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Realising the Ambitions of the UK's Defence Space Strategy

Factors Shaping Implementation to 2030

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Preface

This is a final report for a study commissioned by the Development, Concepts and Doctrine Centre (DCDC) in the UK Ministry of Defence (MOD) on behalf of the MOD Space Directorate. Its purpose is to analyse strategic, policy and capability choices facing the implementation of the new *Defence Space Strategy*. The study was conducted between January and May 2021 and had three core research objectives (ROs):

RO1. Mapping the overall decision space for implementation of the *Defence Space Strategy*.

RO2. Articulating the 'unique value proposition' of UK Defence in the space domain.

RO3. Preparing guidance to help the UK MOD, specifically the Space Directorate and the newly established Space Command, navigate upcoming capability management decisions around the 'own-collaborate-access' framework outlined in the 2021 *Integrated Review* and the associated *Defence and Security Industrial Strategy* (*DSIS*).

This report captures key findings related to all research objectives and is accompanied by a visual decision tool that presents a high-level approach to decision making in relation to the 'own-collaborate-access' framework, articulating potential options and the trade-offs related to them. Further detailed examination of capability management choices and good practices is available in the Interim Report for this project (PR-A1186-1), which supplements the analysis presented in Chapter 4 in this final report.

This report is intended primarily for the UK MOD and other UK Government audiences, as well as others interested in the space domain. This report will be of interest to strategy, policy and capability decision makers within Defence as well as wider cross-government stakeholders involved in delivering the overarching *National Space Strategy*, most notably the UK Space Agency (UKSA) and the Department for Business, Energy and Industrial Strategy (BEIS).

The study was undertaken by RAND Europe, which leads the Global Strategic Partnership (GSP) providing strategic, policy and academic support to DCDC. Part of the global RAND Corporation, RAND Europe is a not-for-profit research institute with a mission to improve policy making through robust research and analysis. RAND has 75 years of experience helping governments and militaries navigate complex choices in the space domain, beginning with the first ever published RAND study, which examined the options for a *Preliminary Design of an Experimental*

World-Circling Spaceship back in 1946.[1] Today, RAND conducts space-related research, analysis, consultancy and gaming for a variety of sponsors, including the UK MOD, Defence Science and Technology Laboratory (Dstl), various United States agencies (including the United States Air Force, United States Space Force and the National Aeronautics and Space Administration) and European, Australian and Japanese authorities.[2]

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1 RAND Corporation (1946).

2 For more information on the RSEI, see RAND Corporation (2021b).

Summary

This RAND research comes at a time of excitement, scrutiny, investment and change. The UK Defence space enterprise will soon embark on implementation of a new *Defence Space Strategy* in support of the overarching vision of the UK's first *National Space Strategy* to become a 'meaningful player in space'.[3]

Against this fast-moving and uncertain backdrop, there is a need for robust, evidence-based analysis of the challenges and opportunities facing implementation of the strategy. There is considerable potential for growth and transformation in the approach of the UK in general, or Defence specifically, to the space domain, which should bring benefits in terms of national security, prosperity and influence.

Defence is approaching the demands of strategy implementation over the coming decade from a relatively low baseline of existing capability – outside of the Skynet satellite communication (SATCOM) system and assets such as the radar installation at RAF Fylingdales, which forms an important node in the United States Space Surveillance Network (SSN), and the UK Space Operations Centre (SpOC) at RAF High Wycombe with its role in understanding and monitoring the space domain. It also has a largely untested set of new organisational structures and a limited pool of suitably qualified and experienced personnel (SQEP).

The UK has recently established a National Space Council (NSC) to help drive coherence across government, and the Ministry of Defence (MOD) has created both a 2*-led Space Directorate and a 2*-led Joint Space Command to direct and deliver the Defence contribution to the broader national space strategy and policy. These new structures hold promise of a more coherent approach to space capability management but will inevitably face challenges arising from the need to manage diverse interests.

In the language of the *Defence Command Paper* released in March 2021 to accompany the *Integrated Review of Security, Defence, Development and Foreign Policy*, space represents a domain of new 'sunrise' capabilities that may offer new ways of delivering strategic advantage in a competitive age; arguably without many of the problems and constraints of having to manage the political, financial and bureaucratic sensitivities of deleting or replacing older 'sunset' capabilities that are approaching obsolescence.[4]

3 HM Government (2021a).

4 MOD (2021b).

Entering this comparatively unfamiliar and uncharted territory, the Defence space enterprise should approach upcoming decisions about strategy implementation by remembering:

- **Space is both similar to and distinct from other domains.** Space shares overlaps with other defence domains and sectors of the economy (see Chapter 2) but also demonstrates important differences. This necessitates a tailored approach to appraisal and decision-making that draws on lessons and models from elsewhere, but also reflects the unique characteristics of space and the various trends shaping developments in this domain.
- **In space, the UK is strong in some areas and weak in others.** The UK benefits from substantial strength in certain niche areas of a governmental, industrial and technological nature (see Chapter 3). Its sovereign capabilities, however, are considerably more limited in other areas and its national space budget is notably smaller than those of peers including France, Germany and Japan. Starting from this relative 'blank slate' is an opportunity but also demands an 'eyes open' approach and ruthless prioritisation of finite resources to maximise the returns on investment and mitigate risks.
- **The UK has a range of options for developing new capability.** The *Integrated Review* and associated *DSIS* have set out a high-level approach to capability management choices that is based on an 'own-collaborate-access' framework (see Chapter 4). There are different benefits, costs, risks, and trade-offs associated with choosing when and where to 'own' sovereign capability, 'collaborate' with other nations or industry on cooperative programmes, or 'access' space products and services from commercial providers. In making these trades, Defence should systematically consider the different options available to it as well as the levers it has at its disposal to influence programme outcomes. Examples of these levers, such as agile acquisition strategies, are included in the report as well as a decision support tool in Annex C to help navigate these complex trade-offs.

Given this complexity, implementation of the *Defence Space Strategy* will be a challenge, but one with the potential for outsized returns – not only in terms of strategic and operational advantage, but also wider benefits to the UK's influence and prosperity. UK Defence is not short of levers of influence in the face of this complex challenge. It has a finite 'window of opportunity' for embracing real change, given strong political buy-in and increased financial investments in space, and can build on the reforms already made since the Forber Review in 2019 and learn lessons from the approaches taken in other domains.

Defence is also not alone in this endeavour. As reflected in the establishment of the NSC and the cultivation of a close relationship between the MOD and UK Space Agency (UKSA), there is a growing recognition across Defence and UK Government of the need for a holistic national approach to space strategy. Every other space faring nation – even the United States – find themselves on a similar trajectory. Some are simply further along than others. There will, therefore, be opportunities to work closely with allies, partners, and industry to share lessons learned, and identify both alternative paths and shortcuts for the UK to take, and pitfalls for it to avoid.

To promote the cultivation of this new Defence space enterprise and culture (which is based around evidence-based and robust decision making, experimentation, innovation and continuous learning), this report presents the findings from a short RAND study on key issues for the MOD Space Directorate and the Space Command to consider as they confront the prospect of implementing the *Defence Space Strategy*. This research and analysis is intended to guide how Defence navigates the choices it will face during the course of implementation, and to ensure it can act with greater knowledge and confidence as it attempts to embrace new ways of doing strategy and policy making reflecting the idiosyncrasies of the space domain.

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Abbreviations

ADR	Active Debris Removal
ADS-B	Automatic Dependent Surveillance - Broadcast
AIS	Automatic Identification System
APNT	Alternative Position Navigation and Timing
CDEL	Capital Departmental Expenditure Limits
CNI	Critical National Infrastructure
COCO	Contractor-Owned, Contractor-Operated
COEIA	Combined Operational Effectiveness Investment Appraisal
COGO	Contractor-Owned, Government-Operated
CONOPS	Concepts of Operations
COTS	Commercial Off-the-Shelf
CSpOC	Combined Space Operations Center
DCDC	Development, Concepts and Doctrine Centre
DEW	Directed Energy Weapon
DLOD	Defence Lines of Development
DME	Distance Measuring Equipment
DOD	Department of Defense
DSIS	Defence and Security Industrial Strategy
Dstl	Defence Science and Technology Laboratory
EDA	European Defence Agency
ELNS	Enhanced Link Navigation System
EM	Electromagnetic
ESA	European Space Agency
EU	European Union
DARPA	Defense Advanced Research Projects Agency
FOA	Freedom of Action
GEO	Geosynchronous Equatorial Orbit

GFI	Government Furnished Information
GOCO	Government-Owned, Contractor-Operated
GOGO	Government-Owned, Government-Operated
GPS	Global Positioning System
GSP	Global Strategic Partnership
HAPS	High Altitude Pseudo-Satellite
HM Government	Her Majesty's Government
IOC	Initial Operating Capability
IP	Intellectual Property
ISR	Intelligence, Surveillance and Reconnaissance
LDACS	L-band Digital Aviation Communication System
LEO	Low-Earth Orbit
LORAN	Long Range Navigation
MBS	Metropolitan Beaconing Systems
MLAT	Multilateration
MOD	Ministry of Defence
MOSA	Modular Open Systems Architecture
MOTS	Modified Off-the-Shelf
NAO	National Audit Office
NATO	North Atlantic Treaty Organization
NSC	National Space Council
OA	Operational Advantage
PFI	Private Finance Initiative
PNT	Positioning, Navigation and Timing
R&D	Research and Development
RAeS	Royal Aeronautical Society
RAF	Royal Air Force
RDEL	Resource Departmental Expenditure Limits
RN	Royal Navy
RO	Research Objective
RQ	Research Question
RSEI	RAND Space Enterprise Initiative
S&T	Science and Technology
SATCOM	Satellite Communications
SDA	Space Domain Awareness
SME	Small and Medium-sized Enterprises
SpOC	Space Operations Centre

SSA	Space Situational Awareness
SST	Space Surveillance and Tracking
SQEP	Suitably Qualified and Experienced Personnel
SWaP	Space, Weight and Power
TACAN	Tactical Air Navigation
TDOA	Time Difference of Arrival
TLB	Top-Level Budget
TT&C	Telemetry, Tracking and Command
TTP	Tactics, Techniques and Procedures
UAS	Unmanned Aircraft Systems
UAE	United Arab Emirates
UAT	Universal Access Transceivers
UKSA	UK Space Agency
UN	United Nations
US	United States

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Within RAND, the study team benefitted greatly from analytical workshops and internal consultations with experts involved in the RAND Space Enterprise Initiative (RSEI).

The team is particularly grateful to Brigadier General (retired) Bruce McClintock, the Head of the RAND Space Enterprise Initiative, for his time and insightful contributions to analysis workshops conducted as part of this study. The team are similarly thankful to Dr Julia Muravska, who coordinates RAND's Defence Industry and Acquisition workstream in Europe and contributed additional insights from previous research for the UK Space Agency, and to Dr Pau Alonso Garcia-Bode, formerly of the European Space Agency (ESA).

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1 Introduction

This introductory chapter provides a brief outline of the study context, its purpose and research approach, as well as an overview of the structure of this report.

1.1. Recognising space as an operational domain demands reflection on how to adopt a holistic approach within UK Defence and beyond

In less than a decade, the perception of space within the UK Government has shifted from a predominantly technological domain to an operational one. Space has been gaining recognition as a critical enabler not only of military operations across multiple domains (including land, air, sea, cyber and electromagnetic (EM)), but also of everything from critical infrastructure, basic services, the economy and financial systems, to modern ways of digital living and the UK's efforts to combat climate change.[5]

Several organisational and structural changes have enabled this shift, both within the Ministry of Defence (MOD) and across Whitehall. In 2019, the Forber Review identified a need for a more coherent approach from Defence to a domain that is becoming increasingly 'congested, contested and competitive', given the rapid pace of change in technology, the threat landscape and global space markets. To drive this coherence and support the MOD's wider ambitions to promote 'multi-domain integration', a 2*-led Space Directorate has been established to consolidate Defence space strategy and policy, coordinating within MOD, cross-government, and internationally. Since April 2021, this has been accompanied by a new 2*-led joint Space Command, responsible for space operations, space workforce and capability development.

In recognition of the need for a more integrated approach across government – and in conjunction with relevant allies, partners, industry and academia – a National Space Council (NSC) has also been established, while the MOD and UK Space Agency (UKSA) are currently working with other departments to develop the UK's first *National Space Strategy*. This will be supported by a *Defence Space Strategy*, which sets out how Defence space policy, operations and capabilities contribute to broader national objectives.

To realise its growing ambitions, Defence will use a share of its broader £6.6b research and development (R&D) budget to support space

5 MOD (2010, 2017a, 2018b); UK Space Agency et al. (2014).

capability development[6], including £1.4b over the next ten years to help[7]:

- Establish the new Space Command, with expected Initial Operating Capability (IOC) in 2022
- Enhance space domain awareness (SDA)
- Establish and mature the National Space Operations Centre (NSpOC)
- Develop a UK-built intelligence, surveillance, and reconnaissance (ISR) capability
- Develop a supporting 'digital backbone' in space
- Create a Space Academy to enhance the skills and talent pool in the Defence space enterprise.

The recognition of space as an operational domain and the policy and funding commitments highlighted above necessitate an evidence-based and coherent approach to implementation of the *Defence Space Strategy* and related policies. Effective implementation of these will require: (1) a holistic understanding of the principal factors, trends and developments shaping the decision space; (2) a sound appreciation of the strengths, weaknesses, opportunities and threats related to the UK Defence space enterprise (including Government, industry and academic actors); and (3) a solid conceptual framework to guide capability management choices.

1.2. This independent study collates evidence to identify key factors that will inform the future implementation of the *Defence Space Strategy*

Though it lacks the breadth and depth found in other more established domains (e.g. centuries-old debates over land and maritime strategy, or over a hundred years of research on airpower), there is a growing body of literature on space strategy,[8] space policy and the use of space by different actors with various ambitions.[9] There is, however, a distinct lack of English language literature covering these topics from the perspective of a non-superpower (i.e. not the United States, which dominates the debate as both a producer and topic of research). Analyses of strategy, defence and security policy are complemented by a broader corpus of literature covering space as a technological domain (which discusses the various technical challenges and opportunities of space, the laws of astrophysics and orbital dynamics and their implications for practical deployment of platforms and systems into space), or as a growing commercial market.

It would be beyond the scope of this study to identify all the relevant publications in this area or revisit all the major debates, even just those from this century. Yet, the *UK Military Space Primer* (2010) provides a useful port-of-call for much of the relevant open-source information pertaining to these issues.[10] There

6 HM Government (2021a).

7 MOD (2021b, 2021c).

8 Selected examples of English language publications from this century include: Bowen (2020); Deudney (2020); Dolman (2001), Klein (2006, 2019); Sadeh (2013); Wright (2019).

9 Selected examples of English language publications from this century include: Coletta & Pilch (2009); Handberg & Li (2012); Harding (2017); Hoerber & Forganni (2020); Hoerber & Lieberman (2019); Sadeh (2004), Sheehan (2007), Townsend (2020); Wang (2013).

10 MOD (2010).

is also a significant volume of literature on different space missions, the space economy and commercial trends in space, many of which are covered in a variety of global space trends reports (e.g. by specialist market intelligence firms, management consultancies and financial companies). Finally, there is, of course, a considerable amount of literature and body of cinematography belonging to popular genres, including fiction and science fiction. This spans many decades and imaginatively explores all of the aspects of space highlighted above – if with ambivalent results, increasing public interest in space but also potentially warping expectations about what may or may not be possible, for example by conjuring unrealistic visions of a near-term *Star Wars*-like conflict in space.

While it is useful for decision makers in UK Defence to understand the development of strategic thought and policy options adopted by various space powers over the last two decades, it is even more important to identify what is most relevant from the unique perspective of the UK as a medium space power with its own attributes, relationships and idiosyncrasies. It is the aim of this short independent study to provide such a digest of those factors that will shape implementation of the UK's *Defence Space Strategy* in the coming years, and that should, therefore, be regularly monitored and understood by those in charge of delivery. In addition, this study also provides a high-level overview of the UK's strengths and weaknesses in space, which will shape the Government's policy options in the next five to ten years, affecting the ambition versus feasibility calculus of different choices regarding whether or not to 'own', 'collaborate' on or simply 'access' different capabilities required by Defence, in and through space.

This short unclassified report is intended to complement, not duplicate, the detailed analyses that are readily available of UK industrial space capabilities and the UK space sector more generally,[11] and the various studies and analyses conducted internally by the Defence Science and Technology Laboratory (Dstl) and others within the MOD on current and future space operational challenges, organisational structure and space capabilities – many of which cannot be cited here directly due to their classification.

1.3. This study provides an initial map of the decision space, with future deep-dives and analyses necessary to populate this in more detail

This study has three core research objectives (ROs), each of which is broken down into specific research questions (RQs) as summarised in Table 1.1 overleaf.

Data collection for this study was conducted between January and April 2021, consisting primarily of reviews of academic publications (some of which are included in Section 1.2 footnotes), open-source literature, Government Furnished Information (GFI) and published and unpublished RAND space-related studies, along with additional evidence collected via stakeholder interviews with senior MOD stakeholders. The report's findings also draw on several decades of previous RAND research and defence acquisition reviews for the UK MOD and other allied governments in the United States,

11 E.g. the London Economics (LE) or, most recently, know.space series of 'Health of the UK Space Sector' reports. See know.space (2021); LE (2019).

Table 1.1. Research objectives and related research questions

Research objective	Subordinate research questions
RO1: Mapping the overall decision space for implementation of the *Defence Space Strategy*	RQ1: What factors, both endogenous and exogenous, will directly shape Defence policy decision making in relation to space? RQ2: Which factors should be prioritised as those that have greatest influence on Defence space policy decision making? RQ3: How can the UK MOD work across Government and with other relevant actors (e.g. space industry and academia) to align priorities in Defence space policy decision making?
RO2: Articulating the unique value proposition of UK Defence in space	RQ4: What are the high-level strengths, weaknesses, opportunities and threats (SWOT) of the UK Defence space enterprise? RQ5: What are the unique aspects of the value proposition of the UK in relation to a) developing its own sovereign space capabilities; and b) collaborating with allies and partners on capability development? RQ6: What are the high-level characteristics of space capabilities, strategy and policy of key potential partners of UK Defence in space? Where does the UK present a complementary proposition? Where does it present a competing or duplicative proposition?
RO3: Designing a decision support tool to help determine the UK MOD's capability management approach (i.e. guiding the decision on 'own, collaborate, access' options)	RQ7: How should the MOD conceptualise the considerations that would drive the MOD towards one of the three options for capability development – 'own, collaborate or access'? RQ8: How should the MOD conceptualise the risks and trade-offs associated with the different capability management options? RQ9: What recommendations can be put forward?

Source: ROs and RQs provided by Development, Concepts and Doctrine Centre.

Europe and Australia,[12] along with a series of internal workshops with interdisciplinary experts from across the RAND Space Enterprise Initiative (RSEI), a global hub for RAND's space-related research.[13] The study team used various clustering and mapping techniques and processes, utilising a virtual whiteboard software 'Mural' to facilitate the workshop discussions remotely given the constraints imposed by the COVID-19 pandemic.

Given the combination of a vast research area and a limited timeframe for conducting the research, it is important to note a few caveats in relation to the outputs presented in this report:

- The analysis presented here draws primarily on open-source data and a limited amount of GFI.
- It is unclassified and hence does not present detailed information on UK defence

12 For more information on RAND research on military capabilities and acquisition, see RAND Corporation (2021a) for its published studies.

13 For more information on RSEI, see RAND Corporation (2021b).

space capabilities, defence tasks or concepts of operations (CONOPS), nor on those of other countries.

- The study team consulted stakeholders from within the MOD and academia and gathered input through virtual attendance at various relevant events, most notably the Royal Aeronautical Society's (RAeS) President's Conference: UK in the 2020s - An Emerging Space Power (May 2021). However, further engagement with other stakeholder groups such as space industry and academia will be needed for in-depth exploration of issues highlighted in this report.
- The study team had sight of the draft *Defence Space Strategy* throughout the course of the study but acknowledges that there may be changes to the final text. The study team, however, closely examined the broader stated UK policy ambitions related to space – as recently articulated in the 2021 *Integrated Review* and the accompanying *Defence Command Paper* – and is confident that the findings presented here will remain consistent with the content of these published documents.

1.4. This report comprises a series of core chapters, along with an annex containing a practical decision support tool

This report represents the final deliverable for this RAND study. The core chapters cover the following:

- **Chapter 2 – Factors shaping UK defence space decision making:** This chapter highlights the principal factors, trends and developments that are expected to shape future implementation of the UK's *Defence Space Strategy*.
- **Chapter 3 – The UK value proposition in space:** This chapter identifies the high-level strengths, weaknesses, opportunities, and threats pertaining to UK space capabilities, policy, and practice to inform the articulation of the UK's 'value proposition' in space, particularly for collaborative partnerships. This chapter is accompanied by Annex B, which includes high-level summaries of strengths of selected allies and partners in terms of their space strategy, policy and capability.
- **Chapter 4 – Identifying principles for implementing an 'own-collaborate-access' approach:** This chapter provides a structured overview of the key considerations related to capability decision making along the framework of 'own-collaborate-access'. It is accompanied by Annex C, which includes a decision support tool – a conceptual framework for guiding 'own-collaborate-access' considerations with regards to future Defence space capability management choices.
- **Chapter 5 – Conclusions:** This chapter draws together overarching conclusions and suggests areas for further reflection and research.

In addition, a full bibliography is provided, along with a list of the interviewees consulted during the research, where these have not requested anonymity.

2 Understanding factors shaping decision making in space

This chapter provides a brief overview of the principal factors shaping the decision-making space for implementation of the UK *Defence Space Strategy*. This analysis is intended to triangulate and validate the contextual elements of the MOD's draft strategy, along with the overarching *National Space Strategy*. As such, much of its contents should be familiar to a specialist and space-literate audience, but useful to others (e.g. generalists within the civil service or military, or members of the public) who are seeking to improve their contextual understanding of trends in the space domain.

2.1. Various factors will shape UK defence space policy, requiring in-depth analysis and understanding to appreciate their true impact

Policy and decision making in the space domain already is and will continue to be shaped by a variety of exogenous and endogenous factors. 'Exogenous' factors comprise those external developments over which the UK Government has limited direct control and influence. Examples include:

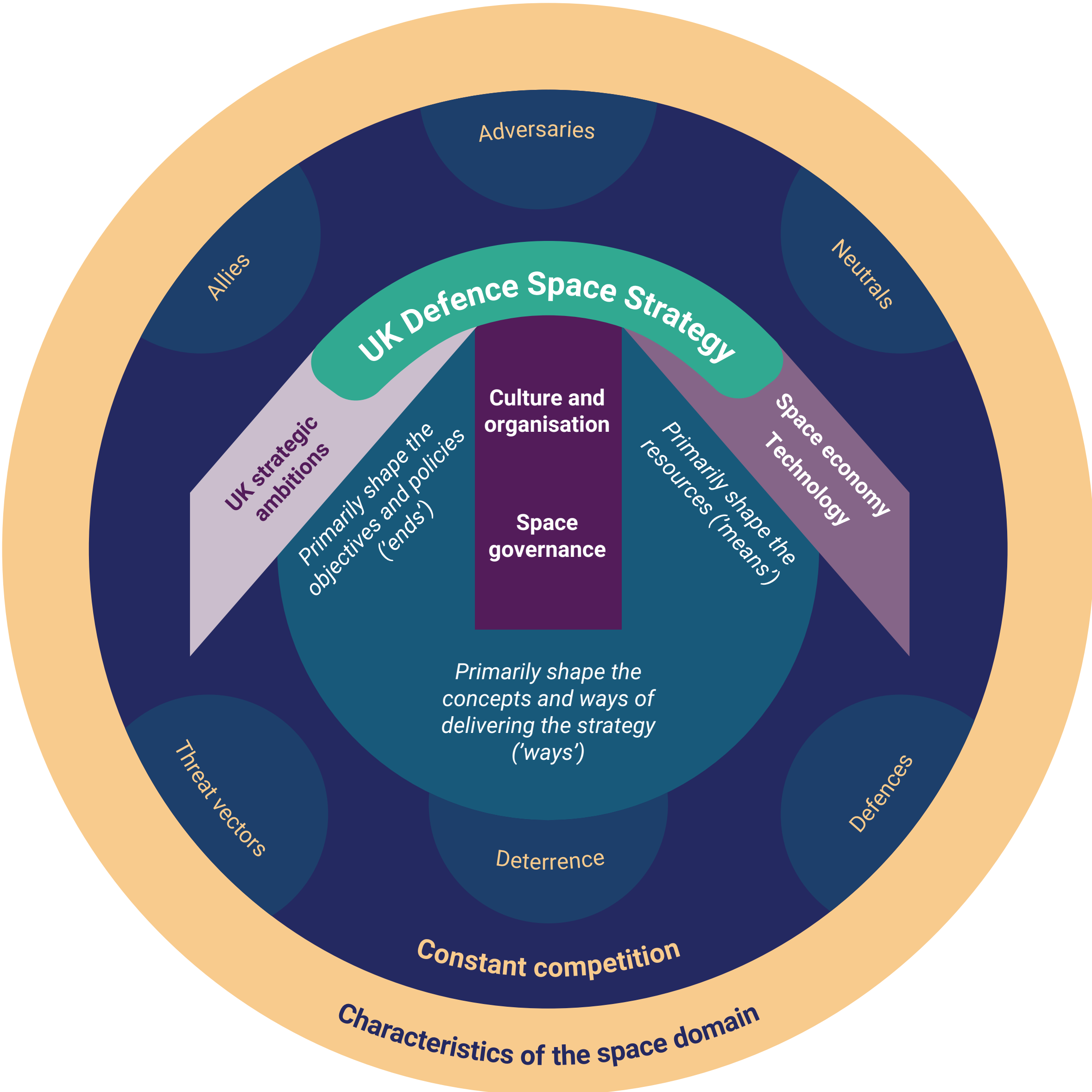
- The physical characteristics of the space domain (e.g. orbital mechanics, radiation).
- Developments in the space-related strategy, policy, concepts, doctrine and capabilities of the UK's allies, partners as well as adversaries and neutrals, including civil and commercial actors.
- Changes in the natural hazards and human-made threats to UK space assets and activities.

