, with NEXT-C orthogonal to the Sun-line. The thruster is activated, and the spacecraft begins to spin with a period of 12 hours. As the spacecraft completes a revolution, the imparted ΔV cancels itself out. This behaviour is observable in Figure 6, which shows the amount of ΔV required to recover from a failure at any point during the neutral burn. That is, if the spacecraft stops the neutral burn in an unplanned manner, we compute the required ΔV from the hydrazine system to recover the impact if a correction manoeuvre were executed 10 days later. In this case, the neutral burn lasts 7 days. The 14 sinusoids correspond to full rotations of the spacecraft about the Sun-line. The maximum correction ΔV required is less than 5 m/s. At the end of the neutral burn period, the electric thruster has imparted approximately 0.3 m/s, despite operating a total of ~140 m/s. If essential, this small final error can likely be corrected by tuning the final revolution. The neutral burns are scheduled for up to seven weeks of the trajectory. These periods can be seen as yellow shaded regions in the trajectory figures above. A one-week neutral burn period is used to calibrate the process, followed by a two-week gap, and then the remaining six weeks of neutral burn. Following this, a hydrazine trajectory correction manoeuvre is used to clean up any residual errors.

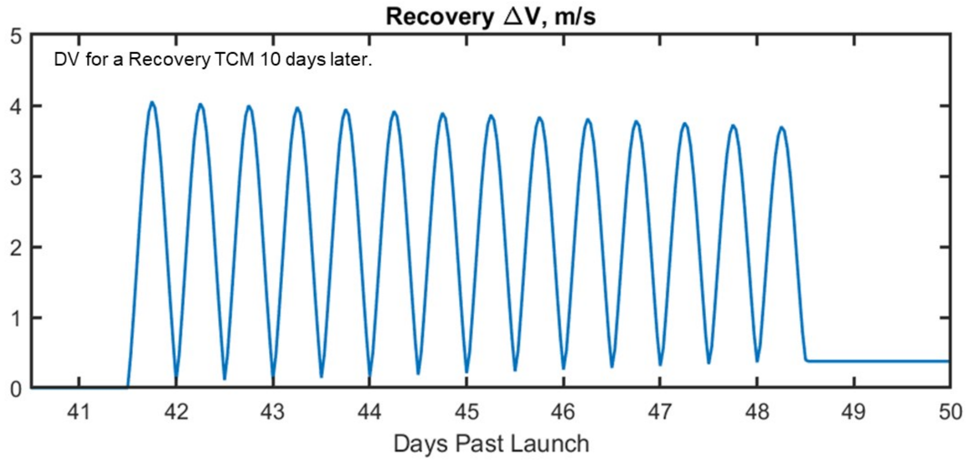

Figure 6: Recovery ΔV cost for a maneuver conducted 10 days following a neutral burn failure.

3. CONCLUSIONS

The DART spacecraft is on schedule to launch in 2021 onto a low ΔV trajectory that satisfies mission requirements and demonstrates a new thruster technology. Its impact into Dimorphos in 2022 will demonstrate our ability to autonomously deflect a small body and will expand our understanding of this important kinetic impact mitigation technique. Prior to impact, the spacecraft will execute a series of neutral manoeuvres that exercise the NEXT-C thruster without risking the terminal encounter.

Acknowledgements

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BREATHING MODULATION OF CARDIOPULMONARY COUPLING – A POTENTIAL WAY OUT OF AUTONOMIC DECONDITIONING AFTER PROLONGED MICROGRAVITY EXPOSURE

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Abstract: Microgravity causes a specific consequence on cardiovascular system – an orthostatic intolerance experienced by astronauts after long space flights. The major reason for this phenomenon is deconditioning of the cardiovascular autonomic regulation due to microgravity environment. Sympathetic withdrawal is the consequence of cephalad shift of blood and body fluids which is considered as a primary cause of several neurophysiologic disturbances during the space flight and postflight recovery (postural hypotension, sleep disturbances, low stress coping abilities). Cardiopulmonary coupling is the issue that potentially offers the possibility of the autonomic conditioning before and during the spaceflight. In humans, as opposed to cardiac rhythm, breathing can undergo volitional control. Paced 0.1 Hz breathing rhythm is characteristic, resonant frequency of many autonomic and cortical circuits, which amplifies heart rate modulation on one side, and recruits central cortical and subcortical circuits resulting in increased sleep propensity and relaxed attentive consciousness. We applied a battery of coefficients estimating the change of self-similarity and irregularity of heart rate and respiratory rate in four different states: supination, standing, supination with 0.1 Hz breathing and standing with 0.1 Hz breathing (Matić et al. 2020). Additionally, we analysed the posture and breathing regime dependence of quotient of pulse per respiration (Qpr), the number of heartbeats in each respiratory cycle. Chosen parameters are of importance for evaluation of cardiopulmonary adaptability and plasticity. Our results (Matić et al. 2020) and state dependent Qpr relation vs. breathing rate support the evidence that cardiorespiratory coupling and cardiorespiratory variability are posture and breathing regime dependent, with the state of combined standing with 0.1 Hz breathing identified as the state with maximal conditioning effect on heart rate, respiratory rate, and cardiorespiratory coupling. We propose this manoeuvre as the autonomic conditioning strategy for the crew before long space flights.

Keywords: microgravity, autonomic nervous system, cardiopulmonary coupling, space flight, autonomic conditioning strategy

1. INTRODUCTION

Autonomic nervous system (ANS) is a functional division of the nervous system, with structural parts in both the central nervous system and the peripheral nervous system, controlling the glands and all the internal organs (viscera) including cardiovascular system. In general, ANS has great ability to adjust physiological functions to respond to internal and external demands, with respect to changes of internal natural rhythms, changing states of activity (standing, sitting, laying, sleeping, running etc.), geophysical conditions and environmental rhythms. Gravity is one of the most important and constantly present factors that ANS accounts while regulating the blood pressure and heart rate (Levy & Martin 1996). Human ANS has evolved to use both homeostatic and homeodynamic regulation patterns in Earth gravitational field of 1 g (Patel 2020, Ernst 2014, Matić et al. 2020).

During sojourn in space stations astronauts are exposed to entirely different conditions due to presence of strong cosmic radiation and almost complete absence of gravity (these two factors might even produce negative synergetic influence on health (Patel 2020)). Even though astronauts float in space stations, the force of gravity there is not zero, rather it is very attenuated. Therefore, it is called microgravity (μg) (Nassef et al. 2020). Acceleration of gravity on Earth is well known g=9.78-9.83 m/s^2 (Faller et al. 2020); and so far, measured acceleration of microgravity varies in broad range: g=10^{-6}-10^{-4} m/s^2 (Dong et al. 2019). Without μg space stations would be unable to orbit the Earth. However, according to astromedical research μg turns out to be very inhospitable and pathogenic condition for human organism (Patel 2020, Antonutto & Prampero 2003, Demontis et al. 2017). For the relevance of astromedicine μg is characterized as "mechanically unloaded condition" (Wuest et al. 2018). Since g of Earth has been almost unchanged during life and human evolution, "there is little or no genetic memory in organisms on how to respond" (Nassef et al. 2020) to shift from g to μg. Therefore, it has been estimated that one week of presence in μg environment decreases size and weight of the heart for about 25% (Hill & Olson 2008). This is equal to atrophy of heart muscle that happens after six weeks of bed immobility (Hill & Olson 2008, Hargens & Vico 2016, Payne et al. 2007). Staying in μg causes similar reductive changes to other structures like skeletal muscles (Trappe et al. 2009) and bones (Holick 2000). In addition to these adverse effects, μg induces a typical consequence on cardiovascular system – an orthostatic intolerance experienced by astronauts after a long space flight (Antonutto & Prampero 2003, Xu et al. 2020, Gaffney 1987), which might be followed by hypotension and syncope episodes (Eckberg et al. 2016).

Orthostatic intolerance is defined as incapacity of the cardiovascular system to maintain required arterial blood pressure in central circulation in orthostatic body position (Goldstein 2001). Orthostatic intolerance can be induced in terrestrial conditions by genetic predisposition, prolonged laying down in bed or infection, while the major reason for orthostatic intolerance in space is deconditioning of the cardiovascular autonomic regulation due to microgravity environment (Goldstein 2001) (Figure 1.).

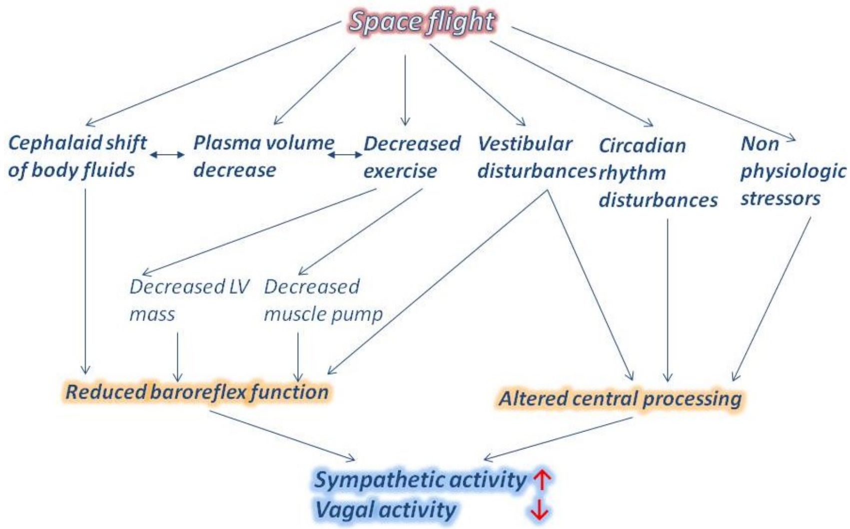

Figure 1: Major physiological disturbances affecting autonomic cardiovascular control during space flight (adapted from Mandsager et al. (2015)).

Cardiopulmonary coupling, an intriguing reciprocal interface of heart period and respiratory signal oscillations, represents the physiological solution for energetic efficiency of oxygen transport (Feldman & Ellenberger 1988) and organism adaptability to external and internal challenges (Porges 2007). Beside eye blinking (Ren et al. 2019), breathing in humans is a rare function that might be shifted from automatic and autonomic control to volitional (paced) performance (Negro et al. 2018). As such, paced breathing, through cardiopulmonary coupling (Migeotte et al. 2003, Xu et al. 2013), is a potential possibility for autonomic conditioning related to microgravity challenge before and during spaceflights.

The physiological terrestrial conditions, important for our paradigm, are:

- Orthostasis: gravity challenge for autonomic cardiovascular regulation, characterized by the highest sympathetic modulation of heart period in physiologic quiescence (Levy & Martin 1996), and
- Paced 0.1 Hz breathing: characterized by resonant frequency of many autonomic and cortical circuits which amplifies respiratory,

parasympathetic heart rate modulation (Matić et al. 2020, Migeotte et al. 2003) on one side, and recruits central cortical and subcortical circuits resulting in increased sleep propensity and relaxed attentive consciousness (Noble & Hochman 2019) on the other side. It is characterized by the highest respiratory mediated vagal modulation of heart period, in physiologic quiescence (Cooke et al. 1998).

The aim of our research was to investigate individual and joint effect of these conditions on cardiorespiratory coupling in nonlinear and linear domains, defining in this way potentially the most beneficial behavioural pattern for cardiorespiratory conditioning before and during the spaceflight. Special focus is put on state dependent changes in quotient of pulse per respiration (Qpr), a bidimensional autonomic parameter closely correlated to ventilation/perfusion relation, and state dependent Qpr vs. BR relations. Paced 0.1 Hz breathing, by optimization of blood oxygenation and together with arterial pressure conditioning (Karavaev et al. 2009), could be an important behavioural strategy for coping with autonomic outburst such as orthostatic hypotension. In this paper we will analyse the cardiorespiratory features of spontaneous and paced 0.1 Hz breathing in supine and standing position, focusing on respiratory rate - heart period interrelation, to compare experimental Qpr with simulated data results (Scholkmann & Wolf 2019).

2. METHODS

Electrocardiogram (ECG) and respiration signal acquisition was done by means of Biopac MP100 system (Biopac System, Inc, Santa Barbara, CA, USA; AcqKnowledge 3.91 software). For details, see Matić et al. (2020).

We investigated in terrestrial conditions 20 healthy human subjects for changes using ECG RR interval (RRI) and respiratory signal (Resp) measures of detrended fluctuation analysis (DFA) (Peng et al. 1995a, Peng et al. 1995b, Peng et al. 2002, Fadel et al. 2004, Ivanov et al. 1999, Gierałtowski et al. 2013, Kristoufek 2014, Barbieri et al. 2017) (α_{1RRI}, α_{2RRI}, α_{1Resp}, α_{2Resp}); multiscale entropy (Costa et al. 2003, Silva et al. 2017a, Silva et al. 2017b, Silva et al. 2016) (MSE_{RRI1-4}, $MSE_{RRI5-10}$, $MSE_{Resp1-4}$, $MSE_{Resp5-10}$); methods of nonlinear cardiorespiratory coupling, cross DFA (Kristoufek 2014, Podobnik & Stanley 2008, Horvatic et al. 2011, Podobnik et al. 2011, Zebende 2011, Kwapień et al. 2015) (ρ_1 and ρ_2), cross MSE (Richman & Moorman 2000, Costa et al. 2005) (X_{MSE1-4} and $X_{MSE5-10}$) and linear cardiorespiratory coupling, spectral coherence (Daoud et al. 2018) ($Coh_{RRI-Resp}$) and pulse/respiration quotient (Scholkmann & Wolf 2019, Hildebrandt 1954, Scholkmann et al. 2019) (Qpr), in four physiological conditions:

- supine position with spontaneous breathing (supin),
- standing with spontaneous breathing (stand),
- supine position with 0.1Hz breathing (supin01) and
- standing with 0.1 Hz breathing (stand01). (Matić et al. 2020)

In the same conditions we analysed the relation of Qpr vs breathing rate (BR, 1/min) to evaluate on experimental data a hyperbolic relation of Qpr vs. BR, previously reported on simulated data (Scholkmann & Wolf 2019).

2.1. DATA PROCESSING

Data processing for DFA, MSE, ρ_1, ρ_2, X_{MSE} and $Coh_{RRI-Resp}$ are explained in (Matić et al. 2020) in detail; R peaks and the beginnings of breathing cycles (B nadirs) were detected within the ECG and respiration signal using Pick Peak tool of Origin software (Microcal, Northampton, MA, USA) (Figure 2.).

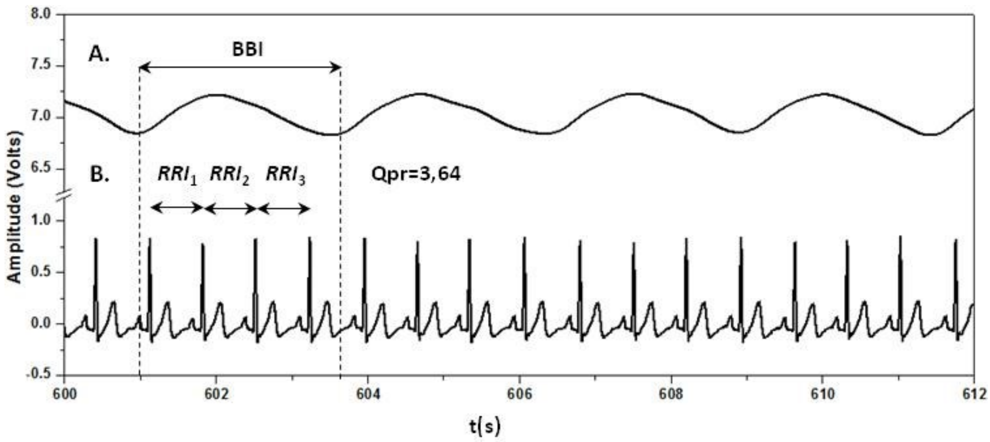

Figure 2: Segment of respiratory signal (A.) and ECG signal (B.) in one subject, recorded simultaneously, in a supine state with spontaneous respiration, for 12s selected from a total of 1200 s registered in this condition. *RRI* -time interval between two adjacent R peaks of ECG, *BBI* -breath-to-breath interval, Qpr -quotient of pulse per respiration, number of heart beat intervals in each breath-to-breath interval.

Then, BB and RR intervals were calculated as differences between successive x coordinates of R peaks and B peaks:

X(i)=col(Pkx)[i+1]-col(Pkx)[i] (1)

col(Pkx)[i] – column of x (time) coordinates of detected signal peaks

col(Pkx)[i+1] – column of x (time) coordinates of subsequently detected signal peaks

X(i) - *RRI*(i) or *BBI*(i), with respect to the type of signal (ECG or breathing)

Qpr was calculated according to the following procedure (explained for the first breathing interval as an example). Suppose that respiratory and R peaks were arranged in the following order (i.e., – points in time when inspiration and expiration started, respectively, r – occurrence of an ECG R peak):

Respiration	e......i1.........e..................i2......				
R peaks	r0......r1...r2 ....r3....r4...r5....r6				
Number of intervals	1	2	3	4	

First, we counted integer number of whole r…r intervals that fell between i1 and i2. In this case there were three of them: r2 - r1, r3 - r2 and r4 - r3. Then parts of the boundary r…r intervals that belong to (i1, i2) breathing interval, as non-integer parts of the Qpr, were added:

b1(i1,i2) = (r1-i1) / (r1-r0),   and   b2(i1,i2) = (i2-r4) / (r5-r4).   (2)

Finally, total (integer and decimal) value of Qpr belonging to (i1, i2) breathing interval was calculated as
Qpr(i1,i2) = 3 + b1(i1,i2) + b2(i1,i2).   (3)

3. RESULTS

To investigate the relation of Qpr with breathing rate (BR) we plotted Qpr values vs. BR (Figure 3.)

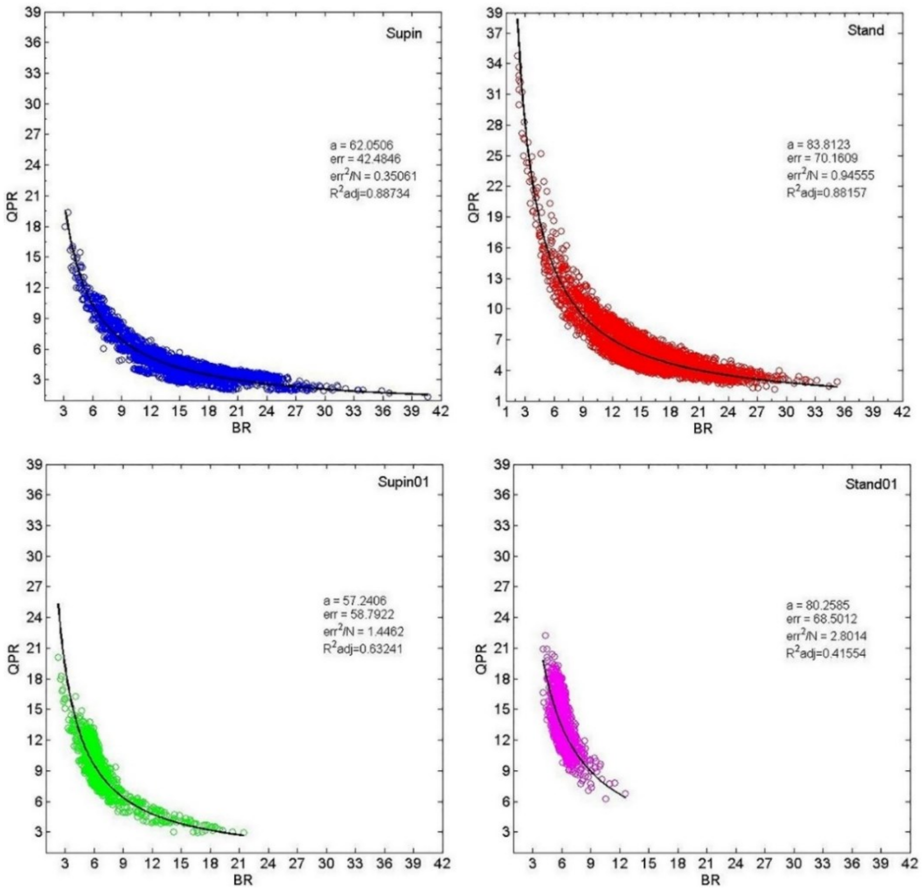

Figure 3: The state-specific correlation pattern between pulse respiration coefficient (Qpr) and breathing rate (BR, 1/min) for 20 healthy subjects. supin-supine position with spontaneous breathing; stand – standing; supine01-supine position with paced 0.1Hz breathing; stand01 - standing with paced 0.1 Hz breathing.

Table 1: Linear and nonlinear parameters (mean ± SD) of 20 healthy subjects (adopted from Matić et al., 2020 and completed by Qpr data for comprehensive analysis). Supin-supine position with spontaneous breathing; stand - standing; supin01-supine position with paced 0.1Hz breathing; stand01 - standing with paced 0.1 Hz breathing; RRI - interval between two adjacent R peaks of ECG, i.e. heart period; mRRI - mean value of RRI signal; sdRRI - standard deviation of RRI signal; α_{1RRI} - short term fractal scaling exponent of RRI signal; α_{2RRI} - long term fractal scaling exponent of RRI signal; θ_{RRI} – inter-fractal angle of RRI signal; MSE_{RRI1-4} - short term multi scaling entropy of RRI signal (for 1-4th sample); $MSE_{RRI5-10}$ - long term multi scaling entropy of RRI signal (for 5-10th sample); mResp - mean value of respiration signal; sdResp - standard deviation of respiration signal; α_{1Resp} - short term fractal scaling exponent of respiration signal; α_{2Resp} - long term fractal scaling exponent of respiration signal; θ_{Resp} – inter-fractal angle of respiration signal; $MSE_{Resp1-4}$ - short term multi scaling entropy of respiration signal (for 1-4th sample); $MSE_{Resp5-10}$ - long term multi scaling entropy of respiration signal (for 5-10th sample); $Coh_{RRI-Resp}$ - RRI-respiration spectral coherence; Qpr – quotient of pulse per respiration; $\rho_{DCCARRI-Resp}$ - RRI-respiration detrended cross correlation coefficient; ρ_1 - short term scaling RRI-respiration detrended cross correlation coefficient; ρ_2 - long term scaling RRI-respiration detrended cross correlation coefficient; X_{MSE1-4} - short term RRI-respiration cross multi scaling entropy; $X_{MSE5-10}$ - long term RRI-respiration cross multi scaling entropy.

group	parameter	Supin	Stand	Supin01	Stand01
Cardiac parameters	mRRI [s]	0.9937 ± 0.1377	0.7263 ± 0.1021	1.0592 ± 0.1257	0.7480 ± 0.0867
	sdRRI [s]	0.0621 ± 0.0237	0.0465 ± 0.0175	0.0905 ± 0.0347	0.0702 ± 0.0225
	α_{1RRI}	0.8975 ± 0.1925	1.3114 ± 0.1379	1.0342 ± 0.1421	1.3408 ± 0.1005
	α_{2RRI}	0.8232 ± 0.1244	0.7874 ± 0.1249	0.6922 ± 0.1647	0.5545 ± 0.1463
	θ_{RRI} [^{0}]	2.2 ± 8.3	14.5 ± 5.6	11.5 ± 8.7	24.6 ± 6.7
	MSE_{RRI1-4}	1.7936 ± 0.1783	1.5583 ± 0.2974	1.6713 ± 0.2463	1.4715 ± 0.1784
	MSE_{RR5-10}	1.7706 ± 0.2138	1.8951 ± 0.2391	1.4991 ± 0.1848	1.9123 ± 0.1732
Respiratory parameters	mResp [s]	4.55 ± 1.45	4.56 ± 1.78	10.0605 ± 0.1942	9.9676 ± 0.1466
	sdResp	0.89 ± 0.61	1.09 ± 1.35	1.4235 ± 0.9437	1.0313 ± 0.4060
	α_{1Resp}	0.3679 ± 0.2603	0.4975 ± 0.2728	0.9268 ± 0.3133	1.1387 ± 0.2357
	α_{2Resp}	0.5848 ± 0.2319	0.6119 ± 0.2132	0.4850 ± 0.2003	0.3759 ± 0.1028
	θ_{Resp} [^{0}]	-10.3 ± 18.8	-5.5 ± 18.5	16 ± 16.1	27.5 ± 7.2
	$MSE_{Resp1-4}$	1.4456 ± 0.2631	1.3185 ± 0.4117	1.3772 ± 0.3074	1.0995 ± 0.2837
	$MSE_{Resp5-10}$	1.1396 ± 0.2532	1.0423 ± 0.3523	1.3040 ± 0.3065	1.3382 ± 0.3132
Cardio-pulmonary coupling	$Coh_{RRI-Resp}$	0.8983 ± 0.0563	0.7397 ± 0.1986	0.8703 ± 0.1137	0.8663 ± 0.1363
	Qpr	4.8118 ± 1.6659	6.3854 ± 2.4308	9.4144 ± 1.2062	13.4761 ± 1.6591
	ρ_1	-0.2419 ± 0.1905	-0.2002 ± 0. 1916	-0.0096 ± 0. 2665	-0.0697 ± 0.2787
	ρ_2	-0.1346 ± 0. 1314	-0.0190 ± 0.1234	-0.0232 ± 0.2471	0.0097 ± 0.2429
	X_{MSE1-4}	2.2733 ± 0.20298	2.2719 ± 0.40199	2.1490 ± 0.24829	1.9344 ± 0.21773
	$X_{MSE5-10}$	2.1765 ± 0.21385	2.1253 ± 0.27514	2.3176 ± 0.15034	2.4292 ± 0.46726

Table 2: Change of linear and nonlinear cardiorespiratory parameters in different conditions (p-value of Wilcoxon signed-rank test for 20 healthy subjects (adopted from Matić et al., 2020 and completed by Qpr data for comprehensive analysis); ↓-decrease of the change; ↑-increase of the change). supin-stand – supine position (with spontaneous breathing) vs. standing position (with spontaneous breathing); supin-supin01 – supine position (with spontaneous breathing) vs. supine position with paced 0.1 Hz breathing; supin-stand01 – supine position (with spontaneous breathing) vs. standing with paced 0.1 Hz breathing; bolded numbers - results with statistical significance ($p<0.05$); RRI - interval between two adjacent R peaks of ECG, i.e. heart period; mRRI - mean value of RRI signal; sdRRI - standard deviation of RRI signal; α_{1RRI} - short term fractal scaling exponent of RRI signal; α_{1Resp} - short term fractal scaling exponent of respiration signal; α_{2RRI} - long term fractal scaling exponent of RRI signal; α_{2Resp} - long term fractal scaling exponent of respiration signal; $MSE_{RRI1\text{-}4}$ - short term multi scaling entropy of RRI signal (for 1-4th sample); $MSE_{RRI5\text{-}10}$ - long term multi scaling entropy of RRI signal (for 5-10th sample); $MSE_{Resp1\text{-}4}$ - short term multi scaling entropy of respiration signal (for 1-4th sample); $MSE_{Resp5\text{-}10}$ - long term multi scaling entropy of respiration signal (for 5-10th sample); $Coh_{RRI\text{-}Resp}$ - RRI-respiration spectral coherence; Qpr- quotient of pulse per respiration; ρ_1 – short term scaling RRI-respiration detrended cross correlation coefficient; ρ_2 – long term scaling RRI-respiration detrended cross correlation coefficient $X_{MSE1\text{-}4}$ – short term RRI-respiration cross multi scaling entropy, $X_{MSE5\text{-}10}$ – long term RRI-respiration cross multi scaling entropy.

group	parameter	supin-stand	supin-supin01	supin-stand01
Cardiac parameters	mRRI	**0.000↓**	0.306	**0.000↓**
	sdRRI	**0.072↓**	**0.021↑**	0.831
	α_{1RRI}^{*}	**0.000↑**	**0.030↑**	**0.000↑**
	α_{2RRI}^{*}	1.065	**0.027↓**	**0.000↓**
	θ_{RRI} [^{0}]	**0.000↑**	**0.006↑**	**0.000↑**
	$MSE_{RRI1\text{-}4}$	**0.015↓**	0.471	**0.000↓**
	$MSE_{RRI5\text{-}10}$	0.120	**0.000↓**	0.063↑
Respiratory parameters	mResp	1.805	-	-
	sdResp	2.968	-	-
	α_{1Resp}^{*}	0.273	**0.000↑**	**0.000↑**
	α_{2Resp}^{*}	2.775	0.273	**0.000↓**
	θ_{Resp} [^{0}]	0.942	**0.000↑**	**0.000↑**
	$MSE_{Resp1\text{-}4}$	1.335	1.485	**0.000↓**
	$MSE_{Resp5\text{-}10}$	1.149	0.258	**0.054↑**
Cardio-pulmonary coupling	$Coh_{RRI\text{-}Resp}$	**0.018↓**	2.703	2.712
	Qpr	**0.000↑**	**0.000↑**	**0.000↑**
	ρ_1	1.194	**0.003↑**	**0.072↑**
	ρ_2	0.015	0.228	0.105
	$X_{MSE1\text{-}4}$	2.397	0.402	**0.000↓**
	$X_{MSE5\text{-}10}$	0.981	0.189	**0.051↑**

4. DISCUSSION AND CONCLUSION

Our results show that cardiopulmonary coupling exhibits state specific characteristics in both linear and nonlinear domain. Standing with slow 0.1 Hz breathing (stand01), the physiologic condition characterized by the highest capacity for cardiopulmonary adaptation (Tables 1. and 2., nonlinear cardiopulmonary coupling) resulted with the highest mean values and the lowest standard deviation of Qpr.

This speaks in favour of the hypothesis that development of adaptive capacity and sympatho-vagal responsiveness (Eckberg et al. 2016, Malik et al. 2019) of the organism to external demands (parameters of nonlinear cardiorespiratory variability) occurs during highly regular relation of HR vs. BR (Qpr). Regarding the Qpr vs. BR relation, states with spontaneous breathing (supin and stand) are characterized by specific hyperbolic correlation, with high standard deviation. These conditions characterized by typical cardiovascular patterns (dominant vagal vs. dominant sympathetic HR modulation, respectively) form two distinct hyperbolic distributions analogue to the "family" of different, parallel hyperbolas, as it was reported in Scholkmann & Wolf (2019). The results of hyperbolic Qpr vs. BR dependence were, until now, reported only on simulated signals, in spontaneous breathing regime (Scholkmann & Wolf 2019). Our data, for the first time, confirm this relation on experimental signals.

Breathing rate, as a *modifiable variable* both in healthy and diseased subjects, invokes special interest for its impact on cardiovascular variables and cardiopulmonary coupling. In our results it was shown for the first time that BR restricts the deviation of Qpr values to BR range specific for our study (6.1±1.4/min), without changing the "y level" of respective posture specific Qpr vs. BR hyperbola. This relative Qpr constancy, specific for paced 0.1 Hz breathing could be of particular importance for memory and learning process of cardiorespiratory networks in physiologic conditions requiring greater adaptive capacities of cardiorespiratory system (specific pattern of nonlinear RRI and Resp variability, Table 1. and Table 2.). In general terms, terrestrial respiratory pacing (i.e., "tuning") of desired Qpr could be the strategy of cardiorespiratory autonomic networks training for the optimal ventilation/perfusion efficiency of cardiorespiratory system in accordance with behavioural demands and the duration of planned spaceflight. Additional, extra terrestrially applied respiratory training protocol, in the conditions of artificial gravity could be preparation of ventilation/perfusion adaptive efficiency for the return into gravity conditions. To confirm these hypotheses, additional necessary studies are needed, regarding, in specific, the scale of long-term learning of cardiorespiratory networks (i.e., days, weeks or months). In parallel with space physiology, the practice of BR and postural manoeuvres could also have significant medical benefits as the ICU interventions beneficial for re-training of cardiorespiratory autonomic networks of artificially ventilated patients and their preparation for artificial respiration weaning (Matić et al. 2020, Papaioannou et al. 2011, Welsh et al 2020).

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IMAGE COMPRESSION IN EARTH OBSERVATIONS – AN APPLICATION ORIENTED INSIGHT FROM THE LOSSY PERSPECTIVE

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Abstract: In this talk we will give a brief overview of the still image compression approaches applied in Earth Observation (EO) and offer an application specific insight into effects of an efficient lossy compression solution in this context. Besides a general overview of lossless and near-lossless techniques for compression of satellite based hyperspectral and multispectral images, which are mainly present in the currently used onboard and ground-based implementations of the EO data distribution systems, we will also focus on the compression techniques that are specifically oriented towards the ground segment and the specific end-user needs. In line with the above mentioned, we will consider different lossy compression solutions with the high compression gain and analyse the performance sensitivity of the thematic mapping application to different encoding scenarios. In comparison to usual constraints that are characteristic for the onboard signal processing and the corresponding downlink communication requirements, end-user oriented EO applications that are placed at the other end of the data distribution chain offer much broader range of design possibilities in the context of the data transmission and processing. In that sense, applications of different lossy compression schemes with higher image quality could be considered as acceptable solutions for such application scenarios, even at the cost of higher encoding complexity in comparison to onboard designs. However, performance of the specific EO applications that are utilizing such compressed data is usually more important than the general image quality, which makes the required sensitivity analysis of the specific applications a highly desirable research topic of interest.

Presented analyses are the result of the joint work with my colleagues Miloš Radosavljević and Predrag Lugonja.

Presentation link: https://www.youtube.com/watch?v=YrUrpBy0e6A

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STATION-KEEPING STRATEGY FOR A SOLAR SAIL SATELLITE AT LOW EARTH ELLIPTICAL ORBIT

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Abstract: An elliptical Low Earth Orbit for Earth observation mission is sized and shaped such that aerodynamic drag effects are minimized with a perigee altitude of 400 km and an apogee altitude of 1400 km. The lower parts of the orbit (below 800 km) are allocated for Earth observation whereas remaining parts of the orbit (above 800 km) is used for solar sailing for reshaping, resizing, or reorienting the orbit. The mission orbit is then optimized for a given region of interest (latitude and longitude) in terms of classical orbital elements (inclination, argument of perigee and right ascension of ascending node). This mission orbit for the given region of interest has a lifetime which can be given in advance by the customer/end user or caused by environmental disturbances (aerodynamic drag and/or asphericity effects of the Earth's gravitational attraction). To increase the mission lifetime, a station-keeping strategy is proposed in this study. The adopted dynamics of the classical orbital elements of the proposed strategy is based on the Gauss Variational Equations. Different cases in terms of station-keeping of perigee altitude, semi-major axis, argument of perigee, right ascension of the ascending node or combination of those, are investigated. The coupling effects of variations in the classical orbital elements are taken into considerations. Detailed mathematical derivation of the proposed strategy is provided along with the simulation results.

Keywords: solar sail satellite, station-keeping, gauss variational equations, elliptical orbit, low earth orbit.

1. INTRODUCTION OF THE SUBJECT

Satellites are used for various missions with capable sensors to provide information. The information may be in different forms; communication signal, position-time tag for navigation and images of the Earth at several wavelengths. The demand for satellite images has been present since the start of space age. The information can be used for various applications such as disaster monitoring or environmental surveillance for forestry and agriculture, to name a few. To achieve desired performance from observation satellites, mission designers try to optimize the resolution and coverage (or revisit time in other perspective). Low Earth Orbit (LEO) provides the utmost performance for such considerations. Even though, mission designers generally choose sun-synchronous or polar orbits at LEO for global coverage resulting in constant revisit/coverage performance, the observation performance in terms of revisit frequency can be increased by using inclined prograde orbits at LEO. However, the orbit is then successful only for the given region of interest not for the new sites. Moreover, changing the orbital parameters is too expensive in space, even with the electric propulsion. On the other hand, Solar Sail Satellites can be utilized for their propellant-free manoeuvre capability due to the Solar Radiation Pressure. The concept of Rapid Response Solar Sail (R2S2) is proposed to combine the advantages of LEO and Solar Sail Satellites.

1.1. R2S2 CONCEPT

Propulsion through solar sails is expected to be the future of the spaceflight within the solar system mainly for interplanetary travels or escape trajectories (McInnes 1989, Wie 2008, Vulpetti et al. 2008). Moreover, large sail areas with a low total satellite mass (low ballistic coefficient) result in quick decay of the orbit at lower altitudes. To overcome this difficulty while utilizing the advantages of employing LEO an elliptical orbit is proposed for the R2S2 concept (Figure 1).

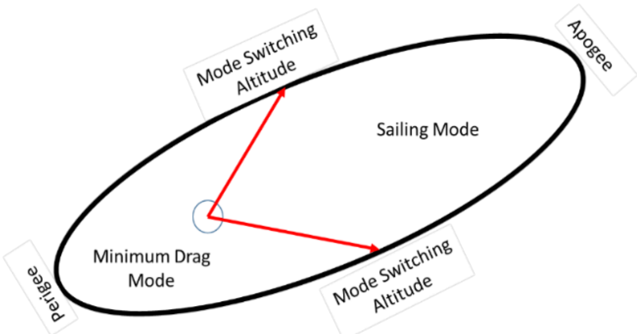

Figure 1: Elliptical Mission Orbit

The lower altitude part of the orbit is where the Earth observation is carried out while orienting the sail such that aerodynamic drag is minimized. The higher altitude part of the orbit is where the advantages of solar sailing are utilized. The sailing manoeuvres, when resizing, reshaping, or reorienting is necessary, are carried out in this part of the orbit while orienting the sail such that required control force is provided with limitations coming from the relative Sun’s position with respect to the sail and shadowing of the Earth.

This mission orbit has a lifetime due to two reasons: Mission-specific and Disturbance-specific. Mission-specific lifetime comes from the mission designer depending on the observation of the region or post-disaster campaign duration. Disturbance-specific lifetime comes from the environmental disturbances exerted on the satellite such as aerodynamic drag and asphericity effects of the Earth. The mission phase ends at the end of mission-specific or disturbance-specific lifetime (whichever comes first). Then, transfer phase is started to raise the orbit above mode switching altitude. This means that solar sailing can be done at all locations along the orbit. Transfer phase ends when suitable standby orbit is achieved. At standby orbit, the solar sailing manoeuvres are used for resizing, reshaping, and reorienting the orbit to maximize the revisit performance for the new region of interest. This cycle is maintained as shown in Figure 2 and the feasibility study results show that successive phase transitions (400 km of perigee altitude and 1400 km of apogee altitude) are achieved with characteristic acceleration ranging from 0.1 to 1.5 mm/s^2 (Polat & Tekinalp 2019).

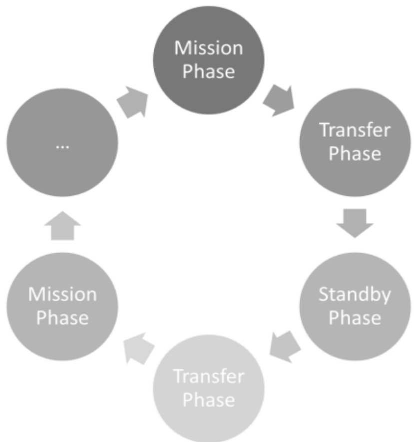

Figure 2: Phase Transitions

1.2. MODE HIERARCHY

The R2S2 concept with continuous phase transitions and solar sailing manoeuvres uses 4-tier mode hierarchy (Figure 3) for mission control. The first mode (Mission Mode) is for defining the orbit type, then Task Mode is defined with respect to the aim (station-keeping, minimum energy loss, raising or decreasing the orbit). After that, the Orientation Mode is determined according to the altitude of the satellite with respect to the mode switching altitude. This allows to give green flag to make sail rotations for desired attitude with negligible aerodynamic drag effects. The last tier is used for only Station-keeping Task Mode. The definitions are given in Table 1.

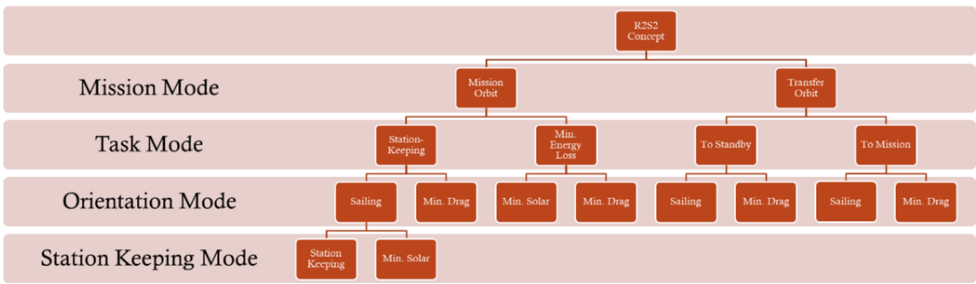

Figure 3: Mode Hierarchy

Table 1: Mode Definitions

Mode Name	Definition
Mission Orbit	This mode is the indication of the orbit type. The selected elliptical orbit is employed for the Earth observation mission and pre-determined orbital parameters are maintained by station-keeping.
Transfer Orbit	This mode is the indication of the orbital transfers between mission and standby orbits.
Station-Keeping	This mode is active when mission orbit is employed and triggering conditions for selected orbital parameters are activated. Necessary orbital manoeuvres are performed to maintain the mission-specific orbital parameters.
Minimum Energy Loss	This mode is the indication of that there is no manoeuvring needs, therefore minimum energy loss is aimed. This aim is accomplished by the Minimum Drag and Minimum Solar modes.
To Standby	This mode, belonging the Transfer Orbit, is the indication of necessary manoeuvres to be performed to reach the standby orbit by raising the perigee altitude above the mode switching altitude.
To Mission	This mode, belonging the Transfer Orbit, is the indication of necessary manoeuvres to be performed to reach the mission orbit by altering the perigee altitude, inclination, right ascension of ascending node and argument of perigee.
Sailing	This mode is the indication of that the altitude of the satellite is above the mode switching altitude and the satellite is free to orient its sail to generate required thrust for manoeuvring needs.
Minimum Drag	This mode is the indication of that the altitude of the satellite is below the mode switching altitude and sail orientation should be kept tangent to orbit to minimize the aerodynamic drag.
Minimum Solar	This mode is the indication of that the altitude of the satellite is above the mode switching altitude and there are no manoeuvring needs. Therefore, the sail orientation should be kept tangent to the ecliptic plane to minimize the Solar Radiation Pressure effects on the orbit.

