SPACE STUDY

THE USE OF HOSTED PAYLOADS FOR IMPROVED RESILIENCE AND DETERRENCE IN SPACE

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With ongoing wars in the world, both in Ukraine and the Middle East, military presence in space has become more important than ever. The space domain allows for eyes from above that transcend all borders and numerous boundaries due to its physical location that no nation can claim as its own. The benefits of space are evident, and optimising forces in space can maximise the use of this domain, which offers a unique vantage point.

The concept of hosted payloads, i.e. payloads that utilise the available power, mass and space of a host spacecraft to provide space-based capabilities for additional customers, usually governmental, represents a solution to increase resilience. Furthermore, the concept enables the user to achieve further economic-, operational- and technological benefits, as well benefits in strategic communication, deterrence, interoperability and cooperation. In addition, this concept allows for a higher number of payloads without adding to the number of individual flying objects in space.

The use of hosted payloads holds the potential for many opportunities for NATO Nations and Allies. Collaborating in this domain and improving resilience and deterrence through strong partnerships and strategic asset placement can be critical to safeguarding the unhindered use of space for the Alliance, as space assets and capabilities are likely to be high-priority targets in future conflicts.

This study by the NATO Space Centre of Excellence aims to explore the benefits that the employment of hosted payloads can bring to the military use of space within the Alliance. In particular, the study will demonstrate that they can provide a cost-effective and flexible option for NATO Nations and Allies to increase their space resilience and address emerging threats. The study will also identify the best practices and challenges for implementing this concept within the NATO context.

WHAT IS A HOSTED PAYLOAD?

A thorough understanding of the definition(s) is required, in order to study the use of hosted payloads. This section presents several definitions in support, both historic and contemporary.

Payload

- Originally a seafaring term for revenue-producing cargo on a ship. In space terms, it refers to those elements of the spacecraft specifically dedicated to producing mission data and then relaying that data back to Earth.[1]

Hosted payload

- A portion of a satellite, such as a sensor, instrument or a set of communications transponders that are owned by an organisation or agency other than the primary satellite operator [Owner]. The hosted portion of the satellite operates independently of the main spacecraft, but shares the satellite's power supply, transponders, and in some cases, ground systems.[2]

- An instrument or package of equipment — a sensor or communications package, for example — integrated onto a host satellite, which operates on orbit making use of the host satellite's available resources, including size, weight, power, or communications.[3]

- "Satellite-as-a-service," "hitchhiking", or "piggybacking". The idea is to share the spacecraft bus platform with other payloads and still achieve mission success.[4]

In brief, the term hosted payload refers to a payload that is hosted on a satellite that belongs to someone other than the owner of the payload. The owner of the payload reserves an assigned payload position on the satellite, and the payload is then launched into space and brought into orbit as such. The payload remains aboard the satellite for the entire duration of its lifetime, given its dependence on the satellite.

HISTORY AND ANALYSIS OF USE CASES

Throughout the years, the number of satellites in space has increased significantly. The demand for transportation to space has increased, which has caused the price to lower and led to an increase in launches. Though the opportunities to explore, observe and test in space are endless, there is a responsibility to care for the vicinity of the planet. For this reason, and for the many others that this paper will discuss, combined efforts and joint missions are beneficial for responsible and optimised use of the space domain.

The use of hosted payloads allows the Alliance to join forces, strengthen the commercial space industry, and support the responsible use of the planet. At the same time, it has the potential to reward the user with strategic advances in terms of deterrence and resilience.

After a few efforts to host payloads on commercial satellite platforms, in 2010, the U.S. National Space Policy encouraged an active search for inventive arrangements for the use of commercial space, in which it specifically mentioned hosting government capabilities on commercial spacecraft.[5] Four years later, in 2014, the U.S. Air Force selected several companies to support this endeavour, to explore and test the use of hosted payloads for military use cases.

Before looking at the arguments for using hosted payloads, several examples are provided, to present the opportunities and to give a clear view of the extent of the potential applications of hosted payloads. The use of hosted payloads is relevant for a variety of applications. This ranges from Space Situational Awareness to Earth Observation, but also to data collection and communications.[6] Furthermore, research and development are sensible use cases for such payloads, leveraging existing projects to test new concepts. In principle, the majority of the functions used for a satellite could be valid use cases for a hosted payload.

The Hosted Payload Alliance presented examples of hosted payload case studies by describing the different mission types that can be applied. The following five examples describe potential use cases and applications for which hosted payloads could be opted.[7]

- **UHF payload**
  The Australian Defence Forces launched UHF payloads in support of their satellite communications programme. Using such payloads, which are effective for various terrain types and are not sensitive to weather conditions, the tactical communications infrastructure is strengthened. Using hosted payloads allows for a cost-efficient and rapid deployment of systems.

Wide Area Augmentation System
The U.S. Federal Aviation Administration tasked the use of a Wide Area Augmentation System as an accurate navigation system for civil aviation. With this, horizontal and vertical position information can be provided for approach operations,[8] in addition to more standardised decision approaches, mission approaches and departure guidance. The system provides augmentations to standard GPS signals.

Wide field-of-view infrared sensor
The U.S. Air Force launched an infrared-sending payload called the Commercially Hosted Infrared Payload, CHIRP. This enabled the on-orbit test of an infrared sensor from geosynchronous orbit, and the technology focused on providing continuous coverage within the field of view.[9] The payload was launched on a commercial satellite which transmitted data to ground for analysis.