'Endogenous' factors, on the other hand, capture those internal trends and developments that the UK Government can shape and influence, albeit to varying degrees. Examples include:

- The UK's strategic and policy ambitions in and through space
- Space culture and organisation
- Space governance
- Space economy
- Adoption of new space technologies and operating models through innovation.

These principal factors were identified through review of open-source literature, GFI and past RAND space-related research, and were iteratively grouped, challenged and validated during internal workshops with experts within the RAND Space Enterprise Initiative. Figure 2.1 provides a simplified depiction of how these factors shape the *Defence Space Strategy* in terms of its objectives ('ends'), concepts and approaches to delivering the strategy ('ways') and resources ('means'). It can, of course, be argued that all factors somehow influence all three building blocks (ends,

Figure 2.1. Simplified depiction of exogenous and endogenous factors



Source: RAND Europe analysis.

ways and means) to some degree; indeed, they are also interrelated and influence each other in a complex, dynamic and sometimes unpredictable manner. The purpose of this simple graphic is therefore not to depict all these complexities.

The following sections provide a more detailed elaboration of each of these factors, highlighting the key aspects of each factor to be studied and understood by decisionmakers in the UK Defence space enterprise.

2.2. The space domain has unique characteristics which need to be understood to avoid taking misleading lessons from other domains

There are three broad fundamental differences between the space domain and other domains:

- **Space has a unique role as an enabler,** underpinning the vast majority of Defence operations, enabling activity in other domains (land, maritime, air and cyber and EM) and delivering decisive advantage to warfighting capabilities. By the estimate of some Defence officials interviewed for this study, a considerable proportion of warfighting capabilities are reliant on space in one way or another.[14] There are similarly substantial dependencies on space across wider (civilian) end users and critical national infrastructure (CNI), and close synergies with the cyber and EM domain in terms of providing the information architecture upon which modern society and the digital economy depend.
- **Space represents a 'dual-use' arena where both civilian and military actors are highly active,** pursuing a variety of strategies driven by political, scientific, commercial, or other interests. The stated ambition of the Outer Space Treaty (1967) is to promote the peaceful and shared use of space as the 'province of all [hu]mankind', and many governments and civil society actors are active in campaigning to avoid the weaponisation of space (though the Treaty only prohibits the testing or deployment of weapons of mass destruction). While the UK and others have legitimate defence and security interests in space, this operational domain must also be shared with various civil and commercial stakeholders using 'dual-use' satellite and launch technologies who may have overlapping or divergent interests. This includes stakeholders across UK Government.
- **Space has unique and challenging physical characteristics** that must be well understood to appreciate the opportunities as well as challenges it presents for military operations and capabilities (just as there are unique idiosyncrasies to operations elsewhere, e.g. in cyberspace or underwater).

These characteristics support arguments for not only differentiating space as a separate operational domain (as NATO has recognised since 2019), but also for adopting novel approaches to UK Defence space strategy, policy and capability development. These should be informed by lessons learnt from other domains, but unrestricted by their (sometimes cumbersome) legacy processes, cultures and mindsets.

Physical characteristics of space domain

Most countries and commentators recognise space as beginning 100 km above mean sea level, the so called 'Kármán line', roughly the altitude where the atmosphere is so thin that aerodynamic lift is no longer viable to maintain altitude[15] and where objects pass from the 'realm of aerodynamics' to the 'realm of astronautics'.[16] Here, the forces of lift, weight, thrust and drag act differently on aircraft/spacecraft and need to be well understood to

14 Interviews with RAND Europe, 2021.

15 Drake (2018).

16 MOD (2010).

appreciate the challenges of both placing and keeping assets (e.g. satellites) in orbit for long periods of time as well as for manoeuvring or timely de-orbiting.[17]

Space is also defined by a deeply hostile environment that is marked by a vacuum, punishing extremes in temperature, and radiation that poses a danger to both organic life and electronics. Though space is not empty, there are typically vast distances between celestial bodies. As such, there is much less in the way of 'terrain' to hide behind or manoeuvre around, compared to operations on Earth, and – for the near term at least – no human settlement besides those astronauts aboard the International Space Station (ISS).

Instead, gravity is a key consideration. In addition to understanding the basic differences between the air and space domains in terms of aerodynamics/astrophysics, it is also important to grasp the key characteristics of different orbits and how and why they can be useful for military (and other) purposes. Essentially, satellites need to be placed in the right orbit to fulfil specific roles and/or to fill a capability gap. The altitude, the orbital period (i.e. the time taken by the satellite to complete one orbit around the Earth) and the latitudinal and longitudinal position (i.e. relative to the Equator and poles) will determine the orbit's utility and efficiency for a particular role.

Different orbits offer particular benefits for space capabilities. These include, but are not limited to:

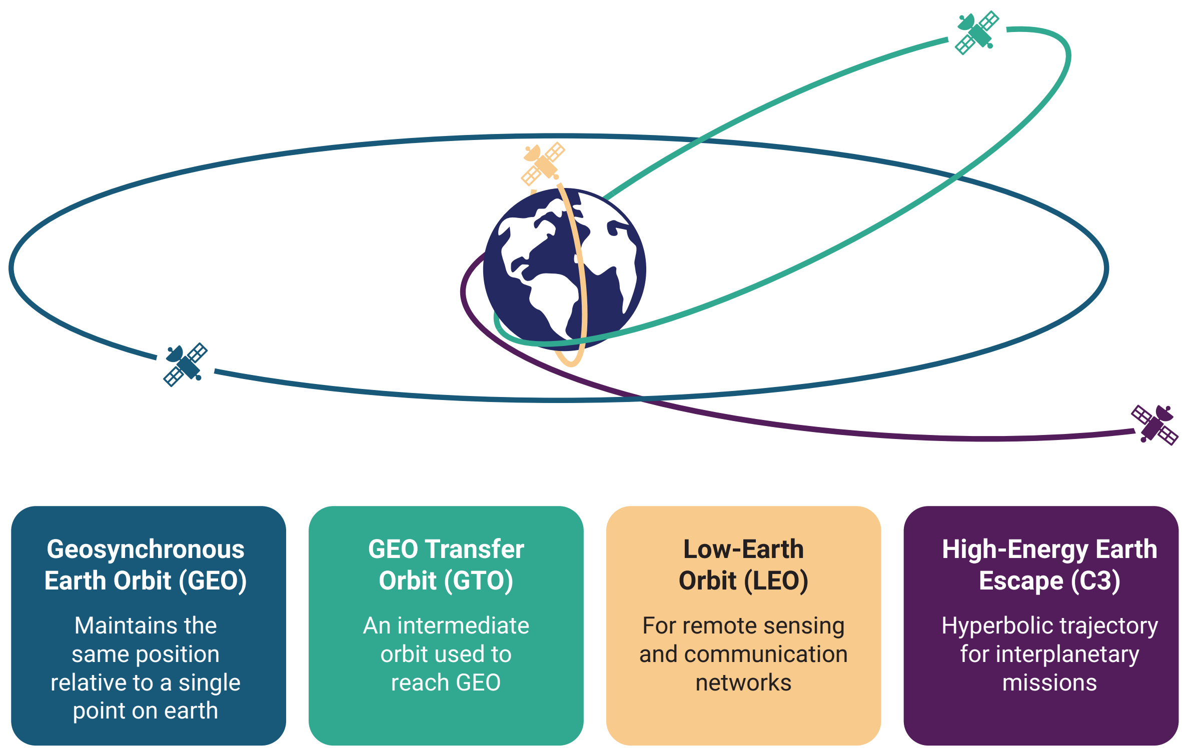
- **Low-Earth Orbits (LEO)** with benefits in terms of high resolution and signal strength due to relatively close proximity to Earth (with benefits for ISR in particular), but also some challenges (e.g. atmospheric drag, reduced gaze).
- **Medium Earth Orbits (MEO)** with utility for positioning, navigation and timing (PNT) and communications applications.
- **Geo-synchronous orbit** with an orbital period of 24 hours (same as Earth's rotation time around its axis), with a special case of 'highly prized' geosynchronous equatorial orbits (GEOs), which enable the satellite to point directly to the same place on Earth all the time – and thus appear stationary in the sky – making it very useful for communication, weather data and information collection and missile early warning applications.

Other significant orbits include: (1) polar orbits, enabling the quickest way to ensure coverage of the North and South Poles; (2) highly elliptical orbits (HEO), including Molniya orbits, enabling efficient coverage of high North or South latitudes thanks to long dwell times over these regions; and (3) Sun-synchronous orbits, with their unique benefits for satellites' solar power generation due to their constant exposure to the Sun. Looking decades into the future, it may also become increasingly relevant to talk about the strategic value of locations in and around Earth's Moon and cis-lunar space, as well as other celestial features such as the Lagrange points (e.g. between the Earth and the Moon, or between the Earth and the Sun) or any future bases on Mars or further afield.

In short, therefore, the roles that satellites can and cannot fulfil are determined in part by where (on which orbit) they are placed in space and their related orbital period. Also, not all Earth orbits can be reached easily from all launch sites and the geographical location of that site is important in considering which orbit needs to be reached in the most fuel- and cost-efficient manner. In some respects, the UK has a potential advantage in having access both

17 MOD (2010).

Figure 2.2. Graphical depiction of a selection of different space orbits



Source: RAND Europe, based on United Launch Alliance (ULA) illustration of orbits

to the northern (the British Isles) and southern hemisphere (e.g. the Falkland Islands) as well as to Equatorial areas (e.g. Ascension Island, Diego Garcia), presenting distinct opportunities to leverage a global footprint for potential future launch activities.

Conceptual boundaries of space

Beyond the unique physical characteristics of the space domain, there are also unique conceptual definitions of space that shape strategic thinking of larger and smaller space powers, as well as commercial and civil actors with ambitions to utilise space. As noted above, the Outer Space Treaty (1967) defines space as the 'province of [hu]mankind',[18] but disagreements exist between countries – and even between consecutive governments within a single country[19] – as to whether space can or should be considered a 'global commons'. Embracing such a stance would imply joint responsibility of national governments to look after the space environment and prevent its uses for nefarious purposes – just as it has been originally envisaged by the UN Outer Space Treaty. There are also complex political, legal and normative questions about sovereignty in space, with national and international approaches likely to continue to evolve as exploitation of the space domain further intensifies in the coming decades. Various

18 UN (1966).

19 Silverstein & Panda (2021).

analogies have been drawn between space and terrestrial geography, with space being compared to oceans[20] and referred to as the 'cosmic coastline' or Earth's littoral.[21] These frequent analogies and descriptions underline the fact that space surrounds the Earth, the planet upon which (virtually) all humans live, and that any country or non-state actor operating in space has the ability to shape the space environment in such a way that it can potentially impact not only other users of space but also every person, object or location beneath it.

At the same time, the central role played by space architecture (e.g. satellites, networks, downlinks etc.) in facilitating global communications (e.g. satellite communications [SATCOMs]), generating data (e.g. from Earth observation) and providing PNT services that enable so many electronic systems to function means there is an important and complicated set of interdependencies between space and the cyber and EM domain, as well as activities in what UK Defence calls the information environment. Importantly, these 'new' domains and environments are still relatively poorly understood, given their relative novelty, compared to the far more mature set of concepts, doctrine and organisational structures found in the 'traditional' domains (i.e. land, maritime and air). Different actors' understanding of, and approaches to, the space domain are therefore also partly shaped by ongoing shifts in how they perceive, and operate in, those other interlinked arenas.

Space as an enabling domain

From a military standpoint, space can be an effector in its own right, which also underpins the Armed Forces' ability to operate in other domains. Indeed, the majority of Defence operations rely on space in some fashion, including the provision of secure SATCOMs, PNT to enable navigation, guidance and timing, ISR to provide GEOINT data over broad areas of interest, missile warning and tracking, environmental monitoring, and supporting electromagnetic interference (EMI) deconfliction. Through these capabilities, space enables delivery of decisive effects across the other domains (land, maritime, air, cyber and EM). Space is, therefore, at the core of multi-domain integration and needs to be organised and managed as such, which is now the case under the Joint Space Command set up in April 2021, with IOC expected in the spring of 2022. This also implies a need for careful consideration of the ramifications for capabilities in the space domain of the ongoing shift towards what the UK MOD calls 'Multi-Domain Integration' (MDI) or what key allies such as the United States term 'Joint All Domain Operations' (JADO). Interests in space cut across traditional stove-pipes between individual Services and domain-centric Top-Level Budget (TLB) holders.[22]

Finally, space is similarly a key enabler of critical national infrastructure, much of which relies on space systems for global communication, PNT, Earth observation, and weather and climate monitoring.[23] In recognition of these substantial and growing dependencies, the UK Government has designated space as a CNI sector. These capabilities underpin government and emergency services, as well as economic prosperity and the function of globally-connected digital societies.

20 Howell (2013); Mangu-Ward (2013).
21 Bowen (2020).
22 Black & Lynch (2021); MOD (2020c).
23 Falco (2018); UKSA (2015).

2.3. The growth of space activities will require sound space domain awareness and market intelligence to minimise risks to the UK

Over the last decade, the space environment has often been described by three buzzwords: 'congested, contested and competitive'.[24] The number of objects in space has grown significantly in the last decades, with the United States Space Surveillance Network (SSN) currently including about 17,000 on-orbit objects in the public satellite catalogue (SATCAT) and approximately 6,000 additional on-orbit objects for which information is less detailed, less reliable or sensitive, and therefore cannot be disclosed.[25] Potential adversaries are acquiring, testing and fielding capabilities to deny, degrade, deceive, disrupt or destroy space assets and infrastructure, through more or less sophisticated technologies such as jamming or anti-satellite weapons to the detriment of national security.[26] An increasing number of commercial actors as well as non-traditional (i.e. less well-established) government actors are also developing and operating assets in space.[27]

Figure 2.3 provides a graphical overview of examples of stated ambitions for the use of space by various actors (commercial and civil) as reported in publicly available sources.

The drivers and factors that shape space aspirations are as diverse as the actors that hold them, but many enablers of the recent surge in space-related investment and activity (e.g. miniaturisation of parts, expanded launch options, governments enabling the private sector to take on more missions in space, etc.) reflect common trends. In addition to the 'traditional' large space faring nations (i.e. the United States, Russia and, in the last two decades, China), smaller states and commercial actors have entered the space industry. These are often motivated by the vision of commercial gains from the space economy and the exploitation of the market opportunities that have emerged particularly in the fields of broadband communication, or the collection and use of Earth observation and geographic information systems (GIS) data.

These economic drivers provide powerful incentives for commercial activity, with countries like Australia, Canada and Japan seeking a dynamic growth of high-tech, highly-skilled space start-ups and commercial space activity, with ambitions for future growth. Others, such as Luxembourg, seek to specialise in specific niche activities (e.g. space mining) or perceive space exploration as a benefit to humanity as a whole and an opportunity to build up a high-skill, high-value space enterprise while also delivering political prestige to the nation, as is the case with the United Arab Emirates (UAE). Adding to the complex picture are multilateral organisations and groups such as the United Nations (UN), the European Space Agency (ESA), the Five Eyes alliance and NATO, who directly or indirectly influence space activity via regulation, capability development,

24 Schulte (2011).

25 SAIC (2021).

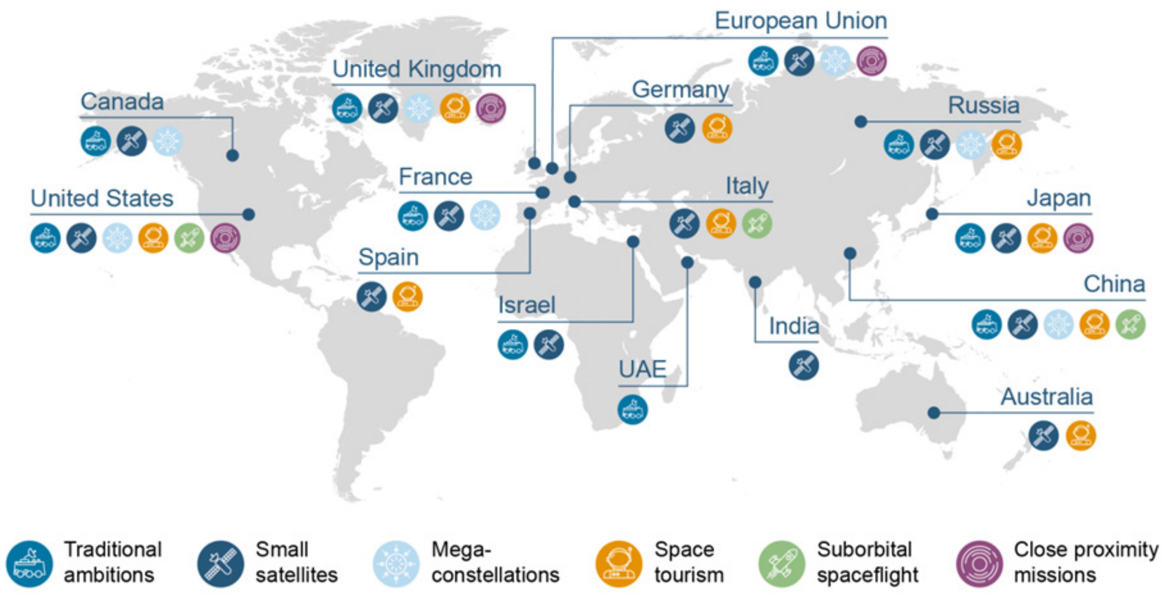
26 Schulte (2011). On 11 January 2007, for example, China conducted an anti-satellite missile test from Xichang Satellite Launch Centre. The projectile did not contain an explosive charge or any other kind of payload; rather, by attaining a high muzzle velocity, these objects convert their kinetic energy into destructive shock waves and heat. Anti-satellite (ASAT) missile tests, especially those involving kinetic kill vehicles, contribute to the formation of orbital space debris which can remain in orbit for many years and have the ability to interfere with future space activity, as proved to be the case with the Chinese ASAT test. See Zissis (2007).

27 National Academies of Sciences Engineering and Medicine (2016).

operations and/or fostering collaboration between their respective member states.

The complex web of actors, activities and ambitions presents both opportunities and risks that the UK MOD will need to understand and manage. To do so, the UK will need SDA along with horizon scanning and market intelligence drawing on unclassified sources to supplement the classified activities of Defence Intelligence. Indeed, investing in and enhancing the UK's own understanding of what is happening in space via space surveillance and tracking (SST) combined with intelligence assessment is likely to enable both faster detection, attribution and deterrence or mitigation of hostile activities in space as well as minimise the risk of collision of assets or damage by space debris. Effective SDA/SST is critical to enable greater resilience and protection of UK and allied assets in space.

Figure 2.3. Examples of aspirations of commercial and civil actors for the future use of space



Source: RAND Europe analysis of publicly available data on aspirations of national governments, national and international space agencies and large industry players identified within countries with large space economies.[28]

28 This map focuses on the primary ambitions of established large actors rather than small start-up companies. 'Traditional' ambitions capture government and industry ambitions that require large volumes of investment as well as highly advanced technology and know-how. Examples include lunar exploration, Mars exploration, solar probes, the James Webb Space Telescope, and the Global Navigation Satellite Systems (GNSS).

2.4. Space-based capabilities are difficult to 'hide' and face both natural hazards and man-made threats, placing a premium on resilience

Though it depends on a given satellite or craft's size and design, it can be hard to conceal space objects once they are placed in orbit and are thus tracked by the various actors (state and non-state) involved in SST, compared to assets in other domains. The growing reliance of modern militaries on space infrastructure also increases the incentives for hostile actors to seek asymmetric advantage in any conflict by destroying or degrading a nation's satellites, networks, and related infrastructure.

A range of threats, hazards and risks are present in space, requiring mitigation and resilience. These include:

- **Natural hazards** (e.g. debris, radiation, space weather).
- **Threats and risks to space-based assets** (kinetic and non-kinetic effects either originating from Earth or from co-orbital threats within space).
- **Threats and risks to ground-based segments** (e.g. cyber, espionage, kidnapping, kinetic strikes) to include not only launch sites and ground stations, but also wider industrial supply chains.
- **Threats both above and below the threshold of open armed conflict** (i.e. covert, ambiguous, or overt activities in the 'grey zone') in the context of persistent great power competition.

In terms of mitigation and resilience, as in other domains, space offers the possibility of **deterrence** either 'by punishment' or 'by denial' (through a mix of counter-force and active and passive defensive measures), and **resilience** building, for example via partnering, increasing redundancy within and across different constellations of satellites, or adopting a mix of both space-based solutions and terrestrial alternatives and reversionary modes.[29]

Directed threats

Threats of permanent or temporary degradation or denial of satellite capabilities range from non-kinetic to kinetic effects and include: counter-ISR, electronic warfare, dazzling, jamming, cyber-attack, ground site attack, directed energy weapons (DEWs), co-orbital anti-satellite (ASAT) capabilities, direct ascent ASAT missiles and exo-atmospheric nuclear attacks. State actors such as the United States, Russia, China and, most recently, India have invested in ASAT capabilities, such as specialised missiles, space mines, DEWs or close proximity missions using co-orbital systems, with varying levels of success. Given the proliferation of relevant technologies, even non-state actors have attempted the hacking, jamming, or spoofing of commercial satellite feeds. Such threats do not only pose a challenge for military operators of satellites, but also for the entire orbital environment. This is because any attack on a satellite may, intentionally or otherwise, cause debris or collisions that, in turn, threaten the safe use of other orbits for civil and commercial purposes, or disrupt the flow of data upon which so many satellite-enabled services depend.

Ground stations and data links are also vulnerable to a range of directed threats, as these are critical nodes not just for military uses of satellite systems but for an uninterrupted and secure functioning of CNI

29 Harold et al. (2017); McLeod et al. (2016); Morgan et al. (2018).

more broadly (e.g. emergency services rapid response, monitoring of gas and energy infrastructure, the function of financial systems and other important applications). Telemetry, tracking and command (TT&C) systems may present vulnerabilities to cyber-attacks and the physical infrastructure of ground stations may be at risk of sabotage or outright attack by criminals, terrorists, special forces or other malicious actors. Past cases demonstrate some of these vulnerabilities. In 2008, an internet connection was used to hack into a ground station that controlled Terra EOS AM-1, a NASA scientific research satellite.[30] The system was compromised and the responsible party achieved all of the steps required to control the satellite but, fortunately for NASA, did not issue any commands.[31] For satellite constellations, further risks pertain to the communication signals between the satellites themselves (as well as uplinks/downlinks between ground stations and satellites), with the growing complexity and interconnectedness of these networks adding new vulnerabilities to exploit.