2. STATION-KEEPING STRATEGY OF THE MISSION ORBIT

The station-keeping strategy of the mission orbit of the R2S2 concept is explained below in detail. First, orbital elements effecting the mission lifetime is explained to give the rationale behind the need for station-keeping. Then, principles adopted in this study are provided with a list of all cases considered. After that, mathematical formulation of the strategy is given with case-based control logic. Finally, simulation results are presented with discussion.

2.1. ORBITAL ELEMENTS EFFECTING MISSION LIFETIME

The mission lifetime, as explained above, depends on two reasons. Mission-specific lifetime will not be discussed further here since it is coming from the end user. On the other hand, disturbance-specific lifetime is the concentration point of this study.

Four orbital parameters (out of six) are taken into consideration for station keeping: semi-major axis, eccentricity, argument of perigee and right ascension of ascending node (RAAN). Since the ellipticity of the mission orbit is vital to the concept, semi-major axis and eccentricity are tracked in terms of perigee and apogee altitudes. Moreover, perigee and apogee altitudes are crucial for the safety of the concept because the failure of keeping these altitudes will result in decay of the orbit exponentially. Without station-keeping, the lifetime in the mission orbit may vary between 20 days to 3 months depending on the Sun-Earth-Satellite orientation. As it will be seen in the final section, proper station-keeping of the perigee and apogee altitudes may raise the mission life to 6-12 months.

Argument of perigee and RAAN values are important for mission success (revisit frequency and access number within the finite mission lifetime). The details of these effects may be found in another study (Polat & Tekinalp 2020). In summary, there are some intervals of values for argument of perigee effecting the mission performance relevant to the altitude criteria for an acceptable access of the satellite to the observation site. Similar intervals are also present for RAAN values for given day of the year effecting the mission performance relevant to daylight condition. To better understand, three conditions of the R2S2 concept conditions for an acceptable access are given below:

- The site is illuminated by the Sun (daylight condition is needed for electro-optical satellite to view the site),
- The altitude of the satellite is below 800 km (R2S2 Concept proposes the use this altitude range, 400-800 km for mission mode),
- Small Line-of-Sight angle between site and satellite is achieved (i.e., 20 degrees for half sensor angle for pointing off-nadir).

Changes due to J2 effects (apsidal and nodal precessions) are to be reduced by solar sailing to extend the mission lifetime with high performance observation metrics. The intervals shall be optimized for the mission orbit at the beginning with the trends of J2 perturbation. Although it is impossible to compensate for the asphericity effects of the Earth continuously, this tendency may be reduced through solar sailing.

2.2. PRINCIPLES

Two-tier control is applied to perigee and apogee altitudes to avoid chattering. 350 km is defined as the lower limit to trigger the perigee altitude station-keeping mode and is active until 400 km is achieved. Similar approach is applied for apogee altitude with 1350 km as lower limit resulting in an active station-keeping until reaching 1400 km of apogee altitude.

Depending on the initial orbital parameters and analysis on the observation performance of the mission orbit with requested mission lifetime, station keeping may be triggered for argument of perigee and/or RAAN as well. However, this should be done at the beginning of the observation task and should be continuously carried out.

When possible, in-plane and out-of-plane force components shall be used separately for controlling the orbit size (in-plane for perigee and/or apogee altitudes) and orientation (out-of-plane for argument of perigee and/or RAAN) control.

For cases with multiple orbital parameters, the priority order is as follows: perigee altitude, apogee altitude, argument of perigee and RAAN. The rationale behind for the priority is simple: First mission safety, then mission performance.

2.3. CASES FOR STATION-KEEPING

With four parameters to be considered for station-keeping a list of cases is generated and given in Table 2. All 16 combinations are considered for station-keeping strategy including Case Zero where no station-keeping condition is triggered. Each case is indicating the need for a time rate of change of a specific orbital parameter or combination of those depending on the triggering conditions. The need to generate the time rate of change of these orbital parameters are then met by solar sailing manoeuvres.

Table 2: Case List

Case Code	Condition	Case Code	Condition
Case A	$\dot{r}_p$	**Case I**	$\dot{r}_p + \dot{r}_a + \dot{\Omega} + \dot{\omega}$
Case B	$\dot{r}_a$	**Case J**	$\dot{r}_p + \dot{\Omega}$
Case C	$\dot{\Omega}$	**Case K**	$\dot{r}_p + \dot{\omega}$
Case D	$\dot{\omega}$	**Case L**	$\dot{r}_a + \dot{\Omega}$
Case E	$\dot{r}_p + \dot{r}_a$	**Case M**	$\dot{r}_a + \dot{\omega}$
Case F	$\dot{r}_p + \dot{r}_a + \dot{\Omega}$	**Case N**	$\dot{r}_p + \dot{\Omega} + \dot{\omega}$
Case G	$\dot{r}_p + \dot{r}_a + \dot{\omega}$	**Case O**	$\dot{r}_a + \dot{\Omega} + \dot{\omega}$
Case H	$\dot{\Omega} + \dot{\omega}$	**Case Zero**	No Condition

Due to the principles of the station-keeping strategy of the R2S2 concept, triggering condition for the argument of perigee and/or RAAN will be initially conditioned and continuous. For that reason, the need for the time rate of changes of argument of perigee and/or RAAN will be always the same (they exist or not). Only perigee and apogee altitude needs may change. As triggering conditions for perigee and apogee altitudes occur, case codes change. Similarly, as perigee and apogee altitudes are increased to their mission parameters by station-keeping manoeuvres, case codes change again. This behaviour results in four different cycles for case transitions (Figure 4) and the subplots are ordered as:

- no argument of perigee and RAAN station-keeping,
- only argument of perigee station-keeping,
- only RAAN station-keeping,
- both argument of perigee and RAAN station-keeping.

During the mission lifetime, station-keeping cases change to a different case within the cycles shown in Figure 4. No interchange for case codes is possible between case cycles.

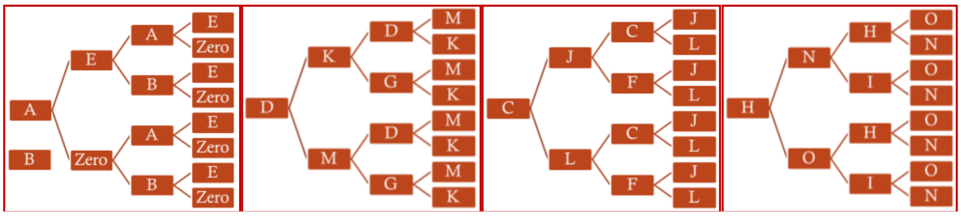

Figure 4: Case Cycles

3. VARIATION DYNAMICS OF THE ORBITAL ELEMENTS

In this section, the proposed approach to the control of shape, size and orientation of the orbit is given.

3.1. GAUSSIAN VARIATIONAL EQUATIONS

The control logic is implemented by utilizing the Gaussian Variational Equations (Battin 1987). GVEs, listed in Eq. (1), provides the dynamics for classical orbital elements under the influence of two-body Earth's gravitational attraction. All the other disturbances/control forces are treated as control input. Nomenclature for Eq. (1) is given in Table 3.

$$
\begin{aligned}
\dot{a} &= \frac{2a^2}{h}\left[eR\sin\theta + \frac{pT}{r}\right] \\
\dot{e} &= \frac{1}{h}\left(pR\sin\theta + \left[\left(p+r\right)\cos\theta + re\right]T\right) \\
\dot{i} &= \frac{r\cos(\omega+\theta)}{h}N \\
\dot{\Omega} &= \frac{r\sin(\omega+\theta)}{h\sin i}N \\
\dot{\omega} &= -\frac{r\sin(\omega+\theta)}{h\tan i}N + \frac{1}{eh}\left[-pR\cos\theta + (p+r)T\sin\theta\right] \\
\dot{\theta} &= \frac{h}{r^2} + \frac{1}{eh}\left[pR\cos\theta - (p+r)T\sin\theta\right]
\end{aligned}
\tag{1}
$$

The dynamics of the classical orbital elements given in Eq. (1) depends only on their values with no control input. For variables h, p and r, Eq. (2) is given for demonstrating the strict dependence on classical orbital elements.

Table 3: Nomenclature

a	Semi-major axis	h	Specific Angular Momentum
e	Eccentricity	p	Semi-Latus Rectum
i	Inclination	r	Magnitude of Position Vector
Ω	Right Ascension of Ascending Node	R	Force per Unit Mass-Radial Direction
ω	Argument of Perigee	T	Force per Unit Mass-Transverse Direction
θ	True Anomaly	N	Force per Unit Mass-Normal Direction

$$
\begin{aligned}
r &= \frac{a\left(1-e^2\right)}{1+e\cos\theta} \\
p &= a\left(1-e^2\right) \\
h &= \sqrt{\mu a\left(1-e^2\right)}
\end{aligned}
\tag{2}
$$

When we evaluate the principles of station-keeping of the R2S2 concept, perigee and apogee altitude dynamics are important. Therefore, Eq. (3) is given with differentiation of the perigee radius which is equivalent of the differentiation of perigee altitude.

$$
\begin{aligned}
r_p &= a\left(1-e\right) \\
\dot{r}_p &= \dot{a}\left(1-e\right) - a\dot{e}
\end{aligned}
\tag{3}
$$

Then, Eq. (1) is inserted into Eq. (3) and Eq. (4) is obtained. Same is applied to apogee radius as can be seen in Eq. (5).

$$
\begin{aligned}
\dot{r}_p &= \frac{2a^2}{h}\left[e\sin\theta\left(1-e\right) - \frac{\left(1-e^2\right)\sin\theta}{2}\right]R + \ldots \\
&\left[\frac{2a^2 p\left(1-e\right)}{hr} - \frac{a}{h}\left[\left(p+r\right)\cos\theta + re\right]\right]T
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
r_a &= a\left(1+e\right) \\
\dot{r}_a &= \dot{a}\left(1+e\right) + a\dot{e}
\end{aligned}
\tag{5}
$$

After setting the dynamics, approximations to these formulations are calculated with respect to the mission orbit parameters (400 km of perigee altitude and 1400 km of apogee altitude). As can be observed from Eq. (6), approximated dynamics of the classical orbital elements now depend on angles (argument of perigee, true anomaly, inclination, and alpha angle) and forces. In Eq. (6), in-plane forces, *T* and *R* are replaced by force *F* and angle α as can be seen in Figure 5.

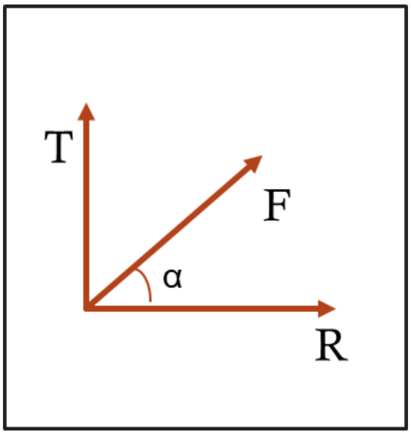

Figure 5: In-Plane Force Component Diagram

$$
\begin{gathered}
\dot{a} = 135.44F\cos\alpha\sin\theta - 1971.54F\sin\alpha\left(0.068\cos\theta - 1\right)\left[m/s\right] \\
\dot{e} = 1.35\times10^{-4}F\cos\alpha\sin\theta\ldots \\
+1.35\times10^{-4}\left(\frac{2\cos\theta + 0.068\cos^{2}\theta + 0.068}{1 + 0.068\cos\theta}\right)F\sin\alpha\left[1/s\right] \\
\dot{i} = \frac{1.35\times10^{-4}\cos\left(\omega+\theta\right)}{1 + 0.068\cos\theta}N\left[rad/s\right] \\
\dot{\Omega} = \frac{1.35\times10^{-4}\sin\left(\omega+\theta\right)}{\sin i\left(1 + 0.068\cos\theta\right)}N\left[rad/s\right] \\
\dot{\omega} = -\frac{1.35\times10^{-4}\sin\left(\omega+\theta\right)}{\tan i\left(1 + 0.068\cos\theta\right)}N - 1.98\times10^{-3}F\cos\theta\cos\alpha\ldots \\
+1.35\times10^{-4}\left(\frac{29.4\sin\theta + 0.5\sin2\theta}{1 + 0.068\cos\theta}\right)F\sin\alpha\left[rad/s\right]
\end{gathered}
\tag{6}
$$

Then rates of changes of orbital elements are plotted with respect to true anomaly, argument of perigee, and in plane force angle α as shown in Figure 6 and 7. In those graphs, all *F* (per unit mass inputs) are treated as unity. In these plots, the current inclination, which appears in argument of perigee and RAAN rate equations, is taken as 55^0. Because the R2S2 concept always uses prograde orbit which results in the situation that inclination does not flip the sign of the formula output. The magnitude changes are negligible in the scope of this study. However, for information, as inclination decreases the changes in argument of perigee and RAAN increase.

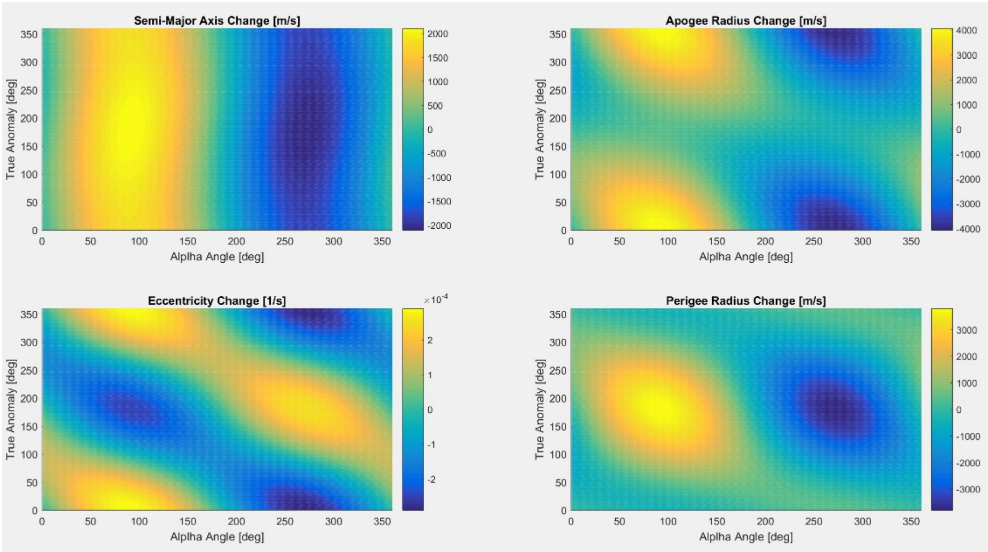

Figure 6: Orbit Resizing Graphs

Since, the lowest characteristic acceleration allowed in the R2S2 concept is in the order of 0.1 mm/s^2, these graphs can be interpreted as the change times 10^{-4}. This implies that approximated changes for orientation angles (Figure 7) are minor relative to the size parameters (Figure 6).

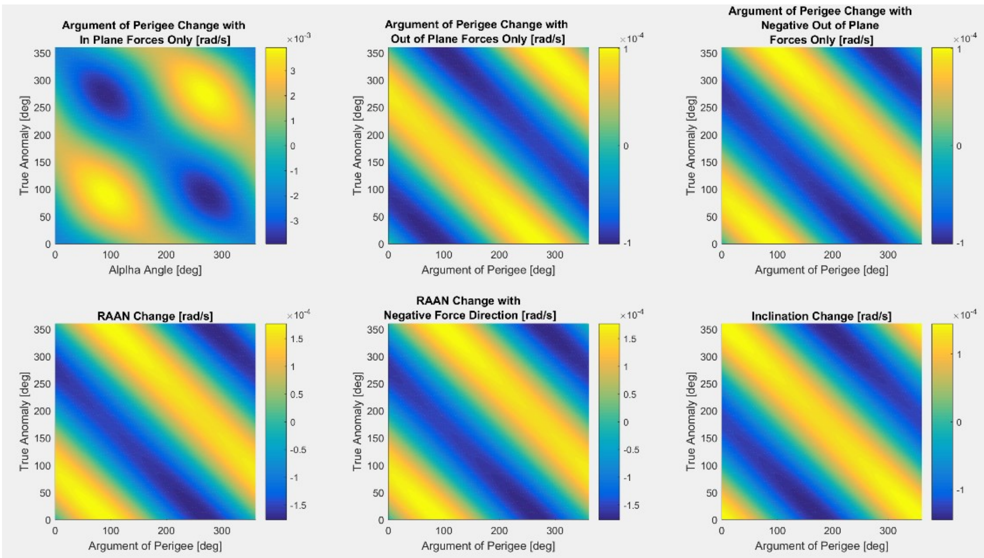

Figure 7: Orbit Reorienting Graphs

This results in only 1% improvement over the mission lifetime due to the argument of perigee or RAAN changes by the asphericity of the Earth. As mentioned earlier, the tendency of shifts of argument of perigee and RAAN by the asphericity effects of the Earth cannot be balanced by solar sailing manoeuvres, only reducing the shift rate is possible. This reduction rate over shifts of the argument of perigee and RAAN at the selected characteristic acceleration of the R2S2 concept is at 1%. But this improvement can be increased if a larger sail area is used (resulting an increase on the characteristic acceleration value to the orders of 1 mm/s^2 or more and eventually an increase on the reduction rate over the shifts).

3.2. CASE-BASED CONTROL LOGIC

The approximated dynamics output of the classical orbital elements are used to determine the control force direction. This process is carried out for each case with their own properties and requirements.

3.2.1. *Case A*

The perigee altitude dynamics depending on the true anomaly and alpha angle is manipulated excluding the true anomaly region from -83^0 to $+83^0$ (due to the no Sailing Zone from the concept itself), values above -10^{-4} s^{-1} of eccentricity change (due to the aim of decoupling the effects of perigee and apogee altitudes) and values below 1000 m/s of perigee altitude change are discarded. The remainder region for manoeuvres is shown in Figure 8. The optimal alpha angle for given true anomaly is then used for controlling the sail orientation when *Case A* is triggered.

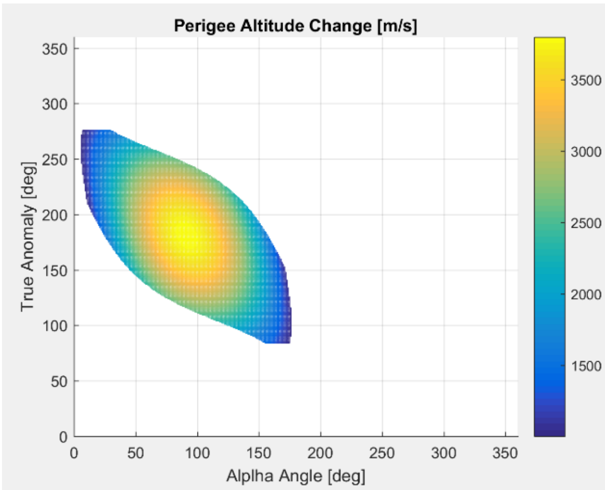

Figure 8: Perigee Altitude Change

3.2.2. *Case B*

Similarly, apogee altitude dynamics are given under the consideration of eccentricity and no Sailing Zone true anomaly region. The resultant graph is given in Figure 9. As may be observed from the graph, the region for manoeuvres is limited. This is since portions of the orbit around the perigee altitude, which are the most effective region for altering the apogee altitude, are treated as no sailing zone. When these portions of the orbit are discarded, there exist very limited opportunities to carry out necessary manoeuvres for increasing the apogee altitude. These opportunities are tried to be increased by lowering the limit of 1000 m/s change to 100 m/s.

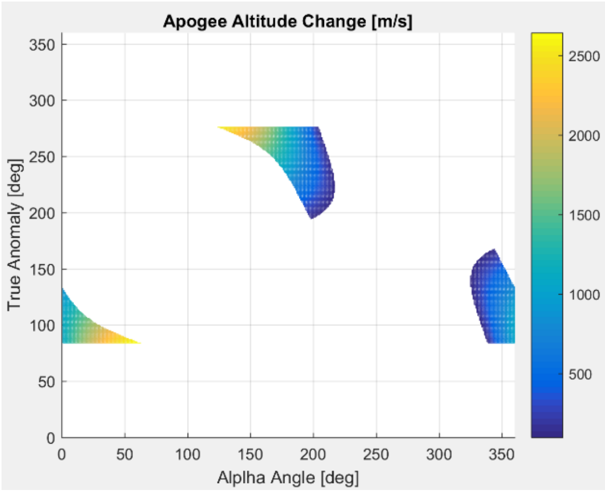

Figure 9: Apogee Altitude Change

3.2.3. *Case C* and *Case D*

The dynamics for RAAN and argument of perigee are given in Figure 10. In here, only out-of-plane force components are used for argument of perigee due to the reasons given above.

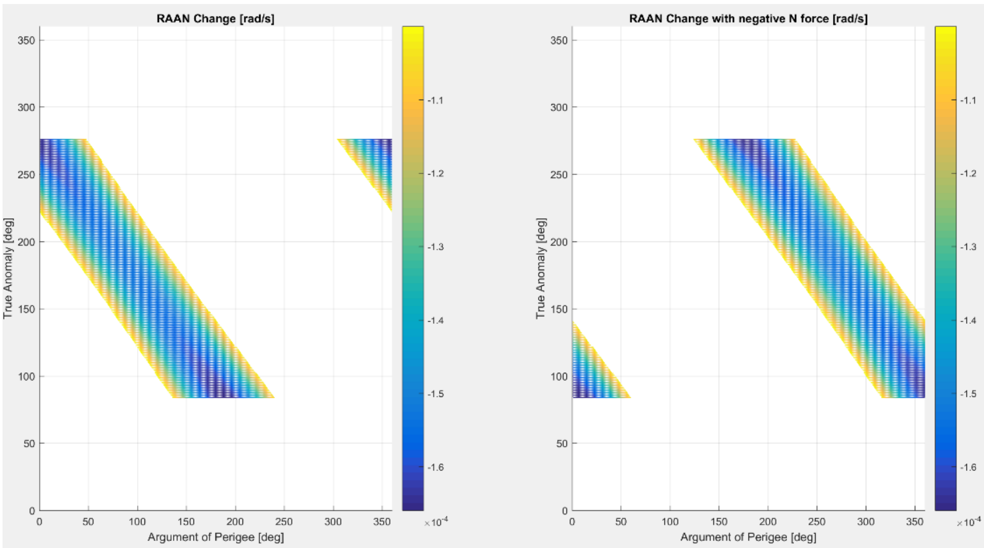

Figure 10: (a) RAAN and Argument of Perigee Changes

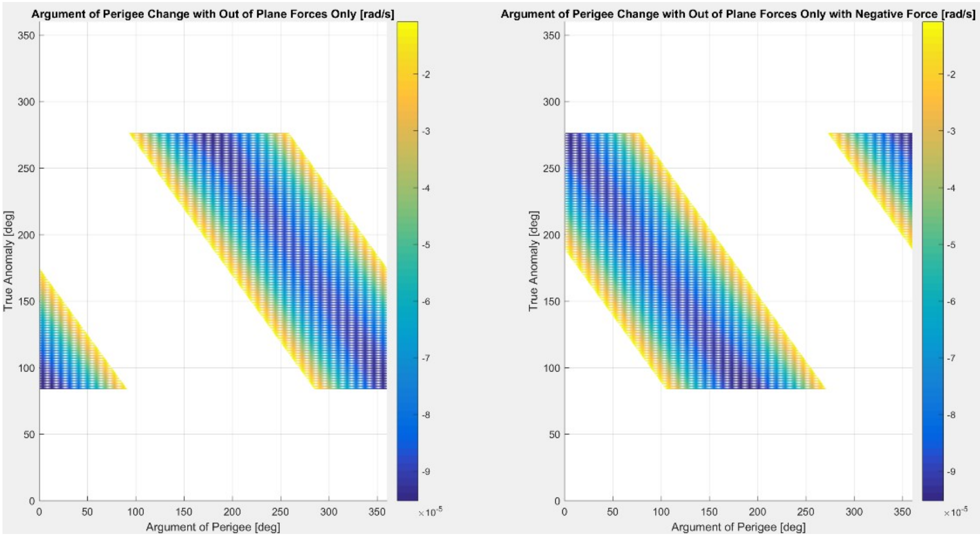

Figure 10: (b) RAAN and Argument of Perigee Changes

3.2.4. *Case E*

This case requests the station-keeping of perigee and apogee altitudes together. Since semi-major axis is the half of the sum of the apogee and perigee radii, the case request is well-met with station-keeping of semi-major axis. The dynamics of the semi-major axis is given in Figure 11. The alpha angle for optimal change for semi-major axis follows the velocity vector as expected.

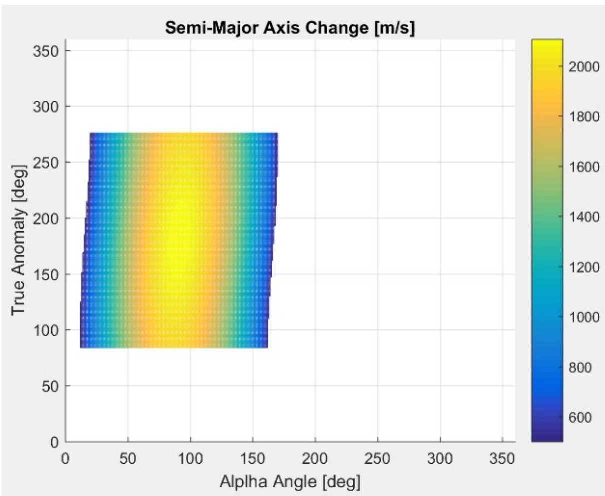

Figure 11: Semi-major Axis Change

3.2.5. *Case F*

Since we have covered the primary cases for individual orbital elements (*Case A-E*), we will see some combination of these strategies. *Case F* is the first example of this. The control force direction is given in Figure 12. *F* force is determined from *Case E* and *N* force is determined from *Case C*. Then, these directions are combined with weighting parameter which gives more force component to the in-plane forces due to the urgent need for station-keeping of the orbit size.

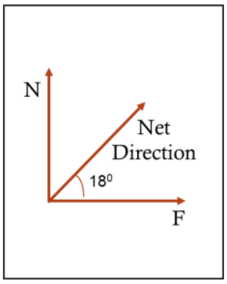

Figure 12: Weighting between In-Plane and Out-of-Plane Forces

3.2.6. *Case G*

In this case, out-of-plane forces are not considered for the argument of perigee, since the portion of the semi-major axis graph affecting the argument of perigee is an order of magnitude higher than the out-of-plane force effects. Therefore, that portion in semi-major axis is discarded and in-plane forces are used for argument of perigee. Final status is given in Figure 13.

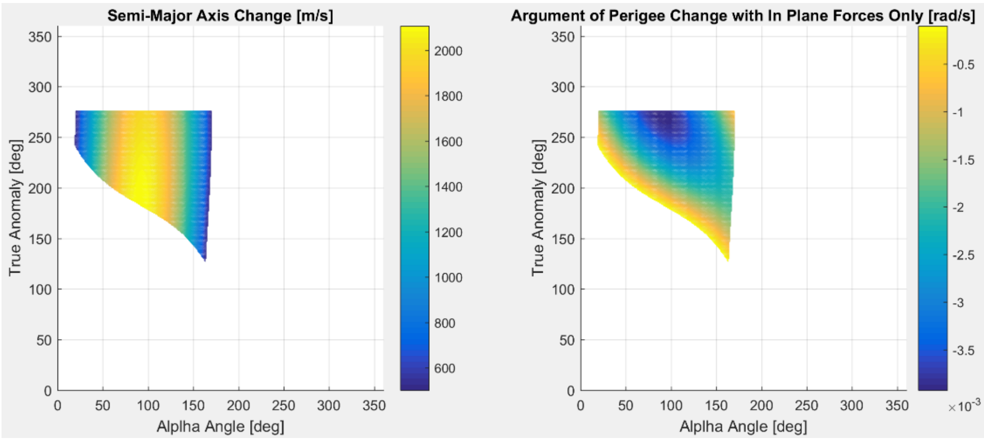

Figure 13: Co-Illustration of Semi-major Axis and Argument of Perigee Changes

3.2.7. *Case H*

When we look at Eq. (1) and Figure 7, the dynamics of argument of perigee and RAAN show that they have the same periodic dynamics with varying magnitude and there is a 90-degree phase shift. This means a particular change for the principles of the R2S2 concept. Hence, RAAN and argument of perigee can't be controlled simultaneously with only out-of-plane forces. Therefore, in-plane forces are considered for argument of perigee. While applying in-plane forces for argument of perigee, regions where affecting the perigee and apogee altitudes are discarded to avoid unnecessary altering of the altitude of the orbit. The resultant graphs for the determination of the control input are given in Figure 14.

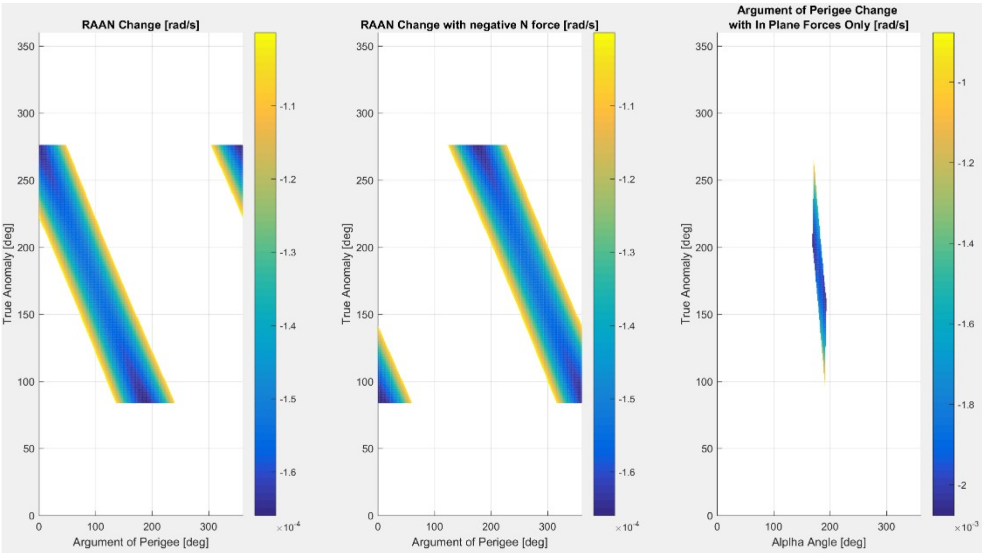

Figure 14: RAAN as a function of Argument of Perigee and Argument of Perigee with respect to α

3.2.8. *Case I*

Similarly, the control force direction is given in Figure 12. *F* force is determined from *Case G* and *N* force is determined from *Case C*.

3.2.9. *Case J*

Similarly, the control force direction is given in Figure 12. *F* force is determined from *Case A* and *N* force is determined from *Case C*.

3.2.10. *Case K*

Like *Case H*, out-of-plane forces for argument of perigee are out of consideration in *Case K*. In-plane forces are used by considering the coupled dynamics of perigee altitude and argument of perigee. The resultant graph for determination of the control force direction is given in Figure 15.

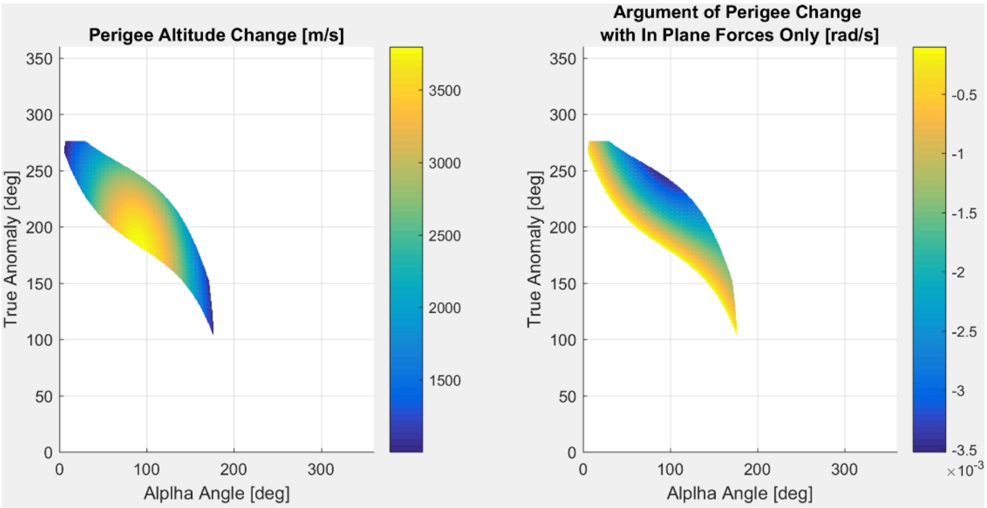

Figure 15: Perigee Altitude and Argument of Perigee with respect to α

3.2.11. *Case L*

Similarly, the control force direction is given in Figure 12. *F* force is determined from *Case B* and *N* force is determined from *Case C*.

3.2.12. *Case M*

Similarly, the control force direction is given in Figure 12. *F* force is determined from *Case B* and *N* force is determined from *Case D*.

3.2.13. *Case N*

Similarly, the control force direction is given in Figure 12. *F* force is determined from *Case K* and *N* force is determined from *Case C*.

3.2.14. *Case O*

The control force direction is given in Figure 12. *F* force is determined as given in Figure 16 and *N* force is determined from *Case* C. The graph given in Figure 16 is generated by considering the coupled dynamics of apogee altitude and argument of perigee.

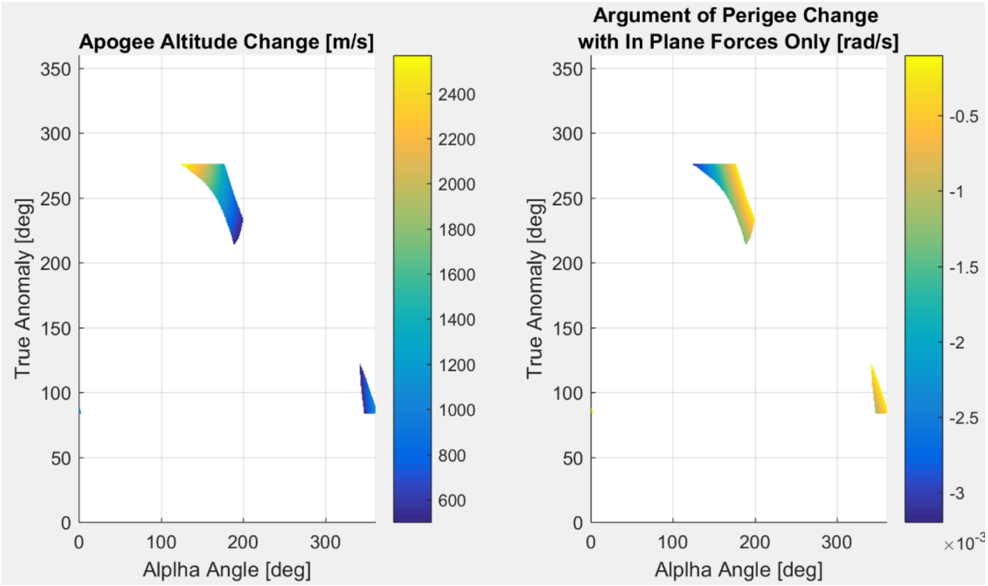

Figure 16: Co-Illustration of Apogee Altitude and Argument of Perigee Changes

3.2.15. *Case Zero* or *Attitude Mode=0* Condition:

This case is valid when no station-keeping condition is triggered. The sail direction is oriented such that minimum energy loss is obtained.

3.3. SIMULATION RESULTS

Finally, an extensive simulation is done. Simulation conditions given in Table 4 result in 384 different combinations. Force models for orbit propagation is modelled as listed in Table 5. Moreover, the satellite properties used in the simulation are also given in Table 5.

Table 4: Simulation Setup

Simulation Conditions	Number of Different Sets
Different Case Cycles	4 sets
Initial Date of Year	4 sets
Inclination	3 sets
RAAN	4 sets
Argument of Perigee	2 sets
Total	384 combinations

Table 5: Force Model and Satellite Properties

Force Models	Satellite Properties
Earth's Gravity	Sail Mass: 77 kg
Earth's Asphericity Effects (up to 4^{Th} Order)	Payload Mass: 37 kg
Third Body Effects (Sun and Moon)	Sail Area: 40x40 m^2
Aerodynamic Drag	Payload: 40x40x75 cm
Solar Radiation Force	Sail Efficiency = 90%

The results of the simulation are given in four graphs to demonstrate the aimed goal of station-keeping strategy of the R2S2 concept:

- Case switching status showing the case transitions based on the triggering conditions,
- Attitude mode showing that there is sailing manoeuvres or not,
- Perigee altitude trends,
- Orbit altitude trends.

First example resultant graphs are given in Figure 17. One can see that successive perigee altitude control between 350 and 400 km. Moreover, apogee altitude drop is diminished.

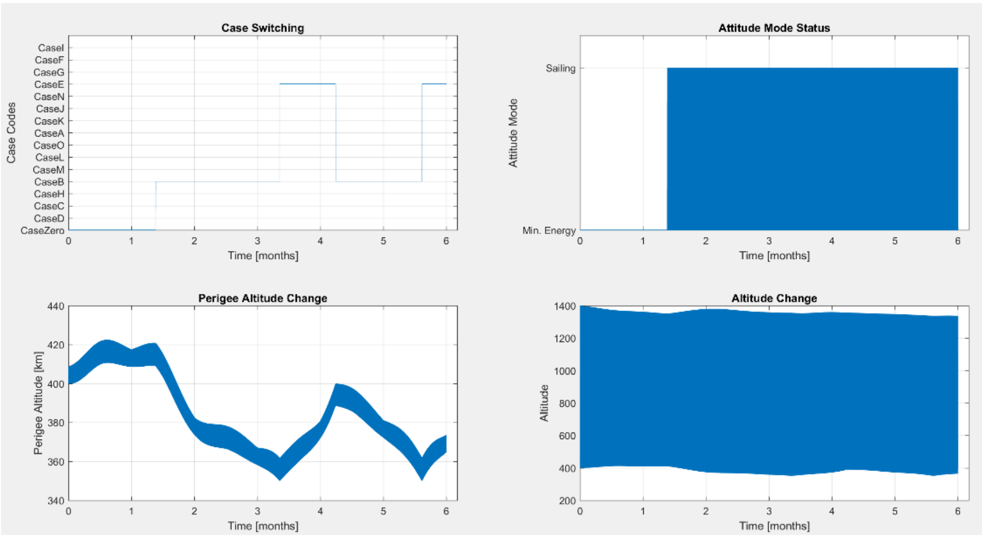

Figure 17: An Example of Simulation Results for First Case Cycle

The example in Figure 18 demonstrates the continuous station-keeping effort on argument of perigee. The switching up and down of cases implies an effective station-keeping effort. One more thing to notice here is the gaps within the attitude mode graph. These are the results of Sun-Earth-Satellite orientation that provides no valid condition for sailing manoeuvre. Thus, providing the requested control force direction is geometrically impossible.

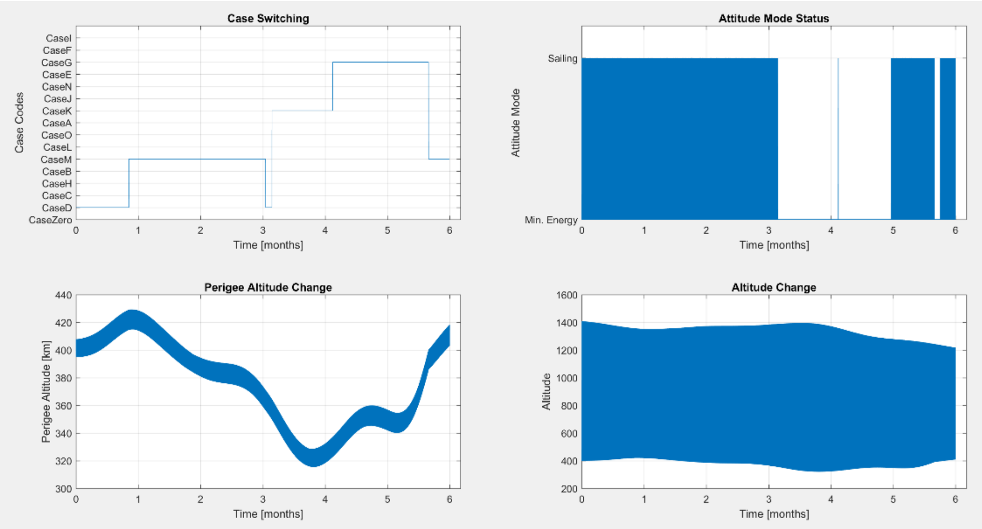

Figure 18: An Example of Simulation Results for Second Case Cycle

Similarly, RAAN station-keeping is continuous in Figure 19 and successful perigee altitude is restored even with the gaps within the attitude mode graph.