Internet router
The Internet Routing in Space, IRIS, is a U.S. Strategic Command payload that is aimed at integrating satellite systems and ground infrastructure. A common network layer protocol is intended to allow military forces to communicate via the internet from all over the world, even from the most remote regions. This will be enabled by IP routers and modems on board commercial GEO communications satellites.[10]

X-band payload
Anik G1, a Canadian GEO satellite for various applications, hosts an X-band government communications payload with coverage over the Americas and the Pacific Ocean Region. X-band is a frequency band that is typically used to support military operations and, due to its coverage, is a great use case for naval activities, such as support to military maritime operations.[11] Furthermore, this payload supports applications such as integrated transit and deployment operations.

The use of hosted payloads has both advantages and disadvantages, depending on the type of payload and the intended use case. Several studies, have explored the benefits of hosted payloads, and it is necessary to take such benefits into account in the design of a payload architecture.[5, 7, 12] These benefits can be extrapolated to use within NATO. The main points, which are expected to be relevant for the majority of cases, are mentioned in this section. There are, however, specific advantages and disadvantages for different scenarios and use cases which are not mentioned here and which would need to be assessed on a case-by-case basis.

THE BENEFITS FOR NATO

ADVANTAGES AND OPPORTUNITIES

When a payload is hosted on a satellite, this typically means that the cost of its end-to-end mission is lower. This is because the cost is limited to the design, development, manufacturing, testing and operations of the payload, while costs related to the satellite bus, integration, and launch, amongst others, are saved. Satellite bus providers typically perform the integration of the, often multiple, payloads onto the bus. The system is then tested altogether for performance and to demonstrate that it can withstand launch conditions.

Given that the price of satellite launches is calculated per unit of mass, a hosted payload would be a fraction of the total cost of the satellite. For NATO, this means that this concept would be a cost-effective solution to fly payloads into space.

Examples of such cost savings are presented by the U.S. Air Force,[3] one for an infrared payload and the other for a programme called Responsive Environmental Assessment Commercially Hosted, REACH. Starting with the commercially hosted infrared payload, launched in 2011, the U.S. Air Force saved nearly $300 million by flying the payload on a commercial communications satellite instead of mounting it on their own satellite. Regarding the REACH programme, the Air Force estimated a $230 million saving compared to a dedicated constellation to fly their sensors. These significant cost savings play a major role in the decision-making leading to the use of commercial host satellites.[3]

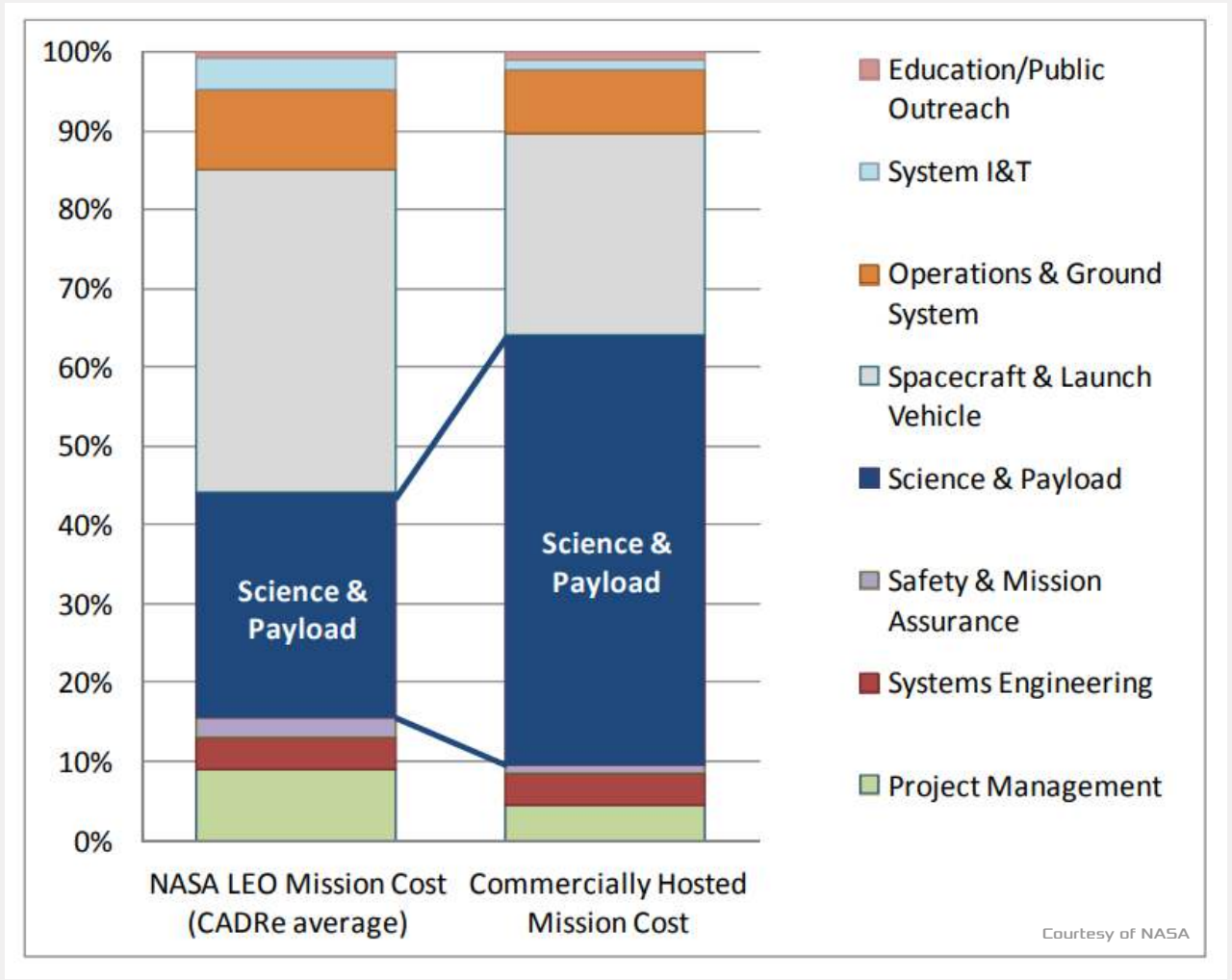


Figure 1 - Mission cost comparison (NASA) [5]

NASA has performed a comparison of mission cost, as seen in Figure 1,[5] which presents the average cost percentages of a total mission, distinguishing the percentages of cost for each phase of an end-to-end mission. From this figure, it can be derived that the budget available to spend on science and the payload is significantly more when the mission is flown as a hosted payload, 54.5%, compared to a standard mission, 28.5%.

Besides the lower cost, another benefit of hosted payloads is the opportunity to fly payloads to space faster and more regularly. The arrangement of a payload host implies that the satellite has already secured a launch date, therefore the time to launch is less than it would be if having to start launch planning from scratch. With that same logic, the rate at which payloads can be sent to space is higher because this process can be repeated with secured launch opportunities. The price of commercial launches is decreasing due to high demand,[13] and at the same time there are waiting times that must be taken into account. Therefore, a secured launch date is of great benefit for any military that needs to launch a payload in space promptly.

An increased use of hosted payloads also means that over time a country can have payloads spread over multiple satellites.

For many payloads, there is an advantage of having multiple sensors in different places. This results in increased coverage, improved precision and no single-point-of-failure, in a domain where often there is no opportunity for a resupply mission in case of a malfunction. Reliability and longevity are critical functions of military operations, and spreading out assets in space supports this, while also providing redundancy and improving deterrence across the Alliance.

Furthermore, it is worth noting that in a traditional military satellite mission, i.e. when the military decides to fly a satellite and builds the infrastructure around it, a significant factor to consider is the ground station. This is a major part of the infrastructure which needs significant logistical support to set up, host and maintain operations throughout the lifetime of a satellite. Opting for a hosted payload, as opposed to owning the satellite, means that the ground station infrastructure has already been arranged. Together with the satellite owner, arrangements for data retrieval and sharing will be made according to the satellite owner's abilities, and the payload owner's needs.

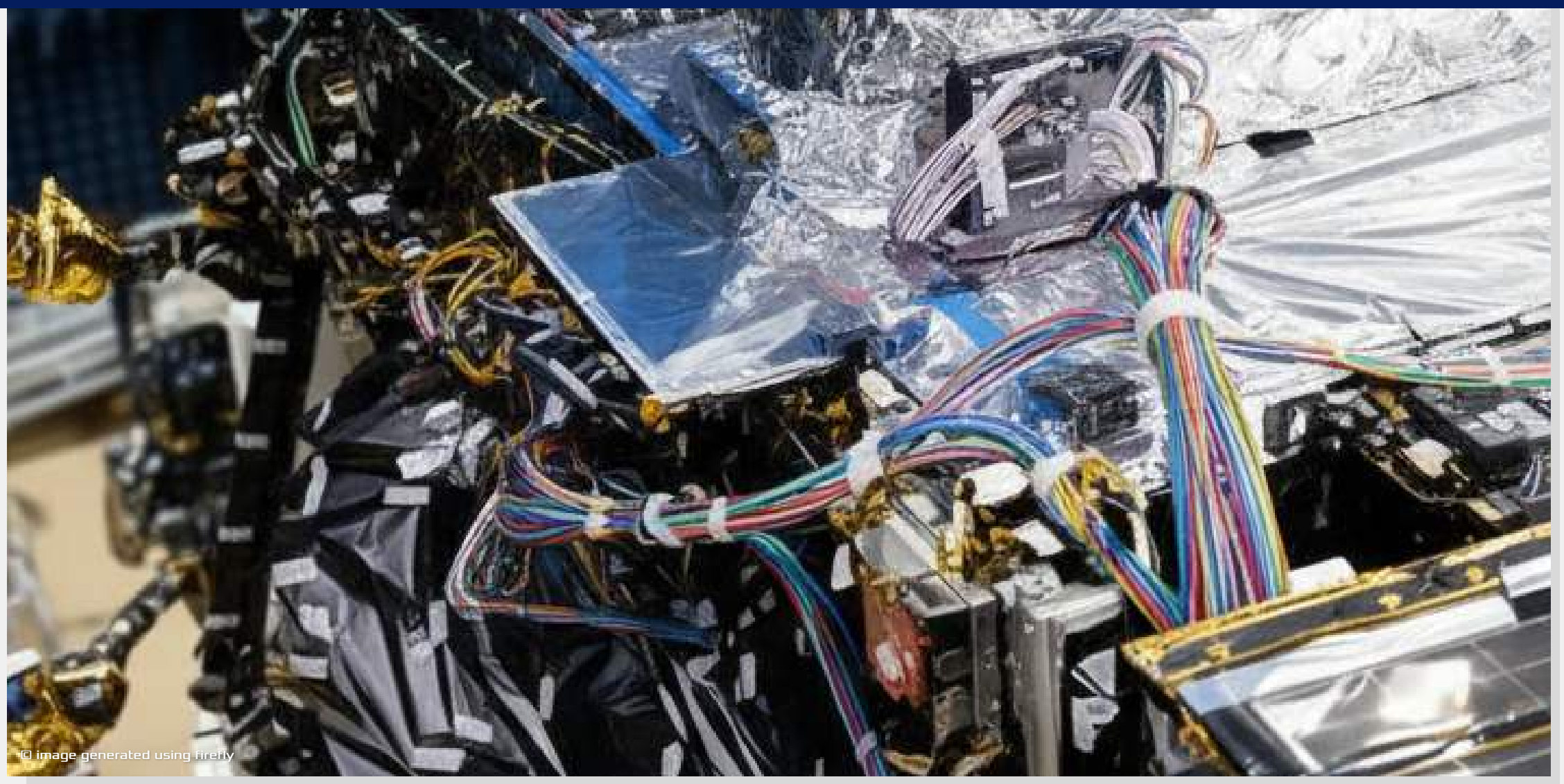
Moreover, the timing of missions and the flexibility of launching a payload play a role in opting for a hosted payload solution. A study from 2017 states that "it's easier to transition to hosted payloads when you're dealing with commercial systems that are part of large satellite constellations launched over a period of months, because you have more flexibility to decide on when to launch a military payload". [14]

In addition to the programmatic and strategic advantages, there are also environmental advantages to the use of hosted payloads. A hosted payload can be viewed as part of an existing satellite, rather than requiring an extra satellite that is to be launched for the same purpose.

Therefore, an increased use of hosted payloads will result in more functionality in space missions available without increasing the number of satellites in orbit. In this rationale, it is important to understand that the satellites that host the additional payloads will be launched regardless of the presence or absence of the hosted payload. The main function of the satellite will be its primary mission, which is different for every satellite, but it will not be that of the hosted payload.

The advantages of hosted payloads are evident. Based on its experience, NASA stated the following, adequately summing up the benefits of hosted payloads: "A series of hosted payloads reduces the risk of total mission loss, reduces overall mission cost, and also allows flexibility for the mission development to be phased to fit within future NASA budget profiles. The hosted payload approach allows simpler payloads to be developed and launched as a form of risk reduction and allows technology to be infused in each subsequent payload". [5]

LIMITATIONS OF HOSTED PAYLOADS



While the advantages of hosted payloads have been discussed, this approach also presents some drawbacks and limitations. The following section will address these challenges. The first point to note is that a hosted payload aboard a satellite will generally not be the priority for the satellite owner. Though this depends greatly on the contract that is agreed upon between the customer and the host, the main idea is that the payload merely uses the satellite platform. Therefore, the host selection process for such a mission must consider the fact that prompt actions to gain or retrieve information is dependent on the type of host and contract. The satellite which hosts the payload will often prioritise its own primary mission, and the hosted payload will be on a 'piggyback ride', as it is often called.

For this reason, payloads with critical functionalities, i.e. those that are time-sensitive and requiring unpredictable tasking, may be better suited to either a conventional satellite mission or to fly with a host which is aware and able to function within such constraints. When the customer is selecting a payload as a candidate to be hosted on a third-party platform, the effect of the satellite system's failure or lack of promptness must be considered and assessed to decide whether it is within an acceptable range. This is not the case if multiple identical payloads are divided over multiple satellites, providing a contingency plan and thus mitigating the risk of failure. As aforementioned, operational constraints greatly depend upon the contract with the host. While the priority of hosted payloads, or potentially the lack thereof, is mentioned as a point of attention or even limitation, this is not necessarily the case. The situation can vary from a low-priority payload that simply rides along on a host satellite, to a high-priority payload for which prompt operational actions can be taken. Considering the rapid growth of the space industry, it is becoming more and more likely that any option is viable if the budget and resulting contract allow it.

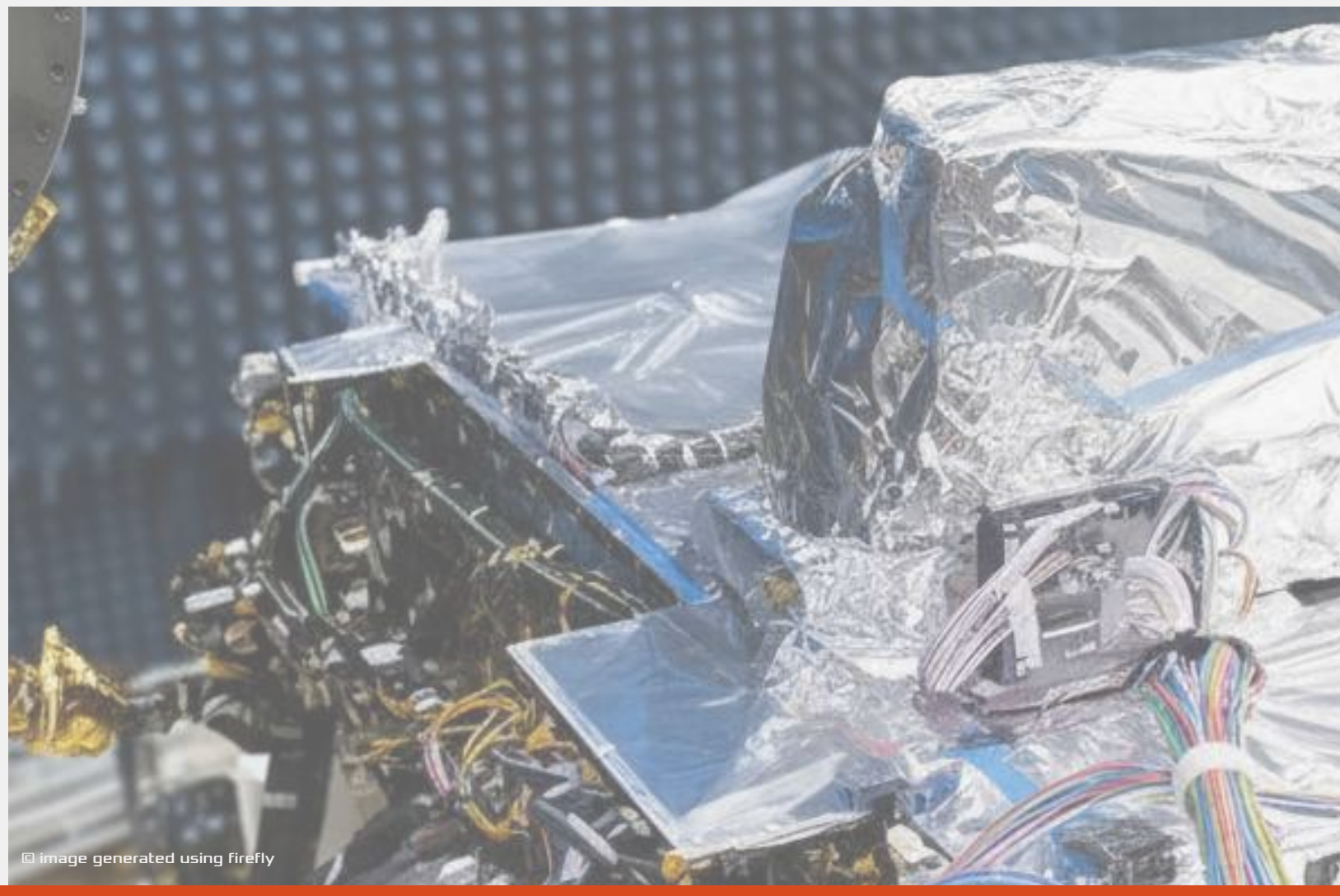
In the same way, the lack of agility of satellite operations for hosted payloads should be considered. Satellite owners plan their operations around their main mission, following all procedures to keep the satellite on track to perform its tasks. System updates, maintenance, and system repair are amongst the many activities that are performed on a regular basis. If a time-consuming activity is planned, which prohibits parallel payload activities, hosted payload customers must have detailed agreements on how to meet their own needs. As mentioned before, this depends upon the host, the budget and, most importantly, the contract that is negotiated.

Another point to take into account is that there will be limitations for a hosted payload, depending on the dimensions, power- and mass budget of the hosting satellite. Therefore, the intended hosted payload must be designed within applicable constraints. The owner of the hosting satellite has the freedom to decide what payloads to carry into orbit, and will design the satellite accordingly. This is not the case for the hosted party who will have to abide by the constraints imposed by the satellite owner. This is one more reason why it is valuable to have common standards within the industry. Often, the satellite owner does not even have the option to change anything in the design of the satellite, when it has already been scheduled for launch and the satellite is in the final stages of its design and/or manufacturing phase. The constraints will vary between different hosting parties, and this must be taken into account during the selection of both the payload and its host.

From a programmatic point of view, hosted payloads allow countries to fly payloads without building a national space infrastructure. Traditionally, a space mission allows an organisation to familiarise itself with its national and partnering space industry, to gain knowledge and build relevant expertise. While this may be an extensive effort at the start, there will be many opportunities from which the organisation can benefit over time. The use of hosted payloads may spark the idea that it could replace national efforts to build space infrastructure and expertise.

The risk here is that new potential spacefaring countries, who use hosted payloads as a means to realise their first space mission, do not continue their efforts to expand their activities in space. This would be a missed opportunity, and a limiting factor in a Nation's endeavours in the space domain.

Finally, security considerations play a critical role when integrating military payloads, particularly in hosted payload scenarios. The military imposes strict security standards and constraints upon their payloads, and the protection of sensitive data must be always guaranteed as any data compromise could significantly harm operations and potentially result in the loss of life. When using hosted payloads, this issue becomes even more pressing due to both the need for information exchange with the platform owner and the physical integration of the hosted payload and the satellite, which can lead to security risks. For this reason, a robust security architecture, incorporating appropriate data protection standards and legal arrangements, and careful host selection are crucial requirements in the case of military hosted payloads.



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NATO'S ROLE IN ADVANCING SPACE PROGRAMMES

Effective collaboration in different military domains is key for NATO. More activity in space brings more opportunities for Allies to work together. The use of hosted payloads is a practice that potentially allows for more members of the Alliance to start or expand their activities in this domain.

Allies active in space thus have the opportunity to join forces and collaborate for shared effort and greater effects. In order to advance space knowledge and capabilities across the Alliance, NATO could play a significant role in matching Nations based on their level of experience and interest in progressing within the space domain.

Matching Nations based on their current needs in the domain would facilitate the flow of knowledge and experience, potentially leading to accelerated progress. Furthermore, Nations would have the opportunity to start with their desired operations without the need to 'reinvent the wheel'.

As a result of the abovementioned cooperations, countries could then become familiarised with opportunities within the domain, without having to invest more resources than required. Learning from the missions, experiments and tests of others would allow them to decide their course of action with a broader understanding of the available possibilities and opportunities. Based on these insights and lessons learnt, they could then take steps to collaborate with either more experienced Nations or with other Nations that focus on extending their reach within the domain.

The deployment of hosted payloads has the potential to extend the reach of NATO members in space, potentially resulting in a higher rate of data exchange between countries spread around the world. This is highly relevant in terms of data, timing and coverage. As NATO members advance in space, so does NATO.

Considering the expansion of the space industry and the increased number of countries taking steps towards spaceflight, hosted payloads may offer a winning strategy for Nations to enter into the space sector. Due to the extent of the effort required and the costs involved, spaceflight can seem out of reach for some Nations. Testing the field may therefore seem less attractive, because tests in this domain require significant investment. Running a test, such as launching a satellite or a payload and studying the data, can be highly valuable in the decision-making process as Nations look to step into the space domain. The challenge is that the high effort required, even just for a test, could lead to Nations disregarding the field before studying its opportunities. The concept of hosted payloads holds the potential to support this early stage of testing and decision making.

By adopting a hosted payload approach for their initial tests, Nations can have the opportunity to launch a payload into space and assess the results, with reduced effort. Such a practical approach can lead to tangible opportunities, and the extrapolation of the outcomes can play a major role in decision-making processes related to further developments in the space domain. Commanders can benefit from demonstrations and use the analysis to decide the future of activities in space and the role of the space domain within their Nation and armed forces.

Having an asset in space, even if it is not a complete national satellite but just a payload, gives countries a seat at the table when it comes to multilateral exchanges in the space domain and the military's role in space. Furthermore, the increased participation of Allies in space activities can help to improve international space-related initiatives such as working groups, wargames and military exercises.

Moreover, even a single hosted payload can unlock new opportunities and lead to a variation of payloads, functionalities and satellite missions. Such an increase in space activities and related opportunities to test a variety of concepts can eventually lead to a growth in national space capacities.

TECHNOLOGY EXCHANGE AND INTEROPERABILITY

Effective use of hosted payloads within the Alliance can benefit from technology exchanges between Nations. While parallel development of technological processes within each Nation will result in individual solutions for each Nation, in terms of efficiency and compatibility across NATO it is not the ideal approach, and makes interoperability much more difficult to achieve. These issues can be avoided by fostering collaboration and exchanging knowledge and technology across the Alliance.

Agreeing on international standards is a first step towards technological exchange. These standards can be applied for elements such as interfaces to ensure the compatibility of subsystems between Nations. Examples of such standards are the Interoperability Standards which are the result of a collaboration by the International Space Station, ISS, membership for the endeavours of space exploration in Earth's vicinity. These collaborations have led to the establishment of Interoperability Standards for power systems,[15] communications systems,[16] and software systems.[17] These standards are established in order to align systems for current and future collaborations. As noted, partnerships benefit from standards by simplifying integration and making it easier for new countries to join multinational endeavours. In addition to their international partners, NASA states that these standards are also available for their commercial partnerships.[15, 16, 17] This allows for more efficient collaborations with commercial parties and promotes compatibility, not only within hardware and software, but also terminology and techniques.

Based on their experience working on the ISS, the aforementioned partners were able to create standards for future operations. The same applies to the Alliance, which has, for many years, developed collaborations in various domains, amongst which, space. Working together towards common standards can benefit the Alliance and its members, and enhance future partnerships in space. Whether Allies plan to host a payload or to provide a payload to be hosted on another satellite, the advantages of common standards are evident.

A significant part of these standards relates to the satellite platforms on which payloads are hosted. NATO could consider the endorsement of satellite platform standards in order to enable operational collaborations in the space domain in which Allies host one another's payloads.

With common standards, the distribution of payloads over multiple platforms will be enabled and easily accessible. Allies can distribute their payloads, i.e. to mount their payloads on another Ally's platform, and vice versa. A satellite platform which flies multiple flags is a more complicated target for adversaries, due to the political implications related to the number of parties involved. In this context, the distribution of payloads across multiple platforms belonging to NATO members has the potential to increase deterrence by reducing an adversary's ability to exploit internal divisions through targeted attacks on specific countries. For these reasons, this approach presents a sound opportunity to protect assets, strengthen the space domain, and simultaneously increase the level of collaboration. Designing common standards for both hosting platforms and hosted payloads enables a smoother implementation process and encourages wider engagement from NATO members.

Another key benefit is that this approach can serve as a testbed for data-sharing systems within the Alliance. Due to the relatively lower cost, a wide range of countries can perform large-scale tests. Such activities can be effective interoperability enablers for future operations involving the Alliance and its partners.

COLLABORATIONS WITH GOVERNMENT, INDUSTRY AND ACADEMIA

Once the technology, including its platform, standards and interoperability, is available for entities to work together on a payload launch, collaborations can be formed. These collaborations can be of varying natures, involving governmental and commercial entities as well. There are different implications for these scenarios and understanding them well is essential for a successful outcome. There are several questions to ask when it comes to selecting partners in such collaborations, and answers will mainly depend on national protocols and policies.

The first question is whether to select a governmental host satellite to fly the payload, or to choose a commercial provider. In the case that a governmental satellite is the desired choice, the options include intragovernmental, in which case both the hosted payload and the satellite would be from the same country, or intergovernmental, which requires collaboration with another country to host the payload aboard their satellite. The main question here is whether the partnership is kept within the country or not.

The next point to consider is whether a payload is hosted on a military- or a non-military satellite. The latter category brings forth the discussion of dual-use systems, which are used by both civilian and military parties. This has significant implications with regards to the status of such a system, in this case a satellite, and can affect the level of legal and physical protection that civil satellites have from an adversary.

Intragovernmental collaborations have the potential to be the simplest option in terms of contracting, procurement and legal aspects. These could be, for example, situations in which military payloads are hosted on a non-military governmental communications or weather satellite. In this case, the satellite would become a dual-use satellite. However, the effects on deterrence in this scenario would be limited. From an adversary's perspective, as the same country operates both the platform and the payload, the implications of any potential hostile act would be the same as for a national satellite.

An intergovernmental collaboration would result in, at least, two countries working together, meaning that the satellite would carry at least two flags. Adversary actions against such a satellite would be much more complicated and impactful, given that multiple governments would be involved in such a situation. Therefore, opting for an intergovernmental collaboration and choosing another government's platform to host a payload would significantly impact deterrence.

Another important consideration for international collaborations is whether or not they involve non-NATO countries. Decisions about which country to collaborate with for future space endeavours will stay a national choice influenced by internal assessments. However, collaborations within the Alliance will most likely be more straightforward in case of the aforementioned development of common standards and other agreements.

As previously stated, another option to host a payload is to choose a commercial partner. On the one hand, there is the discussion on dual-use systems previously mentioned. The benefits of this scenario are the strengthening of the national space industry and customer prioritisation by the commercial service provider. The benefit goes both ways, given that the space industry benefits from governmental contracts through which their business can expand. Regarding the nationality of the commercial party, similar considerations to those previously discussed for governmental partners apply, including whether the entity originates from a NATO country or not.

All in all, the choice between national and international partners must be addressed. If the intent is to grow as an Alliance, expand current operations and increase deterrence, then the partnership selection process should not be too constraining. It is important to note that a variety in partnerships can strengthen the Alliance in the space domain. Subsequently, this is holds the potential to significantly influence deterrence.

By focusing on hosted payloads as a new approach to spaceflight, where smaller investments can bring payloads into space and multiple payloads can be spread over different satellite platforms, opportunities for research and development are vast. Furthermore, this approach allows countries to bring together their governmental, commercial and academic space sectors, and all their possible cooperations, to advance their national space endeavours.

Encouraging research and development on hosted payloads can result in easier access to space. This can be achieved by simplifying standards and platforms, decreasing the mass of payloads by optimising their design, and much more. Due to the relatively lower cost of hosted payload missions, the opportunity to perform experiments and tests in space becomes more interesting. When, traditionally, there was one chance to design, build and launch a payload into space, there was less room for experimentation due to the level of risk involved. In the case where multiple payloads can be launched for a comparable price, due to the fact that the platform costs are not included in a hosted payload mission, there is more room for experimenting with lower risk. Assets can be tested, and results can be compared to one another. Moreover, in the case of a failure, this can be used as test data and result in highly valuable knowledge, without losing the entire mission. With the flexibility that the concept of hosted payloads offers, testing opportunities are significant and the risk of failure is decreased. This allows for undaunted test campaigns and has the potential to significantly advance space system development.

An effect as such will result in increased data from preparing, designing and operating in space. This data is highly valuable for academia, resulting in the advancement of their space knowledge and database. When the academic system is fed with more information, this typically results in an exponential growth of research and development and in an expansion and growth of national space industry and capabilities. Ultimately, when such activities are successfully continued over time, the output is also significant for NATO and its Allies. The first reason is that within the Alliance, there will be a greater understanding and capability within the space domain. Successful space industries within NATO make the Alliance stronger and more prepared for battle. The second reason is that Allied Nations can work together, as stronger spacefaring Nations, to increase deterrence and have a presence in space.

PROPOSED SOLUTION

CONTRIBUTION TO RESILIENCE AND DETERRENCE

RESILIENCE

In a study on resilience, it is stated that "Truly resilient organisations thrive in hostile environments".[18] Looking at the military space domain, it appears clear that space is, in many ways, a hostile environment for NATO and its Allies. First and foremost, space is characterised by extreme environmental conditions that affect any material exposed to it. Some of the most hostile conditions are those that occur naturally, such as the vacuum of space, space weather, extreme temperatures, temperature and light changes, and radiation. Aside from the natural hazards described before, man-made objects can result in debris and even collisions. Though the above describes a set of conditions that are already challenging to deal with, the matter of intentional hazards remains to be discussed. Adversary actions can lead to interruptions, damage and even loss of payloads and satellites. With increasing activities in the space domain, including commercial expansions and military presence, these actions are expected to increase in the future. Therefore, a resilient approach to the use of space and space assets is essential. In order to achieve resilience in space, the approaches to achieve resilience must be studied. JAPCC describes five main approaches to resilience, which are explained as follows.[19]

Disaggregation:
The allocation of different missions, functions or sensors across separate subsystems in space or on the ground.

Diversification:
The ability to contribute to the same mission/function in multiple ways, such as the use of multiple sources to gain information.

Distribution:
The allocation of the same mission across separate subsystems in space or on the ground, collectively behaving as a single system.

Proliferation:
The distribution of multiple units of the same system to provide technical redundancy.

Protection:
Passive measures, such as physical or electromagnetic hardening, to make the system more intrinsically robust.

The use of hosted payloads can be leveraged to enable four out of the five aforementioned approaches to resilience, i.e. disaggregation, distribution, diversification and proliferation, depending on the aim of the payload. Given that there is a variety of manners in which hosted payloads can be used, and thus a variety of resulting effects on the overall mission, it can be stated that the use of hosted payloads has the potential to provide significant contribution to resilience.

DETERRENCE

NATO describes deterrence as the threat of force in order to discourage an opponent from taking an unwelcome action.[20] There are two categories of deterrence, described as follows.

Deterrence by punishment:
Achieving deterrence through the threat of retaliation.

Deterrence by denial:
Achieving deterrence by denying the opponent's war aims.

The presence and increase of military hosted payloads in space allows for enhanced capability in the space domain without requiring the design and build of more satellite platform capacity to launch these payloads. This means shorter launch times and faster access to space without the need for additional development and infrastructure. The use of existing satellites, and their allocation of hosted payloads, allows new and emerging spacefaring countries to propel their role in the military space domain. Consequently, more military payloads can be launched to space in a relatively shorter amount of time. The increase of military payloads from members of the Alliance provides 'deterrence by denial', as the wide geographical spread of capabilities, from various parties and over various systems, makes space systems less rewarding targets.

A level of deterrence can already be achieved with a small number of payloads in orbit, and an increase in Nations joining this effort will strengthen the effect. In addition, it is expected that enhanced collaborations in space will bring increased data-sharing demonstrate unity and strength, resulting in greater deterrence.

The unity of the Alliance working together in this domain is the strongest point of deterrence. Hosting a payload on another Nation's satellite makes it more challenging for a potential adversary attack due to the spread of the impact that involves multiple governments within an Alliance. This makes the sharing of payloads on each other's satellite platform an interesting and effective approach to deterrence.

APPROACH TO THE USE OF HOSTED PAYLOADS

- **Using hosted payloads** allows for more activity in space with the same resources. There is a significant benefit of hosting payloads on satellite platforms that are scheduled to launch, leading to fast access to space, expansion or even reconstitution.

- **Creating deterrence** by joining forces with Allied Nations within the space domain and combining military activities that are ongoing or planned for the future. A fast-growing pace of activities in the space environment will benefit from strong partnerships, just as seen in the other military domains.

- **Taking responsibility** for the planet and its vicinity, i.e. the orbits around the Earth. These orbits host the sensors and satellite platforms that help the members of the Alliance maintain safety and security, by allowing for data retrieval from a unique vantage point. As hosted payloads do not need a dedicated satellite platform, multiple missions can be combined on one platform. This holds the potential to decrease the speed of the growing number of individual orbiting objects in space.

- **National capabilities** in the space domain, in terms of satellites and ground stations, continue to be essential for a Nation's expertise in space. The use of hosted payloads should be considered as a significant benefit, but not as a replacement for the efforts to build national infrastructure. While it is possible to be active in space with payloads hosted on other owners' platforms, only an end-to-end mission, including the design and development phase, offers the possibility to significantly advance a Nation's knowledge and operational flexibility in the space domain. Furthermore, it boosts the Nation's space industry.

- **Careful attention** should be given to adding multiple payloads on a satellite platform. Not all payloads can be combined on one satellite platform, given the environment and the resulting conditions. An example of this is the use of optical payloads and the extensive vibration restrictions that come with operating such a payload. Not all platform conditions work for every payload or combination of payloads. Therefore, it is important to select the host satellite carefully.

- **Data encryption** is an essential consideration in partnerships with other entities, whether commercial or governmental. Negotiations with satellite owners should include data encryption agreements, depending on the need and the use case of the payload. From a technical point of view, it is possible to encrypt data end-to-end. Depending on the type of partnership and mission details, the main legal agreements are made between the host and the payload owner.

CONCLUSION

The use of hosted payloads holds the potential to improve resilience and deterrence in space. Nations can benefit from hosted payloads in the military use of the space domain. Lower payload launch costs allow for more opportunities to send payloads into space, both for countries who are new to space and for the ones who already have a space operations infrastructure. Increased activity in space from an increasing number of Allied Nations result in improved deterrence. Furthermore, quick access to space plays a major role in resilience within the domain, both due to the opportunity to start space operations in a shorter time span and because of the option to resupply assets that malfunction or are destroyed. Since hosted payloads rely on the existing infrastructure of the host satellite, there is no need to develop major ground assets, such as ground stations and communication networks, thus reducing costs.

Even though not all payloads are suitable for flight on host satellites, either due to programmatic, strategic or operational reasons, there are numerous functions that hosted payloads could fulfil. With the right partnerships, either governmental or commercial, Nations can benefit from such an arrangement. Given the conditions, both from a financial and programmatic point of view, resources can be spent on research and development, allowing national industry and academia to benefit and to excel their activities and expertise in the space domain. Above all, the joining of forces within NATO in the space domain is considered essential in safeguarding the security of all its members, and the use of hosted payloads can play a significant role in achieving this objective.

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Lieutenant Colonel Shar Timman is an Aerospace Engineer and graduated from Delft University of Technology. After her Master's degree, she joined the European Space Agency (ESA) between 2015 and 2020 as part of the team working on future human-robotic missions to the Moon. During this period, she obtained her PhD in human-robotic performance for lunar missions. This project was a collaboration between ESA's European Space Research and Technology Centre (ESTEC), Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO) and Airbus Defence and Space.

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