While commercial providers may offer valuable capabilities for UK Defence to draw on, these will have to be considered also in the light of potential security vulnerabilities. Military satellites tend to rely heavily on encryption, but the cybersecurity of civil and commercial systems varies significantly, creating vulnerabilities to potential cyber-attack.[32] These satellites may also be less likely to be hardened against electronic or physical attack, or to include redundancies. This is because all such design and engineering measures introduce additional cost and space, weight and power (SWaP) trade-offs, which may be unattractive to commercial operators who deem the risk of hostile attack on their systems low and are seeking to maximise their profit margins. Even for some older systems used for military purposes, up until the early 2000s it had often been assumed that the data and cryptographic protocols would be too complicated and obscure to crack to require heightened levels of cyber protection.[33] Further concerns in relation to insufficient encryption and cyber protection are currently raised, particularly in relation to the increasing use of small satellites (smallsats) and even nanosats, where the drive towards faster production and one of increasingly larger volumes may overshadow the need to consider cybersecurity requirements.[34]

The internationalisation of supply chains now present in the space industry (in line with other technology industries) and the use of components from a number of manufacturers and from a variety of countries, means that there are also more opportunities for hostile activity in lower tiers of the supply chain. This includes foreign acquisition of strategically important suppliers, industrial espionage, corruption, sabotage, or cyber-attack on the comparatively poorly defended systems of small and medium enterprises (SMEs) who lack the resources to ensure adequate physical or network security. A potential hacker may be able to gain access to a space asset, with each incremental supplier providing an additional opportunity to compromise the whole system

30 Pellegrino & Stang (2016).

31 Pellegrino & Stang (2016).

32 Pellegrino & Stang (2016).

33 Industrial Control Systems Cyber Emergency Response Team (2016); Porup (2015).

34 Bartels (2018).

(e.g. through malware).[35] Parts and electronic components that have been counterfeited or otherwise compromised are a similar threat to both security and the safe operation of hardware in space assets. In one case, the ESA purchased microcircuits that could only be proven to have been degraded at a fundamental level through in-depth microscopic analysis.[36] Had this malicious defect not been detected in time, it could have provided a portal to allow hackers to access the satellite.[37]

Additional risks to national security emerge from EM spectrum interference and the misuse of sensitive data. Despite advances in relevant technologies and electronic countermeasures (ECM), wireless communications using the radiofrequency (RF) spectrum can be vulnerable to malicious actors. A simple RF signal, such as from a mobile phone, can be intercepted with the use of a baby monitor or the Raspberry Pi device. Specific malware programmes (e.g. Air-hopper) have been designed to use radio frequencies and key-logging to attack vulnerable devices.[38] The EM radio spectrum is allocated by government as fixed frequency bands to ensure secure and reliable wireless communication. The significant growth of wireless services has resulted in spectrum scarcity in certain spectrum bands and potentially inefficient utilisation of the assigned spectrum. Space-based assets such as satellites also require access to the RF spectrum, for which they need approval and allocation from designated authorities. With the growth and increasing speed of commercial space activity, the demand for faster and effective spectrum allocation has also grown, creating further demands on coordinating spectrum access, ensuring no interference (either purposeful or due to 'fratricide') and authorising the use of frequencies in a timely manner.[39] For civil and military users of space who rely on access to the RF spectrum and on having no interference, the risks that spectrum access will be limited or compromised by actors who choose to neglect the formal application processes, either for malicious purposes or in order to avoid potential delays in their commercial plans, are increasing.[40]

Natural hazards

In addition to these threats from human actors, the harsh space environment also imposes limits on the performance and lifespan of satellites. These include: meteoroids, cosmic rays, the effects of 'space weather', a term describing a variety of phenomena resulting from the Sun's activity, such as solar flares, increased EM noise, ionosphere interference or prolonged impact by energetic charged particles.[41] This may affect communications, the accuracy of navigation and the performance of sensors. In severe cases, it can also lead to electronic failure.[42] For military applications, radiation-hardened electronics may be adopted to mitigate these risks and increase resilience alongside conscious

35 Schradin (2016).
36 Rabinovitch (2015).
37 Rabinovitch (2015).
38 Shing et al. (2015).
39 NASA (2016).
40 RAND Europe interview (February 2019).
41 Joint Chiefs of Staff (2018).
42 Dawson (2019).

redundancy options, though again any such protective measures may involve cost and SWaP trade-offs (e.g. increasing launch mass). Orbital regime also has an impact in terms of the dose of radiation, meaning that there are also trade-offs to be made in terms of the orbit selected for a given mission and the protective measures taken in satellite design.[43]

A problem of increasing magnitude is space debris. NASA estimates there are about 900,000 space objects between 1-10cm in size.[44] Debris includes a variety of items such as rocket bodies and launchers left behind after satellite launches, debris from satellite explosions or impacts as well as natural objects such as meteoroids. Once objects detach from the original object (e.g. satellite), they initially retain their original orbit, possibly for years or even decades depending on the altitude and velocity, since there may be comparatively few, if any forces (e.g. atmospheric drag) acting upon them in higher orbits. As the number of objects in space increases, so does the risk of collision in the absence of strict space-debris mitigation plans. This may, in turn, lead to the creation of more debris, which, together with a higher overall number of operational objects in space, could result in the Kessler syndrome. This describes the cascading effect of a scenario wherein the high density of objects causes collisions, generating debris that in turn increases the likelihood of further collisions (i.e. collisional cascading), and ultimately renders parts or entire orbits unusable for further space activity. A single Chinese 2007 anti-satellite ballistic missile test launched from Xichang Space Launch Centre against a non-operational weather satellite produced over 3,000 pieces of space debris – some of which passed within four miles of the ISS in 2011.[45] An effective SST process with global coverage and involvement of relevant actors will be critical to mitigate these risks to the orbital environment, as well as the risks to individual satellite owners and operators and to end users reliant on space enabled services. There is also increasing interest in testing and deploying active debris removal (ADR) and management capabilities to either safely de-orbit objects or move them into the so-called 'graveyard' orbits, or to repair and refuel satellites on orbit to increase their operational lifespan and address any faults that may leave them unresponsive and unable to manoeuvre. With the satellite numbers projected to continue to grow rapidly, for example due to the various actors' ambitions to set up megaconstellations in LEO, the risks of collision are likely to increase, requiring more proactive management throughout the satellite life.[46]

2.5. The UK has an opportunity to articulate its role in space but will need to balance resources and relationships to meet its ambitions

While the full *Defence Space Strategy* is still due to be publicly released, there are some high-level indications of the UK's ambitions set out in the *Integrated Review*[47] and *Defence Command Paper*[48] as shown in Box 1.

43 For example, the MEO region includes the Van Allen radiation belts, two zones of energetic charged particles above the Earth's equator, necessitating shielding to protect electronic systems onboard of satellites and spacecraft.

44 Joint Chiefs of Staff (2018).

45 Segal (2011); Weeden (2010).

46 Radtke et al. (2016).

47 HM Government (2021a).

48 MOD (2021b).

Box 1. UK stated ambitions in space

Stated ambitions for UK involvement in space

- The UK is to become a **'meaningful actor in space'** with a national space strategy that brings together military and civil space actors and policy.
- The UK Government will support the **growth of the UK commercial space sector**.
- The UK should have capabilities to protect and defend its interest in space, enabled by the **establishment of the new Space Command and by industry achieving UK sovereign launch capability** by 2022.
- The UK should **develop SDA capability** for both military and civil use.
- The UK intends to **increase its international collaboration** in space, for example, by working with the European Union (EU) on the Copernicus programme; working with NATO and through the Combined Space Operations Centre (CSpOC) and other initiatives with the United Sates and with bilateral partners such as Canada, Australia and Japan.

Source: RAND Europe analysis of HM Government (2021a).

Much of UK Defence's space capability has hitherto been heavily reliant on access to United States capabilities and exchange of data, information, and expertise. Through this collaboration, the UK military has developed pockets of niche expertise but, on the flipside, has become dependent on United States space capabilities in most areas, aside from its recognised sovereign capabilities for SATCOM (i.e. Skynet). In the civil and dual-use arena, the UK has similarly relied heavily on international collaboration through ESA and other frameworks, as opposed to developing and fielding national assets.

With the emphasis on becoming a globally oriented, medium space power with an expeditionary focus,[49] and against the background of emerging uncertainties around the UK's role in European space programmes post Brexit, the UK Government has an opportunity to articulate and begin implementing a more ambitious vision for the country's role in space, including in Defence. A clearly articulated *Defence Space Strategy* with an underpinning understanding of the complex decision space represents one puzzle piece in the overall fresh articulation of the UK's grand strategic and military-strategic ambitions and goals for this domain.

Yet, as with other strategic visions and ambitions, it is important to consider feasibility and how these stated objectives align, or not, with the available resources (political, human, organisational, financial and technical) and other competing commitments across Defence. As noted in Chapter 1, there is an earmarked funding commitment for space for the coming years and indeed, an overall political support of the UK Government behind greater investment in this sector, but there is also uncertainty as to whether this level of political support persists beyond the current Government's term.[50] Moreover, there are risks that not all Whitehall departments perceive

49 Cabinet Office (2021).

50 Interviews with RAND Europe, 2021.

the importance of space in the same way and may not share the same vision for its use and related risks, even with the conscious effort of the MOD and UKSA to collaborate on development of the *National Space Strategy* or with the remit of the new NSC to drive coherence.[51] Several stakeholders interviewed for this study noted that funding commitments and resource, together with a coherent national approach to space and reliable international partnerships, will all present critical ingredients for a successful implementation of the national and MOD-level strategies into the future.[52]

2.6. The 'novelty' of space brings challenges and opportunities that need to be managed to avoid over commitment and underachievement

In the flurry of public events around the establishment of the new joint Space Command, space has often been described by commentators as largely a 'blank slate' for Defence. This highlights the facts that: (1) outside of SATCOM (Skynet), the UK does not possess major sovereign space capabilities; and that (2) until the recent establishment of the Space Directorate and Space Command, the MOD did not have dedicated organisational structures to unify activities in the space domain and provide strategic leadership (2*-level).

While the 'novelty' of space as an operational domain offers opportunities for genuinely new approaches to strategy, policy and capability development, there are also significant challenges that will need to be overcome in the coming years. The principal challenges stem from low numbers of suitably qualified and experienced personnel (SQEP) in the Defence space enterprise (and nationally), limited legacy capabilities besides Skynet, and insufficient space literacy and appreciation of the importance of space both across Whitehall and in the wider public. Yet, this situation is also common to other space powers besides the UK. As one interviewee noted, it may be useful to think of space as a common journey with various nations finding themselves closer or further to the start.[53] As such, there are both opportunities to learn from those that are 'further ahead' and tailor these approaches suitably to the UK context, so as to find alternative paths or short-cuts and to avoid some of the pitfalls encountered by others.

Internally, greater learning could be enabled by better information sharing between different parts of the Defence organisation as well as between Whitehall departments. This has so far been complicated by high levels of classification of much of the space capability and strategic information.[54] Indeed, several interviewees for this study noted that the siloed handling of much of space-related data, knowledge and information due to security concerns hampers not only collaboration between Government, industry and academic stakeholders but also the MOD's ability to start addressing SQEP challenges through learning.[55]

Much like the newly created United States Space Force, the UK's Space Command can offer new career structures and career

51 Interviews with RAND Europe, 2021.

52 Interviews with RAND Europe, 2021.

53 Interviews with RAND Europe, 2021.

54 Interviews with RAND Europe, 2021.

55 Interviews with RAND Europe, 2021.

development opportunities which can capitalise on good practice in recruitment and retention from across the other Services, while adapting them for the unique characteristics of the space domain.[56] At the same time, of course, the relatively small size of Space Command introduces some additional challenges around knowledge and workforce management, or overhead costs, as compared to the larger United States entity. The planned establishment of a Space Academy by the UK MOD promises a much-needed step towards enhanced educational provision, supporting the build-up of a cadre of SQEP that can be fed into the various roles in space. There is, however, an inevitable time lag between education and the practical application of skills, which will have to be taken into account in workforce planning assumptions.

Given the dominance of commercial and civil actors in space, it is also necessary to consider that Defence will face significant competition for the same pool of talent, including from private sector actors not constrained by public sector pay and terms. Defence should therefore look for ways to establish collaborations with industry and academia to ensure it can access and benefit from the limited national SQEP pool effectively (e.g. through secondments in or from industry/academia, setting up liaison officers, joint industry-MOD capability development teams, potential use of sponsored reserves etc.).

In the acquisition realm, there is a unique window of opportunity to develop a capability management strategy based on innovation, experimentation, and non-traditional ways of doing defence acquisition, unencumbered by legacy culture, processes or structures. These opportunities are discussed in more detail in Chapter 4. Here, the UK has genuine opportunities to do things differently, even in contrast to the United States Department of Defense (DOD), which has been acquiring space capabilities for seven decades and has in place various complex and bureaucracy-heavy processes which can limit agility and flexibility. These characteristics of the future space acquisition system will be important if the UK is to successfully run acquisition programmes in this fast-moving environment, dominated by commercial players, constantly pushing the boundaries of innovation.

Reflecting on these characteristics of the organisational landscape, it becomes clear that an effective implementation of the UK Defence Space Strategy will have to be one that carefully balances the opportunities of the 'blank sheet of paper' with a conscious mitigation of risks emerging from low SQEP base, nascent organisational and governance structures and limited sovereign capability in space. Only such a balanced approach can minimise the risk and impact of the MOD Space Directorate and Space Command overextending themselves too early, without having the necessary foundation blocks in place. This will ultimately reduce the likelihood of failure to deliver, whether in the area of strategy, policy, capability development, or operations that take place in or are enabled by space. There is, therefore, a 'window of opportunity' for the UK Defence space enterprise in the early 2020s to benefit from a confluence of new investment, strong political support, and new structures and leadership, but also a pressure to make good on the potential of the *Defence Space Strategy* in a challenging strategic environment.

56 See Spirtas et al. (2020a, 2020b).

2.7. The UK is demonstrating leadership in shaping space governance with the potential to establish itself as an influential space power

Drawing on existing alliances and partnerships (e.g. the UK's permanent membership of the UN Security Council, or its role in NATO, the Five Eyes alliance, or other groupings), the UK has a distinct opportunity to help shape the governance of space as well as to leverage these networks to gain access to space capability or to pursue collaborative capability development programmes.[57]

Over the past two years, the UK has been successfully exercising its political and diplomatic influence in leading the preparation of a UN General Assembly resolution on responsible behaviours in space and the subsequent global discussion on the key principles and norms of responsible behaviour in space in order to increase trust and confidence between space faring nations. In doing so, the UK has enhanced space safety and sustainability as a possible prelude to future agreements around the more sensitive topic of space security.[58] The UK has also signed the 2020 Artemis Accords, indicating its commitment to international collaboration with the United States and other likeminded allies and partners for the exploration and use of the Moon, Mars, comets and asteroids for peaceful purposes.[59]

Additionally, the UK is actively involved in discussions and debates in various international fora on issues and challenges related to space, including: the defined threshold for military action for activities in space within NATO, and discussions on norms and rules for more effective space traffic management, debris mitigation and management and safe operations in space.[60] Despite the low baseline sovereign space capabilities and SQEP, the UK has been able to demonstrate global leadership on critical issues of space governance. In doing so, the UK has shown its ability to exercise influence via diplomatic means and a clear focus on facilitating collaborative approaches to tackling the emerging threats and risks to those operating in the space domain, including civil, commercial and military actors. The UK also benefits in this regard from not having much of the political 'baggage' that the United States has in space in the eyes of many smaller nations, given the historically dominant position of the United States in this domain. The UK Defence space enterprise can also draw on the broader influence provided by its wider defence engagement activities and cross-government levers of 'soft power'.

As a result, the UK is establishing itself as an influential actor and possible 'honest broker' (see Chapter 3), with a potential to bring a meaningful contribution to various aspects of space governance, strategic thinking from the perspective of a medium space power and wider space activities.

57 Interviews with RAND Europe, 2021.

58 HM Government (2020a).

59 UKSA (2020).

60 E.g. via UNOOSA (2021).

2.8. Defence will need to understand the changing dynamics of the national and global space economy to harness new opportunities

Modern societal dependence on satellites for PNT, meteorological services, telecommunications and Earth observation is growing, as is the size of the global space industry market, valued at US$360b (c. £270b) in 2018, and projected to grow to US$558b (£419b) by 2026.[61] The recent surge in trends towards launching objects into space show no signs of decelerating and states no longer have a monopoly on the launching of spacecraft. At the same time, the variety, scale, and number of space objects in orbit is rapidly changing, reflecting new technologies and innovation, such as miniaturisation – driving the use of smallsats – in particular. Industry predictions indicate that the global market for small satellites alone will reach about £10b by 2030.[62] All of these trends present opportunities but also a mix of challenges to space governance, particularly in relation to licensing, de-orbiting, debris mitigation, cybersecurity, insurance and others.

At both the national and global levels, the space economy represents a broad ecosystem of space-based and terrestrial markets and activities, as depicted in Figure 2.4. It involves a wide range of stakeholders in the integration of both space-based and terrestrial activities to deliver value in or enabled by space. Depending on the end user, this value may take different forms, for example new knowledge, political prestige, a tactical military advantage or the generation of profit, exports and jobs.

In the next two decades or so, upstream markets (i.e. design manufacture, launch) are likely to undergo major changes as a result of new technology, concepts and industrial processes, both enabling and driving down costs for existing capabilities and unlocking the potential for wholly new types of space activities.[63] Further to the evolving technology landscape, the future space economy is expected to be shaped by a wide range of evolving concepts for spaceflight and novel designs for satellites, space infrastructure and installations. This will entail a refocusing of production lines and supply chains to focus on digital design, fabrication, assembly, launch and in-service support of an increasing variety and number of space objects. The downstream segments of the space economy, which include 'activities utilising space data to offer products or services (space applications) as well as ground segment applications (space operations)',[64] are likely to see an even greater expansion in the different use cases of space and opportunities to generate economic value. These could include in agriculture, climate and environmental monitoring, logistics, finance, manufacturing, energy, transport, telecommunications, science and many others.[65]

61 Research and Markets (2018).

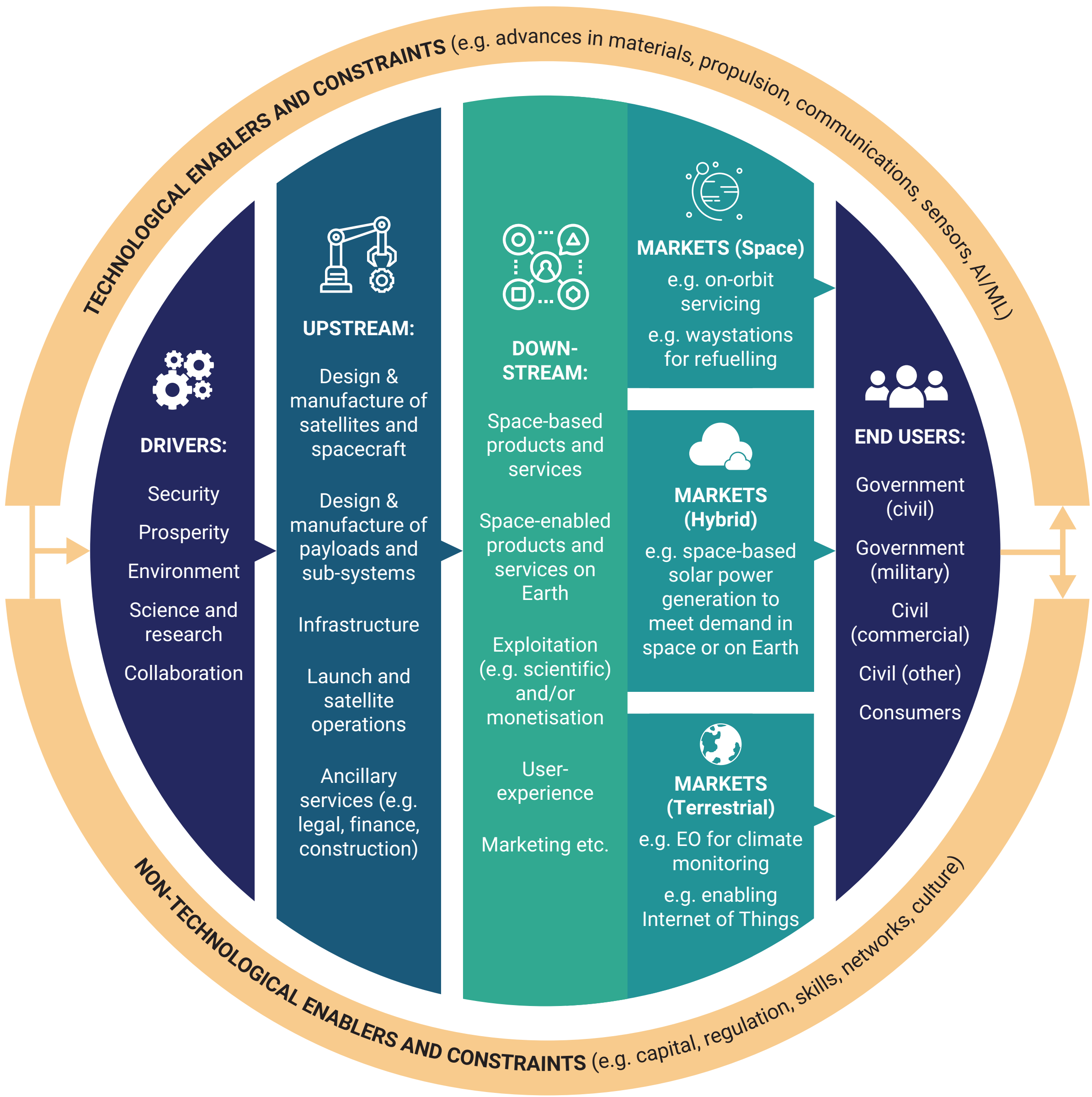
62 Adams (2018).

63 For a detailed analysis of potential future uses of space out to 2050, see Black et al. (2020).

64 Duke et al. (2019).

65 Duke et al. (2019).

Figure 2.4. Taxonomy of the space economy



Source: Black et al. (2020).

The fast growth of commercial space activity in the last decade, including into areas traditionally monopolised by national governments, has shaped the global space market in ways that make any one national government a 'market taker', rather than 'market maker', for many elements of space capability it wishes to access or acquire. This is increasingly true even for the largest players (e.g. the United States) but certainly a major constraint on small and medium players such as the UK, with their comparatively limited resources and market influence. This nonetheless has benefits: UK Defence has an opportunity to tap into a wide range of mature solutions, avoiding long lead times, reducing costs, and boosting resilience. As discussed in Chapter 4, this means that Defence can potentially develop from its low baseline of organic capability (outside of Skynet) relatively quickly, rather than needing to duplicate the learning that has already occurred in other countries or commercial space organisations.

2.9. Technological developments represent key factors shaping UK Defence Space Strategy as they are both impactful and uncertain

Given the physical and market characteristics described in previous sections, space is an inherently technology-intensive sector of the national and global economy. This reflects the physical demands of launching objects into the Earth's orbit or to escape velocity, and the engineering challenges of ensuring these objects survive to fulfil their intended purposes in a punishing environment. It also recognises the new opportunities associated with advancing technology outside of the physical, e.g. in terms of digital design and engineering, or integration of satellites into broader networks and information architecture.

Some of the key 'dual use' technologies currently shaping innovation in space are highlighted in Table 2.1.

Table 2.1. New and emerging technologies expected to shape the space sector in the future

Technology area	Examples of innovation
Advanced manufacturing	• Advances in additive manufacturing (including 3D printing), advanced design technologies, cyber-physical systems and other novel approaches associated with Industry 4.0.
Artificial intelligence	• Application of artificial intelligence (AI) and machine learning (ML) across the CADMID cycle, space sector and wider global economy. • Data analytics and optimisation of industrial and satellite capabilities.
Autonomy and robotics	• Advances in autonomous systems (capable of space operations with the human 'in the loop', 'on the loop' or 'out of the loop' as required). • Improved robotic systems e.g. for manufacturing or use in robonautics.
Biotechnology	• Use of biological organisms and processes for processing materials and chemicals as part of industrial processes for the space sector. • Advances in biotechnology for use in space e.g. in microgravity.
Blockchain	• Use of distributed ledger technologies (e.g. blockchain) and privacy enhancing technologies (PET) for improved cyber and data security. • Use for smart contracts in space industry and to verify satellite data.

Technology area	Examples of innovation
Communications	• Connectivity to enable Industrial Internet of Things (IIoT) in space sector. • Advances in optical, radio frequency (RF) and other telecommunications technologies used by space objects and in space operations.
Computing	• Advances in processing power, costs and efficiency (Moore's Law). • Maturation of cloud and edge computing enabled by 5G connectivity. • Novel approaches such as biological or quantum computing (see below).
Energy	• Improved energy generation (e.g. solar power, fusion). • Improved energy storage (e.g. battery technologies, supercapacitors). • Improved energy transmission (e.g. microwave systems, directed energy).
Materials	• Novel complex materials (e.g. carbon nanotubes) for space structures. • Reductions in mass and improved strength, conductivity or other benefits. • Self-assembling and self-repairing materials for longevity of space objects.
Nanotechnology	• Ongoing miniaturisation of electronics and other components. • New design opportunities for heat shields, sensors and other sub-systems. • Scaled-up, low-cost manufacture of nano-systems and materials for space.
Propulsion	• Advances in solid- and liquid-fuel rocket technologies. • Development of novel systems (e.g. hybrid air-breathing rocket engines). • Advances in ion engines, fusion and other in-space propulsion options.
Quantum	• Advances in quantum computing and application to space sector. • Advances in quantum sensing and navigation. • Advances in quantum communications and encryption for satellites.
Sensors	• Improvement in radar, lidar, optics, machine visions and novel sensors. • Continuing miniaturisation and networking of embedded sensors for use in space industrial processes or in small satellites.

Source: Black et al. (2020).

As discussed in more detail in Chapter 3, the UK has a strong space R&D sector, which invests more than the computer software and telecommunications sectors, though lower than the pharmaceuticals market. The industry is estimated to spend five times more on R&D as a proportion of gross value added (GVA) when compared to the wider economy.[66] This provides opportunities for MOD Space Directorate and the joint Space Command to tap into ongoing innovation with the UK, as well as identify opportunities to work together with academia, industry and international allies and partners to develop the new capabilities that are needed to meet defence requirements. As discussed in subsequent portions of this report, however, this will entail overcoming the long lead times associated with typical Defence processes and taking measures to boost the absorptive capacity of the UK Defence space enterprise for new technologies and ways of doing business, in order to keep up with the rapid pace of change in the technology and industrial landscape.

In addition, the UK MOD will have to monitor carefully the development of relevant non-space capabilities to identify ways in which it can build greater resilience and redundancy to space capabilities. This will entail looking beyond the domain focus of the MOD Space Directorate and Space Command by working closely with the Dstl and the Front-Line Commands. Some illustrative examples of these possible supplements or alternatives are summarised in Table 2.2.