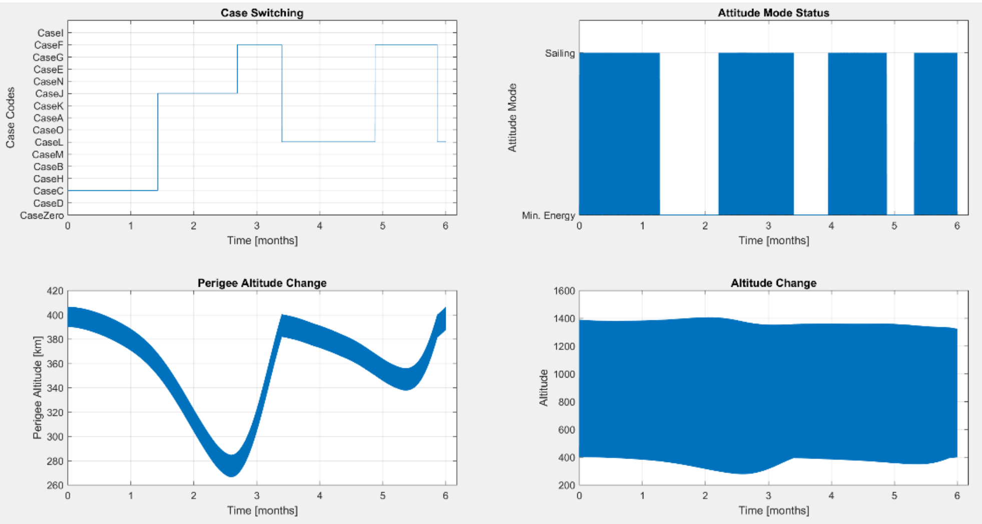

Figure 19: An Example of Simulation Results for Third Case Cycle

Last example is from a case with continuous argument of perigee and RAAN station-keeping efforts and results are given in Figure 20. Case transitions and restoring of the perigee and apogee altitudes are the implications of successful station-keeping strategy.

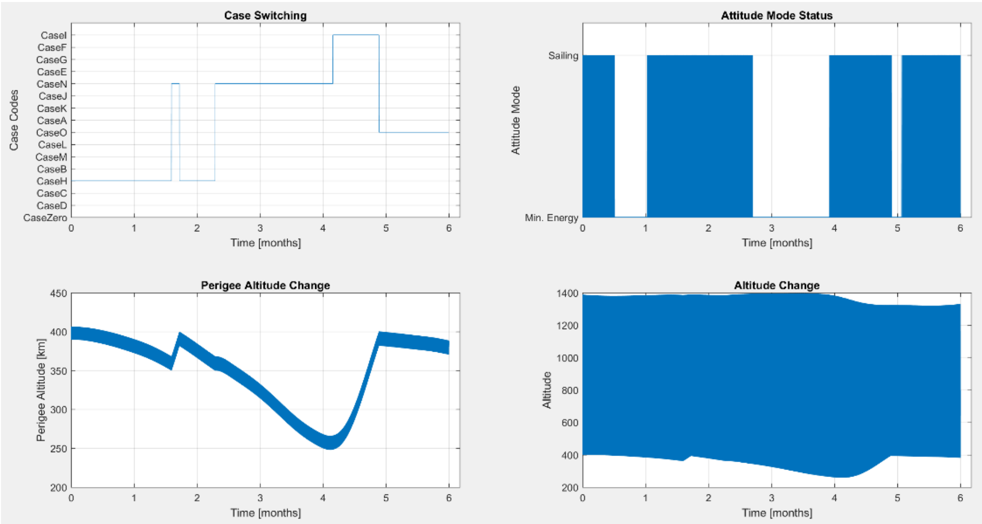

Figure 20: An Example of Simulation Results for Fourth Case Cycle

4. CONCLUSION

In this study, station-keeping strategy for the mission orbit of the R2S2 concept is provided with mathematical formulizations and simulation results. With four orbital parameters in consideration (perigee and apogee altitudes, argument of perigee and right ascension of ascending node), 16 different station-keeping cases are analysed and solution to the control force direction determination problem for each case is explained.

The coupled dynamics of orbital parameters are handled with the approximation of modified Gaussian Variational Equations. The original Gaussian Variational Equations are modified to better exploit for the elliptical orbital dynamics and this modification allows us to determine the control force direction under the coupled dynamics of four orbital parameters in consideration.

Moreover, principles for station-keeping strategy of the proposed concept of R2S2 is also respected when dealing with coupled dynamics of orbital parameters. Finally, simulation results show that solar sailing at low Earth orbit is adequate for station-keeping purposes. However, for the parameters of argument of perigee and right ascension of ascending node, the selected sail dimensions and properties do not give high performance for extending the mission lifetime.

These station-keeping performances (even for the argument of perigee and RAAN) can be increased by either reducing the payload mass (mission satellite), increasing the sail area, or reducing the sail loading (total mass per sail area). The miniaturization technology for the satellites and the improvements on the super-light materials will obviously increase the performance results of this study.

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DOI: 10.5281/zenodo.5645377

CHINA'S SPACE PROGRAMME - BORN OUT OF NATIONAL NEEDS, POISED TO SUPPORT GLOBAL PROGRESS

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Abstract: The 21st century is believed to become the Asian century. In the last decade China has introduced several economic and political initiatives which promote its rise as a global power. Embedded in its development and rise is the national space programme. Western observers tend to look at China's space programme as being small, slow, technologically less advanced, and not significant enough. Is that correctly reflected or what is it then? Is China's space programme able to support not only national advancement in science and technology but also support global societal progress? Which role does the New Silk Road project (One Belt – One Road, BRI) play in this process? How is space technology, embodied in the "Belt and Road Space Information Corridor", supporting the concept of a "community of shared future for mankind" and can it drive global solutions for society? The author, through consulting open-source information and performing in-depth analyses, looks to find qualified answers to these questions and will show how China – which until not so long ago was a developing country – has used science, technology and in particular space as a tool, as a strategic instrument for the comprehensive development of the society and economy. These facts and processes could be of importance for Serbia as well as South-East Europe.

Keywords: China, space programme, Belt-and-Road, Belt-and-Road Space Information Corridor, community of shared future.

1. THE BEGINNINGS OF CHINA'S EFFORTS IN SPACE

To understand any nations' space programme, it is necessary to take the societal and economic context into consideration. This is even more true for China, which conceptualised first space developments after World War II but profoundly reviewed its fundamental strategy for national space programmes at the turn of the millennium. Most important is, however, that at a time when Western nations in Europe, the U.S. and Japan enjoyed economic development and prosperity, the Chinese economy rode on a rollercoaster during the periods of "The Great Leap Forward" and the "Great Proletarian Cultural Revolution".

Initiated in 1958, "The Great Leap Forward" project was supposed to catapult China within 15 years into the league of leading industrial nations. After just 3 years, the economy of the country was broken. The following Five-Year-Plan brought some relief, until in 1966 the "Great Proletarian Cultural Revolution" took its course. The persecution of intellectuals and academics damaged a whole generation and with it most of China's best talents. The economy during the "Cultural Revolution" did not completely stand still, but progress did. Only after the death of Mao Zedong in 1976 the situation could halt. China's firsts in space are embedded into these dramatic decades of the nation's post-war development.

1.1. DONG FANG HONG – THE EAST IS RED

As an outcome of the Korean War, China felt under nuclear threat and asked the Soviet Union for technical assistance in the development of its own nuclear capabilities including long-range missiles. The Chinese request was granted.

Later, the launch of Sputnik 1 on 4 October 1957 by the Soviet Union sincerely impressed the "Great Helmsman", Mao Zedong. Such a satellite he wanted to have for his own nation, preferable with the support of the Soviet Union. For China, the underlying principle was to catch up with leading technology developments in the world rather than driven by a race as compared to the competition between the Soviet Union and the U.S.

The Chinese Academy of Sciences (CAS) set up a task force for the technical and scientific development of an indigenous satellite, connected to a long-term and comprehensive national satellite programme. CAS was fully aware of the relevance of satellites for the national scientific and technical development. Considering the low state of technology by that time in China, a satellite project would provide an objective and a motor for technological progress.

Despite the Soviet Union supporting China's military missile programme, there was no assistance in the civil space sector.

Worse, because of the "Great Leap Forward" too few allocated resources, material, and workforce made it impossible for CAS to succeed with a national satellite.

In 1961, after the "Great Leap Forward", the Chinese leadership focused on the so-called 'Four Modernizations', among which was also science and technology. Despite that, the satellite work group within the CAS was still struggling.

In 1966 the "Cultural Revolution" deeply impacted the Chinese society and shook its foundations. Intellectuals were targeted and scientific institutions became places of conflict and violence. Under those circumstances, CAS and other institutions involved in space developments asked the Communist Party to protect their institutions with the help of the military. Mao approved and since that moment the Chinese space programme and the People's Liberation Army were tied together and have remained in tandem until today.

After 12 years of hard work, impacted by economic and technical constraints and political and societal interference, China launched its first satellite Dong Fang Hong - DFH 1 on 24 April 1970. The 173-kg satellite whose only task was to transmit the heroic Chinese song “The East is Red”, was more of a propaganda instrument than the starting point for a solid, sustainable science programme. China, however, became the fifth nation in the world capable of placing a payload into orbit.

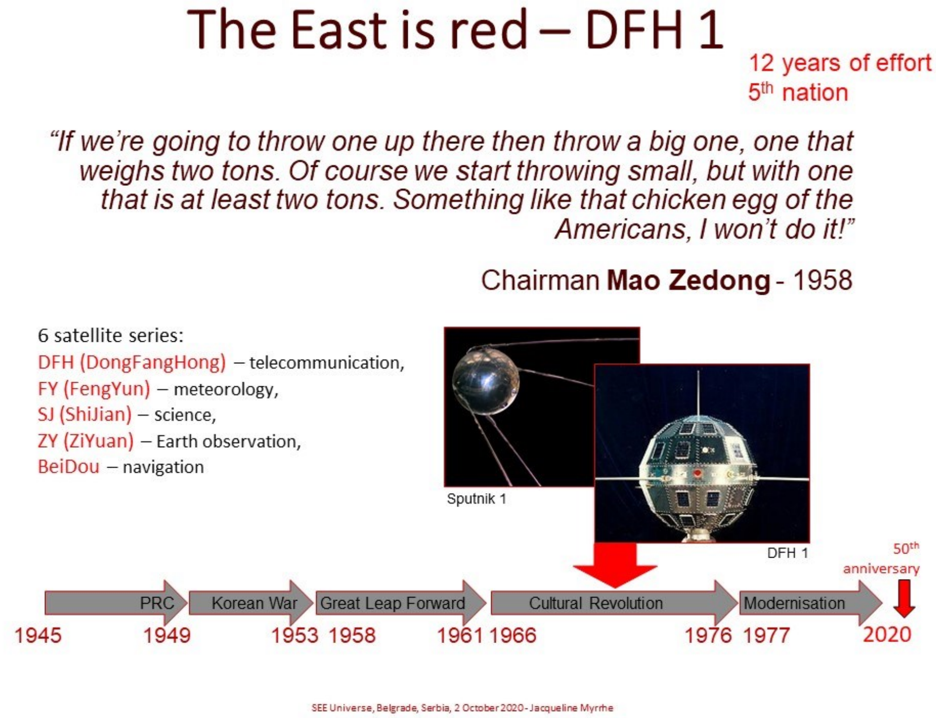

Figure 1: The launch of China's first satellite, the Dongfanghong-1 was a crucial milestone in the development of the nations' space capabilities.

1.2. GEOSTATIONARY SATELLITE

After the end of the “Cultural Revolution” in 1976, Deng Xiaoping was responsible for education, science, and technology – the one of the “Four Modernizations” that he thought to be the most important.

Deng became famous in illustrating his idea in a 1978 meeting when he tried to persuade his comrades to go for a communications satellite programme by saying:

“If we invite a good teacher to give a lecture in the Great Hall of the People only 10,000 people can hear it, but if the same teacher were to give that lecture on television, and everyone had the equipment to receive it, that’s a classroom of unlimited size.” (Kulacki & Lewis 2008).

Deng Xiaoping succeeded in convincing his comrades and the GEO satellite programme went through. Ambitiously, it was also decided to develop a cryogenic upper stage, which led to a delay in the overall programme. At a certain point Deng wanted to buy a communications satellite from the U.S.A., however this initiative did not work out and the self-set deadline for a launch in 1980 was slipping. Again, the insight prevailed that instead of relying on support from other countries, China must find and go its own way. Also, Deng was quoted as saying that China can buy one, two, three satellites, but at the end of the day, a big nation such as China cannot buy satellites forever if the country wants to make critical technological advancements.

In the second half of 1983 China accomplished the five major systems needed for geo-stationary access to space: launch vehicle, satellite, launch site, the tracking and telemetry equipment, and a network of ground stations.

China's first GEO satellite finally launched on 8 April 1984, making China the fifth GEO nation in the world and enabled space applications for economic development.

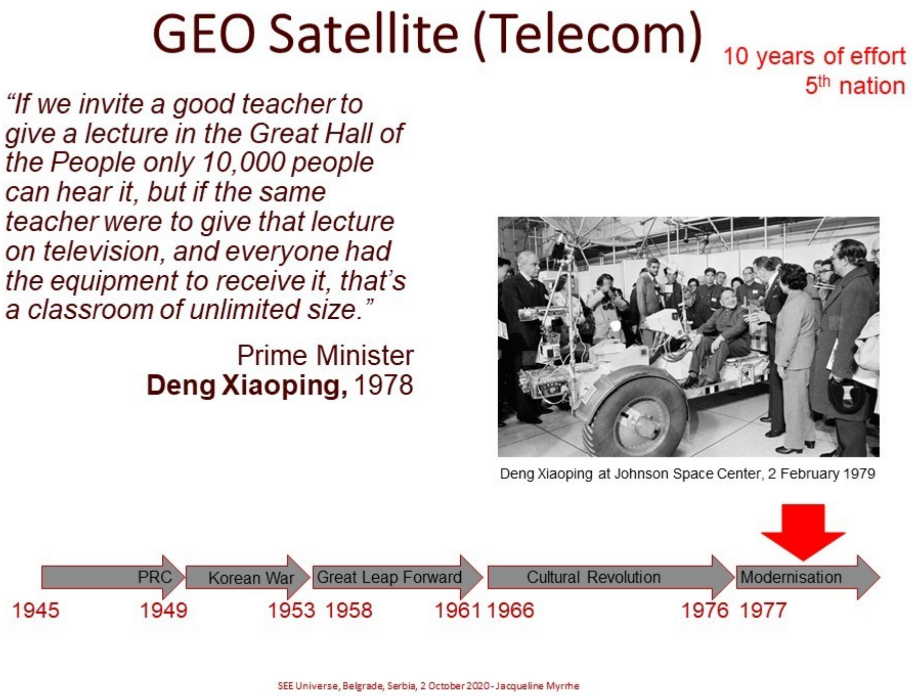

Figure 2: The launch of a GEO satellite showed that China had developed a strong launcher and the related ground segment for geostationary communication.

1.3. MANNED SPACE PROGRAMME

China's human spaceflight programme came late into being since its usefulness for the national and economic development was less obvious.

Deng Xiaoping was interested in space applications, but closed officially the manned space project in 1976:

China *"should not participate in the space race"* and instead we should *"focus our energies on urgently needed practical satellite applications."* (Kulacki & Lewis 2008).

On 23 March 1983, U.S. President Ronald Reagan held his SDI speech. In China, this speech led to discussions on what the role of science and technology is for a country's national development.

In April 1986, the legendary document: "An Outline for National High Technology Planning", the "Plan 863" was published and in October of the same year, the plan was approved, and budget allocated. From now on, the manned spaceflight programme served as an ambitious project that would develop a national space industrial infrastructure and promote the education of the required talent and specialists.

Finally, the Standing Committee of the Politburo approved the space station plan on 21 September 1992, declaring the Chinese Space Station (CSS) the core of China's human space flight efforts.[1]

In 2003 China would become the third nation in the world capable of human space flight.

10 years later, China fulfilled a big legacy of high symbolism when during China's fifth human mission Shenzhou 10, female crew-member Wang Yaping succeeded in turning Deng Xiaoping's vision of a classroom of unlimited size into reality. From aboard the Tiangong 1 space lab, she delivered a science lesson to 60 million Chinese students.

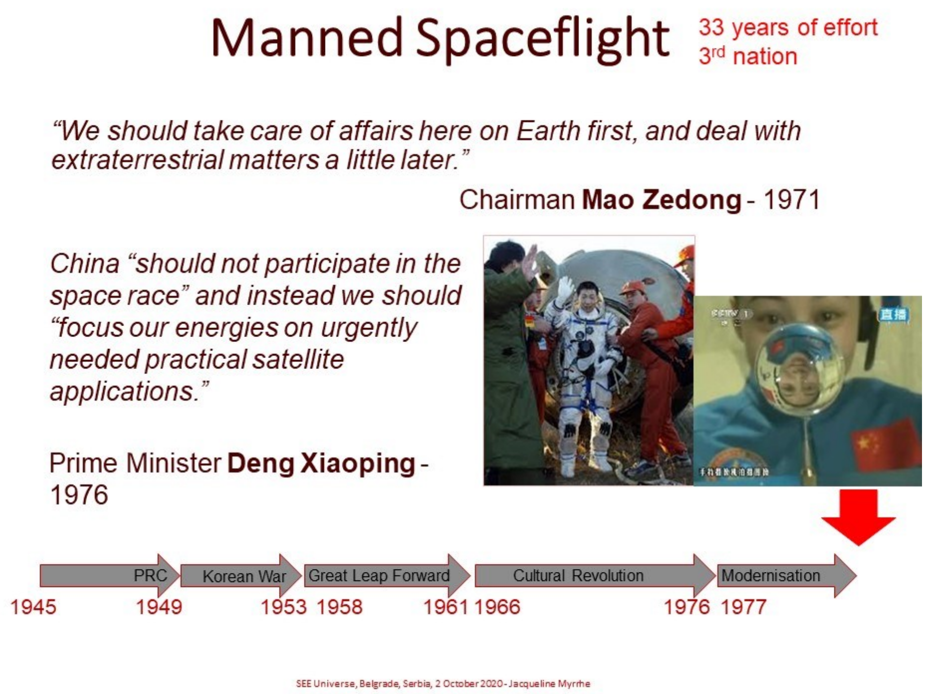

Figure 3: Becoming a human-rated space nation brought China the respect of other space powers.

[1] Kulacki, G: 2012, Why China is Building a Space Station, Union of Concerned Scientists.

2. CAESURA: THE ECONOMIC BOOM, WHITE PAPERS, AND ROADMAP 2050

The economic success at the turn of the millennium not only provided China with the self-confidence and self-esteem to go for big societal concepts, but was also the moment to give science, technology - and with it, space - a fundamental new orientation and direction to meet the needs of the future of the nation.

Since 2001, four "White Papers on Space Activities", published in parallel with the respective five-year-plans explained the achievements and objectives of the national space activities.[2] The most important message reads:

"The Chinese government has all along regarded the space industry as an integral part of the state's comprehensive development strategy…."

Additionally, in 2009, the document: "Space Science and Technology in China: A Roadmap to 2050" was published. Experts analysed the strengths and flaws of China's science community, the worldwide trends in space and technology, and came up with long-term goals and defined the steps necessary to achieve them.

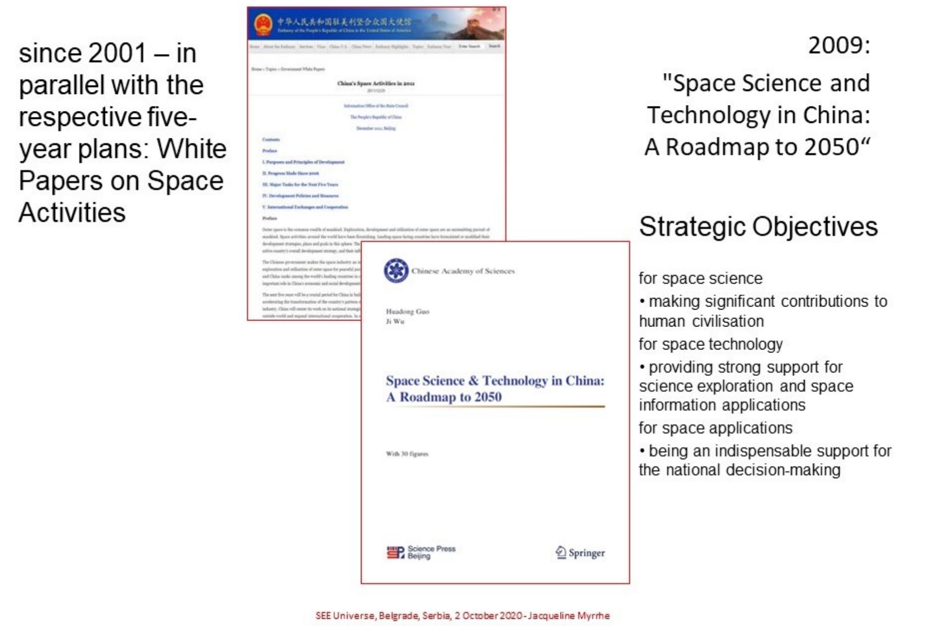

Figure 4: Title page of the White Paper and the Roadmap 2050.[3]

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[2] Carey, W.: 2012, No Giant Leap – A Review of China's Space Activities White Papers (2000-2011), GoTaikonauts! – All about the Chinese space programme, 4, 25-29.

[3] The State Council Information Office of the People's Republic of China – China's Space Activities:
http://english1.english.gov.cn/official/2005-07/27/content_17656.htm
http://www.china.org.cn/english/features/book/183672.htm
http://www.china.org.cn/government/whitepaper/node_7145648.htm
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The roadmap activity aimed at predicting the future developments of science and technology in accordance with the needs of the Chinese nation for the next 20-30 years. It was concluded that science and technology have
"to address the needs of both, the nation and society, the continued growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature." (Huadong & Ji 2010)

Science, technology, innovation, and management must be interconnected with the economic societal base. Space must become a tool for the benefit of the Chinese society, and the achievement of the overarching goals and synergistic efforts as laid out in the roadmap.[4]

Furthermore, it was concluded, that growth by purely extending the economic production had reached its limit. China's economic and social development will largely depend on science and technology through scientific discoveries, through the realisation of so-called "Mega Projects" such as the Beidou navigation system, the High-Resolution Earth observation network, the ground station network, and through new inventions and technological innovation.

The strategic aims of the roadmap are in accordance with the principles of the White Papers. And here another highly interesting quote from the roadmap:
"The past 250 years' industrialisation has resulted in the modernization and better-off life of less than 1 billion people, predominantly in Europe, North America, Japan and Singapore. The next 50 years' modernization drive will definitely lead to a better-off life for 2-3 billion people, including over 1 billion Chinese, doubling or tripling the economic increase over that of the past 250 years." (Huadong & Ji 2010)

Figure 5: China has established a wide range of space activities, covering all relevant areas of a space nation.

[4] Carey, W., Myrrhe, J.: 2014, What if…? Searching for Evidence - An Attempt to Analyse the 'Space Science & Technology in China: A Roadmap to 2050', GoTaikonauts! - All about the Chinese space programme, 12, p. 31-38.

For making this happen, space science and space technology will be the best available tool.

What we witness today, is that China has developed a robust, comprehensive, and strategically oriented space programme to serve its overall national development.

The next, intriguing, question therefore is: What has worked on a national level - could that be applied globally?

3. ENTERING THE GLOBAL STAGE

After China had proven that space infrastructure and space technology is a successful driver for economic and societal development, it offered its space resources to other nations.

China initiated several space projects which ask for international participation and support the build-up of space capabilities in non-space faring nations and offer cooperation opportunities for advanced nations.

Examples for that are:

- United Nations Office for Outer Space Affairs, UNOOSA: access to the Chinese Space Station.
- Payload opportunities within the Lunar exploration programme CLEP.
- Support to African nations to train expert engineers, build satellite ground stations and satellite manufacturing facilities.
- Remote-sensing satellite constellation among the BRICS States (Brazil, Russia, India, China, South Africa).
- Small Satellite Project within the Asia-Pacific Space Cooperation Organisation, APSCO.
- Beidou Satellite Navigation System supporting the Belt-and-Road Region.

Figure 6: Major initiatives with important space cooperation – from the left: Belt-and-Road (Beidou), CLEP (Chang'e), UNOOSA (CSS), APSCO (SMMS), BRICS (remote sensing).

3.1. UNITED NATIONS - UNOOSA

In March 2016, the United Nations Office for Outer Space Affairs UNOOSA and the China Manned Space Agency CMSA, signed a Framework and Funding Agreement to develop the space capabilities of UNOOSA Member States via opportunities on-board China's Space Station (CSS).

China offered:

- to use the CSS for experiment payloads or joint research;
- the joint development of modules, sub-systems, components, or other platforms;
- to train and fly astronauts;
- to share technical know-how[5].

In April 2016, Yang Liwei, China's first man in space told media on the occasion of China's First National Space Day:

"Payload has been reserved in the Chinese space station, due to enter service around 2022, for international projects and foreign astronauts. Upon request, China will also train astronauts for other countries, and jointly train astronauts with the European Space Agency. ... The future of space exploration lies in international cooperation. It's true for us, and for the United States too. China will not rule out cooperating with any country, and that includes the United States."[6]

On 28 May 2018, the First Announcement of Opportunity within the framework of the "United Nations/China Cooperation on the Utilisation of the China Space Station" was launched. China is taking over all cost for hardware upload and operations. The development of the experiments having to be covered by the applicant.

There were three possibilities for orbital experiments in the first round of opportunities:

- Conducting experiments inside the CSS by utilising experiment payloads developed by selected applicants.
- Conducting experiments inside the CSS by utilising experiment facilities provided by China.
- Conducting experiments outside the CSS by utilising payloads developed by selected applicants.

By the deadline in September 2018, a total of 42 applications were submitted from public and/or private organisations based in 27 countries. The science teams came from 60 organisations and were composed of 259 scientists and experts. The selection process and the implementation were jointly done by UNOOSA and CMSA.

[5] QiMing, J.: 2014, Chinese Space Station CSS and International Cooperation, 57th session of the Committee on the Peaceful Uses of Outer Space – COPUOS https://www.unoosa.org/pdf/pres/copuos2014/tech-24.pdf

[6] Liwei Y.: 2016, Xinhua, China open to Sino-U.S. space cooperation, https://www.chinadaily.com.cn/china/2016-04/25/content_24813817.htm

On 12 June 2019 UNOOSA and CMSA published the result of the most comprehensive Announcement of Opportunity (AO) in the history of space flight, where all member states of the UN were eligible to apply. Nine experiments were accepted for entering the preparation and implementation process.

Currently, UNOOSA and CMSA are considering a second AO.

Has the Chinese Space Station the potential to become the World's Space Station?

3.2. CLEP – LUNAR EXPLORATION

On 3 January 2019, China's Chang'e 4 (CE-4) lunar mission soft landed on the far side of the Moon. For the first time in its lunar exploration programme CLEP, China accepted international payloads on a lunar probe. The Chang'e 4 lunar lander hosted the Lunar Lander Neutrons and Dosimetry (LND), a neutron dosimeter, developed by Kiel University in Germany and the rover the Advanced Small Analyser for Neutrals (ASAN), an energetic neutral atom analyser provided by the Swedish Institute of Space Physics (IRF). The Netherlands-China Low-Frequency Explorer (NCLE) and a small lunar optical imaging detector developed by King Abdulaziz City for Science and Technology (KACST) were mounted on the Queqiao relay satellite.

Following the success of the CE-4 mission, Liu Jizhong, Director of the Lunar Exploration and Space Engineering Centre of CNSA, announced on 18 April 2019 in Beijing the opportunity for international participation in the Chang'e 6 (CE-6) lunar mission.

CE-6 is the back-up mission for the Chang'e 5 (CE-5) lunar sample return mission which successfully returned lunar samples on 16 December 2020. CE-6's landing location and detailed mission profile is depending on the outcome of the CE-5 flight. The CE-6 orbiter and lander will each reserve 10 kg for instruments, to be selected from national academic organisations, private enterprises, and foreign scientific research institutions. France's National Centre for Space Studies CNES said in March 2019 that Chang'e 6 would carry French experiments.

3.2. FOCAC - FORUM ON CHINA-AFRICA COOPERATION

During the 1950s, advocated by the then Foreign Minister Zhou Enlai, China approached the developing world to promote diplomatic recognition and establish long-term relationships. Based on barters, China supported building industrial facilities, gave technical training and financial aid. Countries in South-East Asia, North and Eastern Africa benefited from that move.

Later, these exact countries became customers for the China Great Wall Industry Corporation's (CGWIC) scheme of "in-orbit delivery" – an all-round-package comprising the satellite, launch service, operation and often the needed training for domestic engineers.

These long-standing friendly relations between China and governments of developing countries are today the door opener for big-scale infrastructure projects and for closing the digital divide.

At the 2015 Summit of the Forum on China-Africa Cooperation (FOCAC) held in South Africa, the Chinese government promised to provide satellite TV capability to 10,000 African villages. Households in Nigeria, Rwanda, and Malawi were equipped with TV sets, satellite dishes, solar panels, and batteries to power the TV units.

China HEAD Aerospace Technology Co., and its subsidiary HEAD Technology France, built the commercial satellite ground station in Ethiopia for receiving data from the Superview satellites. Additionally, HEAD is also providing data processing software and training for Ethiopian engineers. Moreover, Addis Ababa, capital of Ethiopia, is home to the African Union (AU) Headquarters, therefore it is expected that the satellite ground station and data centre will be ideally placed to disseminate information to various African countries. The African Union adopted a policy on African space development in 2017 and declared that space science and technology could advance economic progress and natural resource management on the continent.

Not only will the further socio-economic development of Africa demand space data and applications in the downstream sector, but also climate change will have a bigger impact on the African continent than on others. For many African countries, space assets will enable them for the first time to monitor and evaluate the impact of human activity on their natural resources and the environment, as well as to assess meteorological situations in real-time.[7]

3.3. APSCO

The Asia-Pacific Space Cooperation Organisation APSCO, is an intergovernmental space organisation for the Asia-Pacific region. It is headquartered in Beijing, China. APSCO aims at capacity-building in its Member States, what includes the training of space experts but also focusses on space applications. Within APSCO, China is driving the use of space capabilities for socio-economic development. For that, the Small Multi-Mission Satellite - SMMS project - is one of its flagship projects.

China’s most modern Fengyun weather satellite is covering the territory of the APSCO Member States and the Belt-and-Road Region. Ground stations in APSCO countries support the reception of satellite data. In return, the data are available for all APSCO members.

[7] Harvey, B.: 2020, China, sanctions and spaceflight, GoTaikonauts! - All about the Chinese space programme, 29, pp. 28-31

3.4. BRICS PARTNERSHIP ON NEW INDUSTRIAL REVOLUTION

Next to Brazil, Russia, India, and South-Africa, China is one of BRICS' Member States – an association of emerging economic powers to find its place in a multi-polar world. This community of developing nations is home to 42 % of the world's population, contributes 18 - 22 % of global GDP, and has generated more than half of the global growth in the past decade, staying its most important engine.

The existing solid space cooperation with Brazil (CBERS programme) is considered a role model for other countries. During the BRICS Summit 2019 in Brasilia, the nations agreed on a "BRICS Partnership on New Industrial Revolution" to strengthen the digital economy and connectivity, among others.

Earlier, China's President Xi Jinping stressed in his speech at the opening ceremony of the 7th BRICS Business Forum on 3 September 2017 in Xiamen, China:

"BRICS is not a talking shop, but a task force that gets things done. Our goal is to build a big market of trade and investment, promote smooth flow of currency and finance, improve connectivity of infrastructure, and build close bond between the people. ... We should seize the opportunity presented by the new industrial revolution to promote growth and change growth model through innovation. We should pursue innovation-driven development created by smart manufacturing, the 'Internet Plus' model, digital economy and sharing economy, stay ahead of the curve and move faster to replace old growth drivers with new ones." [8]

In their declaration after concluding the 9th BRICS Summit on 3 and 4 September 2017 in Xiamen, China, the BRICS Leaders stated:

"We will enhance joint BRICS research, development and innovation in Information and Communication Technologies (ICT) including the Internet of Things, Cloud computing, Big Data, Data Analytics, Nanotechnology, Artificial Intelligence and 5G and their innovative applications to elevate the level of ICT infrastructure and connectivity in our countries." [9]

While in 2015 the option of a joint BRICS space station was briefly discussed, the BRICS Science, Technology and Innovation Ministers signed in March 2015 a 'Memorandum of Understanding on Cooperation in Science, Technology and Innovation' where 'Space research and exploration, aeronautics, astronomy and Earth observation' are explicitly mentioned.[10] In the meanwhile, a solid cooperation project in the area of Earth observation is under way. Igor Komarov, Programme Director of Roscomos State Corporation explained in May 2016:

"The practical initiative, on which we are now working together with the BRICS countries, is a data exchange in distanced probing of the Earth, which will help in quicker responses to emergency situations, natural calamities, pollution and other

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[8] Xi Jinping, 2017, President Xi's speech at opening ceremony of BRICS Business Forum, http://news.xinhuanet.com/english/2017-09/03/c_129695215.htm

[9] BRICS 2017, Leaders Xiamen Declaration

[10] BRICS 2015, Memorandum of Understanding on Cooperation in Science, Technology and Innovation

aspects. I believe, it will find rather prompt and very important practical use for the BRICS countries." [11]

Taking this initiative a step further, a BRICS space project, a joint satellite constellation comprising selected national satellite resources, is currently in the making.

3.5. NATIONAL CIVIL SPACE INFRASTRUCTURE – BEIDOU FOR THE WORLD

China's Civil Space Infrastructure comprises the integrated and coordinated space-based and ground engineering facilities which enable the utilisation of space resources to provide products and services in the fields of remote sensing, telecommunication, navigation and positioning, and other applications. The National Civil Space Infrastructure is considered to be of strategic significance for the overall modernisation of the Chinese nation and for the transformation of the society into an information-oriented and intelligence-oriented community. In parallel, it is indispensable for national security, and an enabler for scientific development, economic transformation, and the realisation of an innovation-driven society based on information application business on a large industrial scale.

The construction of the National Civil Space Infrastructure will be completed by 2025.

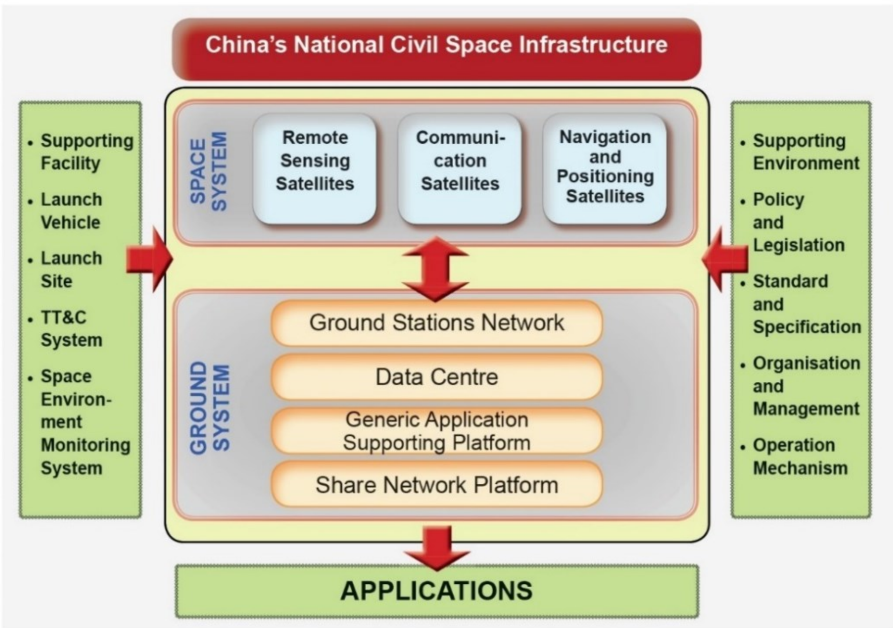

Figure 7: Overview of China's National Civil Space Infrastructure. Credit: CNSA/GoTaikonauts!

[11] Komarov, I.: 2016, BRICS countries plan exchanging data of Earth satellite probing, http://tass.com/science/872101

One of the crucial components of the space infrastructure is the Beidou satellite navigation system (BDS) as an indispensable foundation for down-stream applications and integrated services. This includes smart technologies, a digital economy based on mobile communications, cloud computing, IoT, industry internet, Big Data, and block chain as its pillars. Combined with governmental policies, the Chinese administration expects self-employed businesses, flexible jobs, and new applications to be made possible.

In China alone, the wider navigation service industry generated in 2019 a turnover of 345 billion RMB (about 48.5 billion US$) and predictions state that it exceeded 400 billion RMB in 2020, with Beidou contributing 70 to 80 % of the total.[12]

After the national test run, the first users of Beidou were neighbours in Asia-Pacific and until 2018 countries along the Belt-and-Road and in neighbouring regions were served before the system went global by 2020. Beidou is positioned to support a so-called "downstream industry" providing space-based applications for economic, educational, communication or other purposes.

During a press conference of the State Council Information Office on 27 December 2019 in Beijing, the Director of the China Satellite Navigation System Management Office, Ran Chengqi, told the media that 5G technology will make it possible to establish before 2035 *"a more ubiquitous, integrated and intelligent navigation and timing system with comprehensive national positioning"*.[13]

It is worth mentioning that the Chinese government set up three mechanisms for international Beidou cooperation, encouraging commercial actors to follow: the China-Central Asia BDS Cooperation Forum, the China-Russia Satellite Navigation Key Strategic Cooperation Project Committee, and the China-Arab States BDS Cooperation Forum.

Comprehensive space infrastructure – like the Chinese Beidou satellite navigation system and the Russian GLONASS – are ready to feed space applications, essential for the realisation of the 'One Belt - One Road' endeavour. The Belt-and-Road initiative is complementary to the Eurasian Trade Zone, an initiative by Russian President Vladimir Putin. He confirms: *"For us, China is a key partner in the region."*

3.6. THE NEW SILK ROAD PROJECT - BRI

Since 1989, driven by security concerns, China embarked in Central Asia on a new neighbourhood policy, supporting the now independent post-Soviet States in economic development and social stability. The proclamation of the 'New Silk Road Economic Belt and Maritime Silk Road – One Belt-One Road' project (now called:

[12] Xinhua News Agency, China's satellite navigation industry output up 14.4 pct in 2019 http://www.xinhuanet.com/english/2020-05/18/c_139067354.htm

[13] The State Council Information Office of the People's Republic of China, China to complete Beidou-3 satellite system in 2020, http://english.scio.gov.cn/pressroom/2019-12/27/content_75561879.htm

Xinhua News Agency, China Focus: China to complete Beidou-3 satellite system in 2020 http://www.xinhuanet.com/english/2019-12/27/c_138661806.htm

Belt and Road Initiative - BRI) in 2013, is a consequent continuation of this strategic move. For the revitalisation of the bridge between Asia and Europe to address uneven global development - among other strategic partnerships - SCO and BRICS are of high importance.

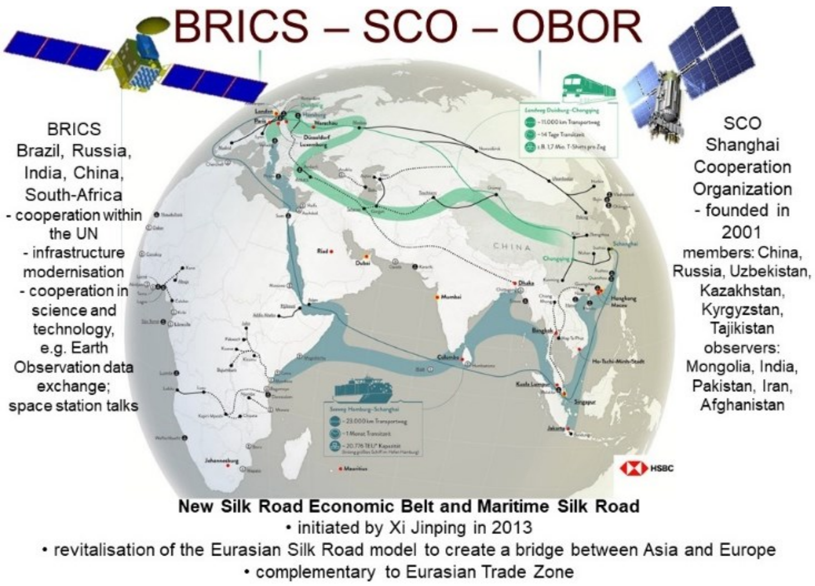

Figure 9: Overview map of the Belt-and-Road initiative.

The SCO – Shanghai Cooperation Organisation – is the biggest regional organisation to date. Its objectives are comparable to the Helsinki Accords/OSCE (Organisation for Security and Co-operation in Europe).

China's Minister for Foreign Affairs Wang Yi, stressed in March 2017 when talking to media:

"The Belt-and-Road is China's initiative, but it belongs to the world. The idea came from China, but the benefits will flow to all countries."[14]

3.7. THE VISION: CONNECTIVITY – A MULTI-DIMENSIONAL INFRASTRUCTURE NETWORK FOR A WORLD ECONOMY

The ‘Belt-and-Road’ mega-project of economic and societal development is perceived as a broad and multi-layered economic as well as geopolitical scheme. It comprises two main components, the overland connection, the so-called ‘belt’, consisting of a grid of several major economic corridors, major rail, fibre optic cabling, energy, and pipeline projects. The second main component, the sea-based ‘road’ covers maritime routes, ports, canals, submarine cabling and cargo handling

[14] Wang, Y.: 2017, Foreign Minister Wang Yi Meets the Press, Ministry of Foreign Affairs of the People’s Republic of China, http://www.fmprc.gov.cn/mfa_eng/zxxx_662805/t1444204.shtml

infrastructure. Even new air routes and air travel hubs will contribute to a 'Air Silk Road'. All of this encompasses the terrestrial infrastructure.

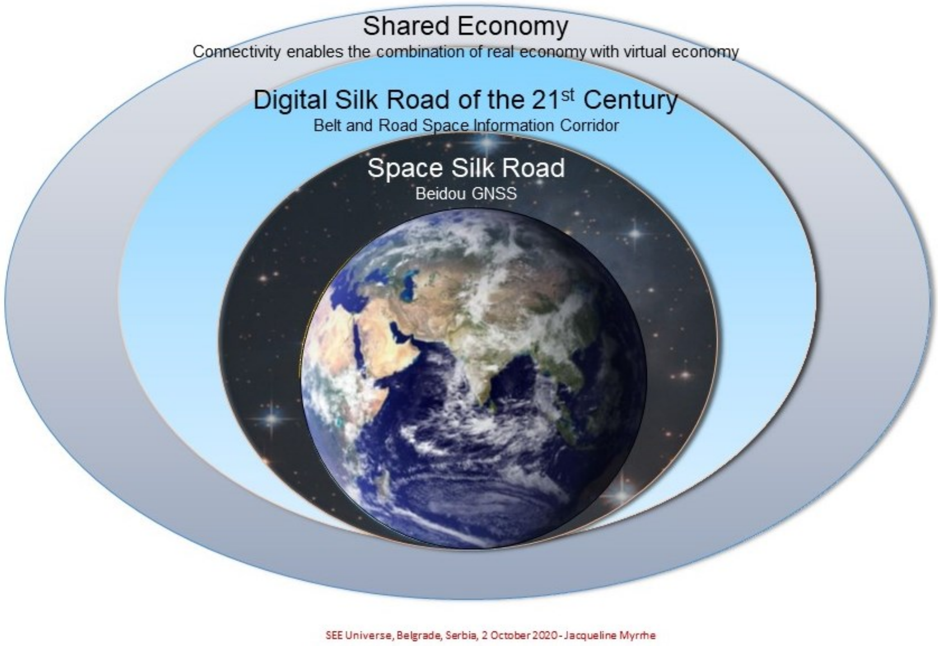

Figure 10: The 'Belt and Road' mega project can be defined as the terrestrial infrastructure, which will be complemented by space-based and space-supported assets, adding an extra dimension, an extra layer or shell, to the core project. Everything together enables the democratisation of a World Economy which not only empowers any person to master its existence, but also lives from the active participation of every single individual. Credit: NASA, GoTaikonauts!

That terrestrial network is going to be supported and extended by space-based resources - the 'Space Silk Road'. China's Beidou satellite navigation systems will provide the 'digital glue' for the infrastructure on 'terra firma', as analyst Trefor Moss rightly described it.[15]

The 'Digital Silk Road of the 21st Century' comprises a 'Belt and Road Space Information Corridor' including several elements reaching from Earth observation, communications and broadcasting, navigation, ground, and application system construction up to space application product development.

'Joint Laboratory Initiative', 'Science Park Cooperation Initiative', 'Technology Transfer Initiative' and much more will enable a full integration of science and technology into a digital economy.

"China encourages the integrated development of the Beidou satellite navigation system and Internet+, big data, and cloud computing, supports the integrated

[15] Moss, T.: 2016, China's 'One Belt, One Road' Takes to Space, https://www.wsj.com/articles/BL-CJB-29694

positioning and innovative utilization of satellite navigation together with mobile communications, WLAN, pseudo-satellites, ultra-wide band and Ad Hoc Network signals, promotes integrated development of satellite navigation and emerging industries such as the Internet of Things, geographic information, satellite remote sensing and communication, and mobile Internet, and encourages people to start their own businesses and make innovations, so as to vigorously upgrade the innovation capability of the industry."[16]

The state of global connectivity – enabled by this multi-dimensional infrastructure network, provides the basis:

- for mass participation in economic processes,
- for mass innovation,
- and consequently, mass entrepreneurship.

Such a model of a 'Shared Economy' *"could unleash everybody's potential... promote social equity and justice..."* as China's Premier Li Keqiang, pointed out at the Opening Ceremony of the 10th Annual Meeting of the New Champions in Tianjin, in June 2016.

"The sharing economy is one of mass participation. Greater economic globalization and the spread of the Internet have provided a big stage and broad space for entrepreneurship and innovation by the people. Through mass entrepreneurship and innovation, we will combine the innovation activities of the elites with the grassroots, the on-line with the off-line, and companies with research institutes, so that individual efforts of numerous market players will lead to greater synergy for innovation-driven development. If we could make full use of the Internet to efficiently match the massive amounts of information about supply with that about demand, we could then bring about cooperation among and sharing of R&D and professional expertise and skills. The sharing economy is something that everyone can take part in and benefit from."[17]

Imagine, all the people could be their own entrepreneur – their own bosses! Technology paves the way for every person on planet Earth to get connected - with just small hand-held devices - to the whole world and the global marketplace to make use of it for securing their existence. Technology becomes the ultimate tool, literally a hand-sized tool, to empower ordinary persons by adding their human ingenuity to set up their own virtual or real workshop, virtual or real production, any type of virtual or real service - independently and freely. Infrastructure enables the distribution of the produced items or services. The winner is the creator of the production and not only the manager or owner of a business.

Economic dependencies – the biggest killer of creativity and motivation – are taken away and the traditional dialectic contradiction between capital and labour is

[16] The State Council Information Office of the People's Republic of China, China's BeiDou Navigation Satellite System, June 2016, http://www.scio.gov.cn/zfbps/ndhf/34120/Document/1480623/1480623.htm

[17] Keqiang, L.: 2016, Address by Premier Li Keqiang at the Opening Ceremony of the Tenth Annual Meeting of the New Champions, http://english.gov.cn/premier/speeches/2016/06/28/content_281475381438561.htm

fading. Science and technology are democratising economy, most likely the global economy. This could become the optimistic vision of a human future for all people, or as Chinese Foreign Minister Wang Yi put it during a press conference in Beijing in May 2017: *"the magnificent goal of constructing a community of shared destiny for mankind."*[18]

3.8. SUMMARY

A hallmark of China's space programmes is that the nation found its own pace on the way to space. Based on its special conditions over the last 70 years, it has not joined the predominant space race between the United States and the Soviet Union.

China's political leadership strongly believes that a robust space programme can promote innovation, technology development, and educational benefits. Based on that, China has set sail on a highly visible, moderate-cost space programme aimed at showing world-class capabilities and contributing new knowledge to the global science community.

China's economic growth will not indefinitely translate via low labour costs. Economic growth of the future will be defined by science, innovation, and technological creativity. Space is one of the best tools for this.

China welcomes the challenges of the market for space science applications and to make best use of it. Consequently, it is joining the competition in the space industry, in particular in satellite manufacturing and launching but most of all in the down-stream applications.

China is incorporating into its space programme comprehensive international cooperation and more involvement in international organisations.

4. WHAT CAN SERBIA LEARN FROM THIS EXPERIENCE?

Until today, space is still considered as the playground of elitist high-tech nations with excessive financial means.

However, the space race of the Cold War era is history. Unprecedented cost reduction in satellite manufacturing, the acquisition of space data and its use in down-stream applications has brought space to private consumers services. The competition of the 21st century is an economic one. Nations strive for a solid foundation in the context of globalisation where everything and everybody is interconnected. And for that challenge, science, technology, and inventions are the tools to enable economic growth and wellbeing of a people. Space exploration cannot and should not be done for the sake of its existence. It has to be interconnected with the economical societal base in order to advance progress and development, as well

[18] Yi, W.: 2017, The Two Major Platforms of the "Belt and Road" and G20 Can Coordinate and Facilitate Each Other, Ministry of Foreign Affairs of the People's Republic of China, http://www.fmprc.gov.cn/mfa_eng/zxxx_662805/t1465540.shtml

as master the digital revolution. Space science and technology have become transformative forces like never before.

Any nation, but smaller nations in particular have to redefine the traditional approach to growth because growth by extending the industrial production is missing the point in a world where resources become scarce, and the side effects of energy production mainly based on fossil fuel are accelerating climate change which threatens mankind's existence. Growth can be interpreted as growth in knowledge, growth in efficiency, growth of recycling rate and sustainable closed-loop processes. Important is that this new type of growth is the modern 'fuel' for progress. From this fundamental change of interpreting the economy, a country like Serbia can start to analyse its existing strengths, available resources and existing gaps and compare them with the trends in the world. In a next step it could be examined how space science and space technology will serve as the best available tools for the modernisation and the further overall development of the Serbian nation.

Apart from the further socio-economic development which will demand space data and applications in the downstream sector, other societal areas will and have to benefit from space. One of the most pressing challenges today is climate change. Countries, with agriculture dominated regions will face a bigger impact from increasing extreme climate conditions. Climate is a global phenomenon and global processes are best monitored from space. Likewise, global solutions are well supported by space-based infrastructure, be it satellite data, communication network or navigation. Fitting those aspects into a strategic approach could make Serbia fit for the future, establish its place in a multi-polar world.

Flexibility can be achieved by setting long-term goals and intermediary steps on how to achieve them, so that the process can be adjusted if needed.

Another question worth considering is whether Serbia's geographical location brings any specific benefits. Its central position on the Balkan, its former role in hosting the capital of Yugoslavia and the historical close relations with neighbouring countries bring advantages. How can they be used as a leverage to knot tight neighbourhood relations for win-win outcomes? Among the resulting benefits could be the participation in international space projects to support the build-up of space capabilities with hands-on projects but declared as national projects to establish a showcase and gain experience.

There is no other way than the government taking responsibility to conceptualise a strategy and policies for that. What profound effect the directed support and commitment of the state has, is nicely comprehensible with the example of China. For that, the foundation in Serbia is prepared as has become evident during the SEE Universe conference organised by SERBSPACE from 30 September to 2 October 2020.

The event brought together a broad spectrum of national stakeholders which exchanged their opinions on the importance of space and space applications for Serbia.

The discussions in the different panels took stock of the available space expertise, resources, and high degree of professionalism in Serbia. Many space research projects are already existing – more than expected.

Among the representatives of the academic community, it was agreed that the Serbian science community would like to see a broader, more recognised, and more coordinated approach regarding national ambitions for space. It was set forth that there are many interesting initiatives ongoing which would lead to more and better results if synergies could be established.

The main take-away of the industry panel was that all players would like to see more support for high-tech applications to establish high-end production and integrated applications based on space resources be it navigation, Earth observation, Internet of Things, or interdisciplinary processes and finally set up an overall national development plan for Serbian space applications.

It has to be noted that a solid astronomical grass-root landscape has been emerged over the past years in Serbia. Teachers, space amateurs and space educators are involved in space projects and gave some insights into what else could be achieved should Serbia go for a national space development programme. Also, several international speakers provided their experience of what other nations do to promote space and to make best use of space for the overall development of the society and economy. Andrea Boyd, the speaker from Australia even outlined a strategy of how to create a national space agency. All those experiences are of high value for Serbia to learn from.

SERBSPACE shall initiate a broad dialogue among all interested national parties to take advantage of the momentum created by SEE Universe. It should be aimed at aligning existing projects in an overarching, strategic way. Already established and well running projects, research and capabilities should meet governmental interests for a strong Serbian development of a future-oriented economy. For that, SERBSPACE shall initiate a discussion with the responsible Ministries but also across Ministries to initiate the drafting of a national roadmap for space.

SERBSPACE shall establish SEE Universe as an annual conference and a national and regional platform for the exchange between space experts, decision, and policy makers, as well as the general public.

Acknowledgements

This paper would not have been possible without the year-long exchange and inspiration by GoTaikonauts! team member and author Chen Lan.

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Contributed Papers

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SATELLITE MISSIONS – A NEW ERA OF ASTRONOMY AND ASTROPHYSICS

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Abstract: There have been several major revolutions in astronomy over the past 500 years. Some were concept-driven, while others were tools-driven. Astronomers have realized that observations from space are a new revolution in astronomy. Some of the larger satellite missions that are already deployed will be presented here and compared with future missions. What are the necessary tools to work with new satellite missions and produces data? How can we introduce the term Industry 4.0 into astronomy and what would Astronomy 4.0 mean?

Presentation link: https://www.youtube.com/watch?v=YrUrpBy0e6A

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DOI: 10.5281/zenodo.5645393

ON THE NUMERICAL STRUCTURAL CALCULATION METHODS OF THE SPACE STRUCTURES AS A RELIABLE REPLACEMENT FOR EXPENSIVE TESTING, STILL A COMMODITY AND WHY

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Abstract: From the perspective of specific techniques and procedures for design, manufacturing, deployment, installation, service, and maintenance, there are three different types of space structures: satellites (structures that orbit the earth), habitats (the buildings erected on other planets or moons or geostationary orbits), and vehicles (structure made for transport of goods, equipment, and passengers). All these space structures are exposed to different sets of loadings, like extremely high temperatures range, high acceleration, space radiation, and others. Ultimately, as on Earth, we must take care that their structural integrity is maintained, while additionally, in habitats (space stations, Moon-habitats, geostationary space hotels, etc.) we must also provide the comfort for humans, plants or animals. To decrease the design and maintenance costs, and provide service away from Earth resources, the goal is the use of virtual reality in their life cycle management. Such a virtual reality should be based on 1) reliable numerical simulation tools for calculating the structural response under loadings, and 2) artificial intelligence decision making. So, it is a future! But what about the present status of numerical methods in space engineering, as the Finite element method? Why FE software is still seen as a commodity, instead of a reliable tool for testing? How the energy needs to attain comfort is simulated. And finally, why the development of numerical simulation tools for calculation of the thermo-mechanical response of the space structures, are not favored and heavily supported by the space sector, as many other innovations? The present paper will try to answer some of these questions.

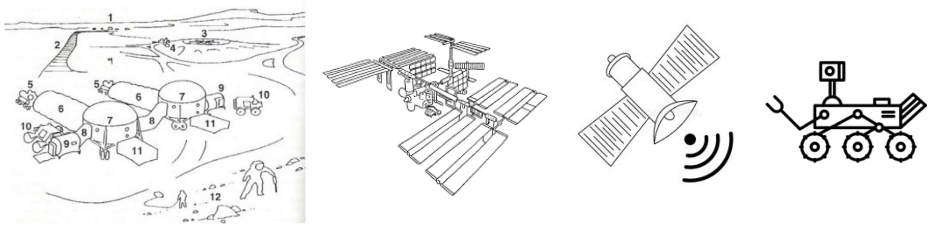
Keywords: space structures, structural integrity, finite element method

1. INTRODUCTION

As may be defined there are three types manmade of structures in space: habitats Fig.1a (Cohen 2015), space stations Figure 1. b., and satellites Figure 1. c., and vehicles Figure 1. d. Let us briefly enplane these structures from its various aspects.

The habitats in space follow the similar requirements as that on Earth. The common words are comfort (Bluyssen 2010), sustainability health and cost.

Comfort in buildings from physical point of view is usually seen from the measurement of temperature, pressure, and humidity.



(a) (b) (c) (d)

Figure 1: Types of space structures: habitats, space stations, satellites, and vehicles

On the other hand, sustainability is mostly related environmental impact. Healthy building is one which maintains and impacts no harm on human health. The most frequent cause of unhealthy condition of building is mold, and others may be related physical quantities in comfort measurement. And lastly, cost is usually not prevailing factor, but it is advised that it be minimal related building performance versus structural and energy efficiency. Let us now define what is habitat in space (other names are: building in space, or out-of-terrestrial building). That is confined human or equipment habitat in space or another planet or moon. In this paper we will consider the most economic tools in design and erections of such buildings.

Satellites are manmade structures that are put in orbit around Earth or another planet or moon; usually they are grouped in space stations or satellites. They require or not artificial gravity, depending on, if they are designated for human living, they are usually called space stations. On the other hand, if they are designated for equipment, they are usually just called satellites. They either can be erected on site or lunched in its simplest form or parts from earth. In that instance they are exposed for re-entry physics, and they are imposed to very high temperature levels. The issue or thermo-dynamics is then to calculate extensively.

Space stations (or human inhabited space stations) are in that point of view orbital confined spaces in which humans spend their time for working and living. It should follow the same requirements for structural and energy efficiency and comfort. They can have artificial gravity or not. For example, International Space Station is in constant none or low gravity state. It is now recognized that absence of gravity can impose severe change in usual blood flow path in human body (Goebel et al. 2019), but it is still unclear how much and how long human can sustain reverse in blood flow. Nevertheless, the calculations are related design, proof-of-strength, thermal resistance, energy efficiency, and other. Present author field of study in this instance is considered to thermo-elasticity and calculation of comfort and energy efficiency.

Space vehicles are designated for transport or humans, animals or biological samples or instruments or machines. They design and manufacturing follow usual prerequisites for any other vehicle that we made on Earth, except gravity and environmental issues. They should be optimized per structural integrity and life cycle pattern and cost. The calculation used are under solid and fluid mechanics theory and tools.

In the rest of the paper, we will be concerned with design and manufacturing or building, based on type of space structures. Specifically on computational numerical (software) tools available contemporary and its effectiveness. It will be shown that in addition to completely correct simulation process from discretization to applying of boundary conditions, loads and material input data, the results are to be expected to be not totally correct if the use of standard displacement-based approach, and that the use of mixed FEM approaches or advanced user expertise is required, before validation, prototyping or manufacturing or construction.

2. ON THE ACCURACY OF THE FINITE ELEMENTS IN SPACE ENGINEERING

In the present paper we are addressing the accuracy of the computational modelling and simulation, of the abovementioned structures, using traditional and new approaches. It is shown in (Mijuca 2010) that using standard displacement based Finite element approach (FE displacement based) or hand calculation, if uniform material structure is loaded only mechanically results are on safe side, while for composite material structures result is on unsafe side. It will mislead the responsible engineer to either overweight the structure, or declare that structure safe for even increased loadings, respectively. In both cases it is not what is wanted in spaces.

The situation is even worse in the case of the thermo-elastic computations. Namely, in finite element displacement-based approach, there is an issue of non-consistency between thermal and mechanical strains. That leads to calculation of the results that will be on unsafe side that is, underestimated. It is a big drawback because the real structure will collapse before calculated time. This malignancy is proven with the comparison with primal-mixed finite element approach (FE HC8/9) in (Mijuca 2008) and experiment. It is probably that in space structures finite element calculation are seen as commodity, and never replacing expensive prototype testing.

In this investigation we will narrow our attention to beam or the plate like structures that are traditionally calculated with dimensional reduction theories. It is for expected that it will deteriorate results, but nobody expected that it will be so detrimental in the case of the standard FEM approach in the setting of thermo-elasticity. That malignancy will be simplest as possible explained here on the also simple set of examples, over the simple coarse meshes. More, it will be explained why in space industry computational engineering is seen as a commodity, rather than confidential tool.

3. PRESENT NUMERICAL SIMULATION SCHEME

Motivated by the shortcomings of the standard thermo-mechanical displacement finite element based scheme widely used in commercial software (FE H8), one of the goals of the present paper is to recommend superior primal – mixed finite element FE (HC8/9), on the rather simple model problems.

A mixed coordinate independent hexahedral finite element HC 8/27 scheme in solid mechanics introduced in (Mijuca 2010), presently is used for the calculation of thermo-elastic structural response. Essentially, it allows straightforward introduction of thermal strains, thus enabling overcoming of the so-called consistency error (Miranda & Ubertini 2001) between thermal and mechanical deformation fields, mainly responsible for spurious oscillations of displacement variable. Present finite element is reliable, even when it is slandered, distorted, or used for the analysis of nearly incompressible or orthotropic materials, up to 7 orders of magnitude, and up to angle of 180 degrees, respectively. Therefore, transition problem of connecting finite elements of different types and dimensions is overcome also. To test convergence of the results, the standard model problems made of homogeneous, orthotropic, or multi-materials are considered. The present approach has a great potential to be reliably used in analysis of simple or complex structures, or to be used for macroscopic analysis in the straightforward conjunction with the numerical analysis on microstructural base in life estimate analysis.

4. BIMETALLIC BEAM-LIKE STRUCTURAL PART SUBJECTED TO THE TEMPERATURE LOAD

The cantilever bimetallic strip of length $l = 10$, arbitrary width $w = 0.1$, and thickness $t = 0.1$, where symmetric part is shown in Figure 2, is presently analysed. The beam is stress free at $T_R = 70$ and subjected to a uniform temperature$T_0 = 170$. Both materials have the same modulus of elasticity and Poisson's ratio, which are $E = 3 \cdot 10^7\ MPa$ and $\nu = 0.3$, respectively. The difference is in coefficients of thermal expansion, which are $\alpha_1 = 1 \cdot 10^{-5}$ and $\alpha_2 = 2 \cdot 10^{-5}$, respectively for the upper and lower material.

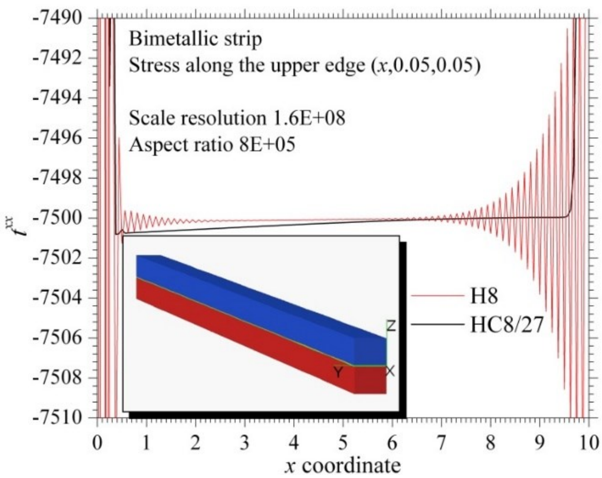


Figure 2: Target results obtained by the dimensional and full finite element theory

The analytical solution at the fixed end for a top surface is obtained by the hand-out simple beam theory (see Roark & Young (1975), page 114) and it is $t^{xx} = -7500$. The dimensional reduction (curve H8) theory gives unrealistic spurious results on the upper edge, while in present case (curve HC8/27) result is smooth, as shown in Figure 2.

5. UNIFORM MATERIAL PLATE LIKE STRUCTURAL PART UNDER SUDDEN TEMPERATURE CHANGE

This model problem is taken from (Mijuca 2008), page 583, case 9. It is an isotropic rectangular solid body of the plate like shape fixed on its physical boundaries. The reference temperature is $T_R = 294.15K$ and the upper face is suddenly exposed to a temperature $T = 350K$. Its dimensions are $8 \times 4 \times 0.25$ $[m]$ in x, y and z axes direction, respectively. The Young's modulus is $E = 34290\,MPa$, the Poisson's ratio is $\nu = 0.2$, while coefficient of thermal expansion is $\alpha = 0.00001°/K$. The plate would normally assume a spherical curvature with radius $\frac{t}{\nabla T\alpha}$, where t is the distance between the hot and cold face. If the edges are fixed, the plate will be held flat by uniform edge moments and the maximum bending stress $t^{xx} = \frac{\nabla T\alpha E}{(1-\nu)}$, obtained by the modified Kirchhoff plate theory (that is: $t^{zz} = t^{xy} = t^{xz} = t^{yz} = 0$) (Mijuca 2008), is $t^{xx} = -23.93871\,MPa$.

It should be noted that thermal loadings through thickness are introduced intrinsically, because no dimensional reduction is used. Namely, heat transfer is natural, not extrapolated, as when using 2-dimensional plate theory. The verification of the presently used numerical technique HC8/9 for the case of the fixed edges is completed with comparison by the modified (Mijuca 2008), in which it is assumed that $t^{zz} = t^{xy} = t^{xz} = t^{yz} = 0$ and plate is held flat by uniform edge moments and the maximum bending stress $t^{xx} = \frac{\nabla T\alpha E}{(1-\nu)}$. The theoretical Kirchhoff plate theory result is for the present model problem given by $t^{xx} = -23.93871\,MPa$.

On the contrary, present approach HC8/9, gives us rather higher maximal stress (see obtained stress distribution, Fig. 3). Therefore, it is significant finding, that deserves further investigation, because it could explain premature failing of real thermally loaded structures that are calculated and proven by standards based on plate theory or standard FE displacement approach.

The results with present approach, primal mixed HC8/9, for two types of topology discretization, are shown in Tables 1 and 2.

It should be perceived that maximal compressive and tension stresses are obtained on the fixed edges (see Figure 3), so we may conclude that thermal protection system in re-entry vehicles should be continuous, and not made of tiles, because they may fall-off.

Table 1: Fixed plate under temperature gradient: Stress t^{xx} convergence, reduced and full HC8/9 approach

Fixed Plate loaded by transversal temperature gradient, FE HC8/9, t^{xx}		
$8N \times 4N \times 2N$	if $t^{zz} = t^{xy} = t^{xz} = t^{yz} = 0$	*full theory*
1	-23.93871	*-32.645*
2	-23.93871	*-32.492*
3	-23.93871	*-32.284*
Target	*-23.93871*	-

Table 2: Fixed plate under temperature gradient: Stress convergence of FE HC8/9 for meshes $8N \times 4N \times 2$, $N = 1,2,3,4$

Fixed plate loaded by transversal temperature gradient, FE HC8/9						
$8N \times 4N \times 2$	t^{xx}_{max}	t^{yy}_{max}	t^{zz}_{max}	t^{xy}_{max}	t^{xz}_{max}	t^{yz}_{max}
1	-32.645	-32.551	-34.033	-0.73360	-1.9245	-1.9597
2	-32.699	-32.694	-33.810	-0.87241	-3.8111	-3.8115
3	-32.764	-32.764	-33.918	-1.27110	-7.4198	-7.4199
4	-33.821	-33.823	-34.404	-2.0495	-12.5330	-12.5330

Present approach shows that if all stress components are unknown and unsuppressed (which is realistically), target solution is substantially different, as shown in Table 1. It should be emphasized that present approach is reliable in thin plates like structures discretized by 3D finite elements, see (Mijuca 2004), and it would not lock under any circumstances.

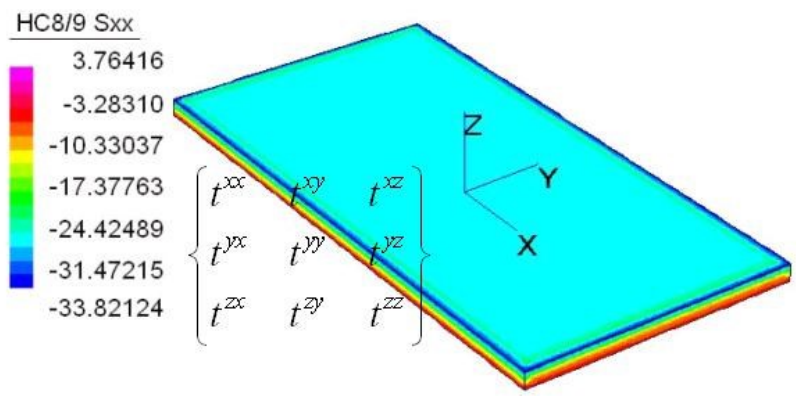


Figure 3: Fixed plate loaded by temperature gradient through its thickness. FE HC9/9 (full theory).

Thus, without doubt, it can be stated that dimensional reduction or neglecting of some stress components leads to substantial underestimation of thermal stresses in structures under thermal loading. This explains premature collapse of structures under fire calculated with plate theory hand-out or finite element approach based on displacement, also.

6. COMPOSITE STRIP UNDER 3-POINT BENDING

Present goal is to show that in reality, in composites maximal stresses are much higher than one calculated by plate theory.

A simply supported 5-layer symmetric composite strip under central line load of $10\frac{N}{mm}$, reported in Taig (1992) is presently analysed. Material lay-up is 0/90/0/90/0. All plies are of the same thickness. Only one half of the model is analysed due to the geometrical central and load symmetry. For the ply rotated by 0 degrees the material constants are: $E_x = 100000$, $E_y = E_z = 5000$, $G_{xy} = 3000$, $G_{xz} = G_{yz} = 2000$, $\nu_{xy} = 0.4$, $\nu_{yz} = 0.3$ and $\nu_{zx} = 0.015$. For the ply rotated by 90 degrees, material constants are: $E_x = E_z = 5000$ and $E_y = 100000$, $G_{xy} = 3000$ and $G_{xz} = G_{yz} = 2000$, $\nu_{xy} = 0.02$, $\nu_{zx} = \nu_{yz} = 0.3$. We emphasize that present FEM HC9/9 approach is not sensitive to mesh quality and shape, so thin layer of finite elements is put on each side of the material interfaces. The central line load is discretized as normal pressure $p[MPa]$ over the long, small area A around centerline. Each inner pile is approximated by four finite elements per thicknesses, as shown in Figure 4.

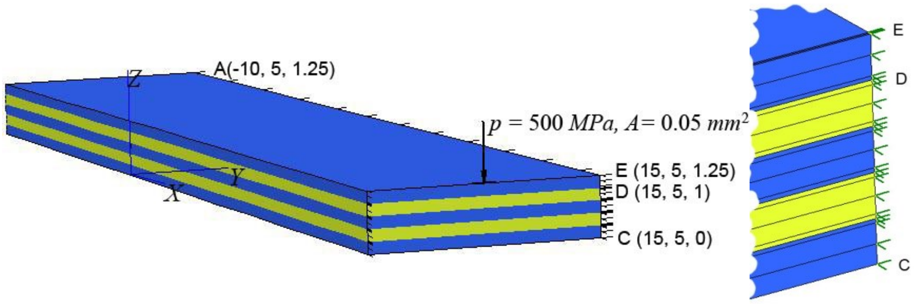


Figure 4: Composite Strip under midspan continual load.

The analytical solution obtained by the modified uni-material simple beam theory, are $t^{xx}(E) = -359$, $t^{yz}(D) = -4.88$ and $u_z(E) = -0.458$. The convergence of the present results stresses in nodes E and D, are given respectively, in Table 3, and converge to substantially higher results than theoretical.

Table 3. Composite strip: Convergence for $p = 50MPa$ and $A = 0.5mm^2$

Composite strip, load $p = 50MPa$ and $A = 0.5mm^2$				
N	$NEL\ (12N+2) \times 1 \times 18$	$t^{xx}(E)$	$t^{xz}(D)$	$u_z(E)$
1	252	-447.7511	-1.5685	-.5670
2	468	-448.3428	-1.5327	-.5667
4	900	-454.2073	-1.5297	-.5668
8	1764	-457.2082	-1.4943	-.5673
16	3492	-458.9545	-1.3591	-.5679
	Target	-359	-4.88	-0.458

We may see that in both cases results normal stress and deflection results converge to a higher value than target ones. The intensity of interlaminar shear stresses at node D depends on the value of the area A over pressure is applied, but it converges to a target value for the smaller value of A. It is shown in (Mijuca 2010) that plate theory underestimates the maximal stress result. Thus, we may assume that by neglecting normal and shear stress components in each of the layer, as usual in plate theory, our result will converge to analytical (plate theory) solution.

7. CONCLUSION

The present paper tries to explain why standard finite element displacement-based simulations (dFEM) are seen as a commodity rather than reliable replacement for expensive and extensive prototype testing, by space industry. First, there is simple lack of trust in simulation, and on the top of that there is always enough money for testing (i.e., investors do not know mechanics), and everybody tends to be on a safe side regarding decisions and responsibility.

Traditionally, dFEM is used by engineers as a *black box* with no proper mathematical education and understanding of its deficiencies. Accordingly, when used improperly, the results obtained will be inconsistent and spurious. Nevertheless, even with all possible knowledge in numerical methods, dFEM is simply incapable to go multiscale, and can be highly inaccurate in thermo-mechanical calculations. There have been myriad cases where bad simulation results resulted in rejection of a good engineering design. And vice versa, structural designs approved by simulations using dFEM failed prematurely. Some of dFEM deficiencies are shown in the present paper through numerical examples.

New era of simulation-driven structural design in space industry should be based on available (Mijuca 2010) mixed finite element approach (FEMIX) that is reliable and validated, and above all beam and plate theories should be abandoned completely. This is presently shown through a few simple numerical examples as well. There is no excuse to consider 3D structure with billions of atoms confined in 3D space, as 2D object.

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IMPLEMENTATION OF MINERALOGY SENSITIVE ICE INITIATION PARAMETERIZATION IN DUST REGIONAL ATMOSPHERIC MODEL (DREAM)

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Abstract: Aerosols in the atmosphere and their interactions with clouds are the source of some of the largest uncertainties in climate sensitivity studies. Aerosols can play a role in cloud processes as cloud condensation nuclei (CCN) and ice nucleating particles (INP). They can have significant influence on the physical properties of clouds and their interaction with radiation, latent heat release, precipitation, and cloud electrification. Clouds typically glaciate at warmer temperatures when INPs are present. INPs in the atmosphere are available in much smaller amounts than CCN. The Sahara Desert is the major source of mineral dust, producing a significant part of atmospheric aerosol globally. Findings from field experiments, modelling and laboratory studies suggest that mineral dust particles are very efficient INPs even in regions distant from the desert sources. Several studies focused on the influence of mineral composition of dust on its ice nucleating ability. It has been shown that feldspar-containing particles are among the most efficient ice nuclei. Since quartz is a major component of atmospheric mineral dust, it has been studied as potential INP contributor and proven that it can be active as an INP. These results suggest use of mineralogy sensitive emission and transport schemes in numerical models and use of mineral specific INP parameterizations for feldspar and quartz components of mineral dust. In this study, mineralogy sensitive INP concentration parameterizations for feldspar and quartz minerals are used in Dust REgional Atmospheric Model (DREAM). We quantify relative contribution of feldspar and quartz to total INPC. Model results are compared to aerosol lidar, and cloud radar observations retrieved from ground based remote sensing instruments and satellite products in the Mediterranean.

Presentation link: https://www.youtube.com/watch?v=YrUrpBy0e6A

OPPORTUNITIES FOR FUNDING SPACE R&D IN HORIZON EUROPE

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Abstract: We will talk about Horizon Europe the new framework programme offered by European Commission. It is expected that Horizon Europe will overcome even the Horizon 2020 which was the most successful European Commission Framework Program to date. This presentation will briefly cover what is expected for the period of next 6 years in the area of the Space research and innovation under Horizon programme. I will also mention the Copernicus and Galileo flagship projects, as well as the opportunities they provide. Some guidelines and recommendations given by the European Commission on applying for Horizon projects will be discussed. Post-presentation questions and discussion are welcome.

Presentation link: https://www.youtube.com/watch?v=eyReEIqN_hg

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RADIAN SYSTEMS

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Abstract: Radian is a cloud-based software that performs thermal analyses for nanosatellites.

Keywords: thermal analysis, nanosatellites, temperatures

1. INTRODUCTION

Radian is a cloud-based software that performs *thermal analyses for nanosatellites*, simulating accurate in-orbit conditions throughout a given mission.

Subsystems aboard a nanosatellite are designed to operate within a safe range of temperatures. Out of that range, they may get permanent damage, leading to mission failure and substantial economic losses. Therefore, previous thermal analyses that simulate these subsystems' temperatures are mandatory to prevent such issues.

In Radian Systems we want to contribute to the democratization of space, providing a more agile and efficient thermal analysis tool for satellites. Our thermal and orbit simulator is based in a simple and intuitive web application, that provides automated designs that reduce the design phase 30 times and smart diagnostics that speed up post-analysis 10 times, supporting decision making and reducing labour cost overruns.

2. COMPARING FOSSASAT-1 TEMPERATURES WITH THERMAL ANALYSES

In December 2019, FossaSat-1 was successfully launched into space, becoming our first case study to reach orbit. FossaSat-1 is a 5-cm sided PocketQube designed to create a global, low-cost IoT network.

All systems are operational to this day. However, the superior panels did not deploy, preventing the folded antennas from deploying too. Nonetheless, the packets received so far have been conclusive enough to validate our thermal analyses.

FossaSat-1 is equipped with three temperature sensors (see Fig. 1), one on the outside and two on the inside. T_{EXT} is attached to the superior panel, T_{CPU} belongs to the onboard computer, and T_{BATT} measures the battery temperature. It is worth mentioning that the telemetry from T_{CPU} has been discarded, as Fossa Systems recommended, because of a lack of data integrity.

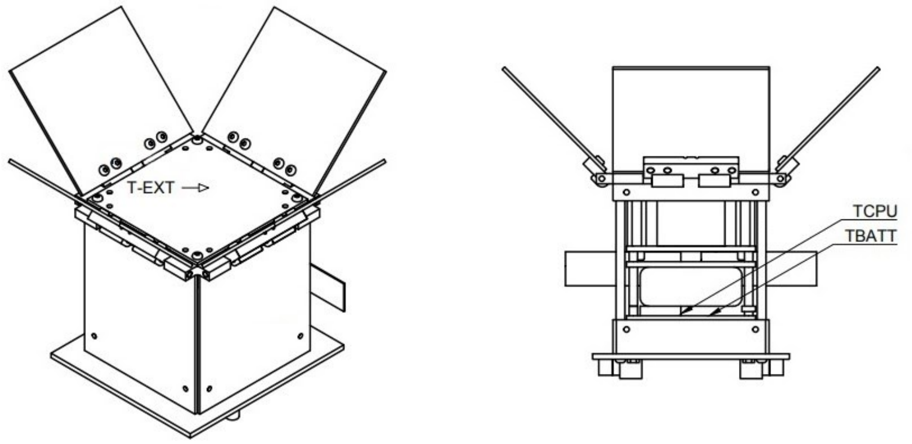

Figure 1: FossaSat-1 temperature sensors

The thermal analyses carried out by Radian Systems comprised a hot case and cold case, derived from the solar irradiance and FossaSat-1 operational modes. They were simulated assuming the deployment of the folded elements, thus deviating from the actual radiative heat fluxes. The degree of detail matched a feasibility study for the thermal subsystem.

Taking into account the extreme temperatures for both cases, the predicted range for T_{EXT} and T_{BATT} is shown in Fig. 2 and Fig. 3. In addition, a 15ºC uncertainty margin is included due to the preliminary character of the modelling assumptions, and a 10ºC environmental margin for mission deviations (see European Cooperation for Space Standardization: Thermal Analysis Handbook and Thermal Control General Requirements). No further adjustments were made, even though correlation activities from both testing and flight data are considered for future study.

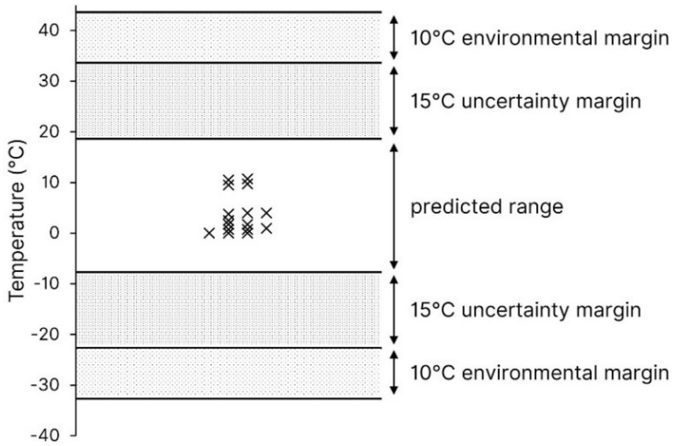

Figure 2: Temperature data from TBATT compared with analysis ranges.

The telemetry data sets comprise 16 samples from T_{BATT} and 20 samples from T_{EXT}, between 7 December 2019 and 26 January 2020. It is worth noting that 2 T_{EXT} measures lie within the mission margin, and 6 measures lie within the uncertainty margin.

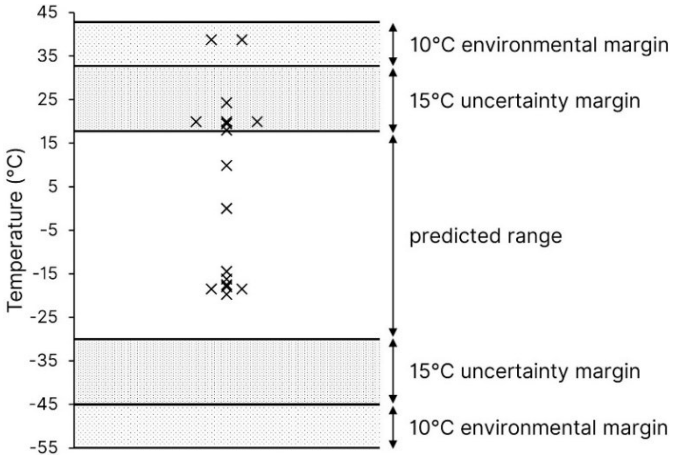

Figure 3: Temperature data from TEXT compared with analysis ranges

As it is presented in both figures, FossaSat-1 flight temperatures lie within the predicted ranges and margins calculated from Radian's thermal analyses.

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EARLY ISS UTILISATION TAXI MISSIONS - A MODEL TO SEND THE FIRST SERBIAN TO SPACE?

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Abstract: In general, space research is perceived as an expensive and complex endeavour. This is exemplified by the fact that space science missions and space stations have been perceived by strong economic nations only. A particular case is that human space flight is even more complex and requires a very wide and sophisticated set of skills, resources, and facilities. This paper aims at demonstrating through three specifically selected examples, that even a small country such as Serbia, although not having a space industry, can engage in international space projects at all levels: that is at the Governmental level, the Institutional level, and the Individual level. Governmental efforts could bring a Serbian citizen within a bilateral agreement to the International Space Station (ISS). Serbian universities or national research institutes could embark on microgravity research by using comparatively less expensive parabolic flight facilities. And last, but not least, even space enthusiasts can nowadays contribute their skills and expertise to international space programmes.

Keywords: Serbia, access to space, ISS, parabolic flight, space amateurs.

1. INTRODUCTION

Mankind achieved access to space since the launch of the first man-made object in 1957. This achievement was possible by a concerted effort of the Soviet Union to pool talent, resources and technologies targeted at the clear objective to gain access to space and demonstrate societal superiority. The same feat was soon accomplished by the United States and only slowly did other nations follow. However, until today, only a handful of nations have built capabilities for space launches and sustainable space programmes. Nevertheless, space nations do tend to develop more advanced technologies and stronger economies, providing evidence that space can be a driver and a tool for progress and comprehensive economic development.

On the other hand, the latest successes in commercial launch capabilities and the diversification of microgravity research platforms, has made it much easier and less expensive for governmental and non-governmental players to become part of the global space community. Nowadays, there are many different possibilities to conduct space research, including options where researchers do not even leave the ground.

The key takeaway message of this paper is to show through three specifically selected examples, that even a small country such as Serbia, although not having a space industry, can engage in international space projects at all levels: that is at the Governmental level, the Institutional level, and the Individual level.

2. GOVERNMENTAL LEVEL

What today is the most complex and most successful space project in low-Earth orbit started as the space station "Freedom", a national project by the United States, intended to bring other Western nations of its political alliance together via bilateral agreements. Space station "Freedom" was perceived as a counter-concept to the Soviet Union's orbital complex "Mir". With the break-up of the Soviet Union and the changing geopolitical context, a completely new situation emerged which called for unprecedented and pragmatic solutions.

Image 1: The International Space Station (ISS) is mankind's only outpost in space. Although initially set up by 4 national space organisations (NASA, JAXA, CSA, and Roscosmos, plus in the beginning also Brazil) and the intergovernmental European Space Agency ESA, it has enabled access for research stemming from scientists and experts from all over the world. Credit: NASA

It became obvious at the time that a partnership between the two strongest players in the space arena, the US and the Soviet Union would support a sustainable, long-term, and peaceful cooperative space project. The idea of an International Space Station was born.

Europe's decision to join the International Space Station (ISS) programme opened enormous possibilities for European space industry and the European science community, that had not previously existed. The European Space Agency (ESA) has been actively guided by their user communities to get the best possible access to the benefits offered by this multinational and multi-continental ISS cooperation.

Europe's biggest contribution to the ISS is the Columbus research laboratory, launched in 2008. The ISS assembly started in 1998 what meant that the European research community would need to wait 10 years, until the European facility was in space. For that reason, ESA decided to give European scientists the opportunity for flying experiments during so-called ‘taxi-missions’. In this respect, ‘taxi’ meant, the flights had an ad-hoc character and were of short-duration. Another important hallmark was that those missions were national missions, supported by one individual ESA Member State.

From the autumn of 2001 until the spring of 2005, a total of 6 missions to the ISS were conducted using the Russian Soyuz manned launcher. These missions were co-funded by ESA, and the 5 ESA-Member States: France, Italy, Belgium, Spain, and the Netherlands, that took advantage of this opportunity. ESA’s taxi missions enabled small countries which had not been traditional human spaceflight nations to send their first or just second citizen into space. Examples in this category are Spain, Belgium, and The Netherlands.

The Russian side drew on its extensive experience gained through the Soviet INTERKOSMOS-Programme - when cosmonauts from its allied Eastern European countries, Asia and Cuba were assigned to flights to the Salyut space station or the Mir Orbital Complex.

In similarity with the INTERKOSMOS programme, most experiments and other activities in the taxi missions were tailored to the needs of the science community in the respective countries. During these 6 taxi missions more than 100 experiments in all fields of space research were carried out, including many educational experiments. These educational experiments were made possible via an allocation of 1% of the ISS research budget for educational purposes.

The total cost for one such mission by that time was a fraction of what needs to be paid now for a seat on a Russian spacecraft. The 'emotional' value of the mission, however, cannot be stressed enough. All taxi mission participants experienced the overwhelming Russian hospitality and high level of professionalism in the area of human spaceflight.

3. INSTITUTIONAL LEVEL

While human space missions are very emblematic space projects, it is reserved for a limited number of persons and still requires a high degree of governmental involvement.

Access to microgravity can also be provided by means of a specially adapted aircraft capable of performing parabolic flight manoeuvres. During such a flight, a plane flying on a horizontal flight path, starts to climb a steep trajectory up to the highest point of a parabolic arc, before 'falling' again up to the end point of the parabola when the pilot must accelerate and bring the plane back into horizontal flight.

Image 2: The Airbus 300 of French company NOVESPACE in Bordeaux, France, used for parabolic flight campaigns throughout Europe. An A310 replaced the A300 in 2015. Credit: NOVESPACE

Parabolic flights are a simple way to get hands-on experience in microgravity research and build space research capacities even for nations which do not have their own space programme. Parabolic flight campaigns are popular with national space agencies which allocated the research spots in the aircraft mainly to national universities and research institutes.

Image 3: The Airbus 310 of the French company NOVESPACE injects into the 43-degree flight path for flying along a parabolic arc. Credit: NOVESPACE

As part of the preparation for a flight campaign all participants are required to attend a safety briefing.

A typical campaign consists of 3 flight days with 31 parabolas flown each day. During each of the three flights of a campaign, the same procedure for each of 31 parabolas is followed:

- Announcement of time to next parabola
- 5, 4, 3, 2, 1 There are three announcements over the audio: “Pull Up” and the plane starts to climb; then “Injection”, followed by ‘Pull Out” at the bottom of the parabola.
- Image 3 shows the point of “injection” ~ 43 degrees.

Images 4 and 5: Experiment teams and their equipment during the microgravity phase of a parabola. Credit: NOVESPACE

Various experiments and their team members (normally around 10-12 individual teams) are shown in Figures 4 and 5.

For Serbia, several options for participation could be of interest:

1. Universities or research institutions should set up long-term strategic partnerships with academic institutions in ESA Member States to take part in teams which are already involved in parabolic flight opportunities. For such an option, the individual team members only must bear their own cost of hardware development and travel costs.
2. Universities or research institutes could address the Serbian government to find a combined funding for a national parabolic flight campaign conducted by NOVESPACE for example but starting from Belgrade Nikola Tesla Airport, since parabolic flight campaigns can be conducted from almost any location in Europe. The overall cost of a parabolic flight campaign might be of the magnitude of 400,000 to 500,000 Euros. The latest quotation needs to be requested from NOVESPACE.
3. Parabolic flights are not limited to large aircraft and can be conducted by any highly experienced flight crew. Technically, parabolic flight campaigns can be conducted from almost any location in Europe. Therefore, provided there are resources and institutional support available, Serbia could set up its own parabolic flight capabilities. Such a move could also be considered within a network of other Balkan countries to share costs.
4. Serbia could join with other former Yugoslavian countries to purchase a parabolic flight campaign with NOVESPACE or join to build its own capacities.

Image 6: The Airbus 310 of French company NOVESPACE in Bordeaux, as used for Parabolic Flight Campaigns. Credit: NOVESPACE

The images 3, 4, 5, and 6 show French company NOVESPACE's[1] Airbus aircraft A310 based at Merignac in Bordeaux. This aircraft is regularly used by ESA, DLR and CNES space agencies.

4. INDIVIDUAL LEVEL

As a last inspiration, a beautiful example of what can be achieved by an individual if one is passionate about what one does and determined to achieve it! Image 7 is a photo of DK5LA, otherwise known as Reinhard Kühn, who lives in the North of Germany (Sörup) and has been a radio amateur since the 1970s.

Image 7: German radio amateur Reinhard Kühn DK5LA. Credit: Reinhard Kühn DK5LA

He started as a youngster, building his own antennas – experimenting with different constructions and configurations. Reinhard Kühn is fascinated in Earth-Moon-Earth connections (that is bouncing signals off the Moon) since 1977 and was able to establish such connections via the Moon, becoming one of 100 radio amateurs worldwide – a very exclusive club.

[1] https://www.airzerog.com

Image 8: The antenna of German radio amateur Reinhard Kühn DK5LA next to his house in Sörup. The Moon was inserted in this photo to illustrate how a radio wave would bounce back upon hitting the Moon's surface. In reality, radio waves are invisible. Credit: Reinhard Kühn DK5LA

In 2017 he and radio amateurs from The Netherlands and South Africa worked together to successfully reactivate the radio amateur satellite ZA-Aerosat. An achievement which became known to the Harbin Institute of Technology (HIT) in China – the radio amateur laboratory there had a payload on the Longjiang 2 satellite – which was launched together with the Chang'e 4 relay-satellite Queqiao (part of the Chinese governmental lunar exploration programme). HIT was looking for a European ground station which could keep a two-way communication contact with the Longjiang 2 satellite after the Moon had set in China. They turned to DK5LA because of his unique 8 x 32 element antenna with state-of-the art transceivers, amplifiers, and computers.

Image 9: View of the antenna of German radio amateur Reinhard Kühn DK5LA next to his house in Sörup. Credit: Reinhard Kühn DK5LA

DK5LA, together with the international team of radio amateurs wrote space history when on 2 July 2019 they photographed a solar eclipse on the Earth taken from the vantage point of the far side of Moon.

Image 10: This modern day "Earth Rise image" showing a Solar Eclipse on 2 July 2019 as seen from the Moon was taken by Inory Eye camera on board the Chinese Longjiang 2 microsatellite. Without the support of the German radio amateur Reinhard Kühn, the data would not have been received. Credit: Wei Mingchuan (Harbin Institute of Technology, BG2BHC/BY2HIT), CAMRAS Dwingeloo Radio Telescope, Reinhard Kühn DK5LA.

Because of advances in technology (internet, miniaturisation, high-performance receivers, etc.) amateurs can contribute at the highest professional level. The AMSAT- Radio Amateur Satellite Corporation is a network, where radio amateurs from around the globe contribute to the promotion of space exploration and communication. For those interested in space, AMSAT offers many areas to become involved. Likewise, there are many examples of technical developments by radio amateurs which could be used commercially. Those examples underline that amateur radio is even today a highly interesting hobby. And by the way: every astronaut is a radio amateur, but not every radio amateur is an astronaut.

4. SUMMARY

Governmental level: support a partnership for the first Serbian in space to generate a wave of public awareness for space, inspire a new generation of talent and for capacity building in the space sector: industry and academia.

Institutional level: universities could strategically delegate students to universities in ESA Member States to join existing teams conducting parabolic flight research or other space research. Alternatively, Serbia could investigate options to find resources for a national or regional parabolic flight campaign.

Individual level: radio amateur enthusiasts are still a strong link to space exploration – with their hands-on activities they can lay the educational foundation for future space projects but can also find ways to directly become involved in governmental space programmes. The same applies to other space enthusiasts to let them contribute to projects for citizen science (e.g., Mars Society).

There are many, many possibilities for hands-on space research – ranging from the utilisation of remote sensing data (ESA's Earth Observation data are for free and publicly accessible!) to the downstream sector of applications and user services. It is hoped that the SEE Universe 2020 conference will lay the foundation and provide the inspiration for a space industry and space research ecosystem in Serbia … and maybe the first Serbian in space?

Image 11: On 24 January 2018, ESA's Proba 1 satellite captured this maze-like image of the capital city of Belgrade, in Serbia.
Credit: ESA/2018, CC BY-SA 3.0 IGO

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THE NEW MARS OUTPOST AND RESEARCH AT THE D-MARS ANALOG SITE

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Abstract: The analog space missions performed at the Desert Mars Analog Ramon Station (D-MARS) are a method to develop and test dual-use technologies, to study scientific methods, and to acquire knowledge for human space exploration, taking advantage of the Israeli start-up ecosystem and the Mars-like geology and morphology of the Makhtesh Ramon crater in the Negev desert, Israel.

The environment in the habitat's vicinity is used for simulated Extra-Vehicular Activities (EVA), where simulated analog fieldwork is being conducted. Various international technologies in agriculture, data handling, communication, robotics, medicine, and more are used within and around the D-MARS facility.

An advanced Mars outpost analog, that will host the international analog Mars mission AMADEE-20 during October-November 2021, is being established at the D-MARS analog site. The central habitat unit in this complex is the D-MARS Hab02 prototype, that is designed to include unique feature; positive pressure as countermeasure for the dust problem, clean room environment for sterile handling of samples, and in the near future we intend to test and demonstrate technology for using local soil layer as a radiation protection.

This paper presents the new habitat, technology, and research that are being carried out these days and in the near future at the D-MARS space simulations center.

Presentation link: https://www.youtube.com/watch?v=nbLZZQS2otU

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MONITORING SOIL HEALTH WITH EARTH OBSERVATION THROUGH THE PRISM OF THE MISSION-ORIENTED APPROACH OF HORIZON EUROPE

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Abstract: The new mission-oriented "Horizon Europe" research and innovation program (EU, 2021-2027) is characterized by the introduction of five Missions, among them: "Soil Health and Food". Soils play an integral role rendering unique ecosystem services that contribute also to the political commitments of EU, i.e., Paris agreement, Green Deal, Sustainable Development Goals (SDGs) of UN. Some of the most important ecosystem services are producing healthy food, protecting the quality of ground- and surface water, capturing carbon, thereby mitigating climate change, reducing emission of greenhouse gasses, and preserving and improving biodiversity on a landscape level. Remote sensing techniques can be used to rapidly assess soil properties, to estimate soil health, essential for plant growth such as %carbon and nutrient contents. These properties do, however, require a lot of manual work or machinery to collect. Rather than following traditional expensive and not very effective approaches, plant development during the growing season can be monitored continuously allowing application of management measures at the right time and location, such as fertilization, irrigation, combatting pests, diseases, and weeds. This cannot only result in higher yields, improved water quality, contributions to climate mitigation and biodiversity, but also in lowering costs by saving nutrient and pesticide/herbicide inputs thereby representing innovative forms of precision agriculture. Earth observations can, in this context, also provide essential information on greenhouse gas emissions contributing to the reporting mechanisms in the EU member states. Coordination among various remote sensing activities in different countries on an international level and development of widely accepted criteria and thresholds for soil health are essential to achieve the full potential of proximal and remote sensing techniques to meet the SDGs.

Presentation link: https://www.youtube.com/watch?v=nbLZZQS2otU

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REVIEW OF BULGARIAN SPACE-RELATED ACTIVITIES WITHIN THE GEO INITIATIVE AND THE EU COPERNICUS PROGRAM

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Abstract: The free and open data policy of the Group on Earth Observation (GEO) and the EU Copernicus program helps many Bulgarian scientists, start-ups, and SMEs to choose Earth Observation (EO) data as a core for their research projects, development of applied products and services. This review summarizes the organizational activities undertaken at different levels to coordinate the efforts of stakeholders for technological development and innovation in the field of space in Bulgaria, directly or indirectly related to the use of EO over the past three decades from a scientific point of view. Bulgarian participation in GEO and ESA Plan for European Cooperative State (PECS) Agreement is also discussed. A review of normative documents, international agreements, the country's participation in space-related programs, research and applied projects, organizational activities, educational initiatives, and training is carried out. The main challenges facing the scientific community in Bulgaria and its efforts to participate actively in space-related international programs, projects and initiatives are outlined. Finally, opportunities for future cooperation within the global initiatives and programs with special consideration such as GEO, EuroGEO, Galileo, Copernicus, EGNOS, and others are given.

Keywords: GEO, Copernicus, Academia, Industry, National space policy.

1. INTRODUCTION

The fully integrated European Union (EU) space programme opportunities spanning 2021-2027 are expected to enhance European competitiveness and sustainable development. The program brings together all EU activities: Galileo, European Geostationary Navigation Overlay Service (EGNOS), Copernicus, Space Situational Awareness (SSA) programme and GOVSATCOM, in one programme providing a coherent framework for investment and developing new space-driven services that will benefit EU citizens and businesses (EC, 2016). Some of the initiatives are related to the European priorities in space research and innovation policy to support Green deal, Digital economy and Prosperity, Space R&D, Digitalisation and Innovation addressing the societal challenges, Space solutions for Sustainable Balkan regional perspectives, including the Danube and the Black Sea regions. Several European and national economies' governing policies and economic sectors rely on products and services developed using satellite image data, geolocation information, and satellite communications. Space-based applications and services support environmental protection, transport safety, precision farming, shipping route monitoring, urban and regional planning, and other public sectors. The potential areas of EO data application are tremendous and not yet fully utilized.

The opportunities offered by the EU space program contribute to enhancing European competitiveness and sustainable development. The newly formed EU Space Programme Agency and the new Directorate-General for Defence Industry and Space within EC and European Space Agency (ESA) will govern EU Multiannual Financial Framework 2021-2027 in the following programme period. The topic 'Space' will significantly impact technological innovation in EU countries and their industrial development and progress. In Bulgaria, this transitional preparatory phase was earmarked by a national conference, “Defense and aerospace industry and research” held in Sofia in 10-12 July 2017. This conference was attended by several EC representatives, the Executive Director of the European Defence Agency, Bulgarian ministries, and dozens of scientists and entrepreneurs in information technology, defence, and space research from different European countries. Recently, the initiatives such as 'Space for better future - EU space research and innovation policy to support Green deal, Digital economy and Prosperity', 'New ecosystems for sustainable growth - supporting accelerated economic development and addressing sustainability, green and inclusive growth and 'One Planet' have been announced. These initiatives will have their imprint on the national and international priorities of EU member states. Currently, in Bulgaria, such EU activities are advertised in public space.

The management of Bulgarian participation in space activities is spread amongst different governmental bodies, whilst the Ministry of Economy (ME) coordinates the space policy at the national and European levels[1]. The government bodies involved in space activities include several ministries such as ME, Ministry of Education and Science (MES), Ministry of Interior, Ministry of Foreign Affairs, Ministry of Transport, Information Technology and Communications, Ministry of Defence, Ministry of Environment and Water, and other authorities.

This paper presents an overview of Bulgarian space-related activities undertaken under GEO and Copernicus programmes during the last three decades. The review is based on a study of scientific publications, reports, and publicly available information from official sources. Inclusion of the GEO country and signing the Plan for European Cooperative State (PECS) agreement with ESA is shortly described in

[1] Europe’s Master Plan for space technology, by ESA and the EU, 2018, 91-94.

Section 2. Highlights of activities carried out by the state, NGOs, scientific and other stakeholders in the period of democratic changes in the country and national legislation, related policy and specially dedicated events are presented chronologically in Section 3. Section 4 presents the scientific community's main challenges in participating actively in international programs, projects, and initiatives in space-related fields. Available opportunities for future cooperation within the global initiatives and programs such as GEO, EuroGEO, Galileo, Copernicus, EGNOS, and other endeavours are given in Section 5. General problems related to effective communication, collaboration, and coordination issues at an institutional level need to be addressed to fortify the partnership among governmental institutions, academia, NGOs and business are identified and discussed in Section 6. Finally, some recommendations are given to consolidate the scientific community and intensify the dialogue with state institutions to develop and adopt a national space program and its implementation plan.

2. MEMBERSHIP OF BULGARIA IN GEO, EUMETSAT AND ESA AND RELATED ACTIVITIES

2.1. ACCEPTANCE OF BULGARIA AS A MEMBER-STATE IN GEO

Following the GEO formal establishment in February 2005 by several governments and the European Commission (EC) during the 3rd Earth Observation Summit in Brussels, the number of participating countries has been steadily increasing over time. The central vision is “to realize a future where decisions and actions, for the benefit of humankind, are informed by coordinated, comprehensive and sustained Earth observation information and services”. The main goal of the intergovernmental partnership is to build the infrastructure Global Earth Observation System of Systems (GEOSS). The EO Groups are based voluntarily and coordinated by governments, intergovernmental, international, and regional organizations to implement and effectively use the EO. They support the interaction between existing and emerging global systems and research programs to improve informed policy-making. The first years after establishment were dedicated to building and strengthening the status while organizing, expanding, and enhancing cooperation based on voluntary contributions from member countries and organizations. A stage has now been reached in which users have access to many datasets containing EO, a significant part of which are freely available.

Within Europe, the interdisciplinary efforts of EO Groups, initiated by GEO member countries, are essential for the EC and EU Member States. Several EC Directorates-General are active GEO members. The Directorate-General for Research and Innovation has a leading role, and the Joint Research Centre provides support services.

After the democratic changes in Bulgaria, individual teams from the scientific and educational community have focused on studying the interest and raising public awareness of the benefits of using Earth Observations (EO) in various socio-economic spheres of life. At the initiative of a scientific team and following coordination procedures between some ministries, Bulgaria's caretaker government decided on full membership of the GEO and the European Space Agency (ESA) with a Minutes of 11.06.2014 from a meeting of the Council of Ministers. Although the Bulgarian Government decided for full membership of the state into both organizations at the same government meeting, there is no official state act to formalize GEO membership and define it as a state commitment.

Soon after this first important step, Bulgaria became the 92nd Member State of GEO. At the XI Plenary Session of GEO in the period 12-14 November 2014, held in Geneva, this act was formally approved (see Pashova & Yovev 2015). Under the motto: ‘Under the pulse of the planet’, over 275 representatives from more than 45 countries participated in this session. The Bulgarian delegates presented a Statement[2] stating the country intentions to participate in implementing the 10-year GEO plan. It is also stated that the necessary steps will be taken to unite the efforts of national institutions and organizations whose primary responsibilities are related to the nine areas of socio-economic benefits of GEO, which are: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. After Bulgarian inclusion in this intergovernmental partnership, several governmental institutions, academia and NGOs have included in GEO initiatives, contributed to the construction of the GEO Knowledge Center, the GEOSS and the development of research infrastructure networks[3]. However, due to the change of several governments and administrative changes at the state level, the Bulgarian ME took over the GEO activities coordinating role at the national level in 2016.

After the official acceptance of Bulgaria as a member of GEO in 2014, the state commitments with this national membership still do not give visible and tangible results. National participation in international initiatives and programs related to space activities is less active than other European countries. Despite some achievements in certain areas of application of space technologies, data, products and services, Bulgaria lags significantly behind other EU countries in the face of growing competition in the space sector, development of the digital economy, smart industrial specialization, and digital transformation. Besides, in recent years, the scientific community has repeatedly raised the issue of state policy in space activities. Other interested communities also demand that these activities be publicly discussed for inclusion as priorities in updating the Bulgarian strategy for smart specialization for the programming period 2021-2027 and in the national program "Science and Education for Smart Growth".

2.2. BULGARIAN MEMBERSHIP IN EUMETSAT

The accession agreement between the Government of the Republic of Bulgaria and the European Organization for Exploitation of Meteorological Satellites

[2] https://www.earthobservations.org/documents/geo_xi/geoxi_bulgaria_statement.pdf
[3] National Roadmap of Scientific Infrastructure. Ministry of Education and Sciences, 2017, https://web.mon.bg/upload/4013/Roadmap_2017_ENG.pdf

(EUMETSAT) was signed during the 79th EUMETSAT Council meeting in Darmstadt in November 2013. The Agreement is ratified by a law[4] adopted by the 42nd National Assembly on 19 March 2014[5]. Our planet's monitoring needs a global satellite system to collect high-resolution information in time and space to ensure reliable coverage. Global and regional Earth-system monitoring can be achieved only through a full international commitment. With Bulgaria joining EUMETSAT as a Member State on 30 April 2014, EUMETSAT has achieved its goal to attain 30 Member States in the same year[6]. Following Article 16.5 of the EUMETSAT Convention, the Republic of Bulgaria pays a significant contribution to EUMETSAT of EUR 1,664,000 against investments already made in the three years to 2017. The country membership of EUMETSAT entitles it to be involved in the governing board strategic decisions; Bulgarian companies can participate in tenders, and Bulgarian citizens can apply for positions in the organization.

Furthermore, the country can have unrestricted access to all EUMETSAT data and products. The National Institute of Meteorology Hydrology (NIMH) contributes actively to developing the applications of the information provided by EUMETSAT. Bulgaria takes an equal part in the joint effort of Europe to develop adequate meteorological satellite systems to maintain the constant flow of data about the atmosphere, Earth surface, sea, and climate, as well as to develop efficient technologies for their increasing use. However, the current situation regarding the use of data from the EUMETSAT constellation shows no significant uptake of users by governmental, academic, and non-governmental organizations, except by specific teams from NIMH. This circumstance implies that NIMH should organize more active dissemination and training activities to facilitate the users' acceptance of satellite data and products offered free of charge as part of the national membership of EUMETSAT.

2.3. PECS AGREEMENT OF BULGARIA WITH ESA

Decisive reasons for creating ESA in 1975 are to pool human, technical and financial resources for developing large space missions; to ensure an industrial policy to develop a competitive and sustainable European space industry; to coordinate national, international, and European space programs. According to Article 2 of the ESA Convention[7], the primary purpose is to promote, for exclusively peaceful purposes, cooperation among European states in space research and technology and their space applications.

Bulgaria has come a long way over the years, from the first achievements in space research in the 70s of the last century to an ESA-PECS full membership, which became a reality only in 2015. Despite strong Bulgarian traditions in space exploration, for more than 25 years after the political and economic system change

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[4] https://dv.parliament.bg/DVWeb/showMaterialDV.jsp?idMat=83713
[5] State Gazzete, Iss. 30/01.04.2014
[6] https://www.eumetsat.int/bulgaria-becomes-eumetsats-30th-member-state
[7] https://www.esa.int/About_Us/Corporate_news/Convention-Rules

in the early 1990s, the country was among the few European countries that were not members of the ESA. The Bulgarian Government signed the European Cooperative State (ECS) Agreement on April 8, 2015. The 43rd National Assembly adopted the Law on Ratification of the ECS Agreement between the Government of the Republic of Bulgaria and ESA on November 26, 2015[8]. Bulgaria joins ESA as a cooperating country, which opens exceptional opportunities for developing the Bulgarian economy, science, and business, financing the development of space technologies, and transferring high technologies and knowledge. The Government signed the Plan for European Cooperative State (PECS) Charter on February 4, 2016. The ME coordinates national policy related to space activities in Bulgaria and declares that it works to increase Bulgarian industrial innovations and competitiveness and raise awareness of space programs and the data they provide through their platforms.

The overall objective of PECS is to connect Bulgaria with the ESA programs and activities and to prepare it in the most effective way for future accession to the ESA Convention. By signing the ECS agreement, supplemented within one year by the PECS Charter for a five-year implementation plan, jointly agreed between ESA and Bulgaria, our country has the right to participate in ESA procurement and activities. The Government has carried out some activities, mainly in research and development, to develop its space industry experience. Following ESA rules, Bulgaria pays the annual instalment due in three consecutive payments within five years, in proportion: 40% by January 31; 40% by June 30; 20% by October 31 every year during the transitional period. According to the public information provided by the ME, PECS projects approved within the six PECS calls are in Space science, Research and applications, Telecommunications, Microgravity studies, Ground engineering and the utilization sector. Table 1 shows PECS tenders distribution, submitted, and successfully contracted projects during Bulgaria's 5-year PECS program period until 2021.

Following this chain of events, after 2015, several international and national meetings and seminars were organized. During the Bulgarian presidency of the EU in the first half of 2018, some events dedicated to the space program Copernicus were organized with the EC and ESA assistance, the Bulgarian Government, the scientific community, and interested stakeholders.

Table 1: ESA tenders issued under the PECS Program for Bulgaria (2015-2020) (source: ME, Bulgaria).

Number of Call		**I**	**II**	**III**
Tender announced	***Open***	11/5/2015	11/10/2016	12/2/2018
	Closed	6/7/2015	12/12/2016	13/04/2018
Project number	***Submitted***	19	25	8
	Contracted	5	9	3

[8] State Gazzete, Iss. 95/08.12.2015

Table 1: continued…

Number of Call		**IV**	**V**	**VI**
Tender announced	***Open***	10/12/2018	11/10/2019	15/05/2020
	Closed	27/03/2019	2/12/2019	30/06/2020
Project number	***Submitted***	18	17	under evaluation as of Nov. 2020
	Contracted	5	7	?

A two-day workshop, "Balkans from space" organized by the Bulgarian Presidency on the EU Council and the ESA, was held on 18-19 April 2018. The event was focused on the space-based services for regional strategies in the digital economy, innovative solutions enabled by EO, Space systems in general and Copernicus in the Balkans and the Black Sea regions.

The feasibility study of Bulgaria under the auspices of ME was launched in 2019 under the PECS program for 2015-2021[9]. The overall objective is to provide a feasibility study to assess Bulgaria's development potential in the space sector and its readiness to cooperate with ESA. Review and evaluation of the Bulgarian subjects with potential for entering the space market, development, and testing of a methodological approach for assessment of the industrial and scientific potential, as well as recommendations for the development of a national space program as a condition for Bulgaria's membership in ESA are the expected results of this study.

3. BULGARIAN LEGISLATION RELATED TO SPACE ACTIVITIES

Our country has significantly reduced research and development volume in recent decades and applied production in space research. The contrast is particularly striking compared to the 1980s when Bulgaria was among the few countries to launch astronauts, participate in ambitious space missions to Venus and Mars and successfully implement the latest advances in microelectronics in space. After the democratic changes in 1989 in Bulgaria and the state's lack of commitment in space activities with the national policy, the occurred socio-economic changes affected all areas of the country's social development. Through the promulgation in the State Gazette of laws and other normative documents, the elaboration, consultation, and official adoption required time and coordination among some interested stakeholders. The first attempt to develop a Bulgarian space program was made at the beginning of the 21st century as an initiative of several Bulgarian Academy of Sciences (BAS) research institutes. The draft space program has been developed but has not been approved by the Government then.

[9] Feasibility Space Study of Bulgaria (FS2B). ESA Contract No. 400012869/19/NL/CRS under the PECS (Plan for European Cooperating States), 2020, https://spaceweeksofia.com/?page_id=648

Nevertheless, over time, several national regulations related to space activities, the obligations of Bulgaria as a member of the EU, and the need to transpose into national legislation several European directives have been adopted (see Fig. 1). Some of these provisions are related to spatial data, EO and relevant information, access to them and their sharing. One of the essential laws is the one passed in 2008 for the e-Government. The main goal of e-Government, through which the Ministry of Transport, Information Technology and Communications (MTITC) coordinates the policy of the Bulgarian Government, is to meet public needs by ensuring the quality and accessibility of administrative services. The e-Government has programs that include reusing open data and data-driven digital governance, assessing the role of information and communication technologies in the public sector, business planning, and developing activities related to the space industry. By developing a National Spatial Data Infrastructure (NSDI), all stakeholders can benefit directly from geospatial information and location intelligence (see Pashova & Bandrova 2017). They can extend the EU INSPIRE Directive use to other thematic sectors and coordinate vital programs and services for space-based applications from the EU and interinstitutional activities at the national and international level. Bulgaria takes part in the Danube strategy[10] and the Sea basin strategy: the Black Sea[11], which are dedicated to the future of the EU regional policies. The funded projects involving EO data use through different EU instruments can be previewed at the Maritime Data Hub[12]. The list of approved EU projects under the priority areas of the strategies using EO data is listed in Section 4.2.

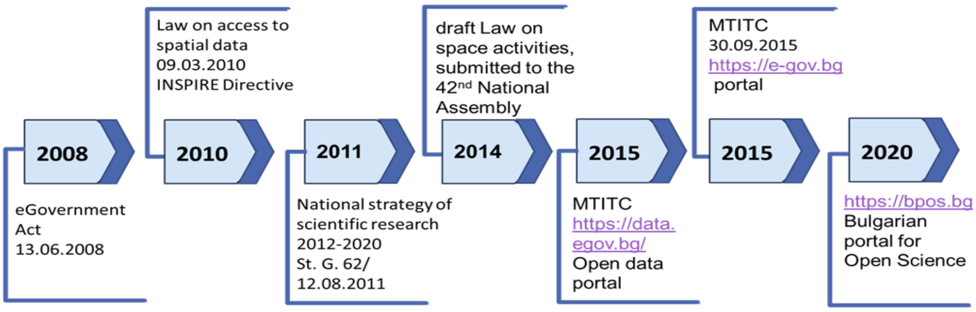

Figure 1: Timeline of some Bulgarian legislation acts and strategies since 2008.

The policy of the Bulgarian e-Government should encourage the development and application of space science and technology in favour of the socio-economic benefit of the country to support the ongoing transformation of traditional production and industrial practices, combined with the latest intelligent technologies, the so-called Fourth Industrial Revolution (or Industry 4.0), to strengthen the cooperation between the state and the industrial IT associations, to increase the competitiveness of the Bulgarian economy internationally. Bulgaria has few national supercomputer

[10] https://www.danubestrategy.eu
[11] https://ec.europa.eu/oceans-and-fisheries/ocean/sea-basins/black-sea_en
[12] https://blackseablueconomy.eu/projects/maritime-datahub

facilities located in BAS[13] and SofiaTech Park. The latter is also a home of a petascale supercomputer PetaSC and a part of the EuroHPC network[14]. On the BAS "Avitohol" are already hosted applications related to geohazards, space geomagnetism, and marine applications using EO data from the Copernicus programme.

Bulgaria has adopted several laws and subsequent provisions on space activities, related areas of public importance and organizational work. After adopting specific national legislation, normative documents are subsequently updated, regulating the rights and obligations of state institutions, agencies and interested stakeholders. Some of these legislative documents directly respond to advancing the national economy, research and development, and education. In 2014, for example, a preliminary text of the Space Activity Act was prepared.

Due to the Government's resignation and early parliamentary elections caused by the instability of the ruling majority in the 42nd National Assembly, this act remained in its archives. Nevertheless, Bulgarian governments have adopted some important legislation, national policies[15,16], strategies[17], plans and international agreements over the last two decades. In addition, several laws, by-laws and ordinances regulate participation in the European space program, the development of National Operational and Research Programs and Networks the link between science and business, coordinated by the ME and MES.

Responsibilities for geoscience issues in Bulgaria are distributed among several ministries, government agencies and services that conduct public policy and coordinate activities to develop strategies, plans and roadmaps for implementation in various thematic areas. State bodies' scientific and operational services with monitoring and expert geospatial information, analysis, and assessments are provided mainly by research institutes at BAS and NIMH at MES. Concerning the environment, monitoring activities are carried out by some government agencies and services, including non-governmental organizations and with citizen participation (Volunteered Geographic Information - VGI and Citizen Science - CS).

To respond to the environmental changes and adverse natural events, a national research program "Environmental Protection and Reduction of the Risk of Adverse Events and Natural Disasters" by the Resolution of the Council of Ministers in 2018 and supported by the MES was approved. BAS coordinates the program, and eight other research organizations and universities are partners. The program provides fundamental scientific results to generate new knowledge about the processes and interactions in the atmosphere, hydrosphere, lithosphere, and biosphere at different scales. In addition, characteristics with impacts on various natural disasters, quality of life, health risks and ecosystems are also expected to be assessed.

[13] https://www.iict.bas.bg/avitohol
[14] https://eurohpc-ju.europa.eu/press-releases/petasc-new-eurohpc-world-class-supercomputer-bulgaria
[15] https://dv.parliament.bg
[16] https://lex.bg/laws
[17] http://www.strategy.bg

In connection with consultations with European institutions to coordinate the national legislation and space-related policies arising from the Republic of Bulgaria's membership in the EU, Working Group (WG) 35 'Space Policy' was established in 2007 by Decree No. 85 of the Council of Ministers. WG35 has the functions of an advisory body to the ME, with the Minister of Economy approving its members. The experts' list is periodically updated and includes representatives from several ministries, governmental institutions and agencies, academia, universities, industry, NGOs, and stakeholders interested in a space domain. At the beginning of its establishment, WG35 actively assisted the ME administration, discussing all contemporary issues in space at regular meetings. However, working meetings and communication between WG35 and the ME on space policy issues have been limited in the last few years. The ME administration rarely approached it, except on coordinating national framework positions and formal signing of protocols. As a result, WG35 is the only administrative body reflecting public interests from the state administration, academia, and the private and non-governmental sectors with delegated competencies regarding space policy and inter-institutional space action in the country. The authors share the opinion that there is no mechanism for active dialogue between all stakeholders in space activities through which to formulate an active state policy and implement it.

4. BULGARIAN PARTICIPATION IN EU SPACE-RELATED PROGRAMS AND INITIATIVES

4.1. THE EUROPEAN EO PROGRAM COPERNICUS

On November 9th, 2010, the EU Regulation No. 911/2010 on the European Global Monitoring for Environment and Security (GMES) program and its initial operations (from 2011 to 2013) had come into force. With this regulation, GMES is becoming operational. Copernicus is the new name of the EC's EO programme, which is announced on the Competitiveness Council held on December 11 2012[18]. In a world facing an increased risk of natural and other disasters, starting from 2014, Copernicus aims to monitor the state of the environment on land, sea, and atmosphere and improve citizens security (Filchev et al. 2018, Filchev et al. 2020). According to recent studies, the program is a driver for economic growth and employment, with the potential to create up to 85,000 new jobs over the period 2015-2030[19].

[18] https://www.eubusiness.com/topics/research/gmes-copernicus
[19] https://ec.europa.eu/commission/presscorner/detail/en/IP_12_1345

4.2. EU PROGRAMS AND INTERNATIONAL RESEARCH PROJECTS WITH BULGARIAN PARTICIPATION

Bulgarian participation in international space research projects is based on a bottom-up approach. Bulgarian teams participate in international projects at the initiative of individual scientists, teams from research institutes or universities. The most important EU projects with Bulgarian participation related to GEO and Copernicus are listed chronologically below in Table 2.

Table 2: List of international projects with Bulgarian participation in the field of EO.

Project acronym	Link	Implementation period	EU funding mechanism
EnviroGRIDS	http://www.envirogrids.net	2009-2012	7th FP
OBSERVE	https://cordis.europa.eu/project/id/265282	2010-2012	7th FP
Balkan GEO Network	https://cordis.europa.eu/project/id/265176	2010-2013	7th FP
IGIT	http://igit.geo.info.hu	2011-2015	7th FP
COSMOS	http://www.ncp-space.net	2008-2012	7th FP
COSMOS+	http://www.ncp-space.net	2012-2014	7th FP
Geo-Cradle	http://geocradle.eu/en	2016-2018	Horizon 2020
e-Shape	https://e-shape.eu	2019-2023	Horizon 2020
COSMOS2020plus	http://www.ncp-space.net	2019-2021	Horizon 2020
GATE Centre of Excellence	https://www.gate-coe.eu	2019-2025	Horizon 2020
Goldeneye	https://cordis.europa.eu/project/id/86939	2020-2023	Horizon 2020
DISARM	http://disarmfire.eu	2014-2020	INTERREG
FPCUP	https://www.copernicus-user-uptake.eu	2018-2023	Caroline Hershel
ENVeurope	http://www.enveurope.eu	2010-2014	LIFE
ECO-Satellite	http://ecosatellite.topo.auth.gr	2011-2013	ENPI
BALGEOS	http://balgeos.cc.bas.bg	2008-2010	Other EU
MIS-ETC 171	http://cbc171.asde-bg.org/index_en.php	2012-2014	Other EU

COSMOS and COSMOS+ were National Contact Points networks for the Space theme under the EU 7th Framework Programme for Research & Innovation. The primary aims of the COSMOS, COSMOS+, and COSMOS2020plus projects were to build a strong support network among stakeholders in Europe by raising their awareness of FP7 funding opportunities and the Horizon 2020 space program. During the implementation of these projects, the National Contact Points (NCP) in the space field shared good practice and taken part in joined training courses to improve their skills.

Bulgaria had national representatives from the Space Research and Technology Institute - Bulgarian Academy of Sciences (SRTI-BAS) in the COSMOS+ Network, a project funded within the FP7 from May 2012 to November 2014. The COSMOS+ generally aimed to interlink the NCPs for Space to improve and balance NCP's services overall quality, add central services, and finally raise the average quality level of submitted proposals. One info day tour event on 16.10.2013 was organized in Sofia, Bulgaria during Horizon 2020: Information Day on 'Space' priority organized by the MES. COSMOS2020 was the continuation of the COSMOS and COSMOS+ projects under the EU Horizon 2020 Framework Programme for Research & Innovation. COSMOS2020plus was the further extension of COSMOS2020 for the period of June 2019 - July 2020. It was the final extension within the Horizon 2020 Framework Programme with a continuation of the Cooperation of Space NCPs by the Means to Optimize Services under Horizon 2020[20].

The SRTI-BAS and CASTRA have joined the FPCUP consortium in 2017 and participated actively in the Agreement's preparatory phase. The FPCUP project officially started in 2018, but the formal start of activities approved in WP 2018 was postponed to the end of 2019 when the final approval of WP2018 was made. Currently, the Bulgarian participation in FPCUP is in three approved by the EC Actions:

1. Copernicus Awareness Raising Programme for Bulgaria - COPE4BG within WP2018[21],
2. Copernicus Promotion Activities in Bulgaria within WP2019[22], and
3. Developing support for monitoring and reporting of GHG emissions and removals from land use, land-use change and forestry (CLIMA)[23].

Some results related to the recent organization of Copernicus seminars are being carried out in the framework of the COPE4BG project, and all the expected results of the individual FPCUP implementation activities can be reviewed following the hyperlinks provided below.

The scientific and educational community in Bulgaria has repeatedly raised the issue of pursuing an active state policy in space activities. These activities can be publicly discussed for their inclusion as priorities in state policy and updated versions of the concept of smart specialization (IP) of Bulgaria for the programming period 2021-2027 and of the national program 'Science and Education for Smart Growth'. We hope that the Government and the responsible ministries will take the leading role, initiating such a discussion.

4.3. INTERNATIONAL RESEARCH NETWORKS

Within the European Cooperation in Science and Technology (COST[24]) Bulgarian scientists have participated in the following Actions directly related to EO, i.e. „Antenna Systems & Sensors for Information Society Technologies – ASSIST" (2007-2011), ES0604 „Atmospheric Water Vapour in the Climate System – WaVaCS" (2007-2011), ES0702 „Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems – EG-CLIMET"

[20] https://cordis.europa.eu/project/id/857691
[21] https://www.copernicus-user-uptake.eu/
[22] https://tinyurl.com/em5tbpas
[23] https://tinyurl.com/yb3b89t9
[24] https://www.cost.eu

(2008-2012), IC0802 „Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems“ (2008-2012), ES1309 „Innovative optical Tools for proximal sensing of ecophysiological processes – OPTIMIZE “ (2014-2018), TD1403 „Big Data Era in Sky and Earth Observation – Big-Sky-Earth“ (2015-2019), and CA17134 „Optical synergies for spatiotemporal sensing of scalable ecophysiological traits – SENSECO“ (2018-2022).

Researchers from academia and university communities are involved in research networks that conduct research using EO and Remote Sensing (RS) to develop a wide range of valuable products, applications, and services. SRTI-BAS and IO-BAS became members of the European Association of Remote Sensing Laboratories (EARSeL) in 2009, and since 2012 Bulgaria has had a national representative at the EARSeL Council[25] (see Filchev et al. 2013). Such network is the South-Central European Regional Informational Network (SCERIN[26]), a regional network of the coordinated international program Global Observation of Forest and Land-use Dynamics (GOFC-GOLD[27]). The Formulation Workshop of SCERIN (initially SEERIN) was in the park-hotel 'Moscow', Sofia, Bulgaria on April 17, 2012. Since its launch, researchers from institutes of the BAS have been actively participating in the network meetings. SCERIN is an informal network of scientists and other professionals based on scientific interests in South-Eastern and Central Europe, which strives to ensure continuity and collaboration between the scientists, professionals, and existing RS networks in the region. SCERIN network has strong linkages with the Northern Eurasia Earth Science Partnership Initiative and the North Eurasia Future Initiative under Future Earth auspices. These initiatives are programs to support research on the Earth system internationally.

The European Association of Remote Sensing Companies (EARSC) is a professional industrial body (trade association) with the mission to foster the growth of the Earth-observation (EO) services sector[28]. In Bulgaria, the TAKT-IKI Ltd. is a member of EARSC.

4.4. SCIENTIFIC FORUMS ORGANIZED IN BULGARIA

In recent decades, several international and national conferences have been organized with professional associations and unions. Most of them include broader scientific topics, while others include narrowly specialized thematic areas in geosciences. In general, the topics discussed in these forums are dedicated to data and information from satellite missions, RS, EO, geoinformation and recent advances in space technology. Some essential scientific forums are presented here.

[25] http://www.earsel.org
[26] https://www.scerin.eu
[27] https://gofcgold.umd.edu
[28] https://earsc.org

Regular scientific forums which took place during the reviewed period:

- Congress of the Balkan Geophysical Society[29], since 1996.
- International Conference on Cartography and GIS (ICC & GIS)[30], since 2006.
- International Symposium "Modern technologies, education and professional practice in geodesy and related areas",[31] organized annually by the Union of Surveyors and Land Surveyors, since 1991.
- Space, Ecology, Safety (SES), organized by SRTI-BAS[32], since 2007.
- Inter-agency Interaction in Crisis Management and Disaster Response[33], organized by the Crisis Management and Disaster Response Centre of Excellence (CMDR CoE), since 2013.
- Surveying, Geology and Mining, Ecology and Management (SGEM)[34], since 2000.

Important scientific forums which took place during the reviewed period:

- Digital Earth Summit[35], 2010.
- FIG working week 2015[36], in Sofia, Bulgaria, 17–21 May 2015.
- 3rd Annual Seminar of the Disaster Risk Management Knowledge Centre[37], 2018, BAS-JRC.
- European Maritime Day Conference[38], in Burgas, 31 May – 1 June 2018.
- International Geography Conference - GEODECADE[39], 2020, Bulgarian Geography Society and EUROGEO.
- First International Conference on ENVIROnmental protection and disaster RISKs[40], 2020.

4.5. NATIONAL SPACE-RELATED SEMINARS

One of the first EO-related workshops held after Bulgaria's accession to the EU was the NIMH Bulgaria - EUMETSAT training workshop "MSG Land Applications: Drought and Fire" in Sofia from 7 to 10 September 2009. It was a significant event for Bulgaria and the Balkan states. EUMETSAT products and monitoring and forecasting activities in the Balkans were presented[41]. Two national GMES Operational Capacity Workshops have been organized with EC, ESA, Government,

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[29] http://www.bggs.eu/nforums-en.html
[30] https://cartography-gis.com
[31] http://geodesy-union.org
[32] http://space.bas.bg/SES/index.html
[33] https://www.cmdrcoe.org
[34] https://www.sgem.org
[35] https://cartography-gis.com/digitalearth/digital_earth.html
[36] https://fig.net/fig2015
[37] https://drmkc.jrc.ec.europa.eu/partnership/Annual-Seminar/Meeting-2018
[38] https://webgate.ec.europa.eu/maritimeforum/sites/default/files/2018-conference-report_en.pdf
[39] http://geodecade.com
[40] http://envirorisk.bas.bg/files/envirorisks_flyer.pdf
[41] http://info.meteo.bg/conferences/EUMETSAT07092009/Programme.pdf

international organizations, academia, research organizations, universities, and NGOs. The first seminar on the operational capacity of GMES - a joint initiative of the Bulgarian Government and the EC was held on March 25 and 26, 2010, at the Sheraton Hotel, Sofia. The European EO Program provides data useful in a range of issues, including climate change, citizens security and border surveillance, land, sea, and atmosphere - each will be observed through GMES, helping to make our lives safer. The second seminar for Earth observation - GMES on operational capacity was organized in Sofia on March 17 and 18, 2011 in coordination with the EC. The Bulgarian Government has actively supported these two workshops. NGOs and stakeholders took an active part in several international organizations such as the EC, ESA, and leading research organizations from Bulgaria and abroad.

The next event related to the Copernicus programme's promotion was a keynote lecture made by Mr Udrivolf Pica from Copernicus Support Office. SRTI-BAS invited him as a part of the Copernicus Academy activities for a keynote speaker at the 13th annual international scientific conference “Space, Ecology, Safety” held in Sofia on 2-4 November 2017[42]. On 5 November 2017, at the RATIO event in the Sofia Event Centre, the Bulgarian audience met with scientists from leading European research centres such as CERN, EC, Goldsmiths, and the University of London. In a language accessible to all, the speakers introduced the audience to topics dedicated to elementary particles in the universe, dark matter and dark energy, the Copernican satellites' work and the data usage for various purposes.

The SRTI-BAS and GeoPolymorphic Cloud supported by the ME have jointly organized, as part of their Copernicus Academy and Copernicus Relays activities, the 1st national Copernicus workshop with training[43] held in the BAS-Administration and SofiaTech Park on 22-23 November 2018, before starting the Work Programme 2018 of the Framework Partnership Agreement on Copernicus User Uptake (FPCUP) project. Following the official launch of FPCUP's WP2018, the 2nd Copernicus National Seminar was organized by SRTI-BAS and Cluster Aerospace Technologies, Research and Applications (CASTRA), represented by GeoPolymorphic Cloud[44]. Both events intended to resume the promotional activities on a national level, after the Copernicus information-day organized by the EC in Sofia on 17 April 2018, regarding Copernicus and promote the use of Copernicus data and products among national governmental, scientific, business, and NGOs. The events were well-attended and adequately matched the user community, which proved successful as a concept and implementation. Both workshops managed to gather a broad audience sustained, diversified, and increased in the following editions. The feedback from the attendees and trainees is predominantly positive, which justifies the efforts to re-establish the national Copernicus platform[45] to exchange results and ideas and create opportunities to spur a debate on the use of Copernicus data and products across various domains.

[42] http://space.bas.bg/bg/news//files/events/2017_SES_Programme.pdf
[43] https://cope4bg2018.copernicus.bg
[44] https://en.cope4bg2020.copernicus.bg
[45] https://copernicus.bg

National Forum for Modern Space Research was organized for the first time by the Cosmos branch of the Union of Physicists in Bulgaria with the financial support of the Faculty of Physics at Sofia University "St. Kliment Ohridski"[46]. Partners of the event have been Eureka Foundation, National Research Fund at the MES, Research Fund of Sofia University, and SofiaTech Park. The event was held on October 21 and 22, 2020 in SofiaTech Park, John Atanassov Innovation Forum. During the forum, participants learned about the state of research conducted by established Bulgarian scientists in three scientific sessions: 'Fundamental Space Research', 'Aerospace Technology', and 'Applied Space Research'. Draft versions of a National Strategy and Program for the Development of the Space Industry and Technologies and a National Scientific Program for Space Research have been discussed with representatives of the scientific community, business, industry, and public administration.

5. EO EDUCATION AND TRAINING IN BULGARIA

5.1. TRAINING AND EDUCATIONAL EVENTS

The 7th ESA Training Course on Radar Remote Sensing - Sofia 2016 has been organized by ESA and Faculty of Geodesy, University of Architecture, Civil Engineering and Geodesy (UACEG) and the Ministry of Economy[47]. The course has addressed to participants from universities, scientific communities, institutions, and organizations using geoinformation. It was dedicated to researchers, students, PhD students and young professionals from Bulgaria, Slovenia, Latvia, Lithuania, and Slovakia (PECS countries).

5.2. BULGARIAN MEMBERS IN THE COPERNICUS ACADEMY

The SRTI-BAS is a Copernicus Academy member since 2016[48]. As a part of its activities, it promotes Copernicus among the scientific community and creates public awareness through its annual conferences, journal, and lectures. The SRTI-BAS organizes an annual international conference "Space, Ecology, Safety - SES" (since 2005)[49] and publishes a book of proceedings in print and digital. The Journal "Aerospace Research in Bulgaria" has a longer tradition with a standing topic of EO (est. 1978, Web of Science indexed since 2005[50]). The institute publishes books on fundamental and applied space science and technology topics and EO[51]. Some of these books are considered as seminal for Bulgaria in the EO domain. Teams from the institute have published curriculum materials for schools within EEOBSS (ESA-

[46] https://bulgarianspace.online
[47] https://rrs16.esa.uacg.bg
[48] https://tinyurl.com/4ayyhse4
[49] http://space.bas.bg/SES/index.html
[50] http://journal.space.bas.bg
[51] http://space.bas.bg/bg/publishing_activity/books_and_journals.html

PECS[52]) and E#COS_LAB (OP "Education with Science", BAS-MES[53]) projects and atlases ('Space School' initiative supported by Bulgarian Astronautical Society[54]). Some of the EO dissemination activities include lectures for pupils and teachers in Bulgaria within the "Space School" initiative - 17 schools, 6 schools within EEOBSS, and 8 schools within E#COS_LAB projects. The "Space School" initiative also organized two GIS days for education in Sofia in 2017 and 2018. Jointly with other scientists from BAS, the institute has participated in Sofia Science Festival with a stand[55] and in science festivals in Sofia and Blagoevgrad in 2020, and in the Astro-party Baykal annual editions since 2018.

The second Bulgarian member of Copernicus Academy is the Department of Meteorology and Geophysics of the Sofia University "St. Kliment Ohridski". The Department's staff participates in integrating the Copernicus products from the thematic services in the taught disciplines in the Department of Meteorology and Geophysics in bachelor and master programs such as Climate Physics, Physical Oceanography, Satellite information in weather analysis, Remote Sensing of the Earth, and others[56]. Since 2018, public lectures and seminars on topics related to the Black Sea-Marine Forecast Centre[57] and Remote Sensing are organized on a regular basis.

5.3. BULGARIAN MEMBERS OF THE COPERNICUS RELAYS

GEOPolymorphicCloud and the Risk Space Technology Transfer Office at the BAS are members of the Bulgarian Copernicus Relay. Both organizations actively utilize the Copernicus data and services in their work routines, organizing hackathons and workshops in cooperation with the Copernicus Academy members, open lectures, and on-site virtual training. Recently, GEOPolymorphicCloud has restarted issuing a monthly bulletin on Copernicus and works with SRTI-BAS and CASTRA to set up the national Copernicus portal.

5.4. HACKATHONS

The hackathons in Bulgaria are presently organized by few entities related to the BAS and Technical University in Sofia. A contemporary but not exhaustive list of the events is provided below.

- NASA International Space Apps Challenge – Bulgaria[58]. Since 2013 generated about 180 projects with over 800 participants.

[52] https://eeobss.space
[53] https://bit.ly/3lgI2aZ
[54] http://spaceschoolbg.eu
[55] https://www.britishcouncil.bg/sofia-science-festival/experiments/zone-42
[56] http://mg.phys.uni-sofia.bg/news_en.html
[57] http://bsmfc.net
[58] http://spaceappschallengebulgaria.eu/en

- First Copernicus Hackathon in Bulgaria dedicated to the EU EO program "Copernicus" takes three days - from April 19 to 21, 2019, and was held in the Technical University[59].
- Two international Hackathons - ActInSpace 2020 and Copernicus Hackathon Sofia 2020 - due to covid 19 all planned events have been postponed for November 2020[60].
- NASA "Scientist for a Day" – 2019-2020 is regularly organized for students in grades 5-12 with the support of several organizations[61].

5.5. EXHIBITIONS

Over the years, different exhibitions related to EO have taken place, mainly in Sofia. For example, the travelling European Space Expo's opened in Sofia's Square Alexander I von Battenberg, from 16 to 25 May 2014. The interactive touch screen and unique visual design attracted 35,443 visitors. It also proved to be a popular field-trip destination for area school children, with more than 35 schools visiting the exhibition. Sofia deputy mayor opened the Expo joined by the Directorate General's Head of Information Activities for Industry and Entrepreneurship at the European Commission. Throughout the week, various informative sessions were held on topics related to Galileo, space and security, weather forecasting and the latest achievements in space research[62].

An exhibition with ten pictures taken by the 2nd Bulgarian astronaut Alexander Alexandrov on board of MIR space station with a Hasselblad photo camera was exhibited in "Sofia Largo" on 07.06.2018 commemorating 30 years from his space flight[63]. The exhibition "Central Europe through the eyes of the European Space Agency" presents photos of different geographical objects taken from space. The exhibition was organized jointly by the Embassy of France in Bulgaria, the French Cultural Institute and ESA during the "The Night of Ideas 2019" on January 31, 2019. As of February 1, 2019, it was on display in the French Embassy building in Sofia[64].

The SRTI-BAS exhibited photographs not shown taken from the spaceship "Soyuz 33" by the first Bulgarian cosmonaut Georgi Ivanov with a Kiev-4 photo camera on its 50th anniversary. The exhibition "Earth through the eyes of the first Bulgarian cosmonaut Georgi Ivanov" was shown on display in the lobby of BAS from 6 to 12 November 2019. Three set-ups of the exhibition entitled "Capitals" were carried out within the "Space School" initiative of SRTI-BAS. The exhibition commemorated Sofia's 140th anniversary as a capital city. The eight posters contained maps prepared by geospatial technologies and modelling and satellite images.

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[59] https://hackathon2019.rst-tto.com/en
[60] https://hackathon.rst-tto.com/en
[61] https://edutechflag.eu/nasa-scientist-for-a-day-2020
[62] https://www.euspa.europa.eu/news/sofia-welcomes-european-space-expo
[63] https://impressio.dir.bg/photography/nebesnata-krasota-na-zemyata-prez-ochite-na-aleksandar-aleksandrov
[64] https://vhugo.org/bg/la-nuit-des-idees-sofia-2019

During the Sofia Space Week April 24-28, 2020, an Exhibition of "New technologies and innovations 4.0" with the participation of leading companies in the aerospace sector was held. It ensured a platform for exchanging ideas and discussions between a wide range of international experts, researchers, decision-makers at the political level, industry representatives, users of space applications, and non-governmental organizations.

6. STATUS, CHALLENGES, AND FURTHER STEPS

After the 1980s, Bulgaria has significantly reduced research and development volume and applied production in space research. Bulgaria was among the few countries to launch astronauts into orbit, participate in ambitious space missions to Venus and Mars and successfully apply for the latest advances in microelectronics. Unfortunately, the right ideas for cooperation between the research community and business, the participation of Bulgarian companies in tenders and competitions at the European level in space technologies and applications, do not find sufficient state support and are not implemented in practice. The lack of an active state policy in space activities and the weak participation in international programs, initiatives, and cooperation, in which Bulgaria is a full member or partner, significantly hinders the effective use of national scientific opportunities for socio-economic development. Some problems at the institutional level that need to be addressed to strengthen the partnership between Government, academia, NGOs, and business have been identified in several forums and meetings.

These circumstances require a rethinking of national policies and strategies to effectively use all opportunities for Bulgaria's participation in the European Space Program and international space initiatives. The authors of this article share the view that space issues should be included in the priorities in updating the concept of smart specialization and research infrastructures of Bulgaria for the programming period 2021-2027, the National Development Programme Bulgaria 2030, and the national program "Science and Education for Smart Growth". High value-added space data and applications, combined with the rapid development of innovation and the digital economy, can offer considerable benefits to the public sector, help to achieve national priorities, and develop the potential of small and medium-sized businesses and start-ups. The opportunities for Bulgaria's future cooperation as an EU Member State in space activities are determined by the national membership and representation in GEO and EuroGEO, the ESA PECS program, and other international programs initiatives described above sections. Elaborating national regulations governing the provision and use of EO, increasing awareness and interest of stakeholders in GEO and Copernicus activities are necessary steps to benefit Bulgarian society. The funding mechanism of the National Science Fund at the MES should promote public-private partnerships and strengthen the mechanism of public control over state institutions that coordinate European funding programs related to space activities. The scientific community is expected to be an active participant in the dialogue with state institutions and stakeholders to strengthen networking and national, regional, and international collaboration. Academia, universities, and NGOs have started to participate voluntarily in regional and European initiatives of GEO and EuroGEO.

The free and open data policy of the Copernicus program helps many Bulgarian scientific teams, start-ups, and SMEs to choose this data as a core for their research projects and services. The MES finances the Bulgarian scientific community for the development of national centres of excellence and competence. Thirteen Bulgarian research and innovation centres receive EC support, including four ‘Centres of excellence’, i.e., fundamental research institutions and nine ‘Centres of competence’, focused on applied research activities with potential industrial uptake. Their subjects are in sectors such as mechatronics, digital technologies, creative and gaming industries and biotechnology and other areas in line with the priorities of Bulgarian smart specialization strategy, its industrial and innovation strategy based on local competitive strengths. Thus, Bulgarian scientists can successfully integrate into the EU research environment to take advantage of all the technologies and achievements in space science.

Intending to focus and centralize the national policy in the field of innovation and research in September 2020, the Government approved a decree establishing a ‘State Agency for Research and Innovation’ as a specialized body at the Council of Ministers for the development and implementation of the policy on research, innovation, and technology transfer. This Agency should deal with the strategic planning, management, financing, and management of research and innovation programs and conduct and support structural reforms. Furthermore, a new policy should be pursued to maximize the effectiveness of the activities favouring the transformation of the Bulgarian economy into one based on knowledge, innovation, and technology.

7. CONCLUSIVE REMARKS

Space science and technologies have a significant impact on the modern world. They are no longer just a scientific field but also have a significant economic aspect with critical social, political and defence dimensions. Since the second half of the 20th century, space technology has gradually become an integral part of many sectors of the socio-economic activity of modern society. Each country's participation in space activities determines its position in the international community, especially those in Europe and the world. The Republic of Bulgaria has a 50-year tradition in the field of space research and technology. The country perceives space activities as an opportunity for the growth of national science and economy. The Bulgarian space sector's development is closely connected with the European space policies and strategies of ESA and the EU. By increasing its space activity, the Republic of Bulgaria gradually builds its reputation as a reliable partner in bilateral and multilateral international cooperation. Copernicus EO's free access to data and information plays a vital role in the digital economy and policy-making processes that benefit citizens and the EU economy. Bulgarian institutions and companies participate in ESA tenders, which allows them to develop their capacity by cooperating with other ESA member countries. Developing innovative products and services, these Bulgarian teams contribute to the Copernicus six-core, top-quality services and applications.

The EC established links with ESA, developing a joint space strategy in 2000 and a space policy in 2003 with flagship space programmes: Galileo for satellite navigation and Copernicus for earth observation. Bulgaria's successful integration into the EU presupposes active participation in setting the EU space policy's main priorities and the EU executive bodies[65]. The signing of the ESA PECS charter by the Republic of Bulgaria is a prerequisite for developing an appropriate strategic framework such as the National Space Program. It will provide a basis for future progress in the Bulgarian space sector, focusing on its space activities and decision-making for participation in European and international projects. The program should stimulate further close cooperation between academia, business, and industry, contribute to developing their capacity and increase the return on public investment in the space sector. Through which the main actors can synchronize their activities for more effective implementation of the tasks of national and European nature, a specific mechanism should refer to the new Space Strategy of Europe 2021[66] and the new industrial strategy for Europe 2020[67]. In the coming decades, strong international cooperation and the active participation of Bulgarian state institutions, academia, industry, non-governmental organizations, and society should play a significant role in the country's sustainable development in the changing environment.

Note from authors: All links provided in this text have been accessed and are working on the day of publishing this article.

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[65] https://www.consilium.europa.eu/en/policies/eu-space-programme
[66] https://data.consilium.europa.eu/doc/document/ST-13758-2016-INIT/en/pdf
[67] https://ec.europa.eu/growth/industry/policy_en

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ARISS PROGRAM:
HELLO ISS! SPACE CREW ZMAJEVCI IS CALLING!

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Abstract: The ARISS (Amateur radio-station on the ISS) educational program is aimed to inspire, educate, and boost the interest of young people worldwide for science and technology. This paper is to present *To the Moon and Back*, project delivered by Primary School "Jovan Jovanović Zmaj" from Sremska Mitrovica, Serbia and the ARISS.

Keywords: ARISS, ISS, *To the Moon and Back Project*

"This was unbelievable! I cannot believe I have just spoken with an astronaut from outer space! One of the best experiences in my life!"
Dositej Čulić, age 15

1. "TO THE MOON AND BACK" PROJECT

Primary School "Jovan Jovanović Zmaj" from Sremska Mitrovica, Serbia was a part of the ARISS educational program for the 2019/20 school year with a project *To the Moon and Back* [1]. The project partner was the Amateur radio-station Novi Sad, YU7BPQ. Being an entire school project, it embraced the pupils from the first to the eighth grade (7 to 15 years of age) who had a chance to learn about the space during their regular lessons or in after-school clubs. The aim was to explore the universe through both social and natural sciences while using different learning and teaching approaches such as STEM, NTC or CLIL.

The warm-up activity was to install the Solar system model[2] in the school corridor by the Art teacher, Vojislav Krstić (Figure 1).

The actual project activities started with the World Space Week where the Solar System theme was introduced to the first to fourth grade pupils.

The first graders modelled the system at Art classes.

[1] https://www.youtube.com/watch?v=4x9efUACPcY&t=38s&ab_channel=JovanJovanovicZmaj
[2] http://zmajsm.edu.rs/wp/sneak-peak-into-a-new-adventure

Figure 1: The Solar System model at Primary School “Jovan Jovnović Zmaj“.

The second graders had the themed costume party[3] and were delegated to present the space to their schoolmates through peer learning.

The third graders used the NTC method to connect the Planets with their Greek and Roman names while competing on a tournament.

The fourth graders connected the space with the primary colours and put up an exhibition. All of them sang the “Zoom, zoom we are going to the Moon” song, played memory games, crossword puzzles and jumbled letters at their English classes.

The fifth to eighth graders had their Little Astronomers after-school club where they looked deeper into the live streaming on the ISS, used ISS Live Now and My Simple Show, made videos about their findings.

The sixth graders explored the planets while the seventh and eighth graders dealt with the Moon landing while preparing themselves for the peer workshops about the conspiracy theories of the same with their Serbian teacher.

The bilingual sixth to eighth graders surfed through the world stage music to find the song with space words and posted them on the online board. The project logo was elected (Figure 2) and we were just getting started.

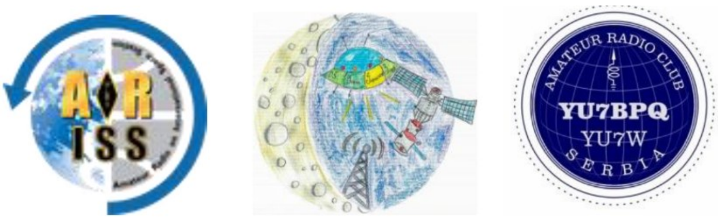

Figure 2: ARISS Logo, *To the Moon and Back* Project logo and Amateur radio-station Novi Sad logo.

For the next two months, there were so many activities. There was a Maths lesson with big numbers using planets and their distance from the Sun. Using the CLIL method, they figured out their Maths problems in English (fourth grade). The fifth graders used shapes from mathematics and created space craft in their Art classes

[3] https://022tothemoonandback.zmajsm.edu.rs/2019/10/09/space-crew-zmajevci/

embracing arts and mathematics. There was an astronomy retrospective throughout history and so on. Each and every class worked on their own pace and according to their abilities. December was reserved for gathering questions for the astronauts. A box was placed at the hall and 20 questions were selected by the Students' Parliament. Even the guide signs for our school visitors were planets[4]!

Throughout this period, the Amateur radio-club Novi Sad placed the antenna and checked their equipment. The pupils had their crash course in radio transmission and heard the radio statics for the first time being the Z generation. They delivered a huge job! We could not have made it without their enthusiasm and help. ARISS gave us the mentor, Armand, who followed our preparations all the way.

2. WE'VE DONE IT!

Being experienced in former projects, we were convinced we were going to deliver it, but we saw some drawbacks right from the start.

No primary school from Serbia has ever done such thing and we were wondering why, though the list of schools waiting for the project approval worldwide is endless. Then, we could not find any radio club to help us. By pure chance we finally reached Novi Sad and it was a sigh of relief. Thirdly, there are only a few windows to apply with educational project proposals and so many schools who wanted in. Another sigh of relief was when we finally got a go.

Then everything went well until the big day, the actual contact with the ISS. **It took place on the 28th of January 2020 at 4.30 GMT.**[5]

The audience was gathering at the smaller hall while the rest of the visitors and pupils had live feed at another school premises. We streamed live on You Tube. The media coverage[6] was also amazing for a small- town school. All 20 questions were answered in due time and all of us - students, teachers, and visitors - had a lifetime experience.

Following the school contact with ISS was the night sky watching[7] with the help of Faculty of Sciences, Novi Sad and "Vobanista" project members. It was planned for the project to continue until June 2020. Alas, Covid-19 emerged.

3. CONCLUSION

Participating in the ARISS project the school had the opportunity to boost pupils' interest in new explorations in science through various activities. The thrill and excitement after the contact was, and still is, a sure sign that teaching and learning should come out of the box/classroom where the board and markers - even computers - are the main teaching tools. Not less beneficial was the school visibility and the gained experience which could lead us to yet another interesting project.

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[4] https://022tothemoonandback.zmajsm.edu.rs/2020/01/27/space-crew-zmajevci-2/

[5] https://022tothemoonandback.zmajsm.edu.rs/2020/01/28/weve-done-it/

[6] https://022tothemoonandback.zmajsm.edu.rs/2020/01/31/others-about-our-space-project/

[7] http://radioactivedragons.com/mali-astronomi/

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ASTER: DEVELOPING A FREE FALLING PLATFORM FOR ATTITUDE CONTROLLED EXPERIMENTS

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Abstract: The verification of a spacecraft component's functionality under microgravity conditions is an important topic for the low-cost development of CubeSat components. The testing and verification of new components is often carried out on technological demonstration missions. To reduce the cost and time required, the verification process can also be undertaken on sounding rockets. To achieve best microgravity conditions, a testing platform must be entirely stabilised. Most sounding rockets are spin stabilised and, therefore, a centrifugal force acting upon the components remains. This force can be eliminated by ejecting the testing platform on a fully stabilised Free Falling Unit. Available attitude control systems are targeted at orbital flights, and therefore act slowly. Such systems measure their attitude control manoeuvres in significantly longer times, which is suboptimal as experiments conducted on Free Falling Units are highly constrained by flight time. Taking these requirements into account, the objective of Project ASTER is to design and test a low-cost, fast acting solution, to stabilise and orientate a free-falling platform in a reduced gravity environment. The results of the project will be published as open source to ensure its future availability to student and low budget research projects.

Keywords: Attitude Control, Attitude Stabilisation, Free Falling Unit, REXUS/BEXUS, Microgravity Experiment

1. INTRODUCTION

In recent years, the amount of space related activities has been constantly increasing. This can be partially attributed to improvements in technology, resulting in the budgetary requirements of such missions to also decrease along with external support therefor. This has subsequently allowed for projects to be undertaken by teams and organisations which would usually not have been able to pursue such opportunities. The complexity of these projects has however not decreased and continues to be a hinderance for many of these aspiring projects (see Berk et al. 2013, Cho 2020, Dubourg et al. 2006, Schmierer et al. 2019).

The Attitude Control System (ACS) of a spacecraft is often one of the most intricate subsystems, requiring significant resources to develop and integrate. As such, this still presents a significant barrier, preventing potential experiments from being pursued by smaller teams (Fasoulas et al. 2017).

ACSs that are currently on the market are mostly targeted at orbital vehicles, which allow slow-operating solutions due to their inherent nature of returning to the same orientation each orbit. Consequently, such systems typically measure their attitude control manoeuvres in much larger timeframes (Cordeau & Laporte 2004). However, experiments conducted on sounding rockets, including those ejected as a Free Falling Unit (FFU), are usually highly constrained by their flight time. Thus, these experiments require a high-performance solution for them to perform desirably in their expedited experiment timeline. Furthermore, current ACSs are usually aimed at projects with extensive funding, ruling out a large portion of student and low-budget experiments, which operate on a limited budget. Therefore, a high performing, low-cost ACS would greatly benefit future sounding rocket experiments with suitable stabilisation and pointing needs.

Project ASTER is a student project which began in the autumn of 2019 at the Luleå University of Technology's Space Campus in Kiruna, Sweden. The project is comprised of Master's students on the various Space engineering programs that are offered by the University. The ASTER mission is undertaken as part of the REXUS/BEXUS (Rocket and Balloon Experiment for University Students) programme which aims to demonstrate a high-performance, low-cost, compact, and easy to integrate ACS platform for FFUs, to be ejected from sounding rockets, and aims to launch in March 2022. It shall be capable of stabilising a FFU after ejection and subsequently performing slewing manoeuvres by means of three reaction wheels. The performance of the ACS will be recorded throughout the mission and will later be analysed to compare the expected performance with the flight data. The developed platform should allow for follow-on missions requiring attitude stabilization, to be easily integrated on the FFU, allowing such missions to concentrate on the experimental payload instead of the ACS. For this reason, the design and findings will be published as an open-source design upon completion, to aid any future experiments.

The REXUS/BEXUS programme is performed under a bilateral Agency Agreement between the *Deutsches Zentrum für Luft und Raumfahrt*[1] (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). Experts from DLR, Swedish Space Corporation (SSC), *Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation* (ZARM)[2], and ESA provide technical support to the student teams throughout the project, to ensure its success. EuroLaunch, the cooperation between the Esrange Space Centre of SSC and the Mobile Rocket Base

[1] The German Aerospace Centre
[2] Centre of Applied Space Technology and Microgravity

(MORABA) of the DLR, is responsible for the campaign management and operations of the launch vehicles[3].

2. EXPERIMENT DESCRIPTION

The ASTER experiment is comprised of three main segments: Free Falling Unit, Rocket Mounted Unit (RMU), and Ground Station (GS).

The main part of the experiment is carried by the FFU. Inside the rocket, the RMU secures the FFU during as-cent and ensures the safe ejection. Additionally, it provides the electrical and communication interfaces to the REXUS Service Module (RXSM). The Ground Station includes the necessary equipment to communicate with the FFU throughout the whole mission profile and to successfully recover the experiment.

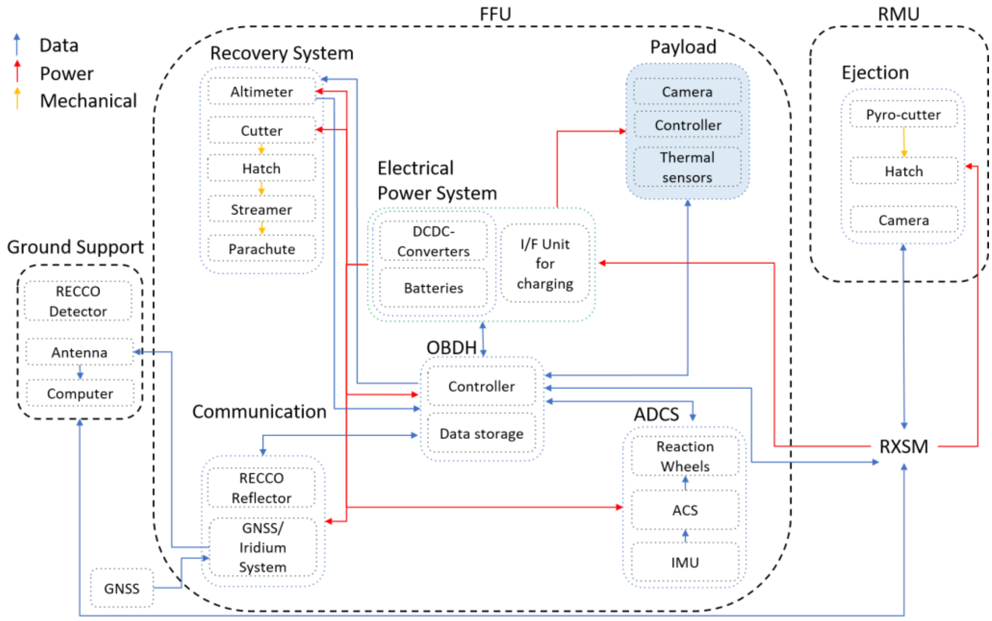

Figure 1: Overview of the Experiment's Functional and Physical Concept

Only the RMU is a subsystem by its own. The Ground Station and FFU are further separated into different subsystems. The Attitude Determination and Control System (ADCS) is the subsystem that defines the success of the mission, as it is responsible for the stabilisation of the FFU and its slewing manoeuvres. The other subsystems are the Electrical Power System (EPS), On-Board Data Handling (OBDH), Communication, Structure, Thermal and Recovery. The payload subsystems act as a demonstrator for future missions and for the verification of the system performance. In our case, it consists of a RaspberryPi Zero and a RaspberryPi fish-eye camera. The block diagram in Figure 1 shows an overview of

[3] Guidelines for Student Experiment Documentation, REXUS/BEXUS Organisers, 2018

the functional and physical concept of the experiment. It displays the three main segments of the experiment and the applicable power and data flows between them.

The FFU is defined as stable if the absolute angular velocity is less than $1°s^{-1}$ with a steady state tolerance of ±10°, while a successful slewing manoeuvre will have an accuracy of ≤10°. These values were determined analytically and are based on the available components and the performance values that can be guaranteed. Three primary and three secondary objectives are defined for the experiment:

1. Develop an attitude controlled FFU to be ejected from a sounding rocket.
2. Demonstrate that the ADCS can stabilise the FFU.
3. Recover the system after the experiment has been concluded and the FFU has landed.
4. Demonstrate that the ADCS can perform slewing manoeuvres of the FFU with the desired accuracy.
5. Design an FFU which can accommodate payloads of future experiments.
6. Design and build an FFU, including the ADCS, that is easy to integrate with future experiments.

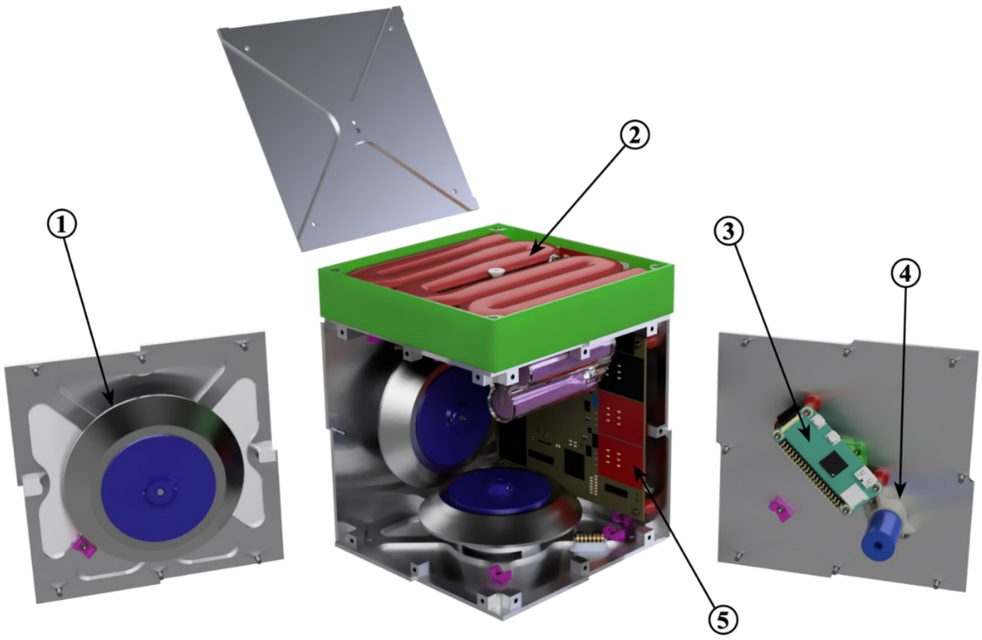

Figure 2: Open View of the Free Falling Unit: 1 – Reaction Wheel, 2 – Parachute, 3 – Payload, 4 – Iridium Antenna, 5 – Main PCB.

Inside the REXUS rocket, the ASTER experiment is located directly underneath the nose cone in a 270 mm high module with a diameter of 350 mm. Three other experiments are accommodated in the rocket, μMoon above ASTER and IMFEX and B2D2 below. The FFU is comprised of a 150 mm cube with an additional 30 mm high recovery module which houses the streamer and the parachute. This configuration can be seen Figure 2. The mass of the FFU is expected to be around

3 kg which will result in a total experiment mass of 13.7 kg, including the module and RMU. The structural integrity of the FFU is provided by 6 5754 aluminium plates with a nominal thickness of 3 mm. Depending on the components mounted to each plate, different cut-outs with a depth of 2.5 mm were added for weight reduction.

2.1. ROCKET MOUNTED UNIT

The RMU is the mechanical and electrical interface between the FFU and the REXUS rocket. The primary task of the RMU is the housing and ejection of the FFU prior to reaching the apogee of the trajectory. The retention mechanism keeps the hatch and FFU in the module via three steel cables. At ejection, four pyro-cutters are activated by the RXSM, which will cut both steel cables holding the hatch, with two pyros cutting each cable to ensure the uniform release of the hatch.

Subsequently, a fifth pyro-cutter separates the retention cable attached to the FFU and a spring ejects the FFU with a velocity of around 1.5 m/s, and a maximum tumbling rate of 0.08 Hz (which is the angular velocity of the de-spun rocket). During the ascent of the rocket, the FFU is connected with the RXSM via pogo pins, which are also used to charge the batteries prior to launch. Once the pogo pins are disconnected during ejection, the free-falling phase begins where power is provided by the batteries. A camera, mounted behind the FFU within the RMU, will record and confirm the ejection process, transmitting a live feed to the Ground Station via the RXSM.

The mechanical design of the RMU is based on a heritage design from the previous REXUS mission Tupex-6 (Sullivan et al. 2018), which was a pico-satellite experiment from the *Technische Universität Berlin* that was launched in March 2019. A render of the module with a removed hatch and the RMU inside can be seen in Figure 3.

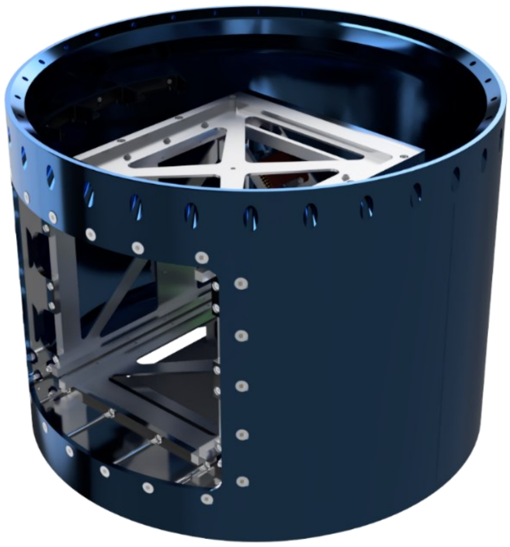

Figure 3: The Rocket Mounted Unit, without the Hatch.

2.2. ATTITUDE DETERMINATION AND CONTROL SYSTEM

This core subsystem of the ASTER experiment can be divided into three parts: the Attitude Determination System (ADS), the ACS and the Reaction Wheels.

The ADS utilises two 9-axis Inertial Measurement Units (IMUs) manufactured by Bosch. These sensors have already been used and tested by MIRKA2-RX (Ehresmann et al. 2016) a previous REXUS experiment of the *Universität Stuttgart*, Germany, which flew in 2016. The block diagram of the electronics design of the ADS is shown in Figure 4.

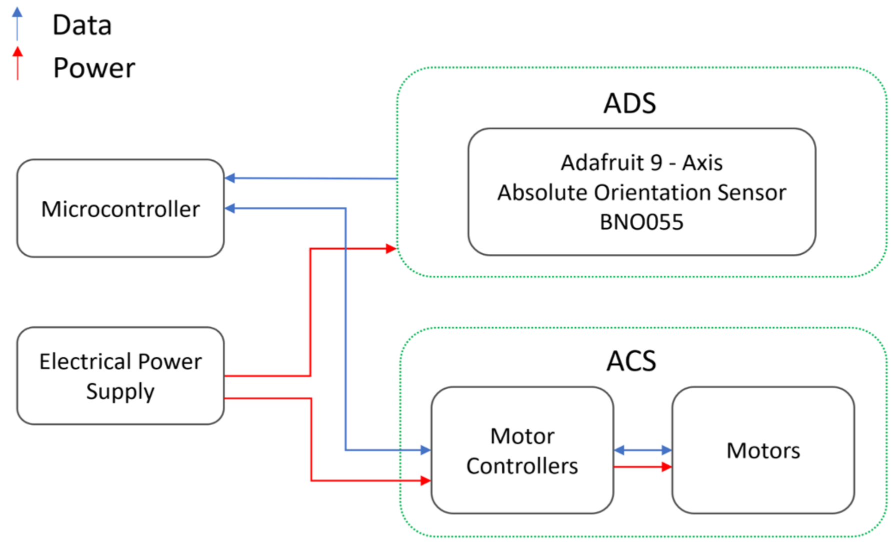

Figure 4: Schematics of the Attitude Determination and Control System Electronic Design.

The IMUs calculate the attitude expressing them as quaternions, which are subsequently used for system verification after flight with all measurements being saved on-board, on redundant SD cards for post-flight analysis of the FFU's behaviour. Since it was not possible to verify the functionality of the IMUs fusion algorithm in reduced gravity, the attitude will not be used for the system's ACS. Nevertheless, the attitude and all other IMU measurements will be logged and analysed after flight to learn more about the inflight behaviour. In combination with the payload camera data, it will be attempted to verify IMU's attitude determination for future uses. Only the gyroscope measurements will be used as input for the ACS control loop. A microcontroller calculates the necessary rotational velocity for the reaction wheels to stabilise the FFU or perform slewing manoeuvres. Different operational modes for different mission phases are utilised by the ACS. This modular approach allows a step-by-step integration and verification of the functionalities and therefore a more rapid development as concurrent engineering techniques are utilised. The different modes are summarised in Table 1. The control parameter's values are obtained through simulations and the tuning of the actual system during the testing process.

Table 1: Attitude Control Modes

Mode	Definition
OFF	Attitude- and angular velocity signal is measured but no signal is sent to the motor controller.
PASSIVE – Constant RPM	Attitude signal is measured but has no effect on control signal. The motor is run at a constant RPM for which a signal is sent to the motor controller
PASSIVE – RPM Sequence	The motor RPM is changed according to a timing sequence. Attitude signal is measured but not used.
ACTIVE – Stability Control	The angular velocity signal is fed to the inner P-controller which produces an angular acceleration. The system will aim to stabilise and achieve zero angular velocity.
ACTIVE – Stability Control with Slewing Manoeuvre	The slewing manoeuvre can start after the stability controller has de-tumbled the FFU. Angular velocity controller setpoint is adjusted to achieve a relative rotation of a certain angle and direction from the current attitude of the FFU.

The three identical Reaction Wheel setups are designed by team ASTER. They consist of the motor, mounting bracket and rotor. Two roller bearings protect the motor axis during launch from the high radial loads. The steel rotor is connected to the motor axis via a 3D printed disc, glued to the front face of the rotor, and two grub-screws. Table 2 gives the rotor properties, while Figure 5 shows an exploded view of the reaction wheel setup. The motor is an EC45 flat brushless DC motor from Maxon with a maximum power of 30 W.

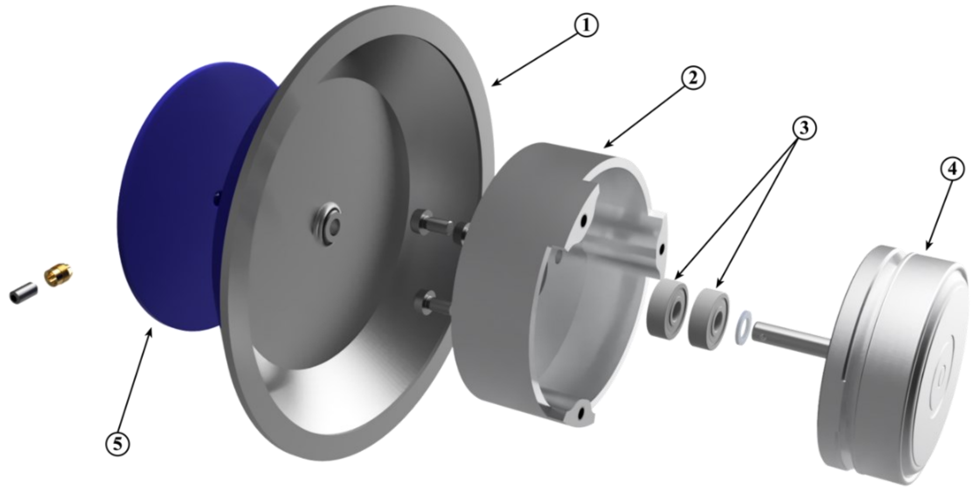

Figure 5: Exploded View of the Reaction Wheel Assembly: 1 – Rotor, 2 – Mounting Bracket, 3 – Bearings, 4 – Motor, 5 – Adapter Disk

Table 2: Rotor Properties

Property	Value
Mass	0.232 kg
Axial inertial moment	$3.841 \cdot 10^{-4}$ kgm^2
Planar inertial moment	$1.972 \cdot 10^{-4}$ kgm^2
Eigenfrequency, first mode	229.4 Hz

2.3. RECOVERY & COMMUNICATION

The purpose of the recovery subsystem along with the communication subsystem is to ensure a safe landing and retrieval of the FFU after completion of the mission. The three main parts are: the parachute, the top plate ejection system, and the communication system.

During descent, the recovery system will be triggered by a signal from an altimeter when the FFU approaches an altitude of 6 km. A secondary trigger is provided by a Global Navigation Satellite System (GNSS) altitude reading of 5.5 km and a tertiary by a timer, set to expire at around 5 km. When this system is activated, a pyro-cutter is used to cut a cord fixed to the retention bracket, releasing the top plate of the recovery compartment. A spark cover protects the electronics inside the FFU from any potential damage which may occur during the firing of the pyro-cuter. The top plate is preloaded using springs, and when ejected exposes the parachute and the streamer to free air. The recovery compartment and its main parts are shown in Figure 6. Once the parachute is completely deployed, the descent velocity of the FFU will be decreased to a velocity of less than 8 ms^{-1}.

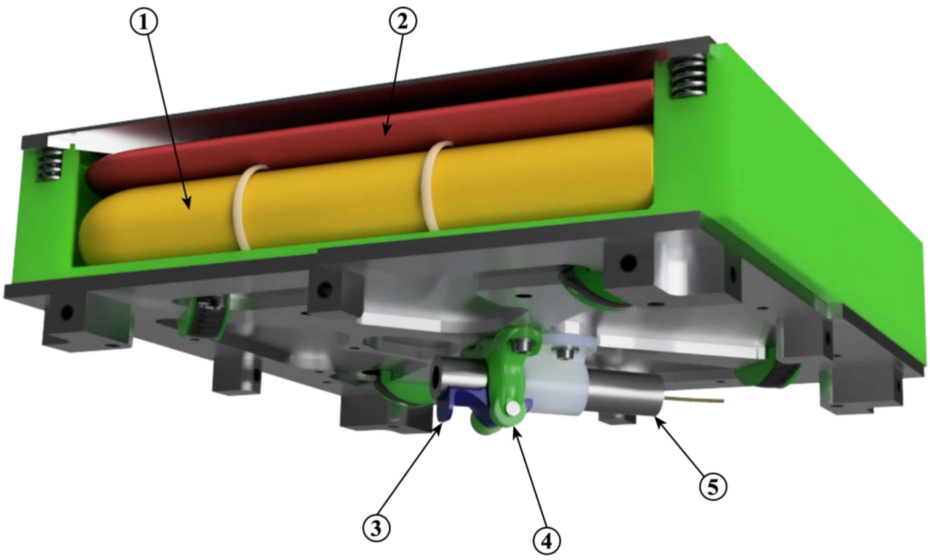

Figure 6: Recovery Compartment: 1 – Parachute, 2 – Streamer, 3 – Spark Cover, 4 – Retention Bracket, 5 – Pyro Cutter

The location of the FFU during the descent is determined using the GNSS data. This location data is then transmitted via the Iridium satellite network to the GS. Measurement data from the IMU will be used for landing confirmation. The location data will continue to be transmitted for around 2 h after landing, and afterwards the communication system will be powered down. This time frame is limited by the battery capacity but is sufficient to validate the final location of the FFU, to ensure it is not being moved by external factors such as wind dragging by the parachute.

Furthermore, the parachute and streamer will be equipped with RECCO reflectors, which are normally used in avalanche rescue operations, to allow the recovery team with its corresponding detectors, to precisely locate the FFU upon arrival in the landing area that is indicated by the transmitted location data.

Along with the location information, attitude and other platform data is sent periodically to the GS to allow basic monitoring during the mission and to provide the team with minimum data in case of a failed recovery.

2.4. ELECTRICAL POWER SYSTEM

The power requirements for the experiment are shared by the RXSM and the internal batteries on-board the FFU, with the source depending on the stage of the experiment. The OBDH system and a MOSFET control the switching between these two sources. The EPS setup is shown in the block diagram in Figure 7.

This switching capability will also be used to comply with the radio silence and payload-off states requirements stipulated by the REXUS/BEXUS programme. This ensures that the ESU and the FFU are switched off during the launch phase using a signal from the On-Board Computer (OBC). After those states are over, external power will be used to turn the microcontroller on again.

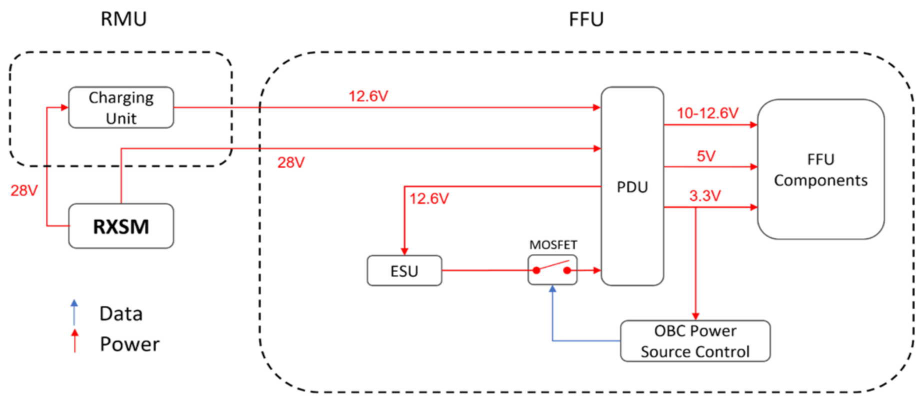

Figure 7: EPS Block Diagram

The internal power is provided by the Energy Storage Unit (ESU). Three Lithium-ion batteries are connected in series and placed within a separate 3D printed compartment in the FFU. Each battery has a nominal voltage of 3.7V and a capacity of 2600mAh. This configuration provides a nominal voltage of 11.1V, which is within the power supply range of the motor controllers, and, therefore, allows to directly supply the voltage from the ESU to the motor controllers.

In order to activate the system on-board the FFU, an external power supply will be required, which prevents any loss of power during transport. Prior to ejection, the RXSM will provide the power to spin up the reaction wheels and the ESU will receive a top-up charge.

Since the power supply to the recovery system is essential for the success of the experiment, a stop-power command from the OBC is implemented for the other subsystems after landing, thereby ensuring that enough power capacity is reserved to power the recovery system for the required period of time.

The Power Distribution Unit (PDU) uses three lines to distribute the power at the required voltages to all the components and to switch between power sources. Using DC-DC converters, the power provided by the ESU, as well as the external power, are converted to 3.3V and 5V. The total power required by the FFU is approximately 14Wh, which is provided by the ESU. An additional 5Wh margin is reserved for the payload. Figure 8 shows the power consumption profile of the FFU over the complete mission phase.

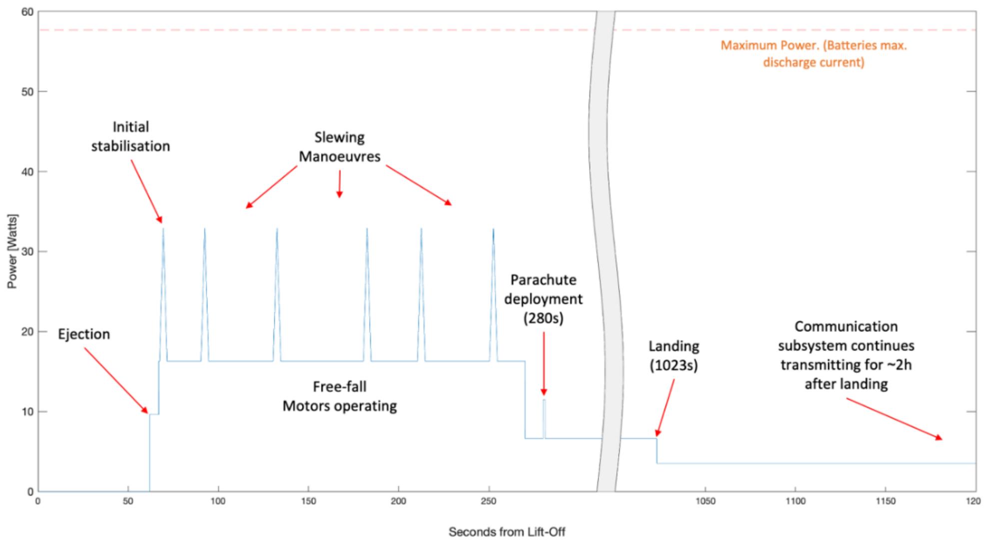

Figure 8: Power Consumption Diagram

2.5. THERMAL SUBSYSTEM

The experiment is expected to experience a broad environmental thermal profile, ranging from +50 °C inside the rocket to -30 °C after landing. These conditions need to be considered as they present a significant challenge to the nominal functionality of the experiment.

The environment is however not the only source of thermal disturbance, with the batteries and reaction wheel motors being identified as the largest thermal disturbances. The batteries generate a significant amount of heat during discharge, which is why the battery compartment consist of an insulated enclosure, shielding the rest of the FFU from the potential heat source. This is additionally done to protect the batteries from the sub-zero temperatures experienced after landing which may reduce the battery capacity, resulting in the FFU potentially not being able to transmit its location for recovery. The motors of the reaction wheels also prove a significant heat source due to their performance and high RPM use. To negate this and prevent overheating, the motors are positioned with the stator housing against the mounting bracket which subsequently act as heat bridges to dissipate the resulting heat to the FFU wall plate.

In order to ensure that the experiment functions as intended when being influenced by the various heat sources and the environment, extensive verification will need to be performed. This includes analytical testing methods such as performing a Finite Element Analysis (FEA) to obtain a model of the thermal distribution, and extends to subsystem, and subsequently system level tests of the experiment in nominal and sub-zero temperatures. An example is shown Figure 9. To obtain a comprehensive overview of the internal temperature distribution, six temperature sensors will be placed throughout the FFU which continuously take measurements. These sensors will additionally be used to provide the temperature profile of the actual mission for the post-flight analysis. This will all be done to verify the experiment and to qualify it for flight on board the REXUS rocket.

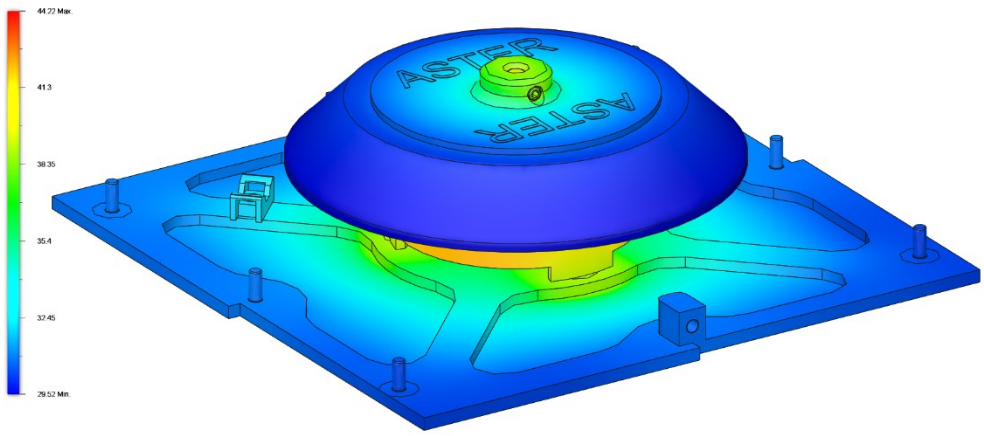

Figure 9: FEA of Reaction wheel showing temperature distribution.

2.6. ON-BOARD SOFTWARE

After launch, the experiment will operate in a fully autonomous manner. The on-board software is therefore responsible for ensuring continued operations of the various subsystems throughout the duration of the entire mission. Additionally, the system needs to be capable of maintaining operations even when confronted with non-nominal conditions and resolving such scenarios as they arise.

To fulfil these tasks the STM microcontroller which acts as the on-board computer, will run the real-time operating system FreeRTOS, with all the on-board software written in C. This allows the system to operate with defined runtimes while ensuring that the system can handle all system interrupts and tasks in time. Furthermore, the on-board software is responsible for maintaining communication with the ground and enables the experiment to respond to telecommands prior to launch. Prior to ejection, the information is transmitted to the Ground Station via the RXSM, whereas after ejection, it is transmitted via the Iridium Satellite network. A copy of all measurement and system data is stored on-board using two redundant SD cards for subsequent analysis following recovery.

For extended functionalities during integration, testing, and verification a test jumper pin is integrated in the system. If this jumper is recognized by the software, it will have more functionalities and more data is available via telemetry. To ensure functionality during flight this jumper is removed and only required commands and telemetry are available.

2.7. GROUND SUPPORT SOFTWARE

The Ground Support Software consists of two components, which are the Ground Station software and the Test Environment Software. During the initial phases following the launch, the Ground Station Software will receive information from the RXSM via the REXUS downlink. Following ejection of the FFU, this information will be transmitted via the Iridium network. The Ground Station Software will be developed by the team through the help of tolls such as Grafana and will be able to decode and display the incoming data in real-time.

The Test Environment Software will be used to test and analyse the system during the testing phase and will be able to send commands and initial test conditions to the FFU while simultaneously receiving measurement data from the on-board sensors. This will allow for any issues that may arise to be identified, rectified, and will permit fine tuning of system parameters such as the controller values in the ADCS.

3. TIMELINE

Through the REXUS/BEXUS programme, students experience all the phases of a space project. Additionally, they are introduced to the redaction of proposals and documentation, as before each review, the teams must submit an updated version of their documentation, the so-called Student Experiment Documentation (SED).

After the acceptance of the project in November 2019, team ASTER successfully passed the Preliminary De-sign Review (PDR) in February 2020. This first review took place during the Student Training Week at the Esrange Space Centre in Kiruna, Sweden, where all the teams participated in workshops and received input from various experts on the projects. The final design of the experiment was approved at the Critical Design Review (CDR) in June 2020. At the end of August 2020, an expert from the REXUS/BEXUS committee visited the team in Kiruna for the Integration Progress Review (IPR) which prompted the approval of all changes pro-posed since CDR.

Due to the COVID-19 situation, the whole REXUS/BEXUS cycle 13 was delayed by a year, including the relevant reviews. The Experiment Acceptance Review (EAR) will now take place in September 2021, along with additional progress reviews happening throughout Q1 and Q2 of 2021, where REXUS/BEXUS experts will verify that the teams are progressing as intended. The integration week at the ZARM facilities in Bremen, Germany, consisting of ejection and vibration tests, will take place in December 2021, while the final tests will be run during the Bench Test week at DLR Oberpfaffenhofen, Germany in January 2022. At this point the project will be fully verified and no further modifications will be allowed.

The launch campaign will take place at the Esrange Space Centre in Kiruna, Sweden during March 2022. After the flight and recovery of the experiment, the team will be given two months to analyse the data and submit the final reports in June 2022, which consist primarily of the final version of the SED with its findings. Figure 10 shows the updated timeline of the project with the key milestones.

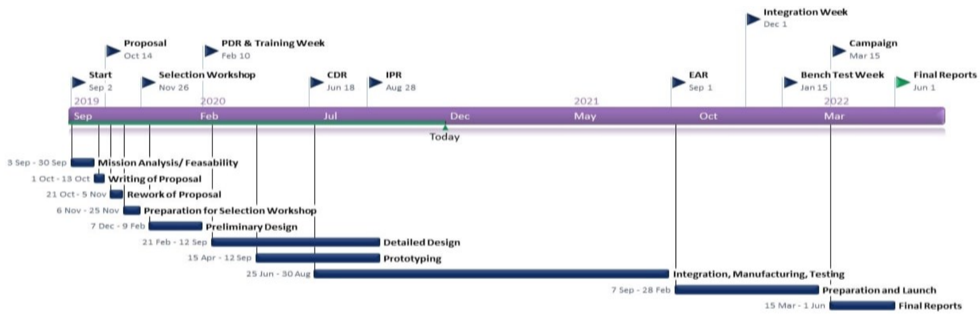

Figure 10: Project Time Schedule

4. CONCLUSION

Having received the bulk of our components, assembly, integration, and testing will become our main priority. The manufactured FFU and RMU as well as the experiment module can be seen in Figure 11. Most of the system verification should be concluded at the end of February and we will have our internal EAR.

The project is therefore well on its way towards being completed in early 2021. The COVID-19 health crisis has resulted in a significant delay of the project and launch schedule, but the team is confident in the given launch timeframe in March 2022 and that the project will be fully verified for its flight by then. The launch will mark the end of the development and testing period and the team will thenceforth focus on the analysis of the gathered data to verify whether all mission objectives were met, and to ultimately validate whether the ASTER platform proves a suitable platform for future free-falling experiments.

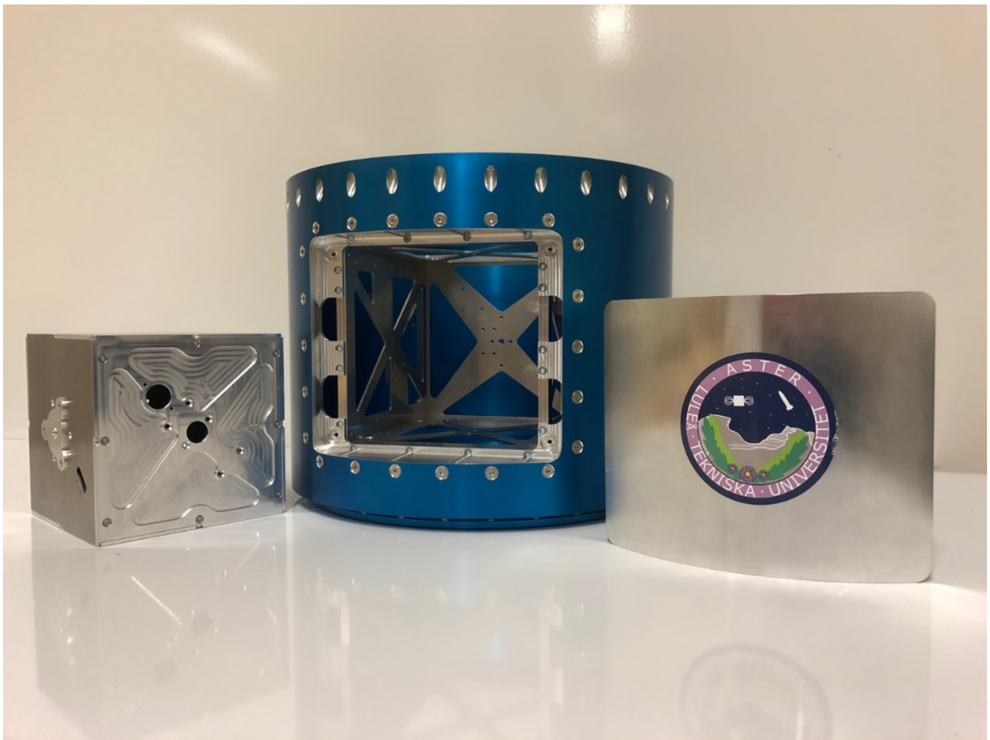

Figure 11: The FFU and the RMU inside the Experiment Module.

Project ASTER is looking forward to contributing to the space sector in the near future, by implementing a fast acting, low-cost and easy to integrate attitude control platform. This will be a viable solution for a variety of different applications and will aid future experiments in their endeavours to perform true microgravity experiments.

Acknowledgements

We would like to acknowledge and thank the various organisation which have afforded us this opportunity to pursue this project. Firstly, we would like to thank the REXUS/BEXUS organisation, which consists of experts from the DLR, SSC, ZARM and ESA, providing technical support to the student teams throughout the duration of the project. Additionally, we would like to thank EuroLaunch, the cooperation between the Esrange Space Center of the SSC and MORABA, who are responsible for the campaign management and operations of the various launch vehicles.

We would also like to thank our endorsing professor at the Luleå University of Technology, Professor Thomas Kuhn, alongside the other members of staff who are providing us with invaluable advice and guidance, namely: Olle Persson, René Laufer, Élcio Jeronimo de Oliveira, Anita Enmark, Chris Nieto, Siiri Talvistu, and Diego Oc-tavio Talavera Maya.

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Posters

Publ. Astron. Obs. Belgrade No. 101 (2021), 191 *Poster*

THE ROLE OF NON-GOVERNMENTAL ACTORS IN SHAPING SPACE LAW: AN EXAMINATION IN THE LIGHT OF PROPOSED LEGAL FRAMEWORKS ON SPACE MINING

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Abstract: In the classical structure of International Law, States were the main actors for the law-making process and the implementation of international law. Through years non-governmental actors specifically non-governmental organizations have started to engage with international matters such as the drafting of an international treaty; they participate in the activities of the human rights' supervisory bodies, as well as cooperate with international organizations, to influence their decision making.

At the international level, the United Nations (UN) has been the pioneer organization in cooperation with the non-state actors. This policy of the UN is also reflected in the UN Committee on the Peaceful Use of Outer Space (UNCOPOUS), and now more than 40 non-governmental actors are granted the observatory status before the Committee.

As an example of the role of non-state actors in shaping space law, I will especially focus on the activities of the non-governmental organizations and non-governmental initiatives, which work on the legal framework, principles, and recommendations concerning the designation of international principles regarding the management of space resources/space mining. Even though these documents are not binding, they are presented to civil society as well as to the UNCOPOUS to encourage the discussions on a future legal instrument concerning the matter.

Consequently, giving a floor to the non-state actors at the meetings of the Sub-Committees and the Committee reveals their contribution to shaping space law, since the Committee has a vital role in the creation of international rules and guidelines on space activities.

Presentation link: https://www.youtube.com/watch?v=nbLZZQS2otU

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THE FUNCTIONAL RELATION BETWEEN MEAN MOTION RESONANCES AND YARKOVSKY FORCE ON SMALL ECCENTRICITIES

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Abstract: This work examines asteroid's motion with orbital eccentricity *e* in the range (0.1, 0.2) across the two-body mean motion resonance (MMR) with Jupiter due to the Yarkovsky effect. We calculated time delays d*tr* caused by the resonance on the mobility of an asteroid with the Yarkovsky drift speed. Our results considered only asteroids that successfully cross over the resonance without close encounters with planets. We found a functional relation that accurately describes dependence between the average time lead/lag d*tr*, the strength of the resonance (SR), and the semimajor axis drift speed d*a*/d*t* with asteroids' orbital eccentricities in the range (0.1, 0.2). We analysed average values of d*tr* using this functional relation comparing with obtained values of d*tr* from the numerical integrations, which were performed in an *ORBIT9* integrator with a very large number of test asteroids. We checked the validity of our previous functional relation, derived for asteroids' orbital eccentricities in the range (0, 0.1) (Figure 1), on the present results for eccentricities in the range (0.1, 0.2) (Figure 2). Also, we tried to find a unique functional relation for the whole interested interval of asteroids' orbital eccentricities (0, 0.2) and discussed it.

Keywords: asteroids, asteroid's motion, eccentricity, numerical integrations

1. RESULTS

Results for *e* in (0, 0.1), $i = 5°$ and $\omega = 60°$ according to equation:

$$\log_{10}(\langle \mathrm{d}\,tr \rangle) = \beta \log_{10}(SR) + \gamma \log_{10}\left(\frac{\mathrm{d}a}{\mathrm{d}t}\right) + c_2 \tag{1}$$

For all 11 MMRs:

$$\beta = 0.44 \pm 0.03, \qquad \gamma = -1.09 \pm 0.20, \qquad c_2 = 4.35 \pm 0.66\,.$$

For the strongest 6 MMRs:

$$\beta = 0.47 \pm 0.04, \qquad \gamma = -0.97 \pm 0.15, \qquad c_2 = 5.11 \pm 0.54\,.$$

So, the two set of parameters are statistically the same.

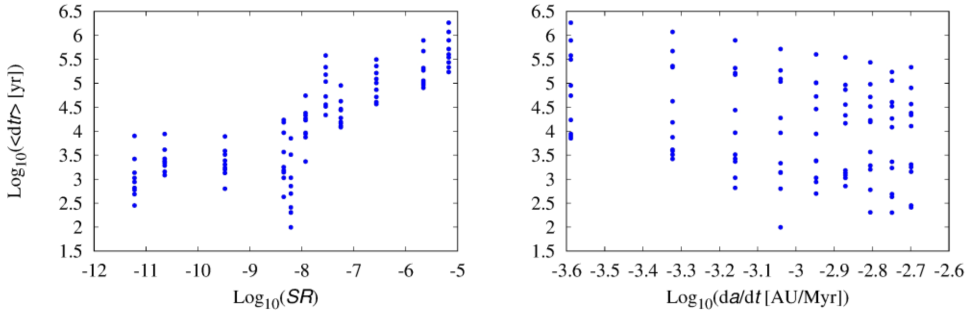

Figure 1: Results for e in (0, 0.1).

Results for e in (0.1, 0.2) according to equation:

$$\langle \mathrm{d}\,tr \rangle = (0.5 + \mathrm{d}a)\log_{10}(SR) + (\mathrm{d}b - 1.0)\log_{10}\left(\frac{\mathrm{d}a}{\mathrm{d}t}\right) + (\mathrm{d}c + 5.0) \qquad (2)$$

For the strongest 4 MMRs:

$$\mathrm{d}a = -1.62 \pm 0.31, \qquad \mathrm{d}b = 2.46 \pm 0.5, \qquad \mathrm{d}c = -5.94 \pm 2.02\,;$$

For the weakest 7 MMRs:

$$\mathrm{d}a = -0.47 \pm 0.03, \qquad \mathrm{d}b = 0.88 \pm 0.09, \qquad \mathrm{d}c = -5.14 \pm 0.32\,.$$

Obviously, two sets of coefficients $\{0.5 + \mathrm{d}a,\ \mathrm{d}b - 1.0\}$ are different in sign, because of different relations for two cases of the weakest and the strongest resonances.

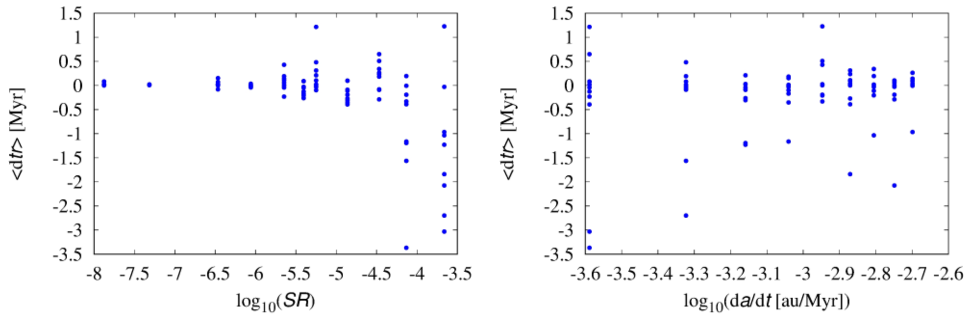

Figure 2: Results for e in (0.1, 0.2).

2. CONCLUSIONS

We presented a new description of the orbital behaviour of resonant asteroids under the influence of the Yarkovsky effect for eccentricity in the range (0, 0.2).

We derived and established Equation (1) that enables easy and fast calculation of the average time that an asteroid spent in a two-body MMR with known resonance's strength in $[6\times10^{-12}, 6.7\times10^{-6}]$ interval, with the Yarkovsky drift speed in $[2.6\times10^{-4}, 2\times10^{-3}]$ au/Myr interval and with an asteroid's orbital eccentricity in the range (0, 0.1).

We derived and established Equation (2) that enables easy and fast calculation of the average time that an asteroid spent in a two-body MMR with known resonance's strength in [1.3×10^{-8}, 2.2×10^{-4}] interval, with the Yarkovsky drift speed in [2.6×10^{-4}, 2×10^{-3}] au/Myr interval and with an asteroid's orbital eccentricity in the range (0.1, 0.2).

Moreover, Equation (1) and Equation (2) can be easily included in any Monte Carlo methods in order to follow the motion of asteroids across the mean motion resonances in the Main Belt.

Our future studies on the interaction between the mean motion resonances and the Yarkovsky drift speeds will include two-body MMRs with other planets, as well as three-body MMRs. Moreover, in future work, we plan to include asteroid's orbital inclination.

Acknowledgements

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INTERNATIONAL SPACE LAW AND THE PREVENTION OF WEAPONIZATION OF SPACE

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Abstract: The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (commonly referred to as the "Outer Space Treaty") have been successfully regulating the space activities of states for more than half a century. The treaty is a tremendous achievement of the international community reached in the challenging and complicated "Cold War" era. It sets up the principles of international space law such as the use of outer space for peaceful purposes and for the benefit of all countries, the prohibition of national appropriation of outer space and celestial bodies, the liability of states for damages, caused by their space objects, the special importance of astronauts as "envoys of mankind" etc. These timeless principles govern and must continue to govern space activities of states in the future. Their importance and relevance cannot be affected by the development of technology. However, some aspects of the Outer Space Treaty are subject to heated discussion and even concern not just in the academic circles, but also on governmental level. The lack of definition of outer space and article IV of the Outer Space Treaty are often recalled as the main causes of concern. This article will discuss these and other aspects of the Outer Space Treaty in their relationship with the prevention of militarization of outer space.

Keywords: space law, Outer Space Treaty, weaponization of space, space weapon, international security

1. INTRODUCTION

International space law is one of the newest branches of public international law. The reason for this is simple: until the second half of the XX century, outer space and celestial bodies were "reachable" to men only in the science fiction. But, as Konstantin Tsiolkovsky wrote: "At first there is always a thought, fantasy, fairy tale. They are necessarily followed by scientific calculation. And in the end, execution is crowned with thought" (Tsiolkovsky 1926). The launch by the USSR of the first artificial Earth satellite in 1957 was epochal event – for the first time in history outer space became a domain of human activity. The reaction to this historic event at the United Nations was immediate: just one year later, the UN General Assembly adopted Resolution 1348 (XIII) which established the UN Committee on the Peaceful Uses of Outer Space. The Committee was established as an ad hoc committee at first but received permanent status at the United Nations in 1959. In 1963 the UN General Assembly adopted the Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space. A few years later, in 1967, international space law received its "constitution" – the Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (hereinafter referred to as the Outer Space Treaty).

The above brief historical overview is used as article's introduction purposefully. In addition to acquainting the reader with space law history, it serves two purposes:

1. An illustration of the speed with which the international community has responded to the advent of the Space Age. International law in the 1960s and 1970s not only regulated the existing space activities of the states, but took a step forward and regulated space activities which were impossible at the time such as establishment of bases, installations, and fortifications on celestial bodies etc. The speed with which international law responded to the new realities in space in the 1960s and 1970s contrasts sharply with the almost complete lack of response to the changes that have occurred in the space sector since then.
2. Reading the brief history of international space law, a careful reader will notice that the latter to large extent "froze" in the 1970s, when the last significant international treaty in this area was adopted – The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (December 18, 1979). Other questions are also likely to arise, such as: what is the situation in space today, almost half a century later? How has technology evolved over the years? What are the opportunities for space exploration in the next 50 years, given the rapid development of technologies such as artificial intelligence and others? Can the legal framework of international space law from the 1960s and 1970s adequately respond to the new realities and challenges that we face today? And tomorrow?

Several such challenges could be named such as: the extraction of resources on celestial bodies; the growing problem with the so-called "space debris", the need for space traffic management, space situational awareness issues etc.

This article however focuses on another important issue which is becoming more relevant with the fast development of space technologies, namely: the prevention of militarization/weaponization of outer space.

In this regard, the article will firstly analyse the current and potential military uses of outer space, underlying the military significance of the latter as the "ultimate high ground". Secondly, the article will provide some terminological remarks on the concepts of militarization and weaponization of outer space in relation with the fundamental principle of using outer space for peaceful purposes.

The article will then analyse the capability of the Outer Space Treaty to prevent weaponization of space, criticizing the “black and white” approach on the matter. Finally, the article will analyse the possible future steps for strengthening the peaceful status of the “Final frontier”.

2. “THE ULTIMATE HIGH GROUND” – MILITARY IMPORTANCE OF OUTER SPACE

The importance of taking the higher position in battle has been recognized by military strategists from thousands of years – “All armies prefer high ground to low”, underlines Sun Tzu (2016) in the Art of War. Holding the high ground offers an elevated vantage point with a wide field of view, enabling surveillance of the surrounding landscape. For the bigger part of human history taking the higher ground required analyzing the geographical characteristics of the terrain. This situation did not change until the early XX century when the Wright brothers built and successfully tested the first heavier-than-air powered aircraft – the Wright Flyer, on December 17, 1903. Just 8 years later the first aerial bombardment was conducted by Giulio Gavotti in the Italo-Turkish War (1911-1912). Thus, the development of technology in the early XX century moved the high ground “higher” – to airspace. The situation changed again in the 1940s and 1950s when the development of ballistic missile technology allowed the building of missiles capable to reach outer space (the first such rockets arguably being the V-2 and R-7 Semyorka). So, technology had once again moved the high ground, this time to outer space. And since there is no domain “higher” than outer space, the latter is commonly referred to as “the ultimate high ground”.

From a historic perspective we can separate the military uses of outer space in two groups - “actual uses” and “potential uses”. We can also apply functional classification and group the military uses of outer space in three large groups:

- Informational (actual use);
- Navigational (actual use);
- Destructive (potential use).

2.1. INFORMATIONAL USES

Artificial satellites are used to gather as well as to exchange information. The major militaries in the world use communication satellites for sharing information. For example, the United States military used extensively communications satellites in their operations in the Balkans, Afghanistan, and other countries (Pike 2002, p. 615). Weather satellites provide cloud imagery and other specialized meteorological, oceanographic, land surface and space environmental data (Pike 2002, p. 621). Early-warning satellites provide information of ballistic missile launch. Ocean-surveillance satellites help identify naval units (Pike 2002, p. 623). Imagery-intelligence satellites provide the military with global situational awareness (Pike 2002, p. 625).

2.2. NAVIGATION

Navigation satellites provide information on geo-spatial positioning, but also are used for the so called “precision-guided munition”. Satellite-guided weapons are known for their extremely high accuracy and precision.

2.3. DESTRUCTIVE (DAMAGING) USES

When we talk about destructive (damaging) uses we mean placing of weapons in outer space which are capable to deactivate, damage or destroy targets in outer space or on Earth. Fortunately, outer space has never been used for such purposes and hopefully never will.

3. MILITARIZATION VS WEAPONIZATION OF OUTER SPACE. SOME TERMINOLOGICAL REMARKS IN THE LIGHT OF THE PRINCIPLE OF PEACEFUL USE OF THE OUTER SPACE

The space law literature distinguishes between the terms "peaceful purposes" and "use for peaceful purposes" (Zhukov & Abashidze 2020, p. 216). If the principle of peaceful use of outer space is established, any military use of outer space will be banned. There are currently two main interpretations of the principle of using space for peaceful purposes. One means "non-military use" and the other "non-aggressive use". In the light of the two interpretations described above, there are two terms describing the use of the outer space by the military: "militarization of space" and "weaponization of space" (Yun & Shengli 2019). "Militarization" refers to the use of outer space for military purposes. This is the broader of the two concepts and encompasses all activities in outer space which have significance for the military. In other words, if the activity provides certain military advantage, not only during an armed conflict, but also in peaceful times – such activity must be considered as military use of outer space (militarization of space). As it was briefly described in section 2.1. and 2.2. of this article such activities usually imply the use of reconnaissance and navigation satellites. In the literature has been emphasized that space has been militarized from the very beginning of its active exploration by men. "Weaponization" on the other hand has a much narrower meaning – it means the placement of weapons in outer space. In the second, narrower sense, the outer space has not yet been used.

4. IS THE OUTER SPACE TREATY CAPABLE TO PREVENT WEAPONIZATION OF SPACE?

The question whether the 1967 Outer Space Treaty is relevant and effective in the XXI century is causing heated discussion in the academic circles. Seems that most opinions are poles apart from each other.

One thesis is that the Outer Space Treaty provides good regulation which is successfully governing the space activities of states long enough to prove its efficacy. According to this opinion the discussions for strengthening the Treaty's regime are counterproductive and dangerous as they could lead to undermining the core principles of international space law.

The other thesis is that the Outer Space Treaty is outdated, inadequate and obsolete in the light of the tremendous development of the technology. The proponents of this thesis contend that a newer and better regulation of the outer space must be adopted.

Both groups of opinions have strong and weak points. However, their main weakness is their over-simplistic approach to extremely complicated issues. The regulation of space activities is by itself a very hard task, which is further complicated by politics, new developments in technology etc.

In this regard I will make couple of remarks:

- The Outer Space Treaty was adopted in the challenging times of the Cold War era. It was negotiated between the two main rivals at the world stage at the time – the United States of America and the Soviet Union. Both sides had to agree to compromise in the name of the peaceful exploration of space. The Outer Space Treaty was a tremendous achievement.
- The Outer Space Treaty sets the principles of international space law such as the peaceful use of outer space, the prohibition for national appropriation of outer space and celestial bodies, the liability of states for damages caused by their space objects etc. These principles are timeless and are not affected by the development of technology or new realities in global politics. Stepping back from those principles would be very dangerous and counterproductive.
- The Outer Space Treaty is not perfect, but so are most (if not all) international treaties. The weaknesses of the Outer Space Treaty are often exaggerated.
- The aforementioned does not mean that the shortcomings of the Treaty must be neglected or that its regime could not be reasonably strengthened. It means that we must approach the Outer Space Treaty carefully and delicately.

The major issue of the Outer Space Treaty in the light of prevention of weaponization of space is Article IV of the treaty. Article IV sets two different regimes for the outer space from the one side and the Moon and the other celestial bodies – on the other hand. The regime of the Moon and the other celestial bodies is obviously much more restrictive than the regime of outer space. Article IV prohibits all military activities on celestial bodies but forbids just the placement of weapons of mass destruction in Earth orbit. Interpreting both paragraphs of Article IV in isolation from the other provisions of the Outer Space Treaty, one could confidently conclude that placing of all sorts of conventional weapons in orbit is allowed under the Treaty.

But would such interpretation be correct? In my opinion, no. The rules for interpretation of international treaties are set by the Vienna Convention on the Law

of Treaties 1969. Under Article 31, paragraph 1 of this Convention "*A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.*" This means that Article IV of the Outer Space Treaty must not be interpreted in isolation from the other provisions of the treaty. Quite the opposite, a proper interpretation must consider the purpose and the spirit of the treaty. The main reason for the adoption of the Outer Space Treaty was to secure the peaceful use of outer space. Article III of the Outer Space Treaty stipulates that:
"*States Parties to the Treaty shall carry on activities in the exploration and use of outer space, including the moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations, in the interest of maintaining international peace and security and promoting international co-operation and understanding.*"

It is hard to imagine that placing weapons in outer space would be in the interest of maintaining international peace and security and promoting international co-operation and understanding.

The above reasoning however does not remove the controversial nature of Article IV. In my opinion, Article IV does not strengthen the regime of the Outer Space Treaty but weakens it. Even though I disagree with the opinion that the Outer Space Treaty allows the placement of conventional weapons in space, the concern that Article IV could be intentionally misinterpreted by certain space actors for achieving military advantages must not be underestimated. In this regard, there is room for strengthening the regime of the Outer Space Treaty. How could this be achieved?

5. PREVENTION OF WEAPONIZATION OF OUTER SPACE – DE LEGE FERENDA

The adoption of international norms regulating the activities of states in the exploration and use of outer space is an extremely difficult, complex, lengthy, and problematic process. The reasons for this are mostly geopolitical and economic. Due to its unique characteristics, outer space has enormous untapped potential to provide economic gains as well as significant military advantages. Competition between the leading countries and their economic and political blocs is fierce in both the civil and military spheres. These two spheres are interconnected. Strong economies allow states to devote significant financial resources to strengthening and increasing the power of their armed forces. The latter, in turn, are often used as a tool to promote certain economic and political interests. For this reason, the interests of the leading space powers too often conflict with each other, and this greatly complicates the rule-making process at the international level. Compromises are made very rarely and on a limited range of issues. Therefore, since the 1970s, not a single international treaty on space matters has been widely adopted. For this reason, more and more issues related to the exploration and use of outer space are regulated by the so-called "soft law". And to what extent "soft law" could qualify as a law in the first place is uncertain.

Considering the above, we will describe several possible options for solving the problem of "militarization of space", depending on the complexity of their further implementation in practice (from simpler to the most complex):

1. Adoption of an optional protocol to the Outer Space Treaty, prohibiting the placement of any weapon in outer space. The advantages of this approach are obvious – due to its optional nature, the negotiation of its text should be easier, and its opening for signature and ratification should be accelerated. Placing weapons in outer space would destabilize international security, so this important problem must be addressed as soon as possible, in its initial stage. Prevention is always preferable to cure. It is much easier to prohibit the placement of any weapons in outer space now, when this process has not yet officially begun, than to negotiate the removal and / or destruction of weapons already in space. The sooner the necessary regulatory changes in this regard are adopted, the better. History has shown that optional protocols as an international legal instrument of regulation are quite effective and viable. A good example in this regard is the European Convention for the Protection of Human Rights and Fundamental Freedoms and the Optional Protocols thereto, which have been signed and ratified by almost all member states of the Council of Europe. The disadvantage of the optional protocol is that such instrument would not be capable to address the issue in much detail.
2. Adoption of a separate international treaty prohibiting the placement of all types of weapons in outer space. Russia and China followed this path, presenting the Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT) at the Conference on Disarmament. The advantages of this approach are that the adoption of a separate international treaty presupposes a more complete and detailed regulation of the problems of preventing the militarization of outer space. Such treaty could also provide definitions of "outer space", "space weapons" (or "space-based weapons"), "space object", "use of force against a space object". However, the question of whether the term "space weapons" could be defined in the first place and even on the need for such a definition remains controversial.
3. The third approach is the most difficult to implement. Its implementation would take the most time, but it is most desirable in the light of the progressive development of international space law and international law in general. This approach implies codification of all major space law issues, through the adoption of United Nations Convention on the Law of the Outer Space. In my opinion, only the UN can become a platform for the adoption of such a convention. Such convention could be adopted by organizing a UN Conference on the Law of Outer Space. Although adopting such a convention would be extremely difficult, we have a historical analogy in the 1982 UN Convention on the Law of the Sea,

> adopted at the UN Conference on the Law of the Sea. The UN Convention on the Law of the Sea is a landmark success in codifying this branch of public international law. The intersection between the law of the sea and space law has been analysed in the international law literature. It is often emphasized that The Outer Space Treaty, the Registration Convention, and the Rescue Agreement are influenced by the ancient law of the sea (Yankov 2011).

The future "space code" can be structurally divided into two parts – general and special. The general part should include the basic principles of space law enshrined in the Outer Space Treaty. One of the main changes should be the introduction of an explicit ban on the placement of any weapons in outer space. Several legal definitions should also find their place in the general part: the definition of outer space, the use of force in space, a space object, an astronaut, etc. The special part could include the rules of the three main space conventions, as well as the rules for extraction of resources from celestial bodies, rules for protection of the space environment, space traffic management rules etc. The Convention must provide a control mechanism and sanctions in the event of non-compliance by a Member State. The Convention could establish new international organization as governing body.

In the adoption of such codification, it will be very important so save the principles of international space law as they are proclaimed by the Outer Space Treaty. Any changes to those principles would be a step back from the wonderful achievements of the Outer Space Treaty and would most probably lead to undesirable consequences.

Of course, at present the adoption of such an international treaty seems unattainable due to the very different interests of many countries and the difficult political situation. But "A journey of a thousand miles begins with a single step".

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IONIZING RADIATION AND HUMAN BODY IN FUTURE MARS SPACE MISSIONS: CHALLENGES AND OPPORTUNITIES

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Abstract: Ionizing radiation represents one of the biggest biological limitations in human space missions. In our daily life, we are protected from most space radioactive sources thanks to the terrestrial atmosphere and geomagnetic field.

The aim of our research was finding the most important clinical consequences of exposure to ionizing radiation on astronauts' health during a typical Mars mission. These data mostly come from radiotherapy patients and survivors to nuclear accidents. In addition, we explored and analysed specific chemical compounds which might be implemented in astronauts' diets to improve their radioprotection during space missions.

Keywords: space radiation, radioprotection, vitamins, lipoic acid

1. MAIN EFFECTS OF IONIZING RADIATION ON HUMAN BODY

According to CDC, 0.7 Gy is the threshold dose for the onset of the acute radiation syndrome which might cause, depending on the radiation dose, nausea, vomiting, hematopoietic disorders, gastrointestinal diseases, or CNS health hazards. Therefore, astronauts may experience several clinical problems linked to the exposure to space radiation and one of the most common symptoms is *fatigue* which does not comply with astronauts' tasks during a space travel.

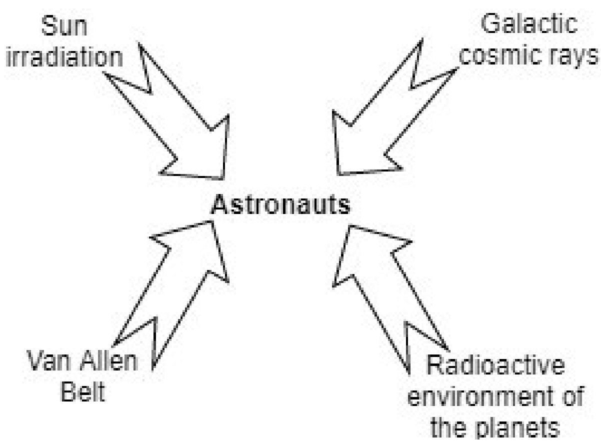

Figure 1: *Main radioactive sources in space missions.* Adapted from Cortese et al. (2018).

Cataracts, observed as a late effect of Chernobyl exposure to ionizing radiation, may have a higher incidence in astronauts. In fact, according to a 5-years study conducted by NASA (NASCA), the posterior subcapsular lens opacity happened to show statistically significant higher values than those for people who were exposed to a normal annual radiation dose.

At proton doses, as low as 0.5 Gy, bone loss might persist for 9 weeks after irradiation and, with 1 Gy doses, it can persist for up to 4 months. Solar Particle Events (SPEs) may have dangerous effects on human skeleton, leading to an increased fragility.

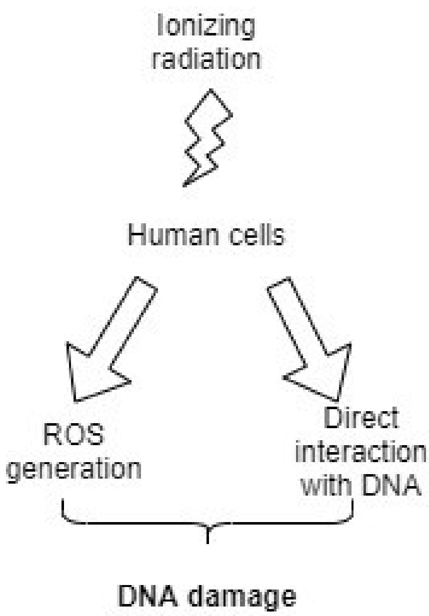

Figure 2: *Effect of ionizing radiation on DNA in human cells.* Adapted from Jeong & Jeong (2017).

Ionizing radiation has many consequences at an intracellular level (Figure 2), causing an initial peroxidation of membrane lipids. Also, there are both direct and indirect processes that lead to DNA damage. A direct pathway consists in the interaction with DNA backbone and nucleic bases, leading to strand breaks and mutations. The indirect pathway is based on water radiolysis, leading to the creation of Reactive Oxygen Species (ROS) that can interact in a second moment with DNA causing similar effects. It has been demonstrated in several articles, available in current literature, that high-LET radiation is more dangerous than equivalent doses of low-LET radiation.

2. DIETARY MITIGATION STRATEGIES

Re-shaping astronauts' diets may represent a fundamental tool which can be regulated to protect them from the radioactive risk in outer space:

- Vitamins = increase the quantity of antioxidant substances like beta-carotene and alpha-tocopherol.
- Peculiar food supplements = dried plum powder seemed to protect mice from bone loss after irradiation with low-LET gamma rays and a mixture of protons and HZE ions, simulating the space environment. Also, curcumin (extracted from turmeric), flavonoids (derived from tea, wine, leafy vegetables) and hydroxycinnamic acids (derived from fruits, vegetables, and cereals) show good antioxidant properties which may represent a potential intertwining between nutrition and space radioprotection.
- Probiotics = might prevent the dysbiosis that happens after intestinal microbiome is exposed to high-LET radiation doses.

In addition, specific pharmacological agents, such as lipoic acid (LA), can help regulate the cell redox potential along with vitamins C, E, and glutathione. Since it is usually inhibited by middle-chain fatty acids, it is recommended that lipoic acid is taken 30 minutes before or 2 hours after eating. DHLA, the reduced form of lipoic acid, can regenerate vitamin E and it is known to have strong antioxidant properties, interacting with biologically unstable chemical species such as singlet oxygen and hydroxyl radicals.

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A LINEAR REGRESSION MODEL FOR SOIL SALINITY PREDICTION IN THE GREAT HUNGARIAN PLAIN USING SENTINEL 2 DATA

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Abstract: Salts occur naturally within soil and water. When exceeding the thresholds, salinity becomes a severe threat, damaging agricultural productivity, water and soil quality, biodiversity, and infrastructures. Multispectral data retrieved from Sentinel-2 MSI sensor were used in this study to predict soil salinity in the Great Hungarian Plain. For this purpose, samples were collected from the upper layer of soil between mid-September and mid-October in the Hungarian Soil Monitoring System framework. The application of multiple linear regression analysis between salt content (g/kg) and remotely sensed data revealed a highly moderate correlation with a coefficient of determination R^2 equals 0.52, a p-value equals 0.001198, and an RMSE equals 0.194 g/kg. The model can be employed to highlight soil salinity levels in the study area and understand the efficiency of land management strategies, considering its moderate predictive power.

Keywords: Soil Salinity, Sentinel 2, Multiple Linear Regression.

1. INTRODUCTION

Salinization is a widespread land degradation form induced naturally by parent material weathering or artificially due to irrigation with saline water (Ondrasek and Rengel 2021). It occurs in dry regions where water balance is negative. Globally, 397 million ha are affected by salinization (FAO 2000), with 3.8 million ha of saline soils in Europe (Stanners 1995). In Hungary, salt-affected soils cover 13% of the total area and exhibit the most natural continental salinization features (Tóth 2009). Using spaceborne and airborne products coupled with adequate methods for salinity prediction has become a valuable alternative to map salt behavior in the subsoil and maintain its levels under control. In this context, many scholars have explored the efficiency of multispectral, hyperspectral, and radar sensors in salinization monitoring (Weng et al. 2010, Bannari et al. 2018, Szatmári et al. 2020, Sahbeni 2021a). This study aims to examine the importance of multispectral sensors, notably Sentinel-2 MSI, in predicting soil salinity with lower costs and acceptable accuracy.

2. STUDY AREA

The study area covers 6903.5 km^2 (Figure 1), at an average elevation of 89m above sea level. It is characterized by a mean yearly temperature of 11°C (Tóth et al. 2014), a mean precipitation yearly rate of 560 mm, and a mean evaporation rate of 900 mm (Hungarian Meteorological Service 2018).

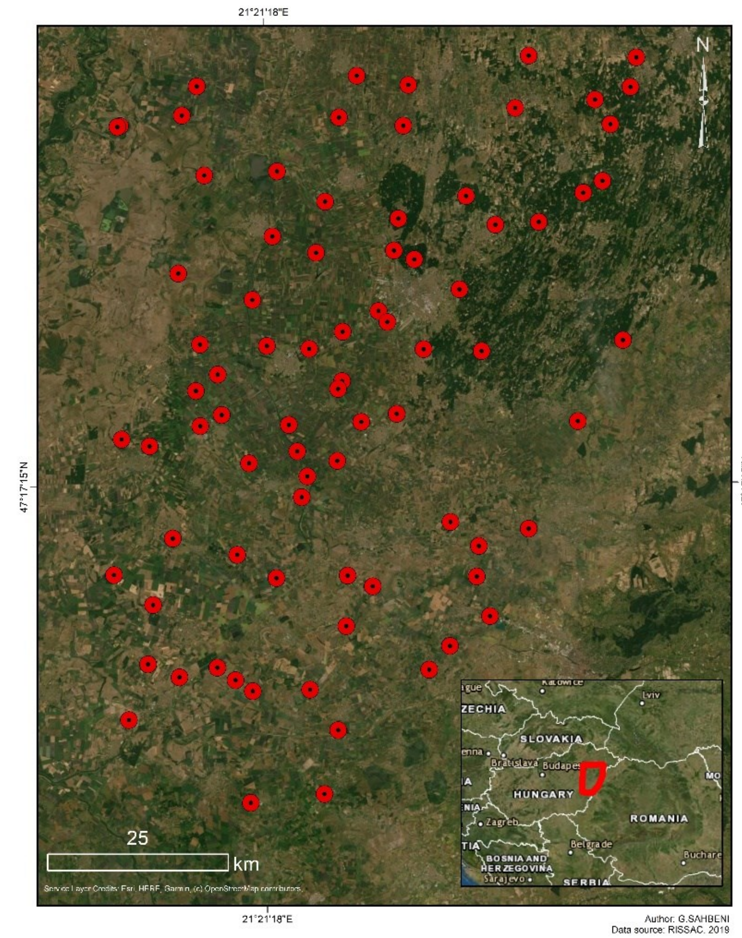

Figure 1: Location of the study area and sampling sites.

3. MATERIALS AND METHODS

3.1. SOIL SAMPLES

Eighty-one soil samples were collected in the Hungarian Soil Monitoring System (SIMS) framework. SIMS is a national soil monitoring program that collects soil data from around 1235 sites and generates Hungary's most unified, thematically detailed, and up-to-date soil database (Bakacsi et al. 2019). An average sample is taken from 9 drillings from the 0-30 soil layer in a 50 m diameter circle (Berényi-Üveges 2015). Salt content values are measured from the saturated paste extract according to the Hungarian Standard MSZ-08-0206/2-1978 (MSZ 1978).

3.2. REMOTELY SENSED DATA

Once the Sentinel-2 MSI image was downloaded from the European Space Agency (ESA) Copernicus portal, atmospheric and radiometric calibrations were applied using Sentinel-2 Toolbox. Then, spectral indices (Table 1) were computed using ENVI IDL 5.3. Additionally, we acquired an SRTM digital elevation model provided by the OpenTopography facility to explore potential associations between salinity levels and elevation. The digital elevation model was reprojected to the Universal Transverse Mercator (UTM) coordinate system using WGS 1984 datum assigned to north UTM Zone 34. Corresponding values to field data were retrieved using ArcMap 10.3, and a database including remotely sensed data and salt content values was developed.

Table 1: Spectral indices and their mathematical expressions.

Index	Expression
NDVI	$(NIR - R) / (NIR + R)$ (Rouse et al. 1974)
NDSI	$(R - NIR) / (R + NIR)$ (Khan et al. 2005)
VSSI	$2 * G - 5 * (R + NIR)$ (Dehni and Lounis. 2012)
BI	$\sqrt{(R^2 + NIR^2)}$ (Khan et al. 2005)
SI	$(R * G) / B$ (Allbed et al. 2014)
SI_1	$\sqrt{(G * R)}$ (Douaoui et al. 2006)
SI_2	$\sqrt{(R * NIR)}$ (Dehni and Lounis 2012)
SI_3	$\sqrt{(G^2 + R^2 + NIR^2)}$ (Douaoui et al. 2006)
SI_4	$\sqrt{(G^2 + R^2)}$ (Yahiaoui et al. 2015)
RVI	R / NIR (Krtalic et al. 2019)
DVI	$NIR - R$ (Tucker. 1979)
Int_1	$(G + R) / 2$ (Bouaziz et al. 2011)
Int_2	$(G + R + NIR) / 2$ (Bouaziz et al. 2011)
SR	$(R - NIR) / (G + NIR)$ (Dehni and Lounis 2012)
SAVI	$(1 + L) * (NIR - R) / (NIR + R + L)$ (Huete 1988)
$SSSI_1$	$SWIR_1 - SWIR_2$ (Bannari et al. 2008)
$SSSI_2$	$(SWIR_1 * SWIR_2 - SWIR_2 * SWIR_2) / SWIR_1$ (Bannari et al. 2008)

3.3. REGRESSION ANALYSIS

A multiple linear regression analysis was conducted via RStudio to define the statistical significance of independent variables in relationship with soil salinity variation. In this context, we employed the R squared model selection to extract only significant variables. R squared represents the proportion of variance for a dependent variable which independent variables can explain. Thus, a model with a larger R-squared (equation 1) value can explain a more significant percentage of data variance (Romero 2007).

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad (1)$$

Where $\hat{y}_i$ is the estimated value, y_i is the actual value, and $\bar{y}$ is the mean value.

4. RESULTS

Data distribution is positively skewed, according to the descriptive analysis report. The mean equals 0.49 g/kg, whereas the median equals 0.3 g/kg. Besides, a spatial variability was found due to the discard between the minimum (= 0 g/kg) and the maximum (= 5.6 g/kg). Table 2 summarizes the main statistical parameters of field data.

Table 2: Descriptive statistics of salt content samples.

	Minimum	1st quantile	Median	Mean	3rd quantile	Maximum
Salt content (g/kg of soil)	0	0.2	0.3	0.49	0.6	5.6

The final model's main characteristics are presented in Table 3.

Table 3: Characteristics of the final model.

R^2	p-value	RMSE	Significant Variables
0.52	0.001198	0.1942	NDVI, SAVI, RVI, DVI, BI, VSSI, SI, SI1, SI2, Int1, B2, B11, and B12

Figure 2 shows the relationship between measured and estimated salinity values using the linear regression model. We split the dataset into two parts: a training set (70%) used to tune the model, and a test set (30%) used to check its statistical significance. Overall, the model yielded acceptable results with a coefficient of determination equal to 0.52, showing a highly moderate correlation and a p-value close to zero (< 5%), revealing a strong statistical significance. Nevertheless, a quite high prediction error was produced due to data redundancy.

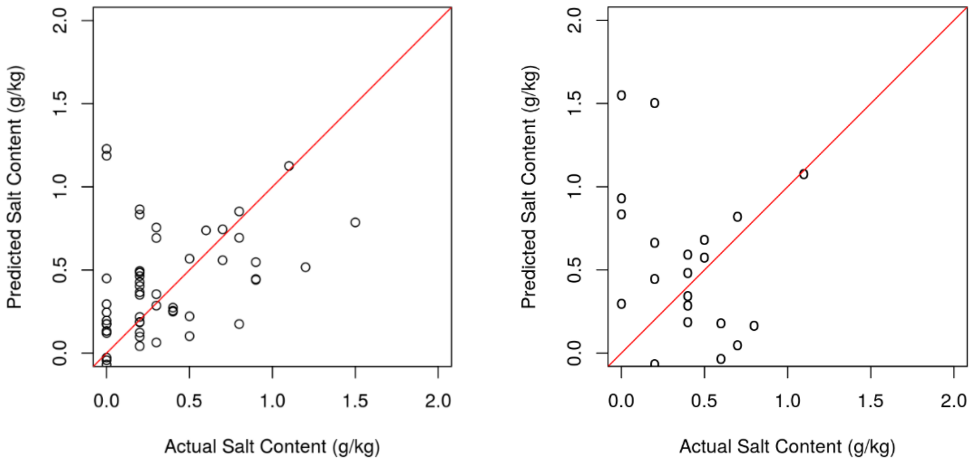

Figure 2: Relationship between actual and predicted salt content values (g/kg); (a) Training set (70%) and (b) Test set (30%).

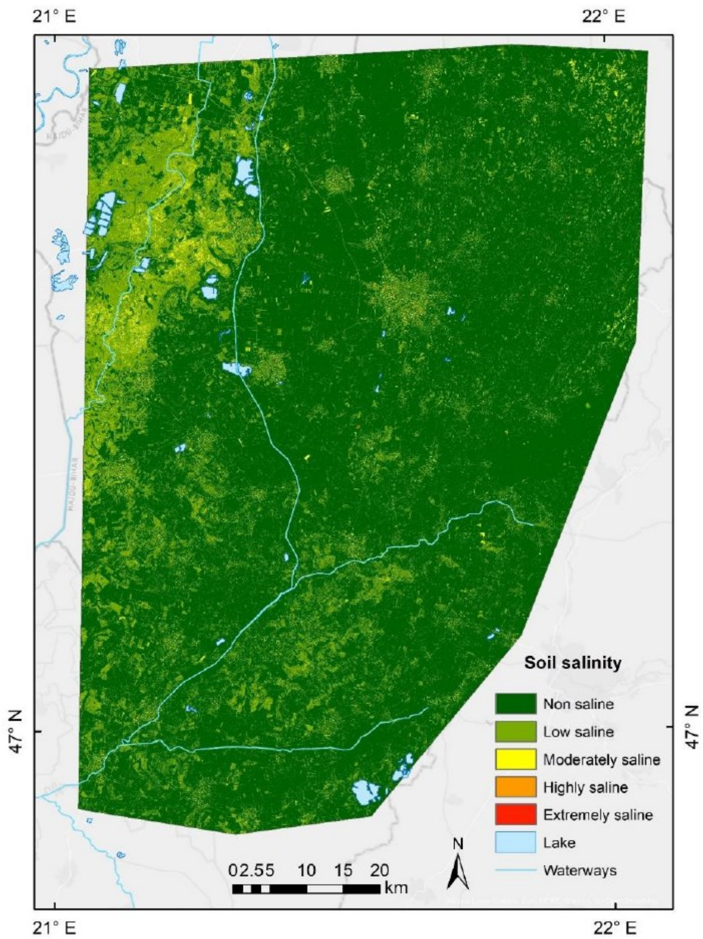

Figure 3: Soil salinity prediction map using the final model.

Around 4% of the total pixels were assigned negative values. This can be explained by the residual noise caused after atmospheric correction (Weng et al. 2010), which will be investigated in future studies. Based on Figure 3, 80% of pixels are classified as non-saline soils and 18% as low saline. This distribution of classes was expected due to the dominance of non-saline samples in the database, followed by low saline ones.

5. CONCLUSIONS

This study demonstrates the efficiency of Sentinel-2 MSI data in predicting soil salinity with acceptable accuracy. Hence, regression analysis offers a reliable approach for soil salinity assessment with affordable costs. The model explains 52% of the data spatial variance, with an RMSE equals 0.1942 g/kg of soil. Overall, remote sensing depicts a valuable alternative for conventional methods when coupled with representative field data. Yet, further research will be conducted to reduce prediction errors and overcome the issue of data multicollinearity.

An improved version of this research can be found in Sahbeni (2021b).

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SRTM elevation model was downloaded in GeoTIFF format from the OpenTopography Facility with support from the National Science Foundation under NSF Award Numbers 1833703, 1833643, and 18336323[3].

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EXPLOITATION OF THE RESOURCES OF THE MOON AND OTHER CELESTIAL BODIES BY STATES AND PRIVATE CORPORATIONS: EXISTING LEGAL CHALLENGES AND DEVELOPING LEGAL FRAMEWORK

S. SHARMA

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Abstract: The passing of the United States Commercial Space Launch Competitiveness Act in 2015 set the stage for a new era in outer space exploration and eventual use and exploitation of the resources on the Moon and other celestial bodies. As of 2020 there are several programs in various stages by the major space faring nations like USA, China, India, and the European Union for a return to the Moon and an eventual habitation of humans on the earth's satellite. The recent announcement by NASA that they are planning to buy lunar soil from a commercial provider has stirred up the international space law domain out of its half a century old slumber. This is in furtherance of the Artemis Accords which is a series of principles and processes developed by the United States towards the exploration and utilization of the resources of the Moon along with partner nations. It has started a new debate among major space powers as to the interpretation of the non-appropriation principle in the Outer Space Treaty of 1967. This treaty continues to be the backbone of the international regime governing space exploration, use and exploitation. In the light of the immense economic potential of the space sector it has become imminent to address the legal challenges posed by the Artemis Accords and the announcements made by NASA. The mining of the resources of the Moon, Mars and other celestial bodies is no longer a distant possibility and will be a big industry within the next three or four decades. The paper seeks to throw light on the legal challenges to the upcoming exploitation of the resources in the outer space. It suggests that given the increased number of actors competing in the outer space, a multi-lateral approach to a clear legal regime is indispensable.

Presentation link: https://www.youtube.com/watch?v=nbLZZQS2otU

AGENDA

WEDNESDAY, 30 September 2020

14:00-14:45	**Opening ceremony**
	- **Milan Mijović, LL.M,** Founder and President, Serbian office for Space Sciences, Research and Development, Serbia - **Dr. Saša Lazović,** Assistant Minister, Ministry of Education, Science and Technological development, Serbia - **Dr. Christian Feichtinger,** Executive director, International Astronautical Federation - **Luc St-Pierre, Chief,** Space Applications Section (SAS), United Nations Office for Outer Space Affairs (UNOOSA) - **H.E. Ruth Stewart,** Ambassador of Australia to Serbia, Montenegro and North Macedonia, Australian Embassy in Serbia - **H.E. Susanne Shine,** Ambassador of Denmark to Serbia, Embassy of Denmark in Serbia
14:45-15:00	***From Space law to Space office***, **Milan Mijović, LL.M**, Founder and President, Serbian office for Space Sciences, Research and Development, Serbia;
15:00-15:30	***Technology, Politics and Warfare: Legal and Future Challenges for Humanity***, **Prof. Steven Freeland, PhD**, Professor of International Law, Western Sydney University, Australia;
15:30-15:45	***Satellite missions – a new Era of astronomy and astrophysics*, Dr. Milan Stojanović**, Research Associate, Astronomical Observatory Belgrade, Serbia
15:45-16:00	***Trajectory Challenges and Considerations for NASA's Double Asteroid Redirection Test (DART) Mission,* Dr. Justin A. Atchison**, Senior Mission Design Engineer, The Johns Hopkins University Applied Physics Laboratory, USA;
16:00-16:20	***Breathing modulation of cardiopulmonary coupling - a potential way out of autonomic deconditioning after prolonged microgravity exposure***, **Tijana Bojic, MD, PhD**, Research Professor of Physiology and Applied Pathophysiology, Vinca Institute of Nuclear Sciences-Institute of National Importance for the Republic of Serbia-University of Belgrade, Serbia
16:20-16:40	***On the numerical structural calculation methods of the space structures as a reliable replacement for expensive testing, still a commodity and why?***, **Prof. Dr. Dubravka Mijuca**, University professor and structural calculation analyst, University Union Nikola Tesla, Belgrade, Serbia;

16:45-17:30	Panel ***Space sciences*** moderator: **- Dr. Milan Stojanović**, Belgrade Astronomical Observatory participants: - **Milan Mijović, LL.M**, Serbian office for Space Sciences, Research and Development, Serbia **- Prof. Dr. Milan Ćirković**, Belgrade Astronomical Observatory - **Dr. Aleksandar Bogojević**, Institute of Physics Belgrade - **Prof. Dr. Aleksandar Simonović**, Faculty of Mechanics, University of Belgrade
17:30-17:45	***Image compression in Earth observations – an application oriented insight from the lossy perspective***, **Branko Brkljač**, **Asst. Professor**, Faculty of Technical Sciences, Novi Sad, Serbia;
17:45-18:00	***Implementation of mineralogy sensitive ice initiation parameterization in Dust Regional Atmospheric Model (DREAM)***, **Luka Ilić**, **Research Assistant**, Institute of Physics, Belgrade, Serbia
18:00-18:15	***Station-Keeping Strategy for a Solar Sail Satellite at Low Earth Elliptical Orbit***, **Halis Can Polat**, **Ph.D. Candidate**, Middle East Technical University/Aerospace Engineering Department, Turkey

THURSDAY, 1 October 2020

14:00	Announcements/Key speakers
14:00-14:15	***A Hero's journey – The story of Space entrepreneurship***, **Helen Tung, Barrister & Senior Associate**, Hamdan Al Shamsi, Australia
14:15-14:30	***Opportunities for funding Space R&D in Horizon Europe***, **Dr. Milan Stojanović**, Research Associate, Astronomical Observatory Belgrade, Serbia
14:30-14:45	***Get your business off the ground with ESA Business Incubation Centres***, **Jeremija Hranjec**, Senior Project Manager / Innovation Consultant ESA BIC Austria
14:45-15:00	***From the first Slovak satellite to high energy astrophysics***, **Marcel Frajt**, Spacemanic, Slovakia
15:00-16:30	Panel ***Industry 4.0 (In Serbian)*** Moderator: **- Prof. Dr. Radivoje Mitrović**, Dean, Faculty of Mechanics, University of Belgrade, Serbia Participants: - **Prof. Dr. Vidosav Majstorović**, Professor, Faculty of Mechanics, University of Belgrade, Serbia; - **Prof. Dr. Dragan Djuricin**, Professor, Faculty of Economics, University of Belgrade, Serbia; - **Vidosava Dzagic**, Serbian Chamber of Commerce, Serbia; - **Vojin Vukadinovic**, R&D & IT Executive director, Metalac ad.

16:30-17:30	***Key note lecture*****, Dr. Andreas Mogensen**, ESA Astronaut
17:30-17:45	***Engineering small satellites in the cloud: Driving innovative solutions from Spain,*** **Laura Gonzalez Llamazares,** Co-founder & CMO, Radian Systems, Spain

FRIDAY, 2 October 2020

14:00	Announcements
14:00-14:15	***Access to Space for All: An initiative of the United Nations Office for Outer Space Affairs***, **Luc St-Pierre**, Chief, Space Applications Section (SAS), United Nations Office for Outer Space Affairs (UNOOSA), Canada
14:15-14:30	***Establishing Australian Space Agency***, **Andrea Boyd**, ESA BME / EUROCOM Team Coordinator, European Astronaut Centre, Australia
14:30-14:40	***China's Space Programme - Born out of national needs, poised to support global progress***, **Jacqueline Myrrhe**, space journalist, GoTaikonauts!, Germany
14:40-14:55	***DLR Keynote*****, Aylin Kilic**, Regional Manager Europe (North, East) & UK, DLR, Germany
14:55-15:05	***Early ISS utilisation taxi missions - a model to send the first Serbian to space?***, **Dr. William Carey**, CEO, Five Owls Technology Limited, UK
15:05-15:20	***The New Mars Outpost and Research at the D-MARS analog site*****, Dr. Hilel Rubinstein**, CEO, D-MARS Space simulations center, Israel
15:20-15:35	***Monitoring soil health with earth observation through the prism of the mission-oriented approach of Horizon Europe*****, Assoc. Prof. Ph.D. Lachezar Filchev**, Space Research and Technology Institute, Bulgarian Academy of Sciences **and Emeritus Professor Johannes Bouma,** Wageningen University (WUR), the Netherlands
15:35-15:45	***Review of Bulgarian activities within the GEO initiative and the EU Copernicus program*****, Assoc. Prof. Dr. Eng Lyubka Pashova**, National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences **and Assoc. Prof. Ph.D. Lachezar Filchev**, Space Research and Technology Institute, Bulgarian Academy of Sciences

15:45-17:00	Panel ***Serbia in international Space community*** Moderators: - **Anastasia Medvedeva**, Co-Host, Spacepals, Co-Founder, Powering space, Russia **- Charlie Bilsland**, Co-Host, Spacepals, Co-Founder, Powering space, UK Participants: - **Milan Mijovic**, Founder and President, Serbian office for Space Sciences, Research and Development, Serbia; - **Anja Nakarada Pecujlic**, Co-Founder, Serbian Case for Space Foundation, NPoC, Space Generation Advisory Council, Serbia; - **Marko Pajovic**, Co-Founder, Serbian Case for Space Foundation, NPoC, Space Generation Advisory Council, Serbia; - **Zoran Tomic,** member, Eureka AS, Serbian Astronomical Society, Serbia
17:00-17:15	***Ariss program***, Tatjana Štefanac, Serbia
17:15-17:30	***ASTER - Attitude STabilised free falling ExpeRiment,*** Jonathan Lange and Bjorn Dierks, Spacecraft design, Luleå Tekniska Universitet, Sweden
17:30-18:00	**Poster session**
	***-P1 The Role of Non-Governmental Actors in Shaping Space Law: An Examination In the Light of Proposed Legal Frameworks on Space Mining*, Dr. Merve Erdem Burger**, Research Assistant, Ankara University Faculty of Law ***-P2 The functional relation between mean motion resonances and Yarkovsky force on small eccentricities*, Dr. Ivana Milic Zitnik**, Assistant Research Professor, Astronomical Observatory Belgrade ***-P3 International Space Law and the Prevention of Weaponization Of Space*, Alexander Nanov,** Russian Presidential Academy of National Economy and Public Administration ***-P4 Ionizing radiation and human body in future Mars space missions: challenges and opportunities*, Roberto Parisi**, Università degli Studi di Salerno, Blue Marble Space Institute of Science ***-P5 A Linear Regression Model for Soil Salinity Prediction In The Great Hungarian Plain Using Sentinel 2 Data*, Ghada Sahbeni,** PhD researcher, Department of Geophysics and Space Science, Eötvös Loránd University, Budapest ***-P6 Exploitation of the resources of the moon and other celestial bodies by states and private corporations: Existing legal challenges and developing legal framework*, Sajal Sharma**, Assistant Professor, University of Petroleum & Energy Studies
18:00-18:15	***Closing ceremony***

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