High Aspect Ratio Satellite Platforms

Understanding and leveraging the potential of slender satellite configurations

NOVASPACE

REFLEX AEROSPACE

INITIUM

EUROPEAN SPACE AGENCY CONTRACT REPORT

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1 | Foreword

In an era propelled by environmental awareness and technological innovation, High Aspect Ratio (HAR) satellites are emerging as a significant innovation in satellite design. Their slender, elongated designs signify a shift towards cheaper, more efficient and sustainable satellite solutions, aligning with the push for commercially viable solutions as well as sustainability. As industry trends lean towards miniaturisation and heightened functionality, high aspect ratio satellites stand out for their ability to combine reduced mass with enhanced performance.

These satellites cater to the evolving needs of our interconnected world, providing solutions for high-speed communication, Earth observation, and scientific research. However, their success hinges not only on technological advancements but also on global collaboration to address regulatory frameworks, spectrum allocation, and space debris management.

As the space industry navigates these challenges, the role of high aspect ratio satellites becomes increasingly crucial in shaping the future of space activities. Industry leaders, policymakers, and researchers must collaborate to harness the full potential of these advancements, ensuring a sustainable and interconnected trajectory for space endeavours.

Novaspace, Reflex Aerospace and Initium Space Consulting are pleased to present this report on the use of high aspect ratio satellites, their benefits and possible use cases, conducted for the European Space Agency between March and November 2023. This report contains an overview of the status quo of the HAR ecosystem, with a focus on three particular use cases developed by Reflex Aerospace, and a development roadmap to facilitate the development of HAR technologies. The purpose of this document is to highlight the potential of high aspect ratio configurations, in order to foster their adoption through a plethora of applications, thanks to ESA's support.

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2 | What are High Aspect Ratio Satellites?

Since the beginning of the space race almost a century ago, the space sector has undergone an unprecedented series of transformations. These have recently culminated in the evolution of this industry into a commercial hub attracting investment and interest from various sorts of private companies and organisations.

In line with this new, commercial space race, there has been a growing trend towards decreasing costs in order to maximise profits and gain a competitive advantage, which has fostered R&D and innovation. This movement, coupled with the growing interest in mega-constellations, has resulted in many companies attempting to minimise the mass and/or volume of their satellites, in an attempt to maximise the number of satellites launched at the same time, minimising costs.

Since the beginning of the 21st century, this phenomenon was exemplified by the rise in popularity of CubeSats, which are optimal for a wide range of missions and experiments. In recent years, players started experimenting with new design approaches and concepts, such as 3D printed satellites, swarms of multiple small satellites replacing one large satellite, or new satellite form factors, such as high aspect ratio satellites. The aspect ratio of a satellite can be defined as: **Aspect ratio (AR) = Length L / Thickness t**. A satellite can be considered HAR when its length (assumed to be the largest dimension) is over four times larger than its thickness. HAR configurations currently present various types of designs and sizes, ranging from extremely thin toast-shaped satellites to satellites the size of a one-bedroom flat.

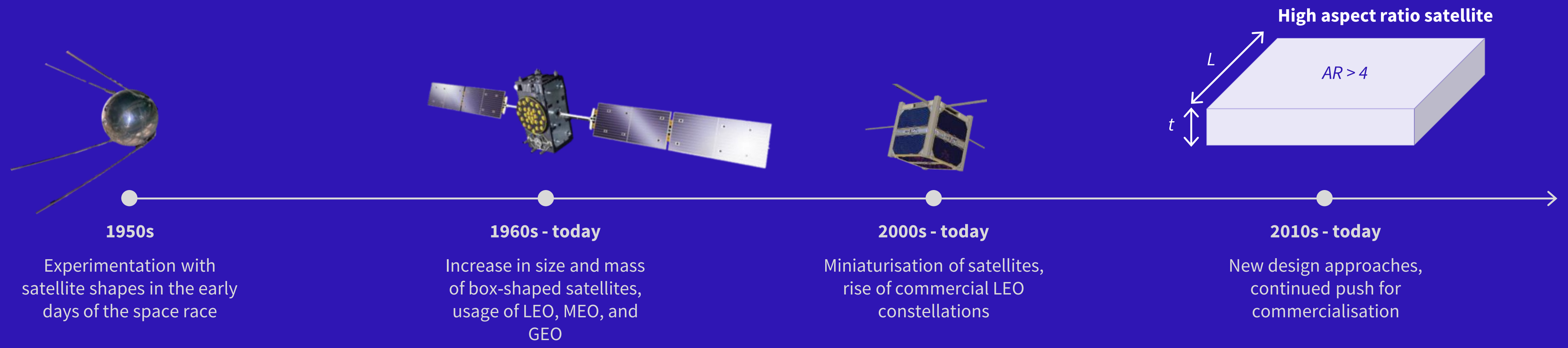


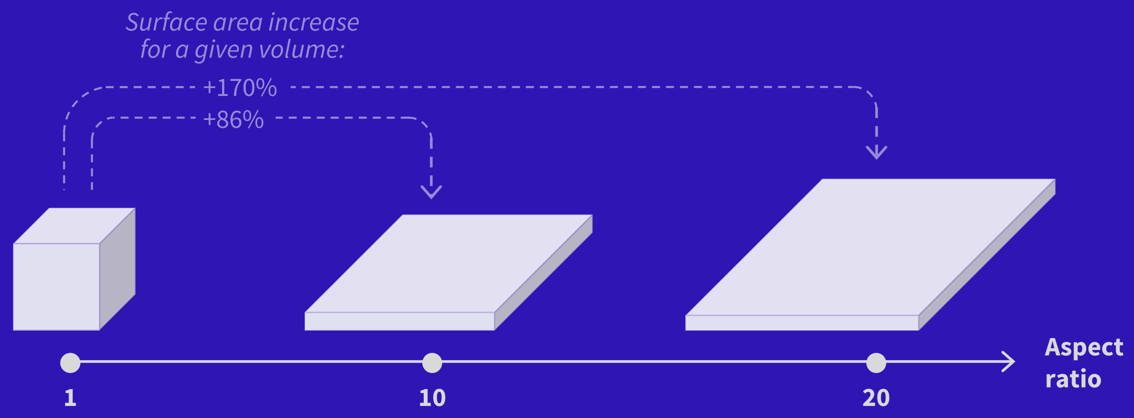
Image credits: ESA, NASA

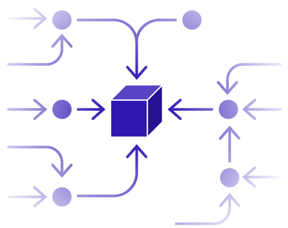
3 | Why is the concept beneficial?

HAR satellites present multiple benefits and advantages that traditional configurations do not. These span the entirety of the satellite lifecycle, from development and launch to operation and decommissioning, and cover both technical and non-technical aspects. Key benefits include higher performance, mass manufacturability, stackability, and the ability to use drag as a tool.

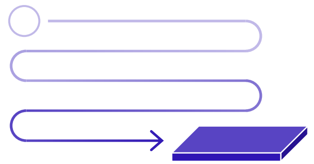
Higher performance enabled by larger surface

For instance, a larger aspect ratio for a given volume corresponds to a larger total surface area, which provides more space for solar arrays, antennas, and other important components and systems. This increases the power-to-volume and power-to-mass ratios of the satellites, giving the option of either repurposing the mass allocation for additional systems (e.g., additional solar panels), or simply reducing the overall satellite mass and reduce costs. An example of this is AST Mobile's BlueWalker 3 satellite. BlueWalker is currently one of the largest and brightest artificial satellites in orbit, as it unfolded after deployment to reveal a 64 m^2 phased array antenna entirely covered in solar arrays. These arrays provide a significant amount of power, enabling the satellite to provide Direct-to-Device (D2D) communication.





Manufacturing of conventional satellites



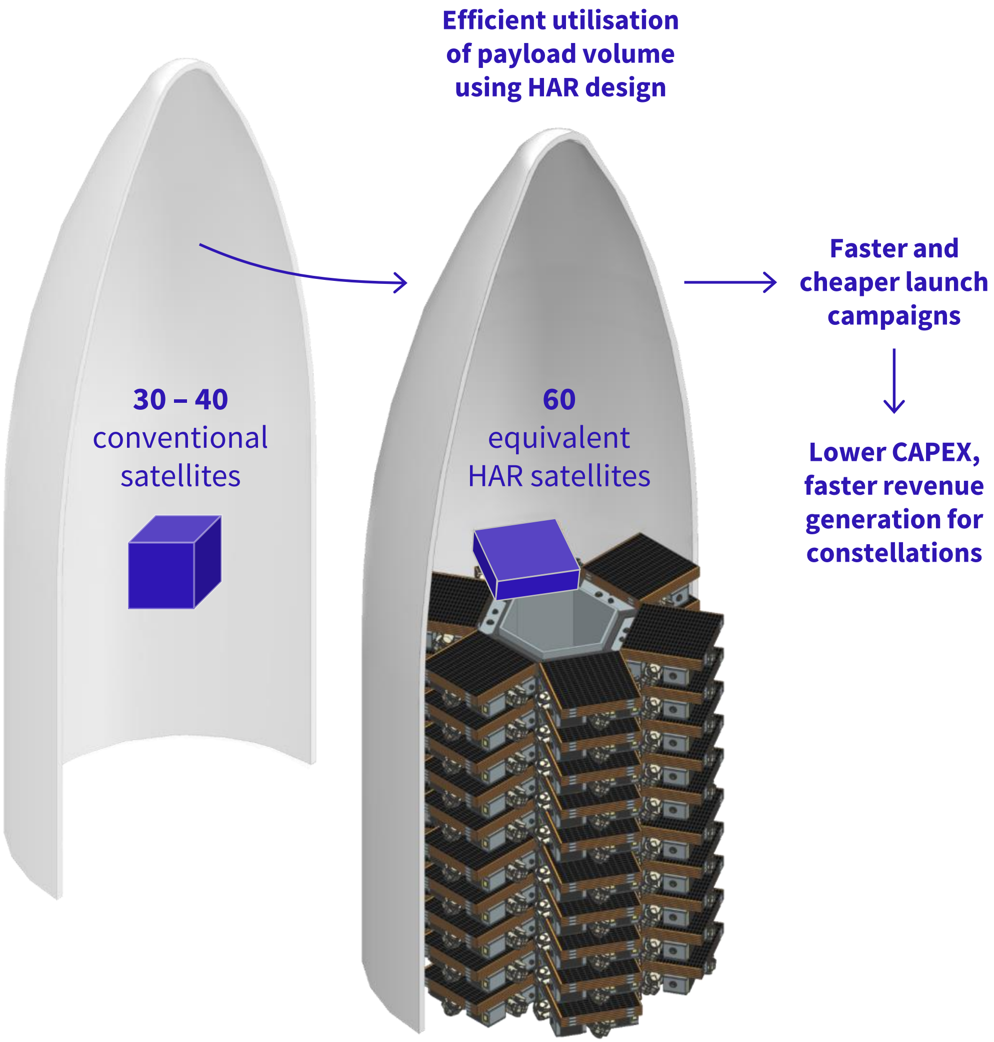
High volume automated manufacturing of HAR satellites

Mass manufacturing benefits

Another advantage of the larger surface area is that the satellite components can easily be spread throughout the satellite body without the need to stack them using cumbersome harnesses and interconnections. This is a clear advantage over traditional cubic satellites, as it reduces the number of complexities and simplifies both the overall satellite structure and the Manufacturing Assembly, Integration and Testing (MAIT) phase.

The MAIT phase being simpler and cheaper also facilitates the mass production of HAR satellites compared to other configurations. By not having to fit components on top of each other within a limited volume, manufacturers can produce HAR satellites at a considerably faster rate than conventional satellites, which is particularly beneficial when designing an entire mega-constellation.

3 | Why is the concept beneficial?



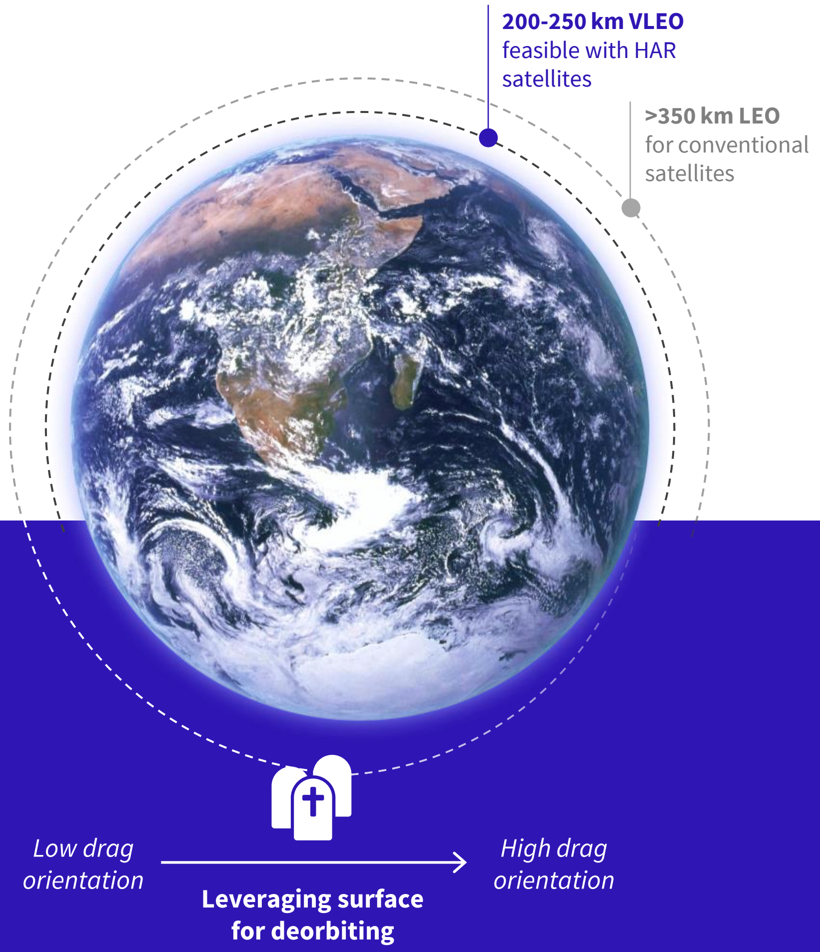
Facilitating stackability

Thin satellites enable to optimise the utilisation of available fairing space and allow for stacking a large number of satellites within a launch vehicle. The main advantage of stacking multiple satellites together is that it increases the number that can be launched at once, be it via ridesharing or dedicated launches. More specifically in the latter case, it would enable the satellite operators to populate their target orbits with fewer launches, in the best of cases even dedicating a single launch per orbit. The volume that would normally be used for additional harnesses to keep differently-shaped satellites together, or that would simply be kept empty due to the inability to fit more satellites, could be reconfigured to fit more stacked satellites, increasing the total number per launch. Thus, stackability drastically increases constellation deployment speed, allowing satellite operators to shorten the time to revenue generation.

The most optimal design for stackability and volume optimisation is a circular configuration, given the shape of launch vehicles. For example, the Aerospace Corporation's DiskSats are circular satellites designed to be stacked, occupying the cylindrical space contained within the payload fairing better than their parallelepipedal counterparts. Also, non-circular HAR satellites allow for a significantly better utilisation of the available payload volume compared to conventional satellites as shown in the example on the left.

In summary, a more efficient usage of the available payload volume directly correlates to economic benefits. The stackability of HAR satellites therefore has the potential to become a game changer for upcoming space players trying to break the glass ceiling of the commercial space industry.

3 | Why is the concept beneficial?



Lower drag for sustainability & new opportunities

From an operational perspective, the lower thickness associated with HAR satellites allows them to be more efficient and sustainable. Assuming operational Attitude and Orbit Control Systems (AOCS) are integrated in the HAR design, which is challenging but feasible if designed correctly, these satellites can be maintained at low angles of attack in order to minimise the effects of drag on the orbital path. This approach could considerably increase the lifetime of a HAR satellite compared to a cubic counterpart experiencing more drag, or simply reduce costs due to less attitude control manoeuvres required. It would also open up the possibility for extended missions in Very Low Earth Orbit (VLEO), where drag is more significant and attitude control requires excessive amounts of propellant.

Adjustable drag enabling decommissioning

Conversely, tilting the satellite would increase both the angle of attack and drag, facilitating orbit phasing and decommissioning without the need for additional propellant. Doing so would also eliminate the need for specific de-orbiting devices, provided the AOCS are robust enough. This would once again reduce costs for a HAR mission compared to a traditional one, which could be taken as a benefit or as a way to reinvest funds on improving other aspects and components. All of these benefits are in line with the current trends within the space industry, as they highlight the agility and potential cost reduction associated with HAR satellites.

Image credits: NASA

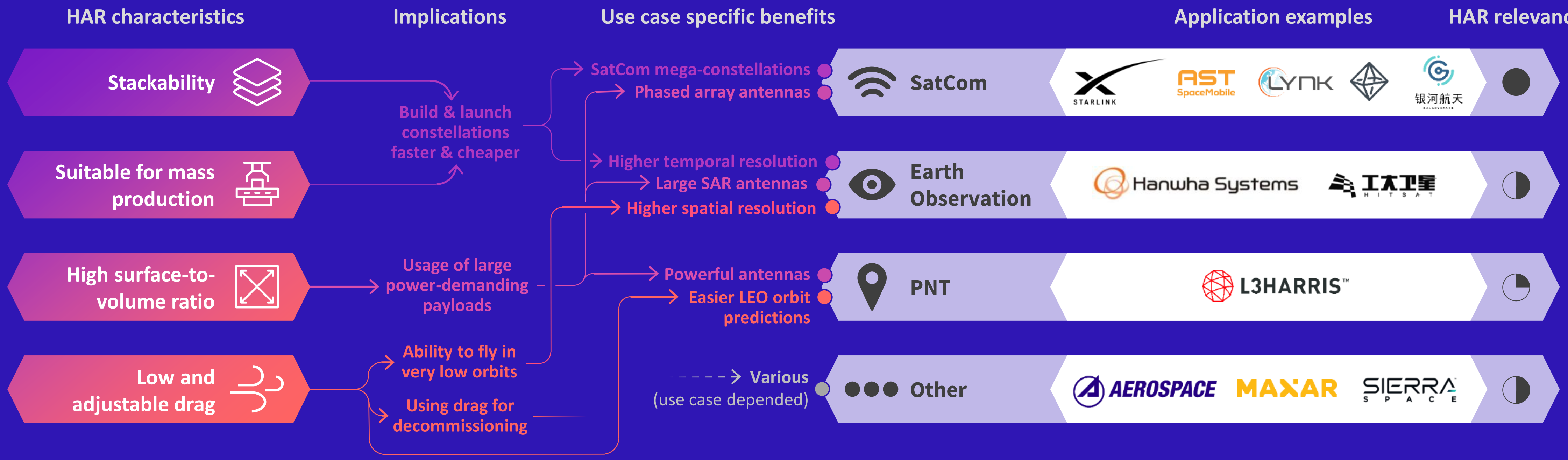
4 | When could it be useful?

Given the distinct advantages of HAR satellites and the prevailing trends in both the space industry and beyond, HAR satellites possess the potential to target specific segments of the market that demand innovative designs to deliver competitive solutions.

In this context, there exists a departure from the traditional satellite design process: whereas earlier spacecraft were primarily shaped around their missions or payloads, the configuration of HAR satellites assumes a pivotal role in guiding and facilitating specific usage scenarios.

This approach aids in optimising the benefits derived from employing HAR configurations, as the mission is developed in accordance with this specific design type.

The stackability, mass manufacturing potential, high surface-to-volume (and power-to-volume) ratio, and reduced drag are key factors driving the selection of HAR satellites' most beneficial applications, such as satellite communications and other domains that would benefit from the use of mega-constellations.



4 | When could it be useful?

SatCom constellations

SatCom is a key satellite application with strategic importance and immense commercial potential and encompass a wide variety of activities, ranging from (secure) brodband connectivity, to Direct-to-Device communications (D2D), and IoT. All of these are also viable use cases for HAR configurations. The HAR design fosters the development of cheaper and faster to launch constellations. This competitive edge made this concept appealing to several profit-centred players. Hence, it is no surprise that the majority of HAR configurations currently operational can be found in this domain.

Current well-known examples of HAR used for operational broadband constellations include SpaceX's Starlink, which aims to provide global broadband internet coverage via a constellation of thousands of satellites deployed in LEO, and AST Mobile's upcoming BlueBird constellation, which directly succeeds the aforementioned BlueWalker 3 and is designed to D2D connectivity.

With an aspect ratio of around 16, Starlinks have been launched in a stacked formation since their first launch in May 2019. The second generation of Starlinks have been shown to be even larger than the previous ones, while maintaining a similar aspect ratio in order to be stacked inside a Starship payload fairing.

The BlueBird constellation, on the other hand, will be composed of over 100 HAR satellites with extremely large, deployable array antennas, and will provide D2D connectivity to its customers. They are not stackable, but fold onto themselves in order to fit within the launcher fairing. Therefore, the BlueBird constellation only makes use of HAR advantages once in orbit.

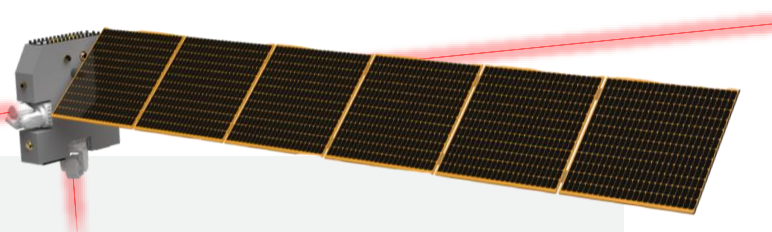
The Chinese government is developing its own broadband constellation as well, and it is called GuoWang. It is expected to consist of around 13,000 satellites of several different kinds. One of them, the SATware-CS200 is a HAR satellite being developed by HITSat at the Harbin Institute of Technology.

IoT constellations also already benefit from layout and stackability of HAR designs, as companies like SWARM and FOSSA Systems have deployed small, HAR satellites based on the CubeSat standard for IoT applications. This type of configuration facilitates the integration of multiple different IoT sensors, and their modularity and larger surface/volume ratios are perfect for the low-power requirements and missions of IoT satellites. The possibility of putting larger antennas and solar arrays, along with the stackability aspect of deployment, ensure that a HAR IoT constellation could be deployed quickly and operated for various applications.

Reflex's take on the HAR concept

Given the growing importance of secure broadband connectivity and the potential that the HAR design offers for this application, Reflex Aerospace developed its own Secure Broadband HAR constellation concept as part of this ESA study, which is displayed on the next page. On the pages thereafter, a SAR satellite concept as well as a concept for a modular bus are presented.

4 | Secure broadband concept by Reflex Aerospace



Secure broadband concept vision

The following constellation concept was designed to enable secure point-to-point broadband connectivity from LEO, in line with European space goals and other, existing initiatives. The design is therefore strategically positioned to leverage geopolitical trends, as its numerous possible applications span secure connectivity for government and enterprise, bridging the digital divide in rural areas, supporting disaster relief and rapid response programmes, and other activities.

Concept description

The constellation is composed of 140 satellites that were designed to enhance stackability and mass production, reducing launch costs and expediting the launch programme. 60 satellites could be launched at once with Ariane 6, using a dedicated deployer system. The HAR surface area can be used for heat dissipation, and to fit solar arrays, optical Inter-Satellite Links (ISL) and phased array antennas. The solar array are mounted and deployed using a solar array deployment mechanism, to always face the sun and power the satellite.

Concept rationale and decision making

In order to reduce development time, the design mainly uses existing Commercial Off-The-Shelf (COTS) components. The surface area available was utilised to the fullest to mount large solar panels to fulfil system power requirements, inclusive of three laser terminals. Additional Thermal Control Systems (TCS) were included in the design to maximise thermal efficiency, while supplementary T-bone structures were added to ensure structural stability and counteract cantilever effects. Each satellite in the constellation was planned to be identical, facilitating mass production and enabling easy stacking during assembly on the launch vehicle.

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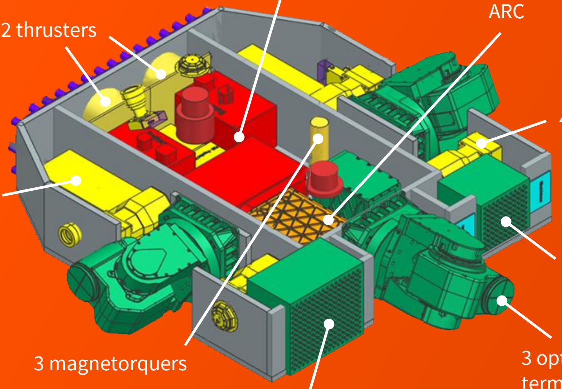
Satellite specifications

Mass: 220 kg

Geometry: $\frac{L}{t} = \frac{142\ cm}{24\ cm} = 6$

Systems:



Constellation design

Type: Walker

Satellites: 140

Orbital planes: 10

Altitude: 2000 km

Inclination: 72°

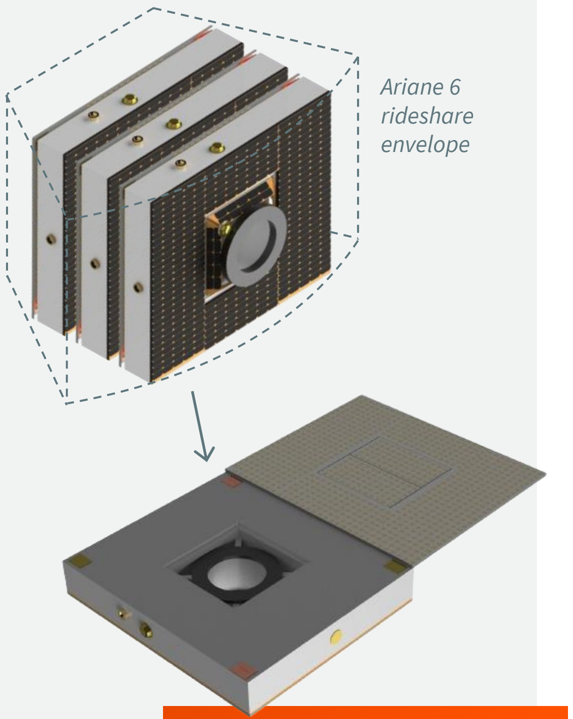
4 | SAR satellite concept by Reflex Aerospace

SAR concept vision

The conceptualised configuration focuses on Synthetic Aperture Radar (SAR) applications. It leverages the stackability and large surface area of HAR to obtain a design that allows for several powerful satellites to be launched at once, to build a large constellation allowing for short revisit times. This combines the growing interest for EO data with the push for cheaper, faster NextSpace® satellite deployment, capitalising on the demand for remote sensing data in commercial and governmental initiatives such as scientific exploration, reconnaissance, marine applications, infrastructure monitoring, and disaster relief.

Concept description

Thanks to their HAR design, up to three satellites can be stacked within a single rideshare slot, reducing launch costs and maximising operational responsiveness. The concept also uses COTS components to ensure cost-effectiveness while adhering to HAR design ratio goals. Its capacity to fully leverage the available large flat surface is facilitated by the use of deployable SAR antennas.



Concept rationale and decision making

The satellite was designed to leverage the complete surface area for efficient thermal radiation and optimal mounting of SAR antennas. The main design challenges faced were those related to the complexity of deployable elements and the selection of the 15” COTS standard separation interface ring. For this reason, body-mount-solar-arrays were chosen to avoid deploying additional elements beyond the SAR antennas themselves, streamlining operations and reducing failure points.

Satellite specifications

Mass: 110 kg

Geometry: $\frac{L}{t} = \frac{240\ cm}{31\ cm} = 8$

Systems: Bespoke SAR P/L

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EO applications

HAR constellations could also play a significant role in the EO domain, as their characteristics could allow for a significantly higher temporal resolution. Reflex Aerospace designed a HAR constellation for EO implementing Synthetic Aperture Radar (SAR) technologies, capable of capturing high-resolution imagery regardless of weather conditions or daylight.

HAR configurations in VLEO would also greatly improve the performance of optical payloads for EO applications, achieving a higher spatial resolution or, alternatively, maintain performance at a fraction of the cost. This type of mission would not be devoid of challenges, as it would require robust AOCS and resistance to degradation due to atomic oxygen. Additionally, the higher temperatures present in the upper atmosphere require additional thermal regulation measures to ensure the correction functioning of infrared cameras.

The size of the optical payloads could also pose a challenge, as their large dimensions would add additional thickness, antithetical to the very concept of HAR. All things considered, using optical EO payloads on HAR satellites could have benefits, but might require significant innovation to mitigate the issues mentioned above.

4 | Modular bus concept by Reflex Aerospace

Positioning, Navigation, and Timing (PNT)

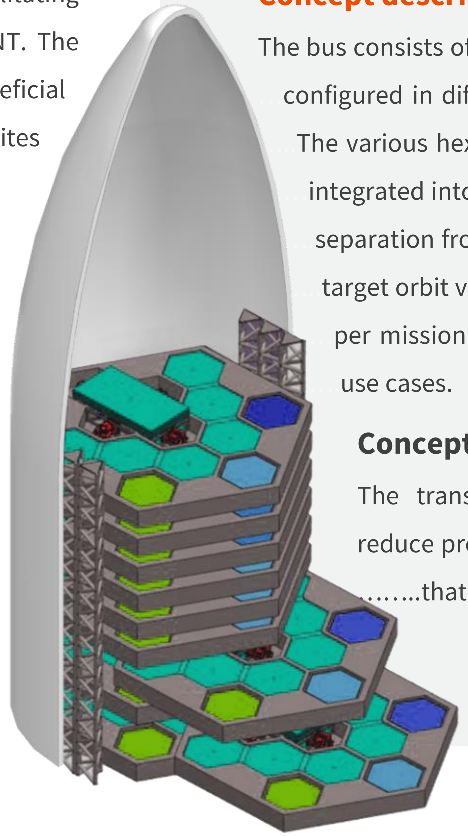
Another possible target use case for HAR satellites is PNT. The larger surfaces provided by HAR designs could help optimally position antennas and solar panels, boosting signal transmission. This enhancement would benefit traditional GNSS in MEO and GEO, while also boosting Lunar and LEO PNT capabilities.

Additionally, due to the reduced drag experienced by this type of configurations, perturbations in the residual atmosphere also have a reduced impact, facilitating orbit prediction and propagation. This is particularly beneficial for LEO PNT. The easier manufacturing and deployment of large HAR constellations is also beneficial to PNT (especially in LEO), as it makes it easier to deploy several satellites rapidly, improving accuracy.

Other use cases

HAR satellites could be used for many other use cases, including military applications such as stealth and reconnaissance, critical secure communication, or rapid response. Their versatility also offers options for scientific missions, such as studying the upper atmosphere, or deploying a radar constellation for astronomical observations. Military and scientific applications alike would greatly benefit from the numerous advantages that characterise HAR designs.

Reflex Aerospace developed a HAR modular bus concept, which could be used for various missions depending on the needs of the clients.



Modular bus concept vision

The idea behind this configuration was to boost the creation of a HAR ecosystem, by devising a HAR-specific transfer vehicle and standard to cater to bigger satellite platforms with a similar level of innovation and versatility. This modular approach enables independent launches at different orbits. It also sets a precedent for HAR satellite standards, streamlining design and enhancing adoption, all while covering a vast range of potential applications.

Concept description

The bus consists of a modular hexagonal transfer vehicle architecture with 13 hexagonal slots. Each slot can be configured in different ways, meaning the transfer vehicle can host multiple satellite types simultaneously. The various hexagons could also be merged to host larger satellites. The transfer vehicles are stacked and integrated into specific fairing structure in the way that each can slide out from the fairing with subsequent separation from the launch vehicle. Once separated from the launch vehicle they can attain the satellites' target orbit via their own propulsion system. The satellites then get deployed at their respective orbits, as per mission requirements. This configuration could also host the satellites developed for the previous use cases.

Concept rationale and decision making

The transfer vehicle's independent AOCS was designed to reduce propulsion unit requirements for the individual satellites ……..that get deployed.

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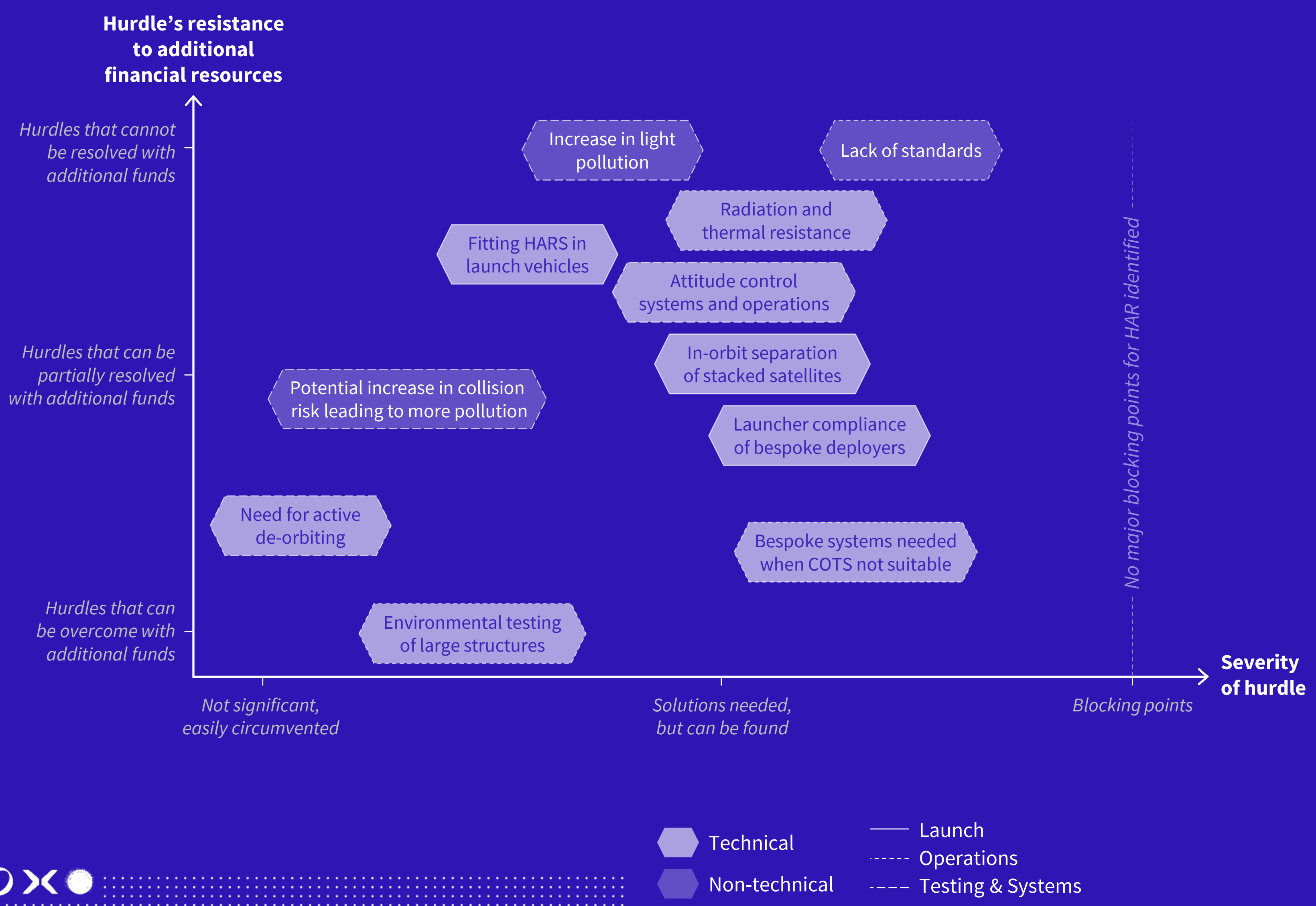
Specifications

Concept:	Hexagonal HAR transfer vehicle for HAR satellites
Geometry:	$\frac{L}{t} = \frac{430\ cm}{30\ cm} = 14$
Systems:	Varying by customer

5 | What are the challenges?



As seen in the previous sections of this report, the benefits of HAR satellites enable a plethora of different use cases and applications. However, as this concept is relatively new in widespread industry use, and the configurations present inherent technical challenges, there are some obstacles to be overcome in order to foster adoption.

These hurdles have varying levels of severity, and some of them have a higher resistance to additional financial resources than others, meaning they could not be mitigated simply by increasing capital expenditures. The non-technical hurdles in particular require more innovative solutions and outside-of-the-box creative thinking.

None of the challenges identified are insurmountable, meaning there are no major roadblocks preventing the adoption of HAR configurations. Nonetheless, certain hurdles, like developing bespoke components and deployers, will require more effort to overcome.

5 | What are the challenges?

Non-technical hurdles

There are a few non-technical hurdles to address in order to develop HAR satellites. One such challenge is the lack of standards, making it more challenging for smaller satellite manufacturers to develop HAR projects. Another non-technical challenge is light pollution, given that flatter configurations reflect more sunlight than traditional cubic satellites, impacting astronomers and the scientific community. There are currently no solutions that fully mitigate this issue, and existing (partial) solutions, such as SpaceX's VisorSats, showcase the need for innovative approaches beyond increased budgets. This hurdle is not a show-stopper with respect to adoption, but it definitely poses a social and moral dilemma when developing large constellations of HAR satellites.

Additionally, operational challenges include the potential increase in collision risk and space debris generation, mainly for larger satellites. However, these can be mitigated by ensuring proper propulsion and control systems are in place.

Technical hurdles

From a technical perspective, HAR configurations face hurdles like the need for bespoke systems and components, including batteries and fuel tanks, leading to higher development costs. Lack of standards also affects adapters and deployers, requiring satellite manufacturers to develop their own, potentially limiting launch options, as a specific adapter/deployer might not be approved by the launch vehicle provider.

Attitude and orbit control systems also pose challenges due to the irregular moments of inertia in HAR satellites, affecting stability and manoeuvrability. Developing functional AOCS that do not negatively impact the thickness of HAR designs could be a challenge for smaller configurations, raising the barrier of entry for smaller players. Additionally, functional AOCS are required in order to have active de-orbiting solutions, which are essential due to the lower drag experienced by these configurations.

Thermal management and radiation resistance are also concerns, as larger surfaces may experience uneven heat distribution. Innovative solutions may offer alternatives, however. Utilising reflective tape or metal heat sinks are two solutions commonly employed in the industry to reduce overheating and facilitate thermal dissipation.

Environmental testing, fitting satellites into launch vehicles, and in-orbit separation are additional technical challenges that require attention. Some of these obstacles require innovative solutions given they are constrained by physical and/or engineering limitations, while others could be overcome with targeted R&D, ideally through additional tailored funding.

While HAR satellites bring great potential, addressing both the technical and non-technical challenges is crucial for their successful adoption and integration into the broader space industry.

6 | How could ESA support?

In response to the hurdles identified, specific strategic initiatives could be established to advance the field of HAR satellites. These initiatives, organised into four main categories, comprehensively address the gaps in the current landscape. The options considered correspond to endeavours that would be challenging for industry players to undertake on their own.

Initiate projects

By supporting companies or consortia in the end-to-end development of specific HAR use cases or the development of a standard, ESA can significantly lower entry barriers for new players and encourage innovation in the sector. While there are risks, proper evaluation and guidance can mitigate them, making this group of initiatives an appealing option with broad industry impact.

Develop technologies

To overcome technological hurdles, ESA could support the development of specific building blocks for HAR satellites. These would include dedicated launch adapters, general components and systems, AOCS, and, optionally, measures addressing light pollution issues. These initiatives aim to benefit not only HAR designs but the entire scientific community, emphasising the importance of overcoming common challenges in satellite development.

Raise awareness

Enhancing connections among stakeholders is crucial for fostering innovation and adoption of HAR concepts. By promoting networking initiatives and establishing a public platform for data exchange, ESA could address the lack of transparency in the space industry. These initiatives would facilitate collaboration, partnerships, and knowledge sharing, providing a supportive environment for the growth of HAR technologies. The main challenge to overcome to implement these initiatives would be to convince potential competitors to collaborate for the greater good of the industry. It can be achieved with ESA's guidance.

Advance the industry

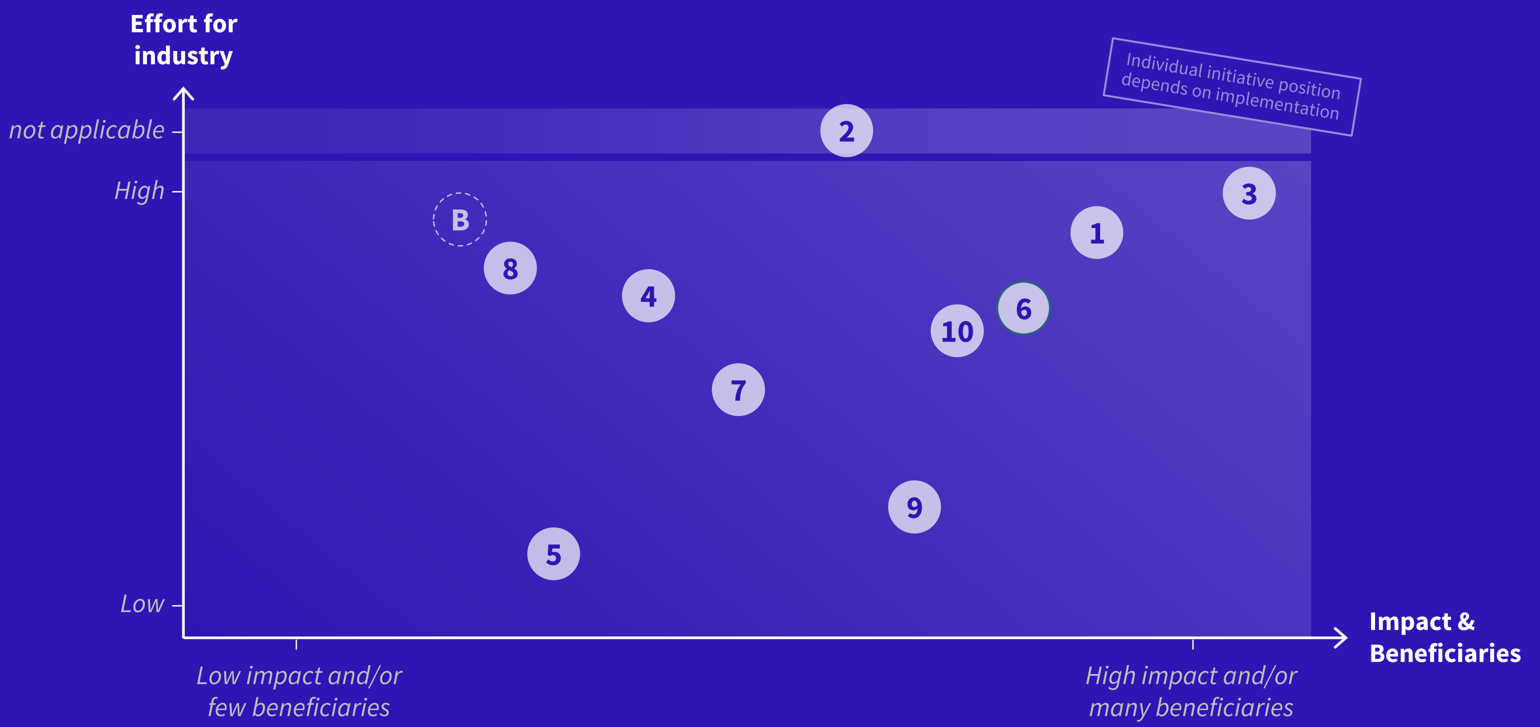
ESA could also aim to propel the space industry forward by supporting the provision of essential resources and facilities for European players. Initiatives include the provision of IOD/IOV and prototyping activities and fostering collaborations with other industries, such as automotive. These efforts not only benefit HAR technology but contribute to the overall advancement of the space sector. Garnering outside interest towards this novel type of technology could turn into a watershed moment for these configurations, as collaborations with larger, more mainstream industry partners around the world would help cement the space industry's position in everyday discourse.

6 | How could ESA support?

Devising the development programme

The evaluated initiatives could be combined to form a cohesive development programme for HAR technologies. After careful evaluation, ten initiatives were selected for the development roadmap, along with a bonus one that would only be used to complement the others. Options 1, 2, and 3 follow similar steps for end-to-end development, while options 4, 5, 6, 7, 8, 9, and 10 could be combined to develop different building blocks simultaneously. Notably, option 6 does not need to be chosen concurrently with option 3.

The bonus option B is a subset of option 4, as a platform for data exchange could only be implemented once there is an existing HAR ecosystem.



Initiate projects

1. Industry-driven HAR use case development
2. ESA-proposed mission leveraging HAR concept
3. Development of new HAR standard

Raise awareness

4. Promotion of networking initiatives

B. Bonus: Public platform for data exchange

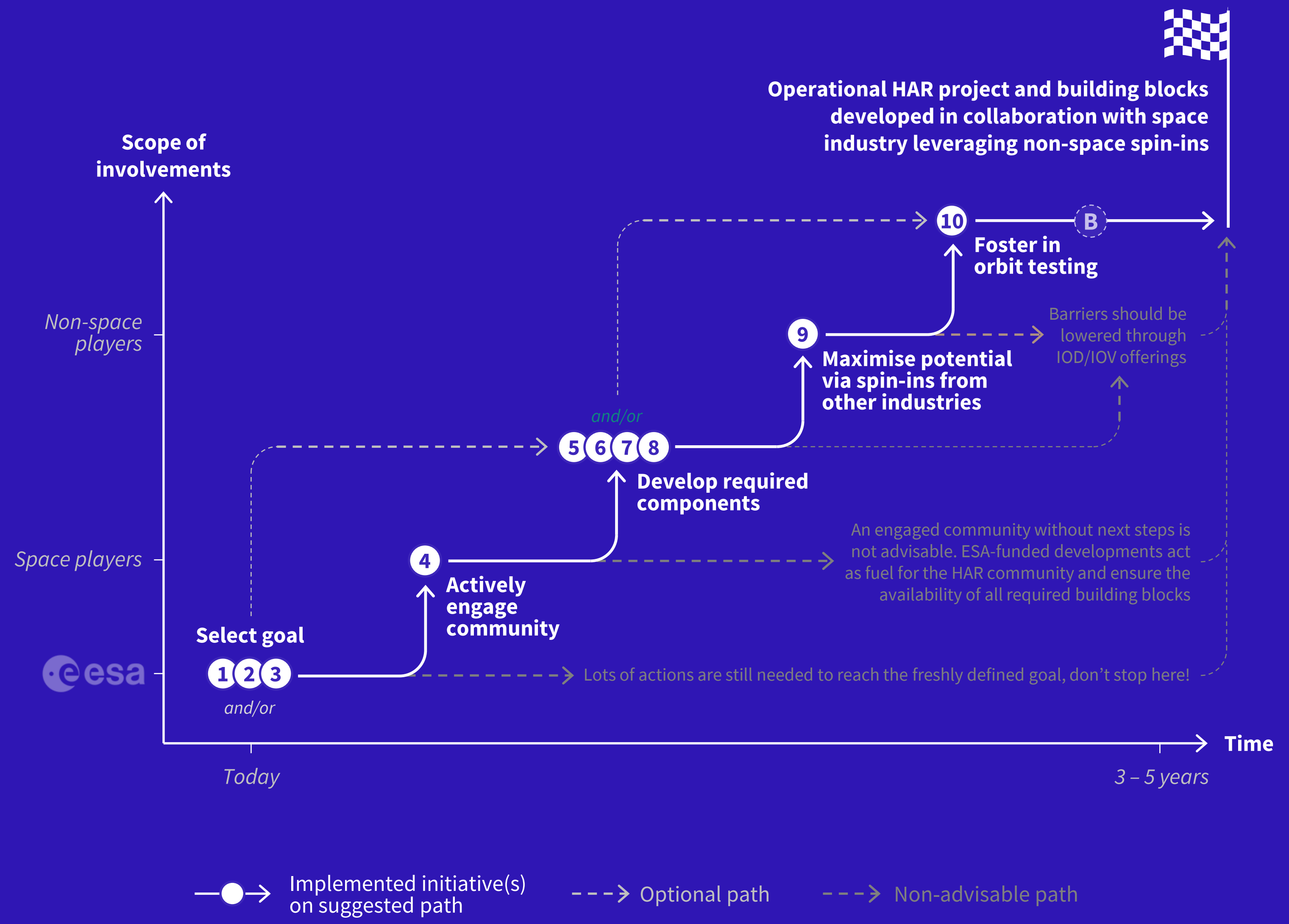
Develop technologies

5. Special launch adapter
6. General components and systems
7. AOCS & End-of-Life
8. Light pollution mitigation

Advance the industry

9. Spin-ins from other industries
10. Provision of IOD/IOV and prototyping activities

6 | How could ESA support?



Roadmap fostering the proliferation of HAR designs

The proposed initiatives and roadmap outlines the steps to take to facilitate the advancement of HAR satellite technologies, while fostering collaboration and positioning Europe at the forefront of space. It incentivises knowledge sharing, lowering entry barriers for European industry. The goal is to present a fast and reasonable roadmap for ESA to follow in case it decides to support the development of a full HAR concept.

Note that some of the steps of the proposed roadmap (and corresponding initiatives) could be skipped, except the first one, meaning the plan could be adapted depending on preference. Nonetheless, the recommended approach is the one that maximises collaboration and involvement of several players, both from within and outside the space sector.

The journey towards the readiness of a novel satellite concept and a linked flourishing ecosystem is not without challenges, but the potential benefits for the space industry and beyond make it a compelling endeavour to approach meticulously.

6 | How could ESA support?

Combining initiatives is the key to successful development

The idea behind the roadmap is to set up a fully fledged development programme, where the initiatives are combined to obtain multiple projects working in synergy towards the same goal. Taking as an example option 1, the Agency could start developing a use case with chosen industry partners.

Through the promotion of networking initiatives (option 4), the industry partners could then find other potential collaborators and investors to support it with its work. The industry needs identified via the networking initiatives could then guide ESA in issuing relevant bespoke ITTs (options 5-8), to entice other partner companies to develop HAR building blocks. The manufacturing and production phases could then be complemented by spin-ins from other industries (option 9), making the programme more appealing to smaller potential players with less infrastructure available. The IOD/IOV phase of the project, along with development of ITTs, could be funded via both new or existing funding programmes, such as the GSTP initiative.

There are multiple benefits to this approach, other than the ultimate result of obtaining a HAR concept. Having multiple players and moving parts does complicate the logistical aspects of this endeavour, but promotes knowledge sharing, collaboration and development, both within and beyond the European space ecosystem. Furthermore, this approach lowers the barrier of entry for smaller players, as the individual resources required would not be excessive, and maximises the potential of geo-return given the wide range of companies involved.

Many enablers already facilitate the implementation of this roadmap

Given the current state of the space industry, there are also many trends, enablers, and multipliers that could facilitate the establishment of the proposed roadmap:

- **Increase in use cases that could leverage HAR:** overall, the interest in HAR configurations has been growing steadily in recent years, as evidenced by companies like SpaceX and AST Mobile designing large constellations around these concepts. Furthermore, research in novel use cases (e.g., D2D, VLEO) means there is a growing market for HAR satellites and their peculiar characteristics. The rising number of large-scale constellations that are being designed which would also definitely benefit from the stackability of HAR designs.
- **Growing interest in sustainability in space:** given the attention that is currently being paid to de-orbiting and sustainability in space, more research is being put into developing satellite configurations that reduce the generation of space debris. The advantageous shape and reduced drag of HAR satellites facilitate de-orbiting.
- **Appeal of mass production:** the simpler design of HAR satellites facilitates manufacturing, in line with the industry's current focus on mass production and cost reduction. Additionally, the recent commercialisation and growing size of the space market have sparked interest from non-space players (e.g., automotive industry), whose facilities and experience could be leveraged to further facilitate manufacturing, testing, and production.

Taking advantage of these enablers and following the suggested timeline, a full HAR concept could be developed in just a few years if desired by ESA.

7 | Outlook for ESA member states

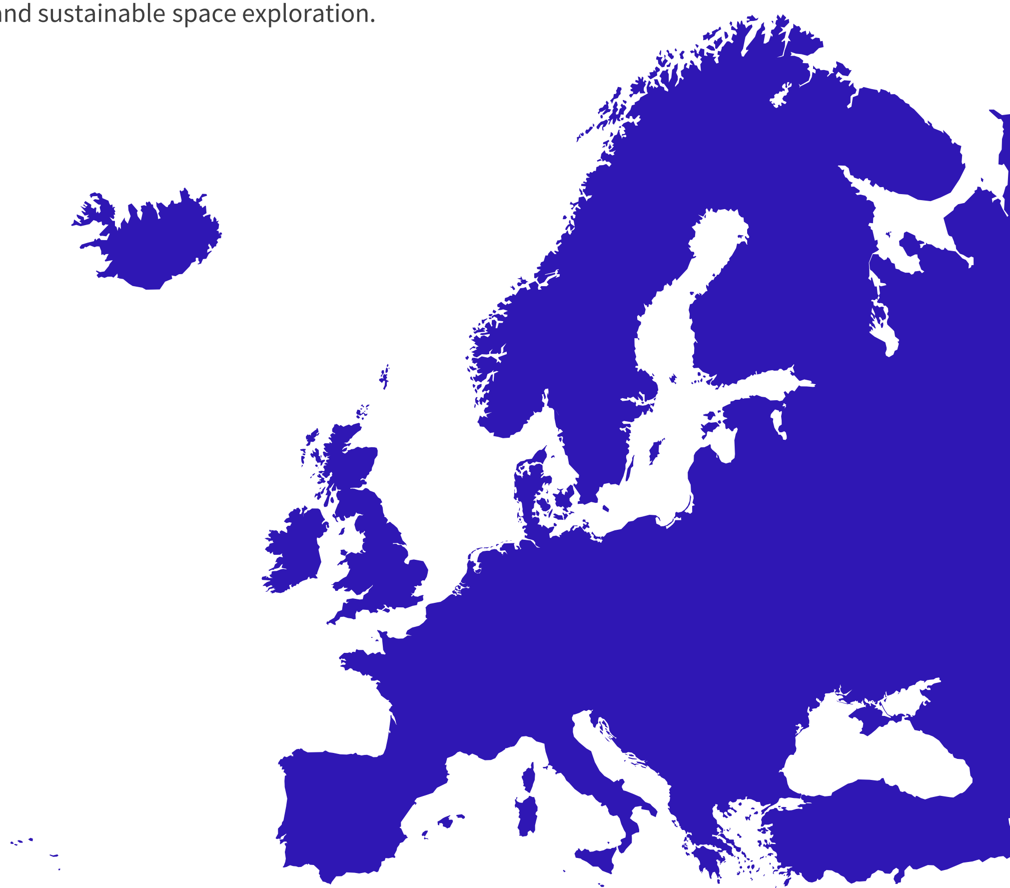
HAR development could be a watershed moment for Europe

HAR configurations have the potential to significantly influence the European space industry. Their cost-effectiveness, stackability, and streamlined manufacturing processes position HAR satellites as optimal choices for large constellations, offering a faster deployment rate compared to other alternatives. This economic advantage, coupled with enhanced connectivity and Earth observation capabilities, aligns seamlessly with Europe's strategic goals in connectivity and the wider space domain, fostering innovation and collaboration across diverse sectors.

Moreover, HAR designs cater to the evolving landscape of the commercial space industry and economy, characterised by a strong emphasis on agility, efficiency, and sustainability. The extended lifespan and simplified decommissioning processes associated with HAR satellites align perfectly with Europe's commitment to sustainability practices in space activities.

Europe and ESA member states could also leverage HAR configurations to explore new frontiers, such as Very Low Earth Orbit (VLEO), complementing the research already being carried out by major European players and redefining the boundaries of modern space missions.

This adoption of HAR technologies would not only position Europe and ESA member states as leaders in cutting-edge space solutions but also has the potential of becoming a catalyst for future European connectivity plans, facilitating the continent’s technological non-dependence. This could also attract increased interest and investment, propelling the region into a new era of innovation, economic growth, and sustainable space exploration.



We combine years of expertise in the space sector with exceptional business acumen

NOVASPACE

Global leading space consulting firm

Novaspace represents the combined strength of Euroconsult and SpaceTec Partners, a united force committed to promoting forward thinking and supporting decision-making for all space stakeholders. Drawing from Euroconsult's four-decade legacy of empowering industry leaders with strategic insights and SpaceTec Partners' innovative approach to management consulting in the space sector, we are positioned to deliver professional services that support programs with both commercial viability and societal impact.

Novaspace provides comprehensive, integrated service offerings to meet the evolving needs of the global space sector, offering strategic and technical perspectives for decision-makers in both private and public entities.

REFLEX AEROSPACE

Custom satellite platform builder

Reflex Aerospace is a NewSpace startup from Munich and Berlin offering rapid, dual-use, secure-by-design small satellite solutions. Our company leverages the latest techniques to modernise payload-centric satellite development and production, achieving significantly faster delivery times and enhanced reliability. We use algorithmic engineering and streamlined system design processes to enable lightning-fast innovation. With a team of over 40 employees and a combined experience of 40+ successful space missions, we are well-positioned to capitalise on the immense projected growth of the satellite manufacturing market.

We prioritise customer mission objectives and offer them the opportunity to get their payload to orbit without compromises.

INITIUM

Technical & business space consultancy

Positioned uniquely at the fringe of technology and business, Initium Space Consulting, through the experience of its founders, brings extensive knowledge in areas like space technology development, project management and implementation, documentation and space product assurance. We provide tailored solutions, seamlessly blending technical expertise with strategic insights aiming to support our clients in their space endeavor. Whether an established non-space company or a young start-up, our customers are driven by their wish to succeed in the ever-competitive space industry.

We can help. We speak Space.