Table 2.2. Illustrative examples of non-space-based supplements or alternatives to space capability

Example	Detail	Maturity	Sources
High precision positioning	Across several sites, the United States has deployed precise positioning systems that do not rely on GPS positioning data. Although the systems cover limited areas, they can provide superior positioning data to GPS.	Commercially available	Homeland Security (2020)
Metropolitan Beaconing Systems (MBSs)	FirstNet is exploring the possibility of deploying MBS to fulfil Enhanced 911 requirements for 3D location of emergency calls in metropolitan service areas. MBS may also meet indoor and outdoor position and navigation requirements.	Commercial prototype	Homeland Security (2020)
Time Over Fibre	There have been advances in Time Over Fibre: Precision Time Protocol (IEEE 1588), demonstrating sub-nanosecond and sub-microsecond time transfer over distances. This technology may become available to offer time-as-a-service over fibre networks.	Commercial prototype	Homeland Security (2020)

66 Know.space (2021).

Example	Detail	Maturity	Sources
PseudoLite	Ground-based transmitters, or 'pseudosatellites', can transfer GPS-like signals, or 'pseudolites'. PseudoLite is an intelligent pseudolite transceiver, using commercially available GPS patch antennas as receivers and transmitters, as well as a 1/4 wave antenna for one of the PseudoLite transmitters.	Academic, early prototype	Sharma (2013)
Enhanced Long Range Navigation (eLORAN)	eLORAN has improved accuracy over the LORAN-C system, a radio-based system used in World War II. Differential monitoring reference stations can be widely deployed, receiving raw eLORAN signals from the main transmitting towers, detecting deviations and sending back corrections to eLORAN towers. The corrections are transmitted via the LORAN data channel (LDC) to users, improving PNT accuracy.	Commercial solution	Shepard (2020)
Terrestrial passive ranging system	Passive ranging has relatively simple architecture and unlimited capacity. Existing signals and systems within the national airspace can be used, such as Distance Measuring Equipment (DME) and Universal Access Transceivers (UAT). The system could be capable of providing data to support advanced capabilities currently not available.	Commercial solution with potential for modification	Lo et al. (2011)
Upgraded distance measuring equipment	Distance Measuring Equipment (DME) and the military equivalent, Tactical Air Navigation (TACAN) are two-way ranging systems with the ability to support future aviation navigation and surveillance needs. Operating in the L-band of radio frequencies, the systems offer high ranging accuracy.	Commercial, military solution	Lo et al. (2013); García-Crespillo (2015)
Multilateration (MLAT) based navigation	MLAT is a navigation and surveillance tool based on Time Difference of Arrival (TDOA) signals, which determine the positioning of a mobile entity.	Commercial solution	Skybrary (n.d.)
Enhanced link navigation system (ELNS)	ELNS is a shipboard system used by United States Navy that utilises existing communications signals from a range of sources systems to provide navigation and landing functions. There is also potential for this system to be used for aerial refuelling.	Demonstrator	Erwin (2018)
Quantum navigation	A transportable, standalone quantum accelerometer device built by Imperial College London and M Squared demonstrated the ability to provide navigation capabilities by measuring properties of supercool atoms.	Demonstrator	Dunning et al. (2018)

Example	Detail	Maturity	Sources
Automatic Dependent Surveillance - Broadcast (ADS-B)	ADS-B was designed to provide automatic surveillance to air traffic control, using UAT signals. With an existing infrastructure of surveillance broadcast ground stations, there is potential to modify systems to enable Alternative Positioning, Navigation and Timing (APNT) capabilities.	Commercial solution with potential for modification	Lo et al. (2015)
L-band Digital Aviation Coms System (LDACS)	LDACS is a communication system offering a wideband terrestrial system which operates in the L-band. Previous trials have shown that LDACS has potential scalability and can enable APNT, with potential to support surveillance activities.	Commercial solution	Eurocontrol (N.d.)
Universal Access Transceivers (UAT)	UAT signal is used by ADS-B as a passive range navigation system. Existing ground receivers for UAT could be leveraged to enable APNT capabilities.	Commercial solution with potential for modification	Chen et al. (2014)
High altitude Earth observation	Specialised remote-controlled unmanned aircraft systems (UAS) at altitudes of up 22 km can be used for earth observation, disaster recovery and response, communication, weather forecasting, military surveillance, or act as a mother ship for drones. The solar-powered Stratollite conducted its test flight with a 50.6-megapixel camera to demonstrate its potential for high-altitude earth observation.	Commercial solution, military prototype	Singh (2017); Hambling (2018); Martorella (2020)
High altitude balloons	Project Loon floats balloons up to 20 km high to provide internet service to rural areas. This service could reach more people for less than the cost of base stations or fibre optic cables. Project Loon has also used its balloons to provide emergency Internet service, such as after Hurricane Maria in 2017 in Puerto Rico.	Commercially available	Nordrum (2018)
High altitude UAS	Zephyr is one example of High-Altitude Pseudo-satellites (HAPS) for communication and observation. The UAS has solar cells mounted on its wings, with the potential to remain aloft for months on end, relaying calls and internet.	Commercial, military solution	Airbus (N.d.)

Source: RAND Europe analysis of open source data.

In the coming decades, innovation across both the upstream and downstream segments of the space sector is projected to benefit not only from continuing advances in space technologies, but also from spillovers from 'adjacent' technical disciplines. The trajectory of these developments is both uncertain and potentially highly impactful, necessitating a clear and realistic understanding of these fast-moving developments as well as their potential implications for implementation of the UK's *Defence Space Strategy* and broader cross-government cooperation on the *National Space Strategy*. To this end, it is important that the UK in general, and Defence specifically, understands its own strengths and limitations as a space actor if it is to realise its ambitions to become a 'meaningful player in space'.[67] With this in mind, the next chapter examines the components of a possible UK value proposition in the space domain, both as a sovereign actor and a collaborator to other international and industry partners.

67 HM Government (2021a).

3 Towards a UK value proposition in space

This chapter begins with a brief explanation of the 'value proposition' concept. It then provides an overview of the UK's strengths, weaknesses, opportunities and threats (SWOT) in the space domain, so as to help understand the elements of UK Defence's value proposition for any prospective future collaboration with allies and partners as well as the commercial sector. While the precise configuration and weighting of different elements of this value proposition will vary from one collaboration to another, based on the capability being developed and the partner(s) the UK is working with, this overview serves to highlight relevant levers of influence and areas of relative disadvantage. This chapter is accompanied by Annex B, which summarises high-level ambitions and key capabilities of selected countries of interest.

3.1. The concept of a value proposition is derived from commercial strategy and marketing and needs to be tailored to Defence

The UK Government aims to ensure effective governance and management of public resources to promote and achieve policy objectives that maximise the social, economic and other benefits enjoyed by the UK – promoting overall 'net social value'. This applies also to its investments and activities in space.

Assessing the potential costs and benefits of options across such different areas of policy is both a highly sensitive and difficult task, compounded by uncertainty over the impact and likelihood of success of many interventions. High-level scrutiny of the 'value for money' of UK public spending is provided through Parliament, including the Public Accounts Committee, with support provided by the Comptroller and Auditor General and the National Audit Office. Guidance for investment appraisals within the public sector is provided by HM Treasury's *Green Book*[68] and other supporting documents such as the *Public Value Framework* introduced in 2017,[69] or the 2021 *Defence and Security Industrial Strategy* (*DSIS*).[70]

There are, however, enduring methodological barriers to understanding, quantifying and articulating the value of different public sector investments. This is especially true in Defence, where outputs such as 'deterrence', 'peace' or 'stability' are notoriously difficult

68 HM Treasury (2020).

69 HM Government (2017).

70 MOD (2021a).

to define, measure and communicate to different audiences, and where the causal links between Defence outputs and broader strategic and policy outcomes may be hard to prove. Defence has, therefore, traditionally focused on understanding the value of inputs (i.e. resources) allocated to different programmes, but this does not account for the opportunity costs of not investing in other programmes instead or necessarily demonstrate good returns on investment. There is a complex relationship between Defence and the recipients of the value it generates, given defence and security are 'public goods' and not things that can be valued based on the price of purchase for an individual 'consumer'. Furthermore, the public may have less tangible or frequent hands-on experiences with Defence, as opposed to their routine engagement with other public services such as health, education, or policing.[71]

Given these theoretical and practical limitations, the UK MOD has taken steps in recent years to improve how it goes about assessing and articulating the value it delivers to different stakeholders and audiences, including other parts of Government, allies and partners, the economy and wider UK society. In 2020, for example, the DCDC commissioned the development of a 'Defence Value Proposition',[72] which fed into the MOD's inputs to the cross-government *Integrated Review* process.[73] Dstl similarly sponsored academic research to understand opportunities for improving the methods used by Defence to quantify and monetise the value of different investments and activities across domains.[74] Both of these initiatives, and the second RO of this report on prospects for implementation of the *Defence Space Strategy*, built on approaches in the commercial sector to defining a 'customer value proposition', as shown in Figure 3.1.

As in the commercial sector, defining the value proposition of the UK Defence space enterprise is always context-specific. How 'value' is understood by different stakeholders will differ, depending on the audience and the programme or partnership in question. In SATCOM, for example, the UK is an established and respected player with existing capabilities (Skynet). Whereas in another capability area, the UK might be seen as more of a market 'insurgent', one that could offer an alternative and innovative way of doing things using niche technical and industrial strengths and unencumbered by legacy structures and processes.

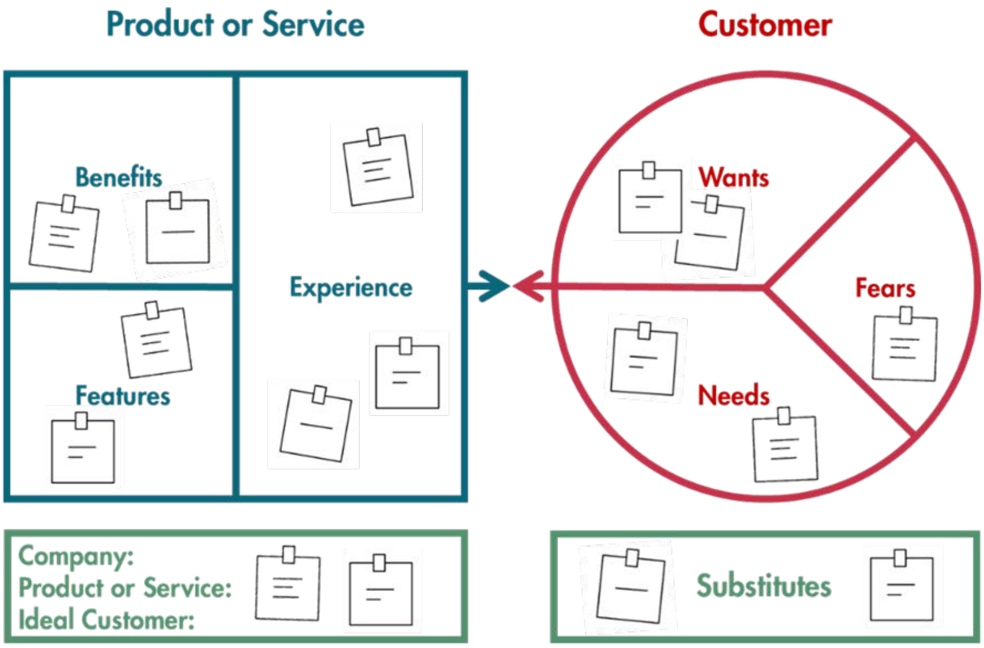
71 Black et al. (2021).

72 Black et al. (2021).

73 HM Government (2021a).

74 Huxtable et al. (2021).

Figure 3.1. Example of value proposition canvas model as applied in the private sector



Source: GSP analysis, adapted from Thomson (2013).

3.2. The UK value proposition in space relies on a mix of strengths which Defence should leverage when negotiating partnerships with others

The building blocks of a UK value proposition in space encompass a variety of defence, civil and commercial factors. These are summarised in Table 3.1 and elaborated upon in greater detail in the remainder of this chapter. The weighting of these building blocks on a given programme or partnership will always be context-specific – shaped not only by what the UK offers but also by what prospective partners want, need, or fear. A robust and 'eyes open' assessment of these SWOT in the UK in general, and Defence specifically, is essential if MOD Space Directorate and the new Space Command are to effectively navigate the choices and trade-offs around 'own-collaborate-access' decisions discussed in Chapter 4.

Table 3.1. SWOT analysis of UK value proposition in space

Examples of strengths	Examples of opportunities
• Strong political support for space (investment, NSC etc.) • New leadership and structures in Defence • Geography (including Overseas Territories and growing UK's interest in polar regions) • Network of key alliances and partnerships (e.g. Five Eyes, ESA, others) • Soft power levers (e.g. on space governance) • RAF Fylingdales and role in United States SSN • RAF High Wycombe UK Space Operations Centre (SpOC) • Lessons of past projects (e.g. Skynet) • Links with assets and activities in other domains (e.g. cyber, air, maritime) • Niche industrial capabilities (linked with New Space growth areas e.g. smallsats, SABRE) • Growing academic sector and basic research	• UK can potentially be more agile and less encumbered by legacy structures than bigger players • Develop strategic or niche capabilities to be more valuable to allies, partners (e.g. small launch, ISR) • Offer redundancy to the United States • Build on extant defence groupings (e.g. the UK-led Joint Expeditionary Force) • Reinforce contribution to NATO in space • Develop alternatives to space • Become an 'honest broker' in space governance, boosting space safety, sustainability, and security • Act as key player on rule of law and regulatory frameworks, given UK levers for soft power • Use space as part of UK climate leadership and/or to drive broader economic and societal benefits
Examples of weaknesses	**Examples of threats**
• Limited baseline of space capabilities e.g. for SDA or protect and defend missions • Potential mismatch between resources vis-à-vis stated ambitions • Insufficient pipeline of space SQEP in both industry and government (including Defence) • Uncertain long-term implications of Brexit • Challenges scaling up good ideas/companies given foreign acquisition • Uncertainty around long-term viability of some actors in the space market	• Lack of coherence across Whitehall in relation to space (despite MOD-UKSA cooperation) • Challenges of realising Fusion Doctrine (e.g. setting out a holistic response to CNI resilience) • Potential for resource crunch in the aftermath of COVID-19 and broader economic uncertainty • UK-EU relationships take time to mend • The United States becomes a less reliable ally; UK is displaced by other rising space powers (including France) • Place costly bets on certain technical or commercial solutions that then prove unviable

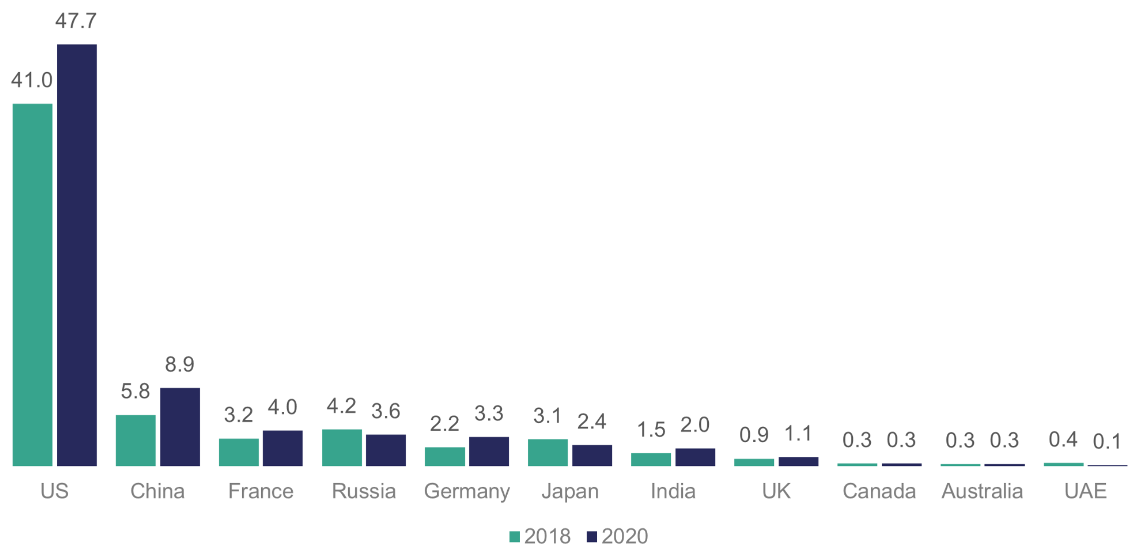
Source: RAND Europe analysis of open source literature and evidence gathered through interviews.

3.3. The UK's relatively low public investment in space masks its ability to access valuable capabilities through industry, allies or partners

The UK Government's level of investment in space programmes has been historically relatively low compared to other countries with similarly sized economies and populations, as shown in Figure 3.2. Notably, in 2020, France's national expenditure on space programmes was about four times higher than UK investment, Germany's three times as high and Japan's more than double. Most national space programmes grew in terms of funding between 2018 and 2020, including across the United States, China, France, Germany and India as well as the UK (though, in this same period, Russia and Japan experienced a decline).

Despite the UK's relatively low baseline of public investment in space, it has been able to access valuable space capabilities and services as well as provide important technical expertise into collaborative programmes with its allies and partners. This has been especially directed through its participation in the ESA for civil programmes and through close collaboration with the United States and the wider Five Eyes alliance on military space programmes. Yet, following the UK's exit from the EU, there is uncertainty over the UK's ability to benefit from future knowledge and learning with European partners as its involvement in some of ESA's projects has stopped or has been limited.[75] The UK's participation in the European satellite navigation programmes Galileo and European Geostationary Navigation Overlay Service (EGNOS) ceased, as did its participation in the EU Space Surveillance and

Figure 3.2. Government expenditure on space programmes, 2018-2020 ($b)



Source: RAND Europe analysis of Euroconsult data (2018, 2020).

75 The UK, however, remains a full member of ESA as this is not an EU agency.

Tracking (EU SST) programme, although users of the SST data are still able to access it.[76] The UK may be able to continue participating in ESA's Copernicus Earth Observation programme as a third party, but the final decision on this is still pending at the time of writing this report.[77] The UK membership of the ESA itself and of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF) and Mercator Ocean is unaffected by Brexit and the UK will continue to collaborate as before. Such organisations retain access to high-bandwidth data that supports the land, marine, climate change and atmosphere services of their participating nations and organisations.

In addition to these civil space programmes, the UK has benefited from access to high-end military capabilities over recent decades through the close partnership with the United States, and into which it has contributed important capabilities such as those residing at RAF Fylingdales, the radar based in North Yorkshire which is a key node in the United States Space Surveillance Network (SSN) and Ballistic Missile Defence (BMD). There are also established information exchange mechanism with other allies related to R&D that enable the UK to identify potential opportunities for collaboration on capability programmes. Such extant connections and relationships may provide a solid foundation for an enhanced UK role in, and benefits from, collaborative programmes as the UK in general, and Defence specifically, increases its investments in this domain to support implementation of the national and MOD-level space strategies in the 2020s. At the same time, there are also opportunities to work with a variety of new partners, both in terms of government and commercial actors, as discussed in more detail in Chapter 4 below.

3.4. Innovative industries have emerged in the UK, fuelling a growing commercial sector that presents market opportunities for Defence

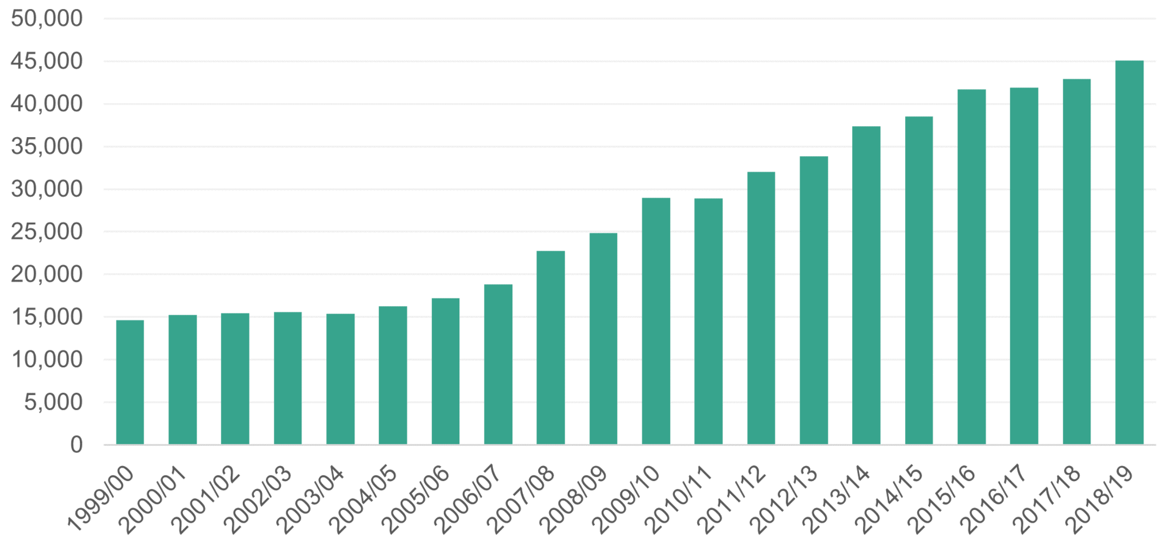
Despite this relatively low public investment in space nationally, the UK commercial space sector has seen significant growth over the last two decades. The periodic analyses of the UK's space sector by London Economics up to 2020 and subsequent data from know.space shows that the number of employees in the sector has increased threefold since 2000, as shown in Figure 3.3.[78]

76 HM Government (2020a).

77 HM Government (2020a).

78 Know.space (2021); LE (2019).

Figure 3.3. Number of employees in UK space sector 1999-2020



Source: RAND Europe analysis of LE (2020) and know.space data.

In the latest report for 2021, know.space estimated that the UK space sector included 1,218 companies, indicating double digit percentage annual growth over the last five years, as shown in Figure 3.4 overleaf. This growth rate exceeds that for the workforce data shown in the preceding graph, suggesting that many firms remain small and/or are making use of automation and other productivity-enhancing technologies. Indeed, these 1,218 companies are not all UK firms; in fact, many (including some of the biggest ones such as Airbus, Thales) are foreign owned, and there are a disproportionate number of smaller space start-ups and space investors in the UK in comparison to global averages. The sector's revenue for 2018/2019 was £16.4b, having benefitted from nearly three per cent growth per annum since 2016/17. The sector is, however, highly concentrated, with 13 organisations accounting for 82 per cent of the overall revenue.[79]

79 Know.space (2021).

Box 2. Example of UK industrial and innovation base: Harwell Campus

Harwell Campus in Oxfordshire is home to over 200 science and technology organisations spread over 700 acres. Public and private organisations, academia, investors and entrepreneurs are brought together to innovate, collaborate and drive research across sectors including aerospace, biotech, energy, engineering, medical science, molecular research and supercomputing. On average, the activities at Harwell Campus generate a GVA of £20.5b per annum for the UK economy.[80] Organisations can access national and global funding sources, with a number of close investors, including Lansdowne Partners, the Wellcome Trust and Oxford Sciences Innovation. The sizable space cluster of 70 space organisations includes the presence of the ESA, Oxford Space Systems, QinetiQ, the UK Space Agency, UK space and Astroscale Ltd. A notable success to come from Harwell includes ESA's Rosetta mission, which secured the first ever material samples data from a comet. Harwell campus has the ambition to expand and establish more links to universities and R&D organisations. Current plans include adding 25 acres of office and leisure space.

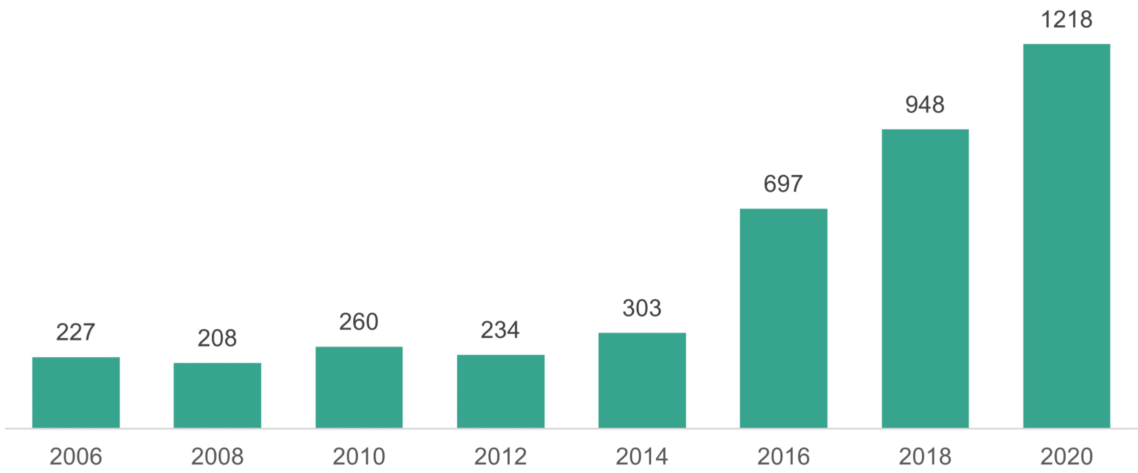
Source: RAND Europe analysis of Harwell (2021b).

Crucially, the UK space industry has been identified as being five times more R&D intensive than the UK average, with £702m (or 10.7 per cent of GVA) invested in R&D, making it into a highly innovative, technology intensive and talent-demanding sector.[81] Given the relatively small market share of UK space sector globally (about 5 per cent), there are clear opportunities for exports and greater market capture that UK companies can capitalise upon with an appropriate investment and strategic approach. Indeed, UK companies are strongly outward-facing, with over a third of their revenues derived from export (unlike commercial actors residing in large space powers such as the United States, China and Russia who primarily respond to the domestic demand signals). In part, this reflects the low levels of domestic demand that have resulted from comparatively low levels of public investment in the past, and may rebalance somewhat as the UK Government proceeds to implement the *National Space Strategy*, but it also means that the UK industrial base is potentially well-configured to adapt with global space markets and to participate in international collaborations and supply chains, including around Defence space capability development programmes.

80 Harwell (2021b).

81 Know.space (2021).

Figure 3.4. No. of companies with activities in space



Source: RAND Europe analysis of LE (2018) and know.space (2021).

Box 3. Example of UK industrial and innovation base: Satellite Applications Catapult

Innovate UK has been establishing so-called Catapult centres to promote research and development. Catapults offer businesses access to expertise and facilities, allowing them to test, demonstrate and improve their ideas. Catapults bring together small, medium and large businesses, government, research organisations, and academia to support the development of solutions to improve business performance.[82] The UK Satellite Applications Catapult helps organisations harness the power of satellite-based services by connecting industry and academia to get research into the market more quickly. Funding comes from sources including private investment, Innovate UK, grant schemes and EASA Business Applications. The Satellite Applications Catapult has plans to increase the size of the UK space sector to £40b by 2030.[83]

Source: RAND Europe analysis of Satellite Applications Catapult (2018 and 2021).

The data analysed above confirm that space is becoming an increasingly attractive market for new entrants, the so-called New Space companies. Although it is clear that private investment in these companies (often through venture capital) have been attracted to the potential to create value, rather than a demonstrable ability to deliver value at scale.[84] As such, there is still inherent uncertainty around how successful these companies will be in the long-term and indeed, which ones will be successful in developing mature solutions at scale. Low barriers to entry are likely to stay, however, as they are enabled by a range of factors including the use of small satellites, new design philosophies, standardisation, rapid

82 Catapult (2021).

83 Catapult (2018).

84 Representing global lower cost commercial space services.

development, mass production and venture capital funding and smaller production costs.

In 2020, the UK Government entered the sector through its acquisition of a 45 per cent stake in the OneWeb megaconstellation, as it was filing for bankruptcy. Since the UK has been excluded from the GNSS programme, there has been frequent public speculation about the option of using the OneWeb satellites to provide some PNT capability (or redundancy); there are, however, also enduring uncertainties as to whether the system will prove commercially and technically viable to deliver the capabilities required.[85] Further UK Government ambition to enter the space market has been announced in the *Integrated Review*, which announced the Government's support to setting up a first sovereign launch site in Scotland for small satellites, in anticipation of attracting wider demand from small satellite providers beyond the UK.[86] The launch site is intended to be operational by 2022, but the level of demand for launch services remains to be seen, as does the site's ability to demonstrate a successful launch capability (which has inherent commercial and technical risk as well as wider demands such as access to infrastructure and regulation).[87]

Box 4. Example of UK industrial and innovation base: entry into new and emerging markets

Active debris removal (ADR)

Astroscale Holdings Inc. is a Japanese company with a UK-based control centre. Using a spacecraft equipped with a robotic arm to remove inoperative satellites, Astroscale UK carried out the first ever ADR mission on 17 March 2021, using the ELSA-d system controlled from Harwell Campus in the UK. Leveraging existing expertise in space law, regulation, insurance and monitoring space weather, the UK is potentially well-placed to become a significant player in this area.[88]

Spaceplane and hypersonic propulsion

Reaction Engines Ltd. is a UK company based in Oxfordshire, England, which is conducting R&D on both a Skylon single-stage-to-orbit combined-cycle-powered spaceplane concept and the associated Synergetic Air Breathing Rocket Engine (SABRE) engine. This initiative has received funding from the UK Government, including Defence, as well as the ESA, European Commission and United States Defense Advanced Research Projects Agency (DARPA) as well as investments and strategic partnerships agreements from key UK defence aerospace prime-contractors, BAE Systems and Rolls-Royce.

Source: RAND Europe analysis of open source data.

85 Hern (2020).

86 Cabinet Office (2021).

87 Interviews with RAND Europe, 2021.

88 Harwell (2021a); Pfeiffer & Seal (2021).

Box 5. Example of UK industrial and innovation base: upstream and downstream capabilities

Small satellites

Within a broader focus on so-called NewSpace capabilities, the UK industrial and technological base is especially well positioned to capitalise on growing demand for the design and manufacture of smallsats, given the dominant position in this global market of UK-based companies such as Surrey Satellite Technology Ltd (SSTL). Originally a spin-off of the University of Surrey, this firm is now owned by Airbus (which is headquartered in Germany). SSTL is highly active in export markets and international partnerships, with recent examples including leasing imaging from NovaSAR-1 to the United States-based Space-Eyes LLC, collaborating with Perth-based LatConnect 60 on the first UK-Australia 'Space Bridge' project, or working with Italian firm Telespazio to explore a possible lunar telecommunications system for the ESA. AAC Clyde Space is another example of a prominent UK-derived smallsats company, though it too is now under foreign ownership with headquarters in Sweden.

Antennae

Oxford Space Systems is another example of niche production and export capabilities in the UK space sector, with a focus on high-quality and miniaturised deployable antennas for space applications. Customers include Airbus, Thales, SSTL, AAC Clyde Space and others, with research funding and other support from Dstl, the UKSA, the UK research councils (e.g. Science and Technology Facilities Council) and the ESA.

Telecommunications

The UK is also an active player in the satellite telecommunications market. In addition to the UK Government's acquisition of a stake in the OneWeb megaconstellation, as mentioned above, the UK is also home to important commercial actors such as Inmarsat, which provides telephone and data services to users worldwide using networks enabled by its more traditional constellation of large satellites in GEO.

Source: RAND Europe analysis of open source data.

Against this evolving background, the UK in general, and Defence specifically, must consider the implications of the strengths and limitations of its industrial and technological base, including SQEP, when navigating capability management decisions around the 'own-collaborate-access' framework in Chapter 4. It must also bear in mind the shifting value proposition of others, as discussed in the next section.

3.5. Allies and partners offer strengths which could be combined with those of the UK to yield effective collaborative programmes

It is beyond the scope of this report to provide a comprehensive overview of all countries' space capabilities, plans and ambitions that might be of relevance to the UK's future space capability programmes. Instead, this study seeks to highlight those of selected countries that have been requested by DCDC and the MOD Space Directorate. These include Australia, Canada, France, Germany, Japan, New Zealand, the UAE, and the United States. As shown in Figure 3.5 and explained in greater detail in Annex B, these countries exhibit not only various strengths that may be attractive to the UK, but also potential gaps which the UK may be able to 'fill' through contributions of industrial, scientific, military and space governance capabilities, and thus strike a bargain that is mutually beneficial and potentially synergistic.[89] When considering where such gaps might emerge, it may be helpful to reflect on several areas:

- **Geographic location:** As explained in Section 2.2, geographic location and the location of space assets on various orbits around Earth are important for delivering different capabilities. The ability to access launch sites in different parts of the world will present opportunities to access orbits that the UK may not be able to otherwise access in a timely and cost-efficient manner. France's ambitions to develop further the use of French Guiana as a space launch site for a wide variety of commercial launches may present one such opportunity, as could Japan's well-established launch industry. Aside from launch, there may be other benefits to location for space capability. The globally dispersed placement of radars for space surveillance and tracking is an important enabler of SST and SDA. Here, countries like Australia and New Zealand could present valuable opportunities for partnerships given their location, as well as existing space situational awareness (SSA) radar capabilities.
- **Resources and space policy:** As Figure 3.2 shows, space budgets have increased in most of the countries of interest. Space is recognised not only as a commercial opportunity with potential prosperity benefits, innovation and enhanced international standing, but also as an area where countries face similar risks and demands for greater resilience given the world's increasing reliance on space systems in the first place. There is, therefore, an expanse of common ground that exists between the policy ambitions of the UK and other countries of interest for potential collaboration – as demonstrated recently, for example, by the establishment of a 'Space Bridge' between Australia and the UK to increase investment and knowledge exchange on space. There are also areas of common interest such as environmental monitoring and climate resilience and disaster relief, where the UK might find shared goals and objectives with countries like France, India and the UAE, or multinational organisations such as ESA.[90]
- **Gaps in capability:** Effective collaborations often arise when actors are able to identify the niche contributions they could each bring into the partnership in a way that makes it mutually beneficial whilst also underwriting longer term commitment through mutual dependency. As such, it is important to consider not just similarities between collaboration partners but also the differences, particularly in terms of capability gaps. France and Germany, for example, have strong space sectors; indeed, they are the biggest contributors to ESA programmes and derive significant

89 Data discussed in this section was gathered from open sources and therefore purposefully does not cover Defence capabilities explicitly. It should be noted, however, that satellites (and underpinning technology and production capabilities) often have a dual use function and are used by both civil/commercial actors and the military.

90 UK Space (2020).

benefits from them. Yet, much of their space capability resides in more traditional, large satellites and operators, with a more limited emerging scene of smaller, commercial NewSpace players (including small launch). The UK, in contrast, has limited capability and heritage in many of the more 'traditional' space missions (e.g. it lacks any sovereign heavy launch capabilities) but has seen a significant growth over the last two decades of its NewSpace sector, as discussed in Section 3.4. As such, it might be valuable to consider where and how partners bring in complementary propositions and capabilities into bilateral or multilateral collaborative fora. At a lower level, countries that possess particular strengths which could fill in specific capability gaps – for example, Canada and Japan have strong heritage in space robotics, while Germany has an excellent scientific R&D base in energy, propulsion and alternative power generation systems for space.

- **Acquisition cycles and processes:** While commonalities in space policy and the presence of capability gaps are important factors, the practical reality of needing to align funding and acquisition cycles to enable collaboration can sometimes be overlooked. Yet, this is a critical factor to enabling successful collaboration and, conversely, it is a critical barrier to collaboration if acquisition cycles and processes cannot be aligned effectively. These challenges have been identified in RAND's wider research into a variety of different United States-led collaborative space programmes, most of which faced challenges in aligning the complex acquisition cycle and processes on the United States side with the shorter, less bureaucratic processes of the United States' smaller partners.[91] The practical question for collaboration therefore becomes: does the UK's timing for delivery of capability align with its potential partners' timelines? If not, are there opportunities to harmonise these?
- **Building on existing collaborative efforts:** It may seem obvious but one of the principal enablers for collaboration is the ability to build on past successful collaborative efforts. These would normally build trust between partners, establishing working relationships that can help iron out differences in approaches over the duration of the programme. In the case of the UK, the long-standing close collaboration with the United States creates a strong incentive to explore where and how further space collaboration may be beneficial to both sides. Similarly, the UK's existing relationships with France and Germany, through ESA, as well as bilateral partnership (with France), present opportunities to build further. This could include initiatives that integrate space into programmes in other operational domains, or encourage multi-domain integration and interoperability with allies.
- **Learning from good practice:** Accepting the assumption that countries are 'all on the same space trajectory but just find themselves on different parts of this journey and are progressing at different speeds', there are opportunities to use international collaborations as a learning process to drive subsequent improvement.[92] Given the challenges ahead

91 For an unclassified and published example of this RAND research, see Kim et al. (2015).

92 RAND Europe interview, April 2021.

for the UK Defence specifically (and the UK more generally), including the need to build up skills, nurture the seedling collaborative partnerships and find ways to access, and where necessary protect, sensitive cutting edge technologies, there may be opportunities to identify good practices from other countries. The UAE, for example, presents a unique case where the combination of high ambitions for space, significant financial resources and reliance on international collaboration that explicitly involved building up skills and expertise locally resulted in successful delivery of complex space missions (especially the launch of spacecraft to orbit around Mars) in a period of only twelve years. Similarly, the UK's ambitions to boost its commercial sector and bring prosperity benefits to different parts of the country are shared with countries like Australia, whose national space agency's sole focus is to boost its commercial space sector and grow its jobs by 30,000 by 2030.[93]

3.6. UK strengths could be undermined by incoherent approaches and low public interest though recent efforts give hope to the contrary

To a greater degree than in most 'traditional' defence domains, the space domain is marked by the presence of many different stakeholders, interests and ambitions. These include various Government departments, international partners, the commercial sector, academia and, ultimately, the public.[94] Given this complex picture, there is always a threat that the various interests and ambitions of the main actors diverge, potentially hampering the ability of the UK to pursue a coherent national or even Defence-wide space strategy and policy. The ongoing preparation of the *National Space Strategy* and the various cross-Government engagements that have been taking place over the last few years have acted as unifying factors designed to bring greater coherence of approach. The establishment of the NSC presents a concrete opportunity to drive coherence of strategy and policy within the UK Government as well as determine priorities for future activities.

This will, however, always be a 'work in progress' as there are likely to be competing priorities for limited resources and different departments will place different premiums on assured operations in space. Hypothetically speaking, for example, while Defence may wish to 'own' particular satellites to ensure secure access to high-resolution imagery of specific parts of the world for the purposes of ISR, parts of the FCDO or other departments and agencies may be satisfied with 'accessing' this imagery commercially.[95]

Further barriers and threats to the UK's success in space stem from the challenges that lie ahead in terms of the significant effort needed to build up space SQEP within the UK. This will require coordination with other Government departments (especially the Department for Education and BEIS), universities, training colleges as well as conscious efforts to build a space culture in the general public in support of the UK's ambitions. The UK's commercial space sector has seen successful growth and has showed great resilience over the last decade and recently, even during the

93 Royal Aeronautical Society's President's Conference, May 2021.

94 See Chapter 4 for a more detailed discussion of the differences between space and other domains.

95 Interviews with RAND Europe, 2021.

Figure 3.5 Overview of select characteristics of key allies and partners for the UK and Defence in the space domain

Key:
- Stated ambition
- Commercial capabilities
- Academic and scientific capabilities

Canada

Stated ambition:
- Partner Lunar Gateway mission
- Next-gen Canadarm
- Invest in SSA, maritime domain awareness, space-based EO, SATCOM

Commercial capabilities:
- Space robotics, space-borne SAR
- Communications

Academic and scientific capabilities:
- Autonomous space robotics
- Space weather and wildfires monitoring

France

Stated ambition:
- Largest € contribution to ESA
- Galileo, ExoMars
- French Guiana major spaceport

Commercial capabilities:
- Secure coms and EO
- Established industrial base

Academic and scientific capabilities:
- Labs involved in NASA's 2018 Solar Parker probe mission
- Contribution to NASA's Mars InSight mission
- Asteroid lander (Mascot)

Germany

Stated ambition:
- Second largest € contributor to ESA
- Darmstadt ESA Mission Control
- Cologne ESA astronaut training centre
- €30m plan for launchpad for smallsats in the North Sea
- Hydrogen-based, networked energy systems

Commercial capabilities:
- Bremen centre for human space flight and space robotics
- Rocket engines, rocket design
- Established industrial base

Academic and scientific capabilities:
- Ca. 1/2 of European ISS experiments come from German research institutions
- Fraunhofer Space Alliance
- Heinrich Hertz R&D programme

Japan

Stated ambition:
- Thriving commercial space sector focused on exports
- Contribute to Lunar Gateway's International Habitation module

Commercial capabilities:
- Advanced technologies
- Greenhouse gases observation
- A number of launch sites
- Robotics expertise

Academic and scientific capabilities:
- 2018 won the European Space Elevator Challenge
- 2020 Hayabusa-2 space probe obtained asteroid dust
- Space Exploration Innovation Hub Centre

USA

Stated ambition:
- 2019 establishment of United States Space Force (USSF)
- NASA collaboration with the private sector
- Lunar Orbital Platform-Gateway
- The Humans on Mars Exploration Campaign

Commercial capabilities:
- Mars landing of NASA's Perseverance rover
- SpaceX transported astronauts to the ISS
- United Launch Alliance joint venture as national launch services provider
- People and payload transport through space

Academic and scientific capabilities:
- California Institute of Technology, Harvard University, University of California – Berkeley, Princeton University, Stanford University, University of California – Santa Cruz, and University of Chicago
- NASA MIRO Center for Space Exploration and Technology Research
- The Center for Space Exploration and Technology Research NASA
- The Mars oxygen experiment

UAE

Stated ambition:
- R&D and satellites manufacturing capabilities
- Hope Mars Mission
- Environmental and climatic monitoring

Commercial capabilities:
- Mohammed bin Rashid Space Centre
- EO satellites
- Integrated satellite coms

Academic and scientific capabilities:
- MeznSat 3U CubeSat
- Five dedicated space programmes

Australia

Stated ambition:
- Stimulate investment
- Regulatory framework
- Moon to Mars with NASA

Commercial capabilities:
- Phased array technology
- Delta-V NewSpace alliance
- Hybrid powered launch vehicles

Academic and scientific capabilities:
- Cubesats missions
- Hypersonic propulsion systems

New Zealand

Stated ambition:
- EO data use for monitoring
- Grow satellite design and manufacturing capabilities
- Grow space science, technology and engineering

Commercial capabilities:
- Orbital launch
- "Kiwi Space Radar" for SDA
- Composite materials and cryo-coolers
- Geospatial data and AI

Academic and scientific capabilities:
- Superconducting magnet systems for satellite thrusters
- Warkworth Radio Astronomical Observatory

COVID-19 pandemic. There are, however, gaps in the UK space ecosystem in terms of linking academic research and teaching with commercial capabilities and cross-Government or Defence policy and investment.[96] A long-term strategic investment in these partnerships will be needed to strengthen the emerging collaborative networks and enable the sector to cross-fertilise existing skills and expertise and build new ones, while also promoting competitiveness.

Finally, international collaboration, while almost unanimously recognised by space powers as a critical part of a country's space ambitions and programmes, also presents inherent challenges and risks. Brexit has already resulted in the UK's exit from the Galileo programme and recent wider diplomatic tensions that are linked to vaccines, fishing, trade, and border policies may take time to mend. Although the UK's commitment to ESA remains strong (as explained in Section 3.3), it remains to be seen how the UK can most effectively engage in European space activities as a third party to the EU. The historic partnership with the United States also remains fundamental to UK Defence space capability but the UK's high level of dependency may create risks if the United States chooses to engage with other partners more intensely instead or chooses to restrict UK's access to these capabilities at some point in the future. As such, there is an enduring pressure on UK Defence to continue to demonstrate the value proposition it brings to its key allies and partners, as well as the benefits derived through space activities for other parts of Defence and government.

96 Discussions at RAeS conference on space 2021.

4 Navigating own-collaborate-access options for space

Understanding the factors shaping the UK's evolving strategy and policy for this domain (Chapter 2) and the contributions that it can make to different partners and end users (Chapter 3) are essential prerequisites for making informed choices about the capability decisions that the MOD Space Directorate and Space Command will face as they seek to implement the *Defence Space Strategy* in the 2020s and beyond.

To inform these decisions, this chapter summarises the principal considerations around the own-collaborate-access framework for capability development. This is an abridged version of a non-public interim report, *'Own, Collaborate, Access' Decisions in Development of UK Defence Space Capability* (PR-A1186-1) dated 11 May 2021, and is further supported by a decision support tool for MOD in Annex C.

4.1. Learning from other domains is important but decisionmakers need to recognise how space is different to tailor acquisition approaches

Much can be learned from capability development in more 'traditional' domains (e.g. land, maritime, air), as well as from Defence's analogous experience of building up knowledge, skills and expertise in the 'new' domain of cyber capability development.[97] Lessons can also be learned from good practices in other countries or commercial organisations, or in other sectors. Ultimately, however, there is a limit to how transferrable some lessons may be to the implementation of the *Defence Space Strategy*. There are attributes of space that require unique considerations and trade-offs to be made when developing, acquiring, or operating and supporting capability in this domain.[98] Equally, when starting from the UK's low baseline and equipped with finite resource, Defence cannot simply replicate the approaches of larger or more established space powers such as the United States or even France. A clear and nuanced understanding of the capability development choices facing Defence, along with practical guidance on how to navigate potential options, is thus required if the UK is to achieve its stated ambition of becoming a 'meaningful player in space'.[99]

As discussed in Chapter 2, it is important to emphasise how and why space is different to better appreciate how good practices may

97 Persi Paoli et al. (2017).

98 Kim et al. (2020).

99 HM Government (2021a).

need to be tailored to space. Examples of relevant characteristics of space include:

- **Heavy focus on 'dual-use' satellites and technologies**, where multiple payloads can be shared or owned between multiple users (including public-private actors or different nations) or one asset can provide different services to different end users (including, for example, different government departments wanting to use the same asset for different tasks on different passes, e.g. sharing Earth observation data on various parts of the world).
- **Less platform-centric domain, with a greater focus on building a 'system-of-systems' from ground segment to launch to orbit to downstream user.** Arguably, much of defence capability development today is centred around a system of systems solution, where individual platforms are integrated into an overarching system of systems. Nonetheless, there remains an enduring attachment to thinking about platforms (ships, planes, tanks etc.) in other domains, rather than how multiple systems and sub-systems all fit together into a coherent architecture to deliver the required military effects.[100] By their very nature, satellites – the principal platforms in space – are part of a system of systems, integrated with other platforms and systems to fulfil their enabling function, supporting military operations across multiple domains. This may be through encrypted communications, provision of position, navigation and timing, or enhancing ISR capabilities via Earth observation. Satellites come in a range of sizes from nanosats, cubesats and other smallsats in low Earth orbit (LEO) to the larger expensive platforms that are most typically deployed in medium Earth orbits (MEOs) or GEOs. **Satellites** are also complex pieces of equipment, requiring specialist expertise and design, production and test facilities. Further, they have to be launched into space from specialised **launch sites** that require heavy infrastructure investment, easy access for logistics and utilities and be located in areas where launched vehicles pass over uninhabited areas and have appropriate (and fuel-efficient) access to the relevant orbits. Many satellite systems also require users on the ground to have appropriate equipment and terminals to access the **data transferred** to and from the satellite. Finally, all satellites need a ground segment, including an **operations centre** from which satellites are monitored and controlled. Synchronisation is, therefore, required between the various segments of space capability, from launch, satellites and ground acquisition programmes. Dependencies are strong; any delays in satellite development will impact launch dates.
- **Capabilities are remote and typically uncrewed.** Unlike manned or even unmanned platforms in other operational domains, almost all space objects are far removed from the operator, the end user and the country or organisation that owns and operates them. In practice, this has meant that, historically, they cannot easily be physically accessed once launched (e.g. for repair, upgrades etc.), although recent demonstrations show promise in successful proximity missions. It also means it is more difficult to diagnose the source of degraded performance (anomaly analysis). Satellites in orbit are largely unable to be physically modified or upgraded, although capabilities for de-orbiting, on-orbit

100 Brose (2020).

servicing, reprograming and reconfiguration are in development and should be monitored closely by Defence. Also, long-term maintenance issues are different from traditional capabilities, for example in terms of disposal (e.g. in graveyard orbits or burn up in Earth's atmosphere).

- Arguably, though it depends on the satellite's size and design, it is **harder to hide space capabilities** once they are placed in orbit and are thus tracked by various actors – commercial and government- involved in space surveillance and tracking (SST) – compared to assets in other domains. Furthermore, not only are space capabilities permanently remote, but their capability and performance are linked to their position (depending on the orbit in which they are placed).
- Contrary to common hype and astro-determinist narratives of space as an 'ultimate high ground',[101] **space assets are inherently vulnerable and held in range of both kinetic and non-kinetic threats,** which places a premium on mission assurance and resilience rather than just reliability or force protection.[102] In addition, legacy assets usually have significant cyber vulnerabilities as they had been designed and placed into orbit at a time when space activity was limited to a handful of key players able to afford to launch and operate large, expensive satellites.
- There are significant **interdependencies with other domains** (e.g. given the importance of SATCOM and PNT to enable multi-domain integration), **and with critical national infrastructure** and cross-Government or civilian users in the downstream.[103] As discussed in Chapter 2, satellites increasingly underpin the functioning of digital society and the economy.[104] As a result, space systems have many stakeholders across the downstream segment of the sector, some of whom may not understand the technical details of space systems but nonetheless rely on their capabilities and have an interest in how Defence develops its space capabilities and operations.
- Space often offers valuable enhancement of capabilities on Earth, particularly via networks and data but should **not be considered as a universal panacea** for all requirements. Delivery of military effect and enhancing operational resilience may not always be best met by space assets and decisions will be required to trade and balance capabilities in other domains to achieve the desired effect/resilience (e.g. airbreathing vis-à-vis space ISR assets). There is a need to consider redundancy and reversionary modes (including Tactics, Techniques and Procedures (TTPs), in addition to alternative technical solutions) for when access to and use of space is contested or denied.[105]
- At the same time, there may be tasks for which space capabilities are uniquely well-suited. Given the fast pace of innovation in space, Defence should continue to look for appropriate opportunities to **adopt new 'sunrise' space-based technologies**

101 For example, contrast the perspectives of Bowan (2020) with Dolman (2001) or Deudney (2020).

102 For different theories of space power, see Bowen (2020); Deudney (2020); Dolman (2001); Klein (2019).

103 MOD & Dstl (2012).

104 Dawson (2018); Government Office for Science (2018).

105 Alkire et al. (2020).

or novel CONOPS to replace 'sunset' capabilities in other domains or to deliver entirely novel missions and effects. From a capability development and acquisition perspective, this necessitates a clear focus on the 'joint' nature and importance of space and coordination with Strategic Command, the individual Services, and senior responsible owners for relevant cross-cutting programmes such as multi-domain integration.[106]

4.2. Differences in space capability are accompanied by differences in the market dynamics that shape capability development

In addition to the inherent differences in space systems themselves, there are also broader economic, industrial, and commercial considerations that make space acquisition different from other domains, building on the SWOT analysis presented in Chapter 3:

- **There is a relative lack of large UK primes** (except Airbus), with the focus more on SME capabilities, and development of niche areas of intellectual property (IP) and expertise.[107]
- There is a distinct **lack of monopoly-monopsony relationships** in the UK space market, with firms much more focused (and reliant) on exports rather than being supported primarily by Defence.
- There is greater **reliance on industry and on international partners** than in other domains, given the inherent 'dual use' nature of most space technologies and the sizeable and fast-growing role of commercial organisations in launching and operating satellites (including megaconstellations) and providing a wide variety of related upstream services and downstream applications.[108]
- The default position for UK Defence space capability management in recent decades has been centred around more reliance on industry and the **use of private financial initiative (PFI) models** rather than the typical government-owned, government-operated GOGO asset (in contrast to other defence domains with their predominance of GOGO platforms), necessitating commercial integration with MOD.
- Many of **the UK's industrial strengths** reside in NewSpace capabilities (e.g. smallsats) and niche areas of IP and expertise, but certain other areas are very limited (e.g. heavy launch).[109]
- The MOD has more **limited capacity in terms of SQEP or understanding** of the market and the breadth of innovation, posing challenges for delivery of its 'intelligent customer' function. This may make it more difficult to anticipate, understand or manage risk, or make informed decisions about where to opt for novel or off-the-shelf solutions, or sovereign or non-sovereign programmes.
- The MOD has **comparatively limited leverage to shape markets** for 'dual-use' products as there is a fast proliferation of commercial companies and export customers in space and even traditional defence space contractors are realigning to be competitive. This is true for all

106 MOD (2020d).

107 Knowledge Transfer Network (2021).

108 Madry (2020); Tkatchova (2018).

109 Knowledge Transfer Network (2021).

governments, but clearly the MOD has less ability to shape markets than, for example, the better-resourced United States DOD.

- Commercial actors are starting to **offer services previously provided only by governments.**[110] Examples include: the Space Data Association,[111] which brings together around thirty commercial space players to combine details of planned manoeuvres with observation data to generate a common understanding of current and near-future activity in GEO; companies offering SST and broader SSA services such as LeoLabs;[112] or the provision of signals intelligence (e.g. Luxembourg-based company Kleos Space,[113] which provides geo-location of communications signals with ship Automatic Identification System [AIS] data to enable tracking of vessels). These developments have clear relevance to Defence from both a threat and opportunity perspective.

These various contextual factors and eccentricities to the space domain all have direct and indirect consequences for how UK Defence approaches upcoming decisions between 'owning', 'collaborating' on, or 'accessing' new space capabilities.

4.3. The generic 'own-collaborate-access' framework will need to be fleshed out to account for the specificities of the space domain

The 2012 *National Security Through Technology* white paper outlined an approach to prioritising between sovereign and collaborative programmes based on Technological Advantage. This has since been supplanted by the 'own-collaborate-access' model introduced in the *Integrated Review* (*IR*) and *DSIS* (2021). High-level descriptions have been provided in the public *IR* document as follows:

Figure 4.1. Own-collaborate-access framework

OWN:	Where the UK has leadership and ownership of new developments, from discovery to large-scale manufacture and commercialisation. This will always involve elements of collaboration and access.
COLLABORATE:	Where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals.
ACCESS:	Where the UK will seek to acquire critical S&T from elsewhere, through options, deals and relationships. This will always be conducted within the bounds of the Assured Capability Framework, cognisant of the fact that there will be differing national levels of assured access requirements.

Source: Integrated Review (2021).

110 Iacomino (2019).
111 Space Data Association (2021).
112 LeoLabs (2021a).
113 Kleos (2021).

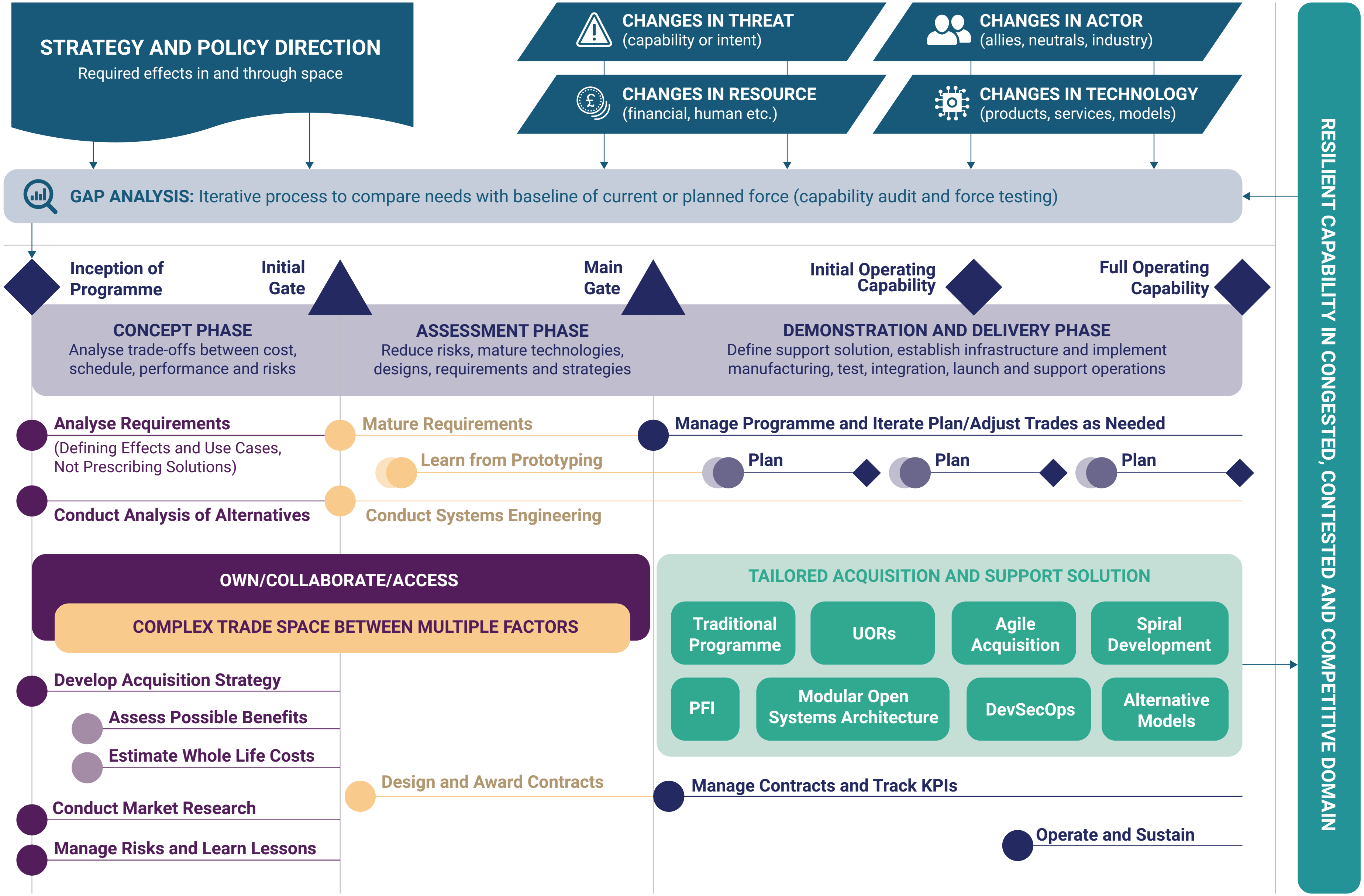
The principles behind determining whether to 'own', 'collaborate' on or 'access' space capabilities are yet to be articulated publicly as a more detailed framework for practical application in the context of capability management. It is already becoming clear that the delineation between the different options is unlikely to be clear-cut, not least because of the various components that form part of space capability, each of which may be subject to a different capability development approach (e.g. including separate arrangements for satellites, ground stations, launch and data). As a consequence, most capability development and acquisition programmes in space are likely to consist of a blend of the three approaches; for example, the UK may lead on a critical part of capability ('own') within a collaborative programme ('collaborate') while also leveraging off-the-shelf parts and components in certain areas ('access'), much like the Team Tempest programme for future combat air, or shipbuilding.[114]

4.4. The UK's choices on 'own-collaborate-access' do not occur in a vacuum and therefore necessitate a contextualised approach

Decisions as to whether to 'own', 'collaborate' on or 'access' a given space capability are deeply embedded in wider force development and acquisition processes: they do not occur in a vacuum. A schematic depiction of the acquisition process is presented in Figure 4.2. While also being tightly informed by broader changes in the threat, technology, resource and external environment, the decision space for considering 'own-collaborate-access' options primarily spans the concept phase and assessment phase, as it is throughout these two phases in particular that the MOD will be considering how best to deliver capability – both in terms of design options and de-risking of potential solutions.

114 MOD (2017b, 2018a, 2021a).

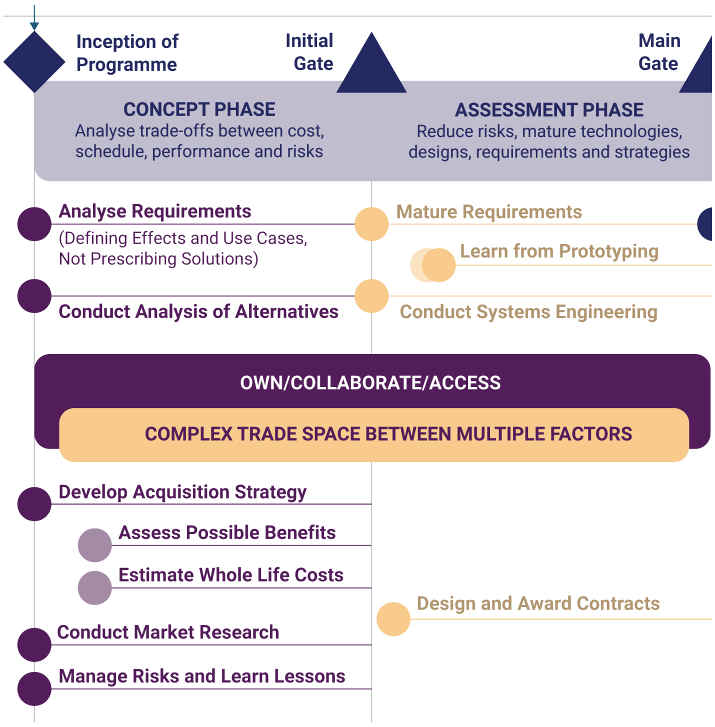
Figure 4.2. High-level framework for managing defence acquisition



Source: RAND Europe analysis, adapted from MITRE (n.d.).

4.5. The 'own' and 'collaborate' options for space will be shaped by the UK's own requirements and its value proposition to others

When Defence is considering its 'own-collaborate-access' options in the concept and assessment phases of the acquisition process for space, it is important to emphasise the point made above – that the UK in general, and Defence specifically, starts with a only a handful of sovereign assets (Skynet in particular) and limited SQEP. As such, Defence will need to set out which capability areas it deems to be of critical importance to strategic imperatives and operational independence to merit the decision to 'own' and provide the requisite resource commitment. This is because the development of these is likely to require a much longer timeframe than acquisition of capability via 'access' to existing capability developed by allies, partners and industry, or even 'jumping on' existing 'collaborate' programmes.



Full 'ownership' of all components (e.g. across satellites, ground segment, launch, data) is unlikely to be feasible for the UK for the majority of future space capabilities – financially as well as due to the lack of baseline sovereign capability to begin with. As noted above, however, choosing to 'own' capability does not necessarily imply full sovereign ownership of all components; rather, it is more likely to describe a situation where the UK 'owns' a niche part of capability that is integrated within a larger 'collaborative' solution and architecture. As such, sovereignty is a matter of degree, not binary.

With this in mind, it will be important for UK Defence to articulate clearly where it can bring value to collaborative capability development programmes and as such trade its way into collaborative partnerships in a way that gives it maximum leverage and benefits (e.g. in terms of control over requirements, workshare). This value proposition to prospective partners may also be different depending on the capability area and the level of capability possessed by the partner(s) in the first place. The considerations on whether to 'own', 'collaborate' on or 'access' a given capability comes in already at the concept phase of capability acquisition driven by analysis of requirements and understanding of the market and how commercial solutions may wholly deliver or partially contribute to the delivery of a desired capability. The analysis is then taken further into the assessment phase where concrete options for 'ownership' (as described above), 'collaboration' or 'access' to services are identified, assessed and, finally, selected for implementation.

4.6. The MOD is likely to be a 'market taker' not 'market maker' for many space capabilities, requiring sound market intelligence

Building on the analysis of previous chapters, it is clear that the fast growth of commercial space activity in the last decade (including into areas traditionally monopolised by national governments), has shaped the global space market in ways that make any one national government a market taker, rather than market maker, for many elements of space capability it wishes to 'access'. This is increasingly true even for the largest players (e.g. the United States) and is a major constraint on small and medium players such as the UK, with their limited resources and influence.

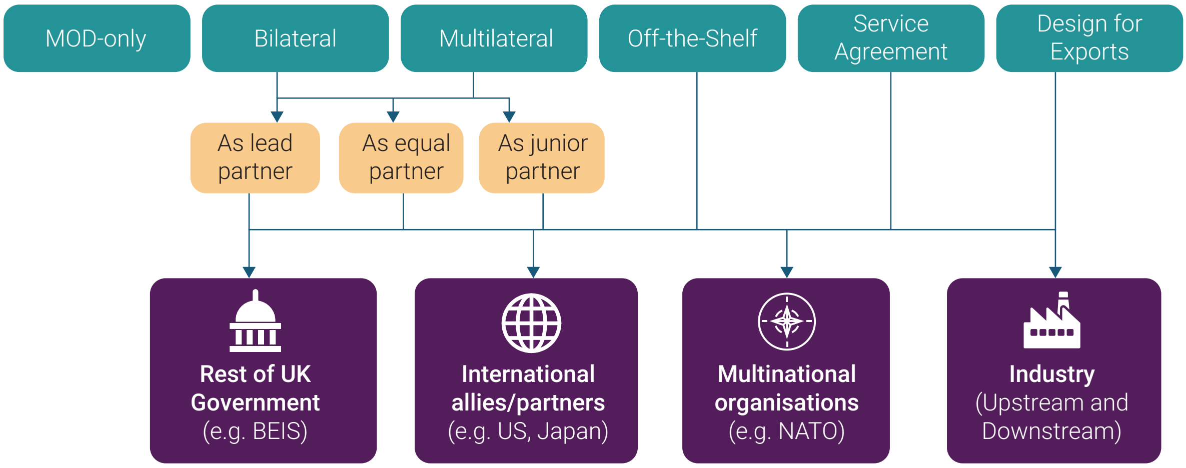
While being a market taker in many capability areas may sound like a constraint and risk for Defence – and certainly an experience rather unlike its more predominant role in other, more established defence markets such as for complex weapons or naval shipbuilding – there are also substantial potential benefits. Defence has an opportunity to tap into a wide range of mature solutions, avoiding long lead times, reducing costs and boosting resilience. This means that the UK can potentially develop from its low baseline of organic capability relatively quickly, rather than needing to duplicate the learning, innovative and iterative product development that has already occurred in other countries or organisations.

To achieve this 'leapfrog' advancement Defence will need sound market intelligence and horizon scanning capabilities to identify, understand and monitor developments in global commercial space markets and the latest science and technology (S&T) developments and innovations of relevance to defence. With this knowledge, Defence is likely to be better equipped to identify whether 'access' is a feasible and appropriate approach for a desired capability or whether there is need to design new bespoke capability (or elements of capability) either alone ('own') or with partners ('collaborate') to ensure the delivery of the desired military effect. In addition to aiding decisions on whether to 'own-collaborate-access', market intelligence and horizon scanning capabilities will also help overall capability management by providing up-to-date information to feed into identification of key drivers of risk, particularly in relation to technical and supplier-related risks. Given limited specialist SQEP in space both now and in the near-term, managing programme risk may present initial challenges to implementation of the *Defence Space Strategy*. Yet, agile acquisition models such as spiral development, rapid prototyping, modular open systems architectures (MOSA) or other tailored approaches may help to mitigate these deficiencies – as discussed in the Interim Report (PR-A1186-1).

4.7. Defence will need to balance a mix of 'own-collaborate-access' options across its portfolio, each entailing different trade-offs

Beneath the superficially simple shorthand of the 'own-collaborate-access' framework, there are many possible combinations of approaches and partner(s), each with different types of benefits, costs, and risks. A high-level overview of these complex options is presented in Figure 4.3.

Figure 4.3. Overview of space capability development options



Source: RAND Europe analysis

Whether the MOD opts for 'own', 'collaborate' or 'access' will depend on a variety of factors, including:

a) What is available:

- Whether the UK has extant capability that it may be able to re-task, adapt, or upgrade.
- Whether the requirement can be readily met by a commercial off-the-shelf (COTS) or modified off-the-shelf solution (MOTS).
- Whether the UK can access the capability via existing collaborative partnership arrangements.

b) What is essential:

- Whether the capability required is critical due to a strategic imperative and/or to ensure operational independence,[115] given military requirements not only in space but across all domains.
- Whether the capability required is critical to other government departments and agencies.

c) What is feasible:

- Whether the UK has sufficient time to develop organic capability, given operational requirements and a changing threat landscape.
- Whether the UK already has mature S&T solutions, IP, niche industrial capabilities, extant relationships and other 'cards to play' that could be traded into partnerships.
- Whether the UK's requirements are aligned with those of potential partners.
- Whether prospective partners have the appetite to collaborate with the UK.

115 Strategic imperatives are defined as 'areas of industrial capability which are so fundamental to [UK's] national security, and/or where international law and treaties limit what [the UK] can obtain from overseas, that [the UK] must sustain the majority of the industrial capability onshore'; Operational independence is defined as the ability to 'conduct military operations as [the UK] chooses without external political interference, and to protect the sensitive technologies that underpin those capabilities'. See MOD (2021b).

d) What is desirable:

- What is the UK's prioritisation and weighting of different potential benefits, costs, and risks (e.g. across military, economic, social and other factors – see discussion of 'trade space' in Section 4.9).

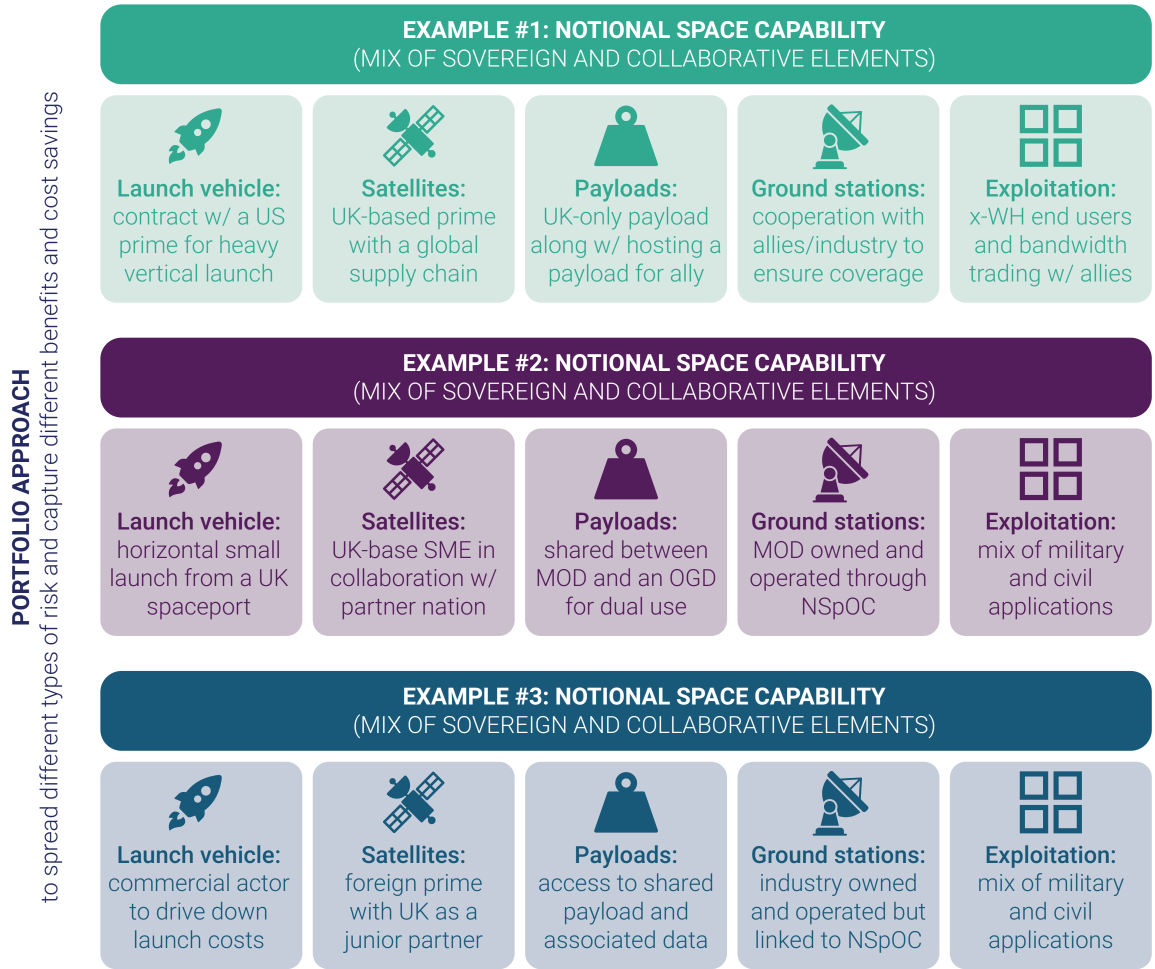
Whichever option the UK chooses in any given situation, it should do so with an 'eyes wide open' approach, appreciative of the lessons to be learned from the past – both on sovereign programmes and collaborations. To this end, the following sections provide a brief overview of relevant drivers and barriers, while Annex C provides a more detailed description how MOD might navigate a decision support tool for these choices.

4.8. The 'system of systems' nature of space capability necessitates a disaggregated view of 'own-collaborate-access' options

Space capability, perhaps more obviously so than other military capabilities, comprises a complex 'system of systems' with distinct elements, including: launch vehicles and launch sites, satellites, payloads, ground stations, user terminals and exploitation by ultimate end users.

A variety of different systems, activities and actors are involved in developing such capability, including **upstream** activities such as design, manufacture, launch and operation of space objects, ground installations and enabling activities (e.g. SSA/SST) as well as **downstream** activities including exploitation of data and services by end users (e.g. PNT, SATCOM, ISR) both within Defence and externally across government, industry or wider society (e.g. as in the case of the United States GPS). As a result of this complexity, space programmes are likely to combine a mix of 'own-collaborate-access' options across different elements of this overall system of systems. Figure 4.4 illustrates a notional portfolio of different capabilities, each entailing a combination of sovereign, collaborative and off-the-shelf elements.

Figure 4.4. Notional portfolio of space capability (mix of sovereign and collaborative elements)



Source: RAND Europe analysis

4.9. Each specific 'own-collaborate-access' option will, in turn, bring risk and trade-offs to be balanced against overarching objectives

In approaching capability development options, Defence should first aim to identify and discount those options at either extreme of the 'own-collaborate-access' framework, namely:

- Capabilities that must be owned (i.e. due to non-negotiable criticality in operational effectiveness).
- Capabilities that can be accessed (i.e. where there are no 'deal-breaker' security or other reasons not to pursue a mature COTS/MOTS solution).

In practice, relatively few programmes are likely to fall unambiguously into either of these extremes. This necessitates closer examination of the complex trade space between either 'own, collaborate or access' that depends on the overall balance of investment appraisal for potential options. Practical guidance on how to navigate the trade-offs between different factors is provided through a decision support tool in Annex C, but, in summary, Defence should make informed trades between:

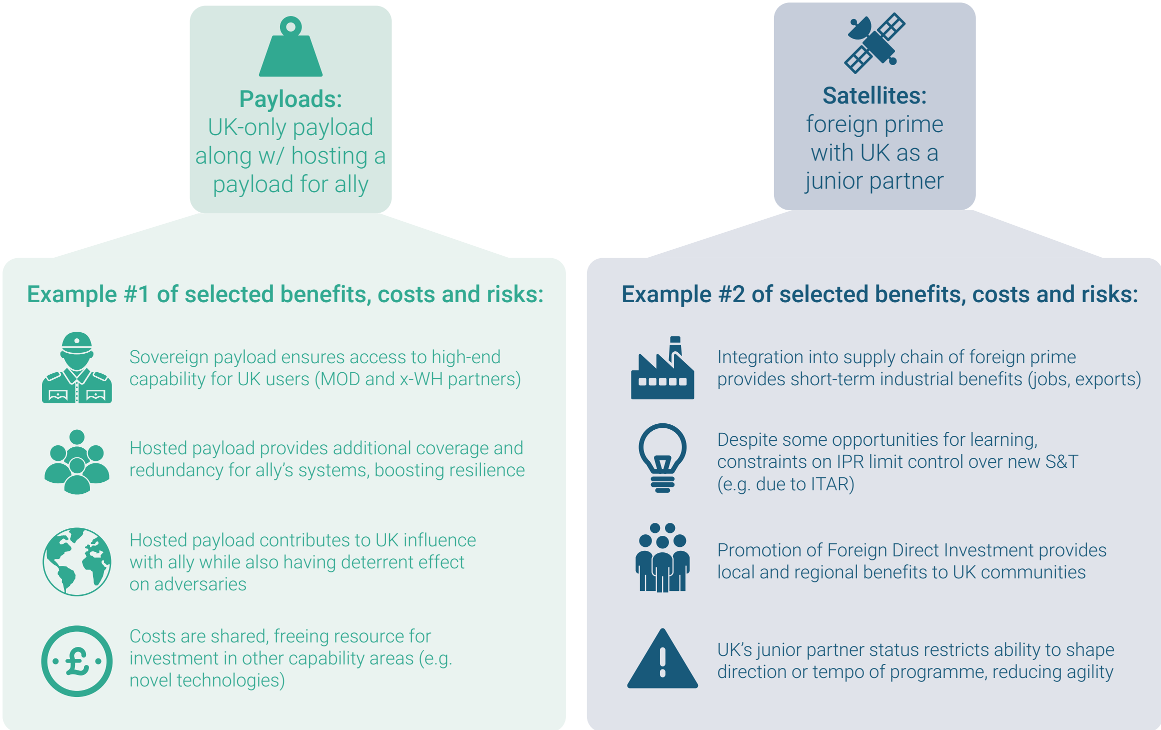
- **Affordability and value for money:** this refers to the distinction between an affordable programme (one that can be paid for in terms of cash flow and resource cost for its duration) and whole-life value for money (the optimal use of resources to achieve the intended outcomes).
- **Operational advantage:** this refers to the UK's ability to maintain a technological and tactical edge over its adversaries in a fast-changing threat environment.
- **Security of supply and freedom of action:** this security of supply refers to the guarantee of supply of goods and services sufficient for the UK to discharge its defence and security commitments in accordance with its foreign and security policy requirements.[116] Freedom of action refers to the UK's ability to determine its own affairs without intervention by another State or non-state actor, and is in line with the UK's legal obligations. Supply chain resilience has become a matter of increasing concern for the UK Government in recent years; with space recently being recognised as a critical sector requiring mandatory notification and enhanced scrutiny of foreign investments in line with the new 2021 National Security and Investment Act.
- **Interoperability:** this refers to the ability of platforms and/or systems to work with other interfaces, products and systems operated by different services and/or different nations.
- **International influence and engagement:** this refers to the ability to shape relations with other countries in a way that brings strategic benefits for the UK.
- **Industrial and commercial impact:** this refers primarily to impact on companies, jobs and skills involved in development, design, production, operation, support and disposal of equipment.
- **Innovation and generation of IP and spillovers:** this includes R&D investment, technology spillovers into other sectors, patenting activity and so on.
- **Wider prosperity benefits, including social value:** this includes national wealth created through economic activity. Such activity may include: exports, gross value added, regional employment, skills development, contribution to tackling climate change and other components of social value as articulated in the 2021 *DSIS*.[117]
- **Risks** (e.g. political, regulatory, commercial, technological): this refers to the probability of an adverse effect or event which may or may not happen, but if it does it will adversely affect delivery.
- **Time:** for fielding capability and opportunities for Defence to learn over time in a nascent domain.

The weighting given to these different considerations will depend on the nature of the programme and/or partner(s) in question, and the MOD's objectives. Understanding how to weight each of these factors should be driven by an appreciation of the UK's value proposition, as discussed in Chapter 3, and must ensure that the MOD has a clear and evidence-based assessment of its own relative SWOTs and those of its prospective allies, partners or competitors, so as to tailor its

116 Adapted from EDA (2009).

117 MOD (2021a).

Figure 4.5. Notional examples of trade-offs and risks in different types of programmes



Source: RAND Europe analysis

proposition accordingly to maximise benefits and minimise the costs and risks. Figure 4.5 illustrates how these benefits and trade-offs could apply on a couple of notional examples derived from the hypothetical space capability development programmes previously outlined in Figure 4.4.

4.10. Programmes will bring benefits and trade-offs which will need to be balanced on a portfolio level to ensure strategic objectives are met

While concrete benefits and trade-offs will apply to each individual programme specifically, it is important to appreciate how they combine on a portfolio level to understand the dependencies between programmes as well as wider systemic benefits or trade-offs.

An overarching view of how different capability development programmes each with their own unique 'own-collaborate-access' arrangements combine on a portfolio level will be important to ensure the overarching ambitions for the UK Defence space enterprise (including the Space Directorate, Space Command, other MOD, and academia and industry) continue to be met.

To illustrate the interconnectedness of individual programmes, it is worth noting that sovereign capability in one area, such as SDA or protect and defend, might de-risk collaborative programmes in other capability areas. In another example, leveraging innovation and economies of scale through 'access' to commercial services might enhance redundancy for more bespoke MOD-only or collaborative programmes (although it may also inadvertently undermine SQEP development if such commercial services are procured from a non-UK entity without in-built provisions for upskilling).

Deconflicting and managing the various trade-offs will be a complex task, which should be carried out both within the defence context (e.g. to understand where there might be redundancy or alternative capabilities available for defence operations and missions) but also on the national level to ensure that individual Defence space capabilities are not viewed in isolation, but coherently contribute to delivery of the *National Space Strategy*. Such coordination should come within the remit of the NSC, and entails a need for closer cooperation on capability development and acquisition with other government departments and agencies – including most notably, but certainly not limited to the UKSA – than has traditionally been the case in other domains where MOD retains a monopoly of interest (e.g. in procuring tanks, aircraft and specialist naval vessels). This necessitates a clear appreciation of the contextual factors discussed in Chapters 2 and 3 to be embedded in the capability management decisions outlined in this chapter and described in more detail in the Annex C decision support tool and the Interim Report.

5 Conclusion

This brief concluding chapter provides final reflections from the RAND study team on key issues for the MOD Space Directorate and new joint Space Command to consider as they set about implementation of the upcoming *Defence Space Strategy* in support of the wider ambitions of the *National Space Strategy*. In addition, the team suggest examples of areas that could merit further research and analysis. Here, the team is conscious of the ongoing learning effort within the UK Defence space enterprise and the need for robust, evidence-based strategy and policy implementation that maximises the returns (e.g. in terms of military, political, economic and broader social benefits to the UK in general and Defence specifically) on the finite resources available.

5.1. Achieving the ambitions of the UK's Defence Space Strategy will require deft navigation of both exogenous and endogenous trends

Policy and decision making in the space domain will continue to be shaped by a variety of exogenous and endogenous factors, as described in Chapter 2 of this report. The physical characteristics of space and shifts in the threat environment, technology landscape and upstream and downstream segments of the space economy have direct implications for future implementation of the *Defence Space Strategy*:

- Space shares some similarities with other domains, but there are also important idiosyncrasies and differences that demand a tailored approach. Good practices in other 'traditional' domains, sectors and countries **may not necessarily translate to the UK Defence space enterprise;** at the same time, there are opportunities to do things differently and embrace novel approaches aligned with the specific demands of competing in this fast-changing 'new' domain.
- Despite considerable excitement and 'hype' around a new 'space race', there is considerable **uncertainty over the future trajectory of trends in this domain,** including the pace and direction of technological change or the long-term viability of new space applications and commercial markets.
- The UK is likely to be a 'market taker' rather than 'market maker' in many cases, given its finite resources and **varying levers of influence to shape future outcomes** in the space domain. This is not a cause for passivity; the UK Government, including Defence, can and should play an important role in exploiting space for the benefit of national security, prosperity and

influence, in line with its ambitions to be a 'meaningful player in space'.[118]

- To maximise its leverage on global space markets and the space activities of other allies, partners, competitors and neutrals, the **UK requires a coherent and integrated approach** across government, industry and academia and working closely with international allies and partners.

5.2. The Defence space enterprise needs a clear understanding of its evolving value proposition both to domestic and overseas audiences

Informed by an understanding of these exogenous and endogenous factors, the UK Defence space enterprise could also benefit from a clearer articulation of the value proposition it offers to different target audiences:

- **Stakeholders across Defence,** including the individual Services, Strategic Command, and senior responsible owners for cross-cutting programmes such as multi-domain integration.
- **Relevant teams across other Government departments and agencies,** including the UKSA.
- **International allies and partners,** including most notably the United States, with which the UK hopes to deepen collaboration on military space capability.
- **Space industry in the UK,** including small and medium enterprises and non-space companies and prospective end users in the downstream that may not necessarily have a strong understanding of the applications of space products and services to their areas of responsibility, and/or that may lack a prior track record of working with Defence. This includes proactive engaging with perspectives beyond the 'usual suspects', i.e. the large prime-contractors, for example through stakeholder engagement fora for non-competitive discussions with SMEs[119] or through the use of challenges, open calls and other mechanisms open to UK Government.[120]
- **Academia, think tanks and civil society organisations** involved in basic research, shaping policy debates and public dialogue, and promoting norms of responsible space governance and use. This requires an understanding of the drivers and constraints on such actors engaging with policy or strategy development (e.g. a desire to publish, potential issues with classification, funding), with past RAND research for Dstl having sought to help understand the levers available to MOD.[121]
- **The public,** most notably in the UK – where there is a continuing need to boost space literacy, enhance public awareness about the importance and value of space products and services (including Defence's unique role in enhancing space security),

118 HM Government (2021a).

119 Enhanced engagement or even co-location of staff and liaison teams with space industry and innovation clusters such as the Harwell Campus, as well as the new Space Park Leicester, could provide one such model. Similarly, the MOD Space Directorate and Space Command should continue to leverage the MOD's wider initiatives promoting dialogue with SMEs beyond just the space domain, including new supply chain initiatives outlined in the 2021 *DSIS*.

120 Within Defence, for example, this includes the work of teams such as the Innovation Scouts in Strategic Command or the outreach activities, competitions and open calls run by the Defence and Security Accelerator (DASA).

121 Freeman et al. (2015).

and demonstrate value for money to voters – but also in other nations, where effective strategic communications are required to strike the UK's desired balance between deterrence and reassurance and trust-building in the space domain.

Chapter 3 of this report has provided a high-level SWOT analysis to identify the principal building blocks of UK Defence's value proposition to these different stakeholders in the space domain. The weighting of these different building blocks will depend on the situation and target audience in question, given the measurement of **value is ultimately in the eye of the beholder**. Furthermore, this value proposition will shift over time as the MOD begins to invest in capability development programmes and other practical initiatives outlined in the *Defence Space Strategy* and overarching *National Space Strategy*; moving from a low baseline of extant capability to a more confident and ambitious position for the UK space sector.

5.3. When developing new Defence space capability, 'sovereign' is not always the best solution, even when this is an affordable option

Understanding this value proposition is also an essential component of making informed decisions about the development of new Defence space capability. Chapter 4 of this report has sought to map out the trade space and wide variety of possible options that exist within the overarching framework of 'own-collaborate-access' first set out publicly in the 2021 *IR* and *DSIS*. This **trade space is highly complex**; with Defence needing to create different acquisition strategies and partners, with each potential approach entailing differing benefits, costs, and risks that may be hard to quantify or compare in a simple like-for-like fashion. There is **no single 'optimal solution' to these trade-offs**; exactly where Defence strikes the balance on a given programme will necessarily be context-specific.

Importantly, the UK must recognise that it has finite resources and is operating from a relatively low baseline of both capability and SQEP in space, as compared to other space powers (e.g. the United States or even France) or more established operational domains.[122] In this context, Defence **simply cannot afford sovereign space capability in all areas.** Nor would this be desirable, even if it were possible, given the potential benefits of collaboration, such as:

- **Diplomatic:** e.g. influence with partner nations, contribution to wider alliances and networks
- **Information:** e.g. encouraging common architectures, standards, and information sharing
- **Military:** e.g. enhancing interoperability and added deterrent value of operating joint assets
- **Economic:** e.g. shared costs, opportunity to develop skills pipeline and increased economies of scale.

Conversely, there are **certain areas where more sovereign capability may be urgently required,** either to better secure and enable the UK's existing equities in space (e.g. Skynet), or to address critical dependencies across wider Defence (e.g. reliance on SATCOM, PNT), government and CNI. RAND research

122 Even the most established actors, such as the United States, face considerable challenges in creating new command structures, acquisition models, career pathways, doctrine, and capabilities for the space domain. Spirtas et al. (2020a).

emphasises the central importance of focusing on **mission assurance and resilience** when developing and operating space capability, given the operational, political, and economic costs that Defence and the wider UK might incur if that capability is compromised (either by hostile action or natural hazards).

Failure to address these increasingly urgent space-related requirements may **undermine the credibility of the broader defence and deterrence strategy, policy and plans,** as well as the feasibility of the various ambitions outlined in the *Defence Command Paper* and the *Integrated Operating Concept (IOpC) 2025*, given space's vital role as an enabler and integrator for forces, operations and effects across other domains. While it is beyond the scope of this unclassified study to identify a list of such areas requiring more sovereign capability, there are extant processes within Defence for conducting capability audits and planned force testing that can be applied to space, and a wider body of research, analysis, modelling and wargaming tools for examining the potential impact of different capabilities and force structures in different scenarios.

This combination of finite resources, a limited baseline of capability and SQEP, and increasing ambitions and requirements in the space domain entails a **need for ruthless and 'eyes wide open' prioritisation;** based on an informed understanding of the various trade-offs discussed in this report and embedded in the decision support tool included in Annex C.

5.4. To maximise use of finite resources, Defence should 'own' where necessary, 'collaborate' where possible, 'access' where prudent

The fact that space is almost a 'blank slate' for Defence, outside of SATCOM (Skynet), presents urgent challenges. Yet, it also presents a unique window of opportunity to develop a capability management strategy based on innovation, experimentation and non-traditional ways of doing defence acquisition, unencumbered by legacy culture, processes or structures. RAND's analysis presents several key takeaways for UK Defence:

- There is potential to adopt a **different mindset and definition with regards to 'sovereignty'.** As the UK in general and Defence specifically currently has limited space capability in most areas, choosing to 'collaborate' with others or even simply 'access' off-the-shelf solutions will, in the short to medium-term, still yield more sovereignty than trying to set up costly and time-consuming sovereign programmes that may not deliver indigenous capability in a useful time horizon. Sovereignty can be pooled with others in a positive-sum game that benefits the UK, and options should be evaluated based on their real-world outputs and outcomes, not merely the degree of formal control that UK Defence has over their inputs and processes.
- In addition, collaboration may provide opportunities for learning and cost-sharing that are especially relevant in the context of standing up a new joint Space Command (i.e. **allowing the UK to 'crawl, walk, run' and** develop nascent space literacy, culture, SQEP, capability and networks both within Defence and across UK Government, industry and academia).
- In a fast-changing domain and global market, Defence should seek to identify innovative new **technologies and concepts with potential for substantial long-term growth** (either in terms of addressing requirements for operational independence, or wider opportunities for UK plc), while retaining agility and driving down costs in other areas by leveraging commercial

or international partnerships wherever possible and seeking to **avoid dependency on any one single solution**.

- Unlike in other domains, the MOD does not face a monopoly-monopsony relationship with UK industry. Given the very different role and levers of influence that the UK generally and Defence specifically have within the space domain, there is an **acute need to develop closer strategic partnerships** with other government departments, allies, partners, industry and academia. This entails a need for close coordination through the NSC and MOD Space Directorate, and with Space Command enabling multi-domain integration across wider Defence, seeking to achieve an approach that is 'integrated by design'.
- To ensure it gets the most from such partnerships, MOD must have **a clear understanding of the evolving value proposition of the UK** in general and Defence specifically, as well as the ambitions, constraints, resources, working practices and government or industrial capabilities of prospective partners. This will enable it to best 'trade its way' into partnerships and shape their governance, decision-making and delivery mechanisms to best align with UK interests, ensuring that when compromises are inevitably made (e.g. on workshare, requirements) these are within the tolerances of Defence's capability management strategy and the UK's broader ambitions for the space sector.

5.5. Practical measures should be put in place to accelerate learning and enable effective implementation of the Defence Space Strategy

As noted throughout the report, space is a new and emerging domain of operations for Defence and for the UK Government more generally. It will take time to mature the new structures that have already been put in place as well as to develop knowledge and expertise in a fast-changing space sector. This entails an even greater emphasis on ensuring that decisions are made on the basis of the best available information and are suitably robust and resilient to deal with future uncertainty and change, so as to deliver value-for-money and fulfil the stated ambitions of the national and MOD-level space strategies out to 2030 and beyond.

To this end, the study team identified several suggested topics and practical measures that could merit further investigation as part of this ongoing learning within MOD Space Directorate and Space Command:

- **Net assessment and deep dive analyses into the evolving strategic, policies, doctrine and capabilities of other actors in the space domain**, so as to help understand the UK's relative position and to diagnose areas of asymmetric advantage or disadvantage.[123] This could build on the unclassified and high-level SWOT analysis provided in Chapter 3 of this report and draw on inputs from classified sources as well as non-governmental and academic perspectives.

123 Net assessment is a diagnostic technique that emerged out of Cold War analyses by RAND researchers including most notably Andrew Marshall, who went on to run the Office for Net Assessment in the United States DOD for multiple decades and pioneered the notion of a 'revolution in military affairs' in the 1990s. The UK MOD has recently established a Secretary of State's Office for Net Assessment and Challenge (SONAC) to build on these methodologies and principles.

- **Horizon scanning and technology watch activities**, building on the rolling horizon scanning of Dstl and its Future Threat Understanding and Disruption programme (in conjunction with RAND),[124] the work of Defence Intelligence, and the new cross-government Space Horizon Scanning Network (SHSN) established with the UKSA as chair in March 2021. This would ensure a continuous effort to identify and monitor the threats and opportunities arising from new and emerging S&T, including detection of 'weak signals' that might presage disruptive breakthroughs.
- **Gaming, modelling and simulation** to explore not only the UK's defence and deterrence posture in the space domain or its evolving planning and capability development requirements, but also to convene cross-Whitehall seminar games and workshops to explore how Defence and other Government departments might collectively respond to some of the themes identified in the *National Space Strategy* through the vehicle of fictional scenarios and vignettes.[125]
- **Use of assumptions-based planning (ABP) and other techniques pioneered at RAND that are associated with Decision Making under Deep Uncertainty (DMDU),** including Robust Decision Making (RDM) and Three Horizons (3H). These methods vary in their specifics, but are united by a common focus on stress-testing the potentially 'vulnerable' and 'loadbearing' assumptions that underpin Defence strategy, policy and plans. Doing so ensures that those plans are 'robust' and 'future proof' to minimise regret in an uncertain future. Such analysis would build on research by Dstl (in conjunction with RAND and MOD Head Office) to make greater use of these techniques in Defence, in line with the emphasis placed in the *Integrated Review* on boosting resilience through use of more futures and foresight techniques in UK strategy.[126]
- **Deep-dives on specific capability areas to understand the priorities for Defence** in terms of which capabilities to 'own-collaborate-access', the desired force mix and the prospects for collaborating with other allies and partners or else accessing capability from the commercial market.
- **Continuing market intelligence to access and monitor the latest developments** in national and export space markets, as well as adjacent sectors, so as to inform identification of opportunities to 'collaborate' with others or to 'access' new products and services to the benefit of UK Defence.
- **Workforce management and workforce skills studies to inform creation of a Space Academy,** and consideration of the broader opportunities and challenges for Defence, including best practice from other

124 Since a pilot project in 2016, RAND has provided rolling S&T horizon scanning to Dstl. This has involved delivering analytical outputs on a monthly basis and maintaining a database of S&T trends identified and assessed using a mix of English, French, Russian and Mandarin language sources. Similar horizon scanning functions exist through, for example, the Dstl Logistics iHub or the Future Threat Identification project, which has conducted targeted deep dives on space and related technology areas; both of these are supported by RAND's horizon scanning database and software tool.

125 For examples of RAND wargaming or application of game theory of space, see Lynch et al. (2018); Morgan et al. (2018); Triezenberg (2017); along with support to exercises such as Plan Blue or the Schriever Wargame.

126 HM Government (2021a).

countries and sectors with regards to the development of SQEP and space literacy.[127]

- **Industrial and skills base analysis to produce a detailed understanding of the capacity and capability of UK industry to deliver on Defence's space capability requirements** and broader policy ambitions. This should build on wider initiatives within the MOD, such as the creation of the JEDHub to gather economic, industrial and workforce data, the launch of a new supply chain initiative by the Economic Security and Prosperity team, or the implementation of a new *DSIS*.[128]
- **Target audience analysis to inform the tailoring of the value proposition to different stakeholders.** This would include both domestic stakeholders and specific external audiences (e.g. the United States Space Force), with analysis based on a clear mapping of their individual needs, wants and concerns about potential collaboration with the UK Defence space enterprise, as well as the eccentricities of their own individual structures, decision making processes and culture that might have an impact on collaboration.
- **Analysis to understand and address enduring barriers to cross-government cooperation,** critically examining and evaluating the changes introduced in the wake of the Forber Review in 2019, as well as the broader impact of the NSC and Strategy as both begin to mature.
- **Analysis to understand and address enduring barriers to working with industry and academia,** including how to develop more strategic partnerships with key UK suppliers, SMEs, and innovative new start-ups, and how to boost beneficial 'spillovers' between civil, commercial and Defence space, including with other industrial sectors and Defence domains.
- **Analysis to identify relevant lessons learned and good practices as regards space acquisition,** to focus especially on how agile approaches (e.g. rapid prototyping, MOSA) pioneered in other countries, sectors or domains within UK Defence can be tailored to the culture, structures and processes found in the acquisition system for space.[129]
- **Data collection and methods development to help better quantify, monetise and monitor the value of Defence space,** so as to support and inform investment appraisal decisions as well as the communication of benefits cross-government and to other relevant stakeholders (e.g. the NAO, Parliament, the general public), building on recent work by Dstl, Defence Economics and others.[130]
- **Further research into space's interdependencies with Defence's broader ambitions to promote the IOpC and Multi-Domain Integration,** including practical measures for overcoming the fact that strategy, policy and capability and force development cuts across multiple areas of responsibility.

127 For examples of possible lessons from the experience of standing up the United States Space Force, see Spirtas et al. (2020a).

128 MOD (2021a).

129 Kim et al. (2020).

130 Huxtable et al. (2021).

- **Further research to consider how best the UK should specifically approach space strategy, policy and capability development through the aegis of NATO,** as well potentially as other minilateral frameworks (e.g. the Five Eyes alliance or the Joint Expeditionary Force).

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York University. 2021. 'Allen. I. Carswell Observatory.' Yorku.ca. As of 16 June 2021: https://observatory.info.yorku.ca/

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Annex A. Interviewees

This Annex includes the list of interviewees consulted during this study.

Table A.1. List of interviews

Name	Organisation
Anonymous	Anonymous
Anonymous	Anonymous
Anonymous	Anonymous
Air Cdre Jules Ball	Cap Hd Space Directorate
Dr Mark Hilborne	King's College London (support to UK Defence Academy)
Capt David Christopher Moody RN	Ministry of Defence
Gp Capt Martin Ogden	DCDC COS and Space SME
Air Vice Marshall Harv Smyth	Dir Space Directorate
Nicolas Taylor	Dstl

Source: RAND Europe research materials.

Annex B. Overview of selected countries' positions in space

This Annex provides more detailed information on current and future ambitions and space capability strengths of different nations of interest. The list of countries for more detailed analysis was agreed with the DCDC and Space Directorate sponsors. The countries include (in alphabetical order): Australia, Canada, France, Germany, Japan, New Zealand, the UAE and the United States.

B.1. Australia

B.1.1. Stated ambitions

The Australian Space Agency (ASA) aims to grow Australia's space industry from a current $3.9b to $12b by 2030, including the creation of 30,000 jobs in the space sector.[131] The ASA's primary focal point is on growing the commercial space sector.[132] To support and enable the realisation of this ambition, the ASA's specific activities for 2019-2028 are envisaged to include:

- Stimulating a $1b pipeline in inward capital investment in the space industry by 2025.[133]
- Achieving more than 8.5 per cent yearly growth of the space industry.[134]
- Creating a regulatory framework for safe space activities.[135]
- Increasing awareness of space activities.[136]

In addition to the focused support to the commercial space sector, the ASA is also involved in the Moon to Mars (2020-2025) project, which is an A$150m initiative that seeks to allow Australian businesses and researchers to join NASA's plans to return to the Moon and travel to Mars.[137]

B.1.2. Resources and capabilities

The ASA has a budget of around A$73m (ca. £40m) over the next six years.[138] Table B.1 summarises some of Australia's core space capabilities based on open-source information.

131 Pickrell (2019).
132 ASA presentation at the Royal Aeronautical Society's President's Conference, May 2021.
133 Australian Government (2019a).
134 Australian Government. (2019a).
135 Australian Government. (2019a).
136 Australian Government. (2019a).
137 Department of Industry, Science, Energy and Resources (2020b).
138 Pickrell (2019).

Australia has strengths in integrating space sourced data into communications, Earth Observation and GNSS but it has no capability in the manufacture of satellites and limited design capabilities for launch vehicles.[139] A detailed overview of strengths and gaps in commercial capabilities is available in the Government's review of Australia's industrial capabilities published in 2019.[140]

As part of the 2020 Defence Strategic Update and Force Structure Plan, the government announced investment of A$7b over the next decade in space.[141]

This will focus on: a) enhancing sovereign capabilities and access to space; b) deepening international collaboration; and c) investment in technologies to defence and protect assets in space.

Table B.1. Highlighted space capabilities: Australia

Capability	Type	Detail
Satellites	SATCOM	Provides direct-to-home services across Australia, mostly broadband.[142]
	Starlink (proposed)	*SpaceX offered its Starlink internet service in Australia.*[143]
Organisations	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Builds capabilities in Earth observation, radio astronomy, space tracking and facility management.[144] CSIRO developed the Australian Square Kilometre Array Pathfinder (ASKAP), using a novel application of phased array technology.[145]
	Delta-V	Brings together government, large companies, SMEs, start-ups, and university and industry R&D teams.[146] Teams designed Australian payloads as part of the Cygnus OA-7 and QB50 missions.[147]
	New Space	For example, Gilmour Space Technologies developing new launch vehicles powered by hybrid propulsion technologies.[148]
	Mission control centre (proposed)	*Government pledged $8m in 2019 to set up a mission control centre to control robots and autonomous systems in space.*[149]

139 Australian Government (2019b).
140 Australian Government (2019b).
141 Australian Department of Defence (2020).
142 OPTUS (2021).
143 Sheetz (2020).
144 CSIRO (2021b).
145 CSIRO. (2021a).
146 DELTA-V (2021a).
147 DELTA-V (2021b).
148 Gilmour Space (2021).
149 Pickrell (2019).

Capability	Type	Detail
Academic and scientific	Grants	$2m per year was allocated to space research.[150] Upcoming focus: potential development of hypersonic propulsion systems that could burn oxygen during their passage through the atmosphere[151]
	International collaboration	For example, the University of Sydney, in collaboration with Japanese start-up Space BD, plans to launch two CubeSats from the International Space Station.[152]
Other	Geolocation	Southern hemisphere offers a 'unique view into the galaxy'[153] Australia has the only stations that can communicate with the Voyager 2 spacecraft, which has passed beyond the bounds of the solar system.[154] Western Australia has relative radio quietness, which is why the Square Kilometre Array – the world's largest radio telescope once completed – is partly based in the area.[155]
	Participation in international programmes	Australia's geolocation provides Australia has continued to play a role in many space programs, including Nasa's Deep Space Network.[156]

Source: RAND Europe analysis of open source data

B.2. Canada

B.2.1. Stated ambitions

After the United States, Russia and France, Canada was the fourth country to launch a satellite into space and so has a long history of operating in space and is the only non-European member of the ESA. Canada's Space Strategy articulates the ambition to partner on the United States-led Lunar Gateway mission, paving the way for the first visit by Canadian astronauts.[157] Based on open-source information, further plans include:

- Building the next-generation AI-enabled deep-space robotic system to perform critical operations on the Gateway, drawing on a rich heritage in space robotics (e.g. Canadarm).[158]

150 Sinclair (2021).
151 Pickrell (2019).
152 Johnston (2019).
153 Pickrell (2019).
154 Pickrell (2019).
155 Pickrell (2019).
156 Pickrell (2019).
157 Canadian Government (2019).
158 Canadian Government (2019).

- Enabling scientific opportunities and building global partnerships.[159]
- Guaranteeing the future of Canadian astronaut programme via funding and cooperation.[160]

In defence, Canada's Defence Plan 2018-2023 and further defence policy initiatives envisage a greater focus on operational analysis and awareness of the space domain, as well as the ability to defend and protect critical space assets.[161] Canada also foresees the expansion of joint space capabilities such as global satellite communications and earth surveillance.[162] Specific objectives of Canada's defence policy include:

- Defend and protect military space capabilities, including by cooperating with allies and partners to ensure continuous access to the space domain and space assets.[163]
- Promote the peaceful use of space and provide leadership in international norms for responsible behaviour in space.[164]
- Invest in a range of space capabilities, such as SSA, maritime domain awareness, space-based EO, as well as SATCOM with global coverage, including the Arctic.[165]
- Conduct R&D on new space technologies to enhance the resilience of space capabilities and support the Canadian Armed Forces' space capability requirements.[166]
- Introduce a number of new Arctic-focused capabilities to be integrated into a 'system-of-systems' approach to Arctic surveillance, comprising air, land, sea, and space assets.[167] This would include space-based surveillance assets such as the RADARSAT Constellation Mission, as well as naval vessels, Remote Aerial Systems polar satellite communications, operational support sites and new ground vehicles able to navigate the landscape of Canada's North.[168]

B.2.2. Resources and capabilities

Canada possesses a number of perceived strengths given the country's long-standing heritage in space. Based on open-source information, some are highlighted in Table B.2.

159 Canadian Government (2019).
160 Canadian Government (2019).
161 Canadian Government (2018a).
162 Canadian Government (2018a).
163 Canadian Government (2018b).
164 Canadian Government. (2018b).
165 Canadian Government. (2018b).
166 Canadian Government. (2018b).
167 Canadian Government. (2018b).
168 Canadian Government. (2018b).

Table B.2. Highlighted space capabilities: Canada

Capability	Type	Detail
Industry	Variety of space systems companies	Companies engaged in different markets, including: ground receiving stations, remote sensing, satellite systems and components and rockets.[169],[170]
Academic and scientific	University of Toronto	Hosts the Autonomous Space Robotics Lab (ASRL), which focuses on enabling space and terrestrial applications of mobile robots.[171]
	University of Alberta	Created AlbertaSat to design, build, test, launch, and operate satellites. It has launched the Ex-Alta 1 and Ex-Alta 2 satellites to study space weather and wildfires.[172]
	University of British Columbia	Hosts UBC Orbit, a team for satellite capabilities.[173] UBC Rocket is an engineering design team focusing on the design, manufacture and launch of suborbital rockets.[174]
	York University	Home to the Allan I. Carswell Astronomical Observatory.[175]
	Western University	Hosts the Institute for Earth & Space Exploration, which focuses on EO, monitoring and protection, exploration technologies, planetary processes and materials, galactic and stellar processes, space health, space policy, law, business and education.[176]
Defence	Coordination and cooperation	The Royal Canadian Air Force (CAF) is envisaged to take on an increasingly important role in coordinating the defence space programme.47[177] CAF generates space-based and aviation surveillance of Canadian territory.[178] Strong collaboration within the Five Eyes community.[179] Canadian space surveillance satellite, Sapphire, contributes to the United States Space Surveillance Network.[180]

169 AIAC (2021a).
170 AIAC (2021b).
171 ASRL (2021).
172 University of Alberta (2021).
173 UBC Orbit (2021).
174 UBC Rocket (2021).
175 York University (2021).
176 Western Institute for Earth and Space Exploration (2021).
177 Canadian Government (2018c).
178 Canadian Government (2018c).
179 Canadian Government (2018b).
180 Canadian Government (2018b).

Capability	Type	Detail
	SATCOM	Protected military SATCOM project.[181] Mercury Global project to provide high bandwidth communications support worldwide. TNS-GEO, which will provide global narrowband (UHF) SATCOM from 65°N to 65°S. ESCP-P, which will provide satellite communications to enable coverage in the Arctic from 65° - 90°N.
	EO/ISR	RADARSAT Constellation Mission, used to improve the identification and tracking of threats in Canada with Polar Epsilon and Polar Epsilon 2 as ground stations controlling RADARSAT. Unclassified Remote Sensing Situational Awareness (URSA), a mobile, deployable system. Sapphire Satellite, which contributes to the United States Space Surveillance Network. Near Earth Orbit Surveillance Satellite (NEOSSat), which performs space surveillance research and development.
Other	International collaboration	Canada has participated in the majority of key European programmes, including telecommunications, such as Olympus, Artemis and Advanced Research in Telecommunications Systems (ARTES), the General Support Technology Programme, Earth observation and navigation including Galileo.[182]

Source: RAND Europe analysis of open source data

B.3. France

B.3.1. Stated ambitions

At the moment, France lacks its own national space strategy, although it has supported the European Commission's Space Strategy for Europe.[183] France has a strong heritage in space exploration backed by government support through an active industrial policy and a substantive space budget (see Chapter 3). France's space industrial base has seen successes in export sales but has focused around large satellites (mostly for communication), with a much less vibrant sector for small satellites and related services.

France has ambitions to continue its engagement in a number of high-profile space exploration programmes, including but not limited to:

- ExoMars (2022) (ESA-led) that aims to examine whether there has ever been life on Mars.[184]
- MERLIN (French-German Collaboration) (2021/2022) seeks to demonstrate the spaceborne active measurement of

181 Royal Canadian Airforce (2021).
182 ESA (2010).
183 European Commission (2021).
184 ESA (2020a).

atmospheric methane, with a launch scheduled for 2021/22.[185] The platform is developed by the French Space Agency (CNES).[186]

- * Jupiter Icy Moons Explorer (JUICE) (ESA-led) (2022) will observe Jupiter and three of its largest moons.[187] The launch period will start in mid-2022 from Europe's Spaceport in French Guiana.[188]
- Lunar Orbital Platform-Gateway (2024-2026) is being built by the partners of the International Space Station and will enable sustainable lunar exploration.[189] The module will be built by Thales Alenia Space in France, in a joint effort with Thales Alenia Space in Italy and the UK.[190]
- James Webb Space Telescope (2021) will detect light from the first generation of stars and galaxies and study the atmospheres of habitable exoplanets.[191] The launch on an Ariane 5 rocket is planned for 31 October 2021 from Europe's Spaceport in French Guiana.[192]

In addition to the civil and commercial ambitions, France's recent *Defence Space Strategy* outlines plans to include active defence of its satellites, including the use of lasers to dazzle adversaries' spacecraft sensors and employing swarms of nano-satellites to detect hostile activity.[193]

B.3.2. Resources and capabilities

In 2018, €2.4b was invested into French space activities.[194] In 2018, the National Centre for Space Studies (CNES) announced an investment fund of €80-100m to encourage innovation in the space sector.[195] CNES is the government agency responsible for shaping and implementing France's space policy. France possesses a number of strengths given the country's long-standing heritage in space. Some are highlighted in Table B.3, based on open-source information only.

185 Ehret et al. (2017).
186 Ehret et al. (2017).
187 ESA (2019).
188 ESA (2019).
189 ESA (2021b).
190 ESA (2021b).
191 ESA (2020b).
192 ESA (2020b).
193 Ministère des Armées (2019)
194 Government of France (2019).
195 Henry (2018).

Table B.3. Highlighted space capabilities: France

Capability	Type	Detail
Satellites	SATCOM	Seven satellites currently in operation.[196] Military communications: Syracuse 4A, Syracuse 4B and Sicral 3 (proposed for 2021–23).[197]
	EO (Defence)	2018 one of three military imaging satellites launched, to replace the Helios system (four satellites) by the end of 2021, providing high-resolution images for military and intelligence agencies.[198]
Ground-based	Space surveillance	Space surveillance (ground-based radars): V2 (SATAM; low orbit, small objects) (proposed for 2030).[199]
Industry and other organisations	Arianespace	Has more than 50 per cent of the commercial satellite market.[200] French companies and national administrations hold 64 per cent of Arianespace's capital (majority by ArianeGroup).[201]
	Thales group	Designs, operates and delivers satellite-based systems for governments, institutions and companies.[202]
	Collaborative partnership	For example, French technology company Cailabs and French aerospace lab ONERA are cooperating on the CNES Orbital Systems programme, which aims to improve laser satellite communication solutions.[203]
Academic and scientific	International collaboration	NASA's 2018 Solar Parker probe mission used several French laboratories for its spacecraft components.[204]
		NASA's InSight mission, comprises a French seismometre (SEIS) to study the crust, mantle and core of Mars to understand their properties.[205]
		CNES, and Germany's space agency (DLR) joined to develop the MASCOT lander for the Japanese spacecraft Hayabusa2, which allowed an asteroid to be analysed and the collection of samples.[206]

196 IISS (2020).

197 Laudrain (2019).

198 Mackenzie (2018).

199 Laudrain (2019).

200 ESA (2021a).

201 ArianeSpace (2021).

202 Thales Group (2021).

203 Optics (2021).

204 CNRS (2018).

205 Government of France (2019).

206 Government of France (2019).

Capability	Type	Detail
Launch	French Guiana	France has been playing a key role within the ESA, making the Centre spatial guyanais (CSG) in French Guiana available for launches and sharing its expertise in the design of satellites and instruments.[207]
Other	Long standing space collaboration links	France also hosts a User Support Operations Centre (USOC) in Toulouse, which aims to prepare ESA's missions onboard the ISS, and to assist astronauts working in the station.[208] In Spring 2021, French Astronaut Thomas Pesquet will return to the ISS as part of the Alpha mission. This will provide a new opportunity to raise awareness of space and promote STEM careers.[209] CNES has an agreement with the Indian Space Research Organisation (ISRO) to provide training to Indian astronauts aboard the Air Zero Gravity, a modified version of an Airbus A310.[210]

Source: RAND Europe analysis of open source data

B.4. Germany

B.4.1. Stated ambitions

In space, Germany has an advanced scientific and R&D base and provides a strong contribution to ESA's scientific space missions. Germany provides a leading contribution to the understanding and technological advances in propulsion and energy systems as well as launch and rocket technologies.

Based on open-source information, highlighted ambitions include:

- H2ORIZON Project (2018-unknown) is a collaborative effort by the DLR Institute of Space Propulsion and ZEAG Energie AG to create a hydrogen-based, networked energy system, coupling energy, transport and space industries.[211] It is envisaged to generate hydrogen by wind energy, for 'transport and storage, to its use in fuel cells for mobility, for electricity and heat supply or for missile tests'.[212]
- North Sea launchpad (proposed) is a proposal from German industry to create a €30m mobile launchpad for small satellites in the North Sea.[213]

B.4.2. Resources and capabilities

Germany spends 0.05 per cent of GDP on space programmes, putting it behind India, Italy, Japan, China, Russia, France and the United States.[214] The German aerospace and defense market is expected to grow by over

207 Government of France (2019).
208 Government of France (2019).
209 CNES (2020).
210 D'souza (2020).
211 DLR (2018).
212 BMBF (2018).
213 BBC (2020).
214 DW (2019).

9 per cent between 2020-2025.[215] Germany is also the ESA's second-biggest contributor after France. In exchange, Germany was given ESA Mission Control in Darmstadt and the astronaut training centre in Cologne.[216] Nearly half of European ISS experiments come from German research institutions.[217] The Columbus Control Centre (ColCC) at the German Space Operations Center (GSOC) in Oberpfaffenhofen supports the 24 hours per day operation of the Columbus module. The DLR Space Administration programme 'Research Under Space Conditions' has facilitated the publication of over 1400 articles in scientific journals since 2001.[218]

Germany established an Air and Space Operations Centre (ASOC) on 21 September 2020, which 'brings together specialised centres on intelligence, security and situational awareness'.[219] The ASOC aims to grow from 50 to 150 experts by 2031.[220]

Some of Germany's space capabilities are highlighted in Table B.4, based on open-source information.

Table B.4. Highlighted space capabilities: Germany

Capability	Type	Detail
Satellites	SATCOM	Seven satellites, includes COMSATBw-1 and COMSATBw-2 which provide German armed forces (Bundeswehr) in operation with military UHF and X-band plus additional capacity in C and Ku-band over a coverage stretching from the Americas to Eastern Asia.[221]
	electro-optical reconnaissance system	*Georg 1, 2 and 3 (unknown/proposed): is a electro-optical reconnaissance satellite system planned for the German federal intelligence service.*[222]
Launch	Launch services for LEO	Eurockot Launch Services GmbH in Bremen, Germany is a joint venture of ArianeGroup and the Russian Khrunichev Space Center, launching of small satellites into LEO.[223]
Space organisations	The German Aerospace Center (DLR)	Designs and implements Germany's Space Programme. Activities include Germany's national Space Programme and contributions to the ESA and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).[224]

215 Mordor Intelligence (2020).
216 DW (2019).
217 Ehrenfreund (2016).
218 Ehrenfreund (2016).
219 European Parliament (2020).
220 DW (2020).
221 Airbus (2016).
222 Gunter's Space Page (2021b).
223 EUROCKOT (2021).
224 DLR (2021).

Capability	Type	Detail
	Launch companies	For example Isar Aerospace Technologies GmbH is a Munich start-up aiming to launch its first Spectrum rocket by the end of 2021. Eventually, they hope to launch 20 flights a year.
		OHB SE is a European leader in the space, aeronautics and telematics industry.[225] Its launch department, the Rocket Factory Augsburg, is developing its three-stage RFA One rocket, which will lift off from Norway's arctic spaceport in 2022.[226]
	Satellite payloads	SpaceTech GmbH is an independent German medium enterprise offering smart product solutions for satellite platforms and space payloads. SpaceTech is also a partner for the definition and optimisation of satellites and space missions.[227]
	Airbus	International player in the aerospace sector, offering design, manufacture and delivery of satellites and launch vehicles, in addition to providing data services, navigation, secure communications and urban mobility.[228] Bremen is the European centre for human space flight and space robotics programmes.[229]
Academic and scientific	SATCOM	Heinrich Hertz R&D programme is a proposed national satellite communications mission aiming to explore and test new communications technologies in space. The mission will also offer universities, research institutes and industry a platform for conducting experiments.[230]
	Collaborative programmes	DLR and funding provided by the German Federal Ministry of Economics and Technology (BMWi) are supporting several projects. OHB-System AG and Astrium GmbHm are leading a nationwide syndicate comprising Audens Telecommunications, GSOC, IABG and the DLR Institute of Communications and Navigation (IKN) with TESAT Spacecom GmbH, Backnang working on payload technology.[231]

225 OHB (2020).
226 Parsonson (2020).
227 SpaceTech-i (2021)
228 Airbus (2021a).
229 Airbus (2021b).
230 OHB (2021).
231 OHB (2021).

Capability	Type	Detail
Defence	ISR	ISR 5 SAR-Lupe is a reconnaissance system,[232] including an Electric Power Subsystem, hydrazine thrusters and a fuel capacity for 10 years.[233] SARah is the planned follow-on system for the SAR-Lupe radar satellite constellation, consisting of one active phased array-antenna satellite and two passive reflector antenna satellites at a cost of €800m.[234] The satellite will be launched on a Falcon-9 in 2021.[235]
	SST/SSA	The German Experimental Space Surveillance and Tracking Radar has a so-called 'phased array' that enables operators to pan across the sky and spot debris. Aims to provide the data to universities and research facilities in Germany, as well as the European tracking project EUSST so that satellites can avoid space debris.[236]
Other	International collaboration	In June 2019, Spectrum-Roentgen-Gamma (SRG) a joint German–Russian mission was launched into space to conduct a mapping mission, tracking 100,000 galactic clusters by detecting the X-ray glow from intergalactic plasma. [237] NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA).[238] In December 2020, France and Germany agreed to collaborate and successfully conclude the Ariane 6 project, a European next-generation rocket launcher. The agreement also commits the two governments to working on 'micro-launchers' to send smaller payloads into orbit.[239]
	NATO Space Centre	In October 2020, a new NATO Space Centre was agreed on, to be based at Allied Air Command in Ramstein, Germany. The centre will engage in space observation and awareness, gathering information and data on potential threats to satellites.[240]

Source: RAND Europe analysis of open source data

232 IISS (2020a).
233 EO (2021).
234 Gunter's Space Page (2021c).
235 Gunter's Space Page (2021c).
236 DW (2020).
237 Castelvecchi (2019)
238 Universities Space Research Association (2021).
239 Morgan (2020).
240 European Parliament (2020).

B.5. Japan

B.5.1. Stated ambitions

Japan has a strong heritage in advanced space technologies, particularly space robotics and autonomous systems. Japan's stated ambitions for the future include:

- Ensuring space security and strengthening Japan's space activities: developing space systems for positioning, communication, information gathering, and maritime domain awareness, strengthening capabilities for mission assurance, cooperating with allies and partners and engaging in international rule-making.[241]
- Increasing national and global space resilience: developing space systems for positioning, broadcasting, communications, meteorology, environmental observation, EO, improving disaster prevention and management capabilities.[242]
- Creation of new knowledge through space science and exploration: leading international missions, taking a whole-government approach on the United States-led Artemis Programme and utilising the ISS for international space exploration activities.[243] NASA and the Government of Japan signed a Joint Exploration Declaration of Intent (JEDI) in July 2020. The JEDI describes sets out cooperation on the International Space Station and NASA's Artemis program, extending to both human and robotic exploration.
- Realising economic growth: strengthening space systems and expanding their use. Boosting local economies by collaborating with the Regional Revitalisation Initiative. Doubling the size of the space industry (~¥1.2 trillion) by the 2030s.[244]

In January 2021 NASA and Japan finalised an agreement for the lunar Gateway.[245] Japan will provide capabilities for the Gateway's International Habitation module (I-Hab), as well as batteries for the Habitation and Logistics Outpost (HALO), the crew cabin for astronauts visiting the Gateway. Japan is enhancing its HTV-X cargo resupply spacecraft, envisaged to be used for Gateway logistics resupply.[246] Japan is also involved in the concept and development of an Earth-to-space elevator (2050), which involves simultaneously constructing on the ground and in space. The Department of Precision Machinery Engineering is the developing the 'climber' on the ground while assisting research for assembly in space.[247]

In defence, the Japanese Defence Ministry plans to improve space situational awareness, with an aim of establishing a Space Domain Mission Unit by 2022. The new unit will monitor satellites and space debris. In the revised 2015 *US–Japan Defense Guidelines* Japan pledges to help the United States preserve the continuity of its space operations.[248]

241 Government of Japan (2020).
242 Government of Japan (2020).
243 Government of Japan (2020).
244 Government of Japan (2020).
245 NASA (2021e).
246 NASA (2021e).
247 RedShift (2019).
248 IISS (2020b).

B.5.2. Resources and capabilities

Japan anticipates growing global demand for satellites, aiming to export satellites and launch services to global customers, particularly in the Middle East and South East Asia.[249] The Japanese Space Agency (JAXA)'s Space Innovation through Partnership and Co-creation (J-SPARC) is one of JAXA's most notable R&D programmes to encourage commercial ventures.[250]

Some of Japan's current space capabilities are highlighted in Table B.5, based on open-source information.

Table B.5. Highlighted space capabilities: Japan

Capability	Type	Detail
Satellites	EO	GOSAT-2 (or IBUKI-2) (2018-2023) for the observation of greenhouse gases;[251] SHIKISAI (GCOM-C1) (2017-2022) for global, long-term monitoring of global water circulation and climate change;[252] DAICHI-2 (ALOS-2) (2014-2021) for 'cartography, regional observation, disaster monitoring, and resource surveys';[253] Global Precipitation Measurement/Dual-frequency Precipitation Radar (GPM/DPR) for observations of rain and providing an accurate estimation of rainfall rate.[254]
Launch	Launch vehicles	New 'Epsilon S Launch Vehicle Project' aims to become an autonomous and sustainable transport system. An Epsilon S demonstration launch is scheduled for 2023.[255] H-IIB Launch Vehicle is designed for cargo transport (H-II Transfer Vehicle 'KOUNOTORII'), to the International Space Station (ISS) for daily commodities, spare parts, equipment and samples.[256] S-310/S-520/SS-520 (Sounding Rockets) for astrophysical observation, upper atmosphere exploration and space plasma physics.[257]
Industry and other organisations	Upstream	For example, STARS Space Service Inc. provides satellite parts, parts for CubeSats,[258] as well as Satellite Development Consulting[259]

249 Australian Trade and Investment Commission (2021).
250 Jewett (2020).
251 ESA (2021c).
252 JAXA (2020c).
253 JAXA (2020a).
254 NASA (2021b).
255 JAXA (2020b).
256 JAXA (2020d).
257 JAXA (2020e).
258 STARS (2021).
259 STARS (2021).

Capability	Type	Detail
	Mitsubishi	For example, Mitsubishi Precision Co., Ltd offers data, drive, and power control units of 145 satellites, including the Advanced Land Observing Satellite 'DAICHI'.[260]
Academic and scientific	Technologically complex R&D	In the 2018 European Space Elevator Challenge, Japanese Team Raptor won the Advanced Class and received awards for Safety, Construction Quality, and Innovation.[261] In December 2020 Japanese scientists obtained asteroid dust from a capsule delivered by the Hayabusa-2 space probe. Scientists hope to discover more about the formation of the universe and how life began on Earth.[262]
Other	International collaboration	Joint Global Multi-Nation Birds Satellite (BIRDS) Project is an annual joint project for non-space faring countries supported by Japan (participating countries include Nigeria, Ghana, Mongolia and Bangladesh). Students design, develop and operate five units of identical 1U CubeSats to form a constellation of five CubeSats operated from a network of seven ground stations.[263] In July 2020, the Australian Space Agency and the Japan Aerospace Exploration Agency (JAXA) signed a Memorandum of Cooperation to increase space cooperation. The two agencies are collaborating on range of activities, including the planned return of JAXA's Hayabusa2.[264]

Source: RAND Europe analysis of open source data

B.6. New Zealand

B.6.1. Stated ambitions

The New Zealand space sector model is mostly based on commercial space, driven by entrepreneurial and privately-funded space companies.[265] New Zealand is interested in building on its existing strengths, particularly the use of space-based data in agri-technology, hazard management, oceanography and meteorology.[266] There are also intentions to grow satellite design and manufacturing capabilities and space science, technology and engineering research activity.[267] In addition to bilateral agreements with the United States Government and ESA, New Zealand has joined international space forums including the UN

260 JAXA (2021).
261 Redshift (2019).
262 Agence France-Presse (2020).
263 Birds (2021).
264 Department of Industry, Science, Energy and Resources (2020a).
265 Sanmartí (2020).
266 New Zealand Ministry of Business Innovation & Employment (2021b).
267 New Zealand Ministry of Business Innovation & Employment (2021b).

Committee on the Peaceful Uses of Outer Space (COPUOS).[268]

B.6.2. Resources and capabilities

The New Zealand space sector was worth $1.69b in 2018-19.[269] It is 'New Space'-driven, with a mix of start-ups, well-established enterprises and privately-funded space companies. The space manufacturing and space applications sub-sectors are strong, drawing on local as well as international talent, and with strong ties to the global space economy.[270] The New Zealand Space Agency was only created in 2016, driven by the establishment of a United States Rocket Lab on the Mahia Peninsula in New Zealand.[271] In July 2017, the Outer Space and High-Altitude Activities Act was enacted to regulate space activities, particularly the launch into space from New Zealand.[272]

New Zealand has a Technology Safeguards Agreement with the United States, enabling the transfer of technology and allowing Rocket Lab to launch satellites and payloads for the United States Defense Department.[273]

In December 2019, the Cabinet agreed to a proposal to introduce four banned launch activities under the Licensing Regulations.[274] These include payloads that (i) contribute to nuclear weapons programmes or capabilities; (ii) are intended for damaging or destroying other space assets; (iii) support or enable defence, security or intelligence operations contrary to government policy; and (iv) could ultimately harm the environment.[275]

The New Zealand government recently announced the $3m Catalyst: Strategic Space call, which will build partnerships with leading international space organisations.[276] In 2018-19, the Ministry of Business, Innovation and Employment (MBIE) spent $6.02m on space science research.[277]

The Government's $20b Defence Capability plan includes funding for satellite surveillance systems which will be launched in 2023 to detect risks in the Pacific region.[278]

Some of New Zealand's space capabilities are highlighted in Table B.6 based on open-source information.

268 New Zealand Ministry of Business Innovation & Employment (2021a).

269 New Zealand Ministry of Business Innovation & Employment (2021b).

270 New Zealand Ministry of Business Innovation & Employment (2021b).

271 New Zealand Ministry of Business Innovation & Employment (2021a).

272 de Gouyon Matignon (2019).

273 Sanmartí (2020).

274 Martin (2020).

275 Martin (2020).

276 New Zealand Ministry of Business Innovation & Employment (2021b).

277 New Zealand Ministry of Business Innovation & Employment (2021b).

278 Walls (2019).

Table B.6. Highlighted space capabilities: New Zealand

Capability	Type	Detail
Industrial capabilities	Mix of industrial players	While large international conglomerates such as Thales, Airbus or Boeing have a presence in NZ,[279] the space sector largely consists of new SMEs.[280] Space manufacturing and applications are the two largest sectors.[281] Examples include: Orbica which transforms geospatial data and geospatial artificial intelligence (GeoAI) for government and commercial decision makers;[282] Fabrum Solutions supplying composite materials and cryo-coolers for space applications.[283]
	Commercial launch	Rocket Lab is a United States corporation with a subsidiary in New Zealand, offering orbital launch ranges on the Mahia Peninsula, New Zealand. Rocket Lab's first fully commercial launch was completed on 11 November 2018.[284]
	SSA/SST	LeoLabs offers an advanced phased-array radar system in the Southern hemisphere (Kiwi Space Radar) for providing high resolution data on objects in low Earth orbit.[285] Leolabs' services include Tracking and Monitoring, Collision Avoidance, payload tracking, mission assurance and SDA.[286]
Academic and scientific capabilities	Xerra Research Institute, Alexandria	Research funding of $3.675m to support R&D on combining EO data and new computing technologies such as AI/ML to enhance detection and monitoring of algae toxic blooms, vegetation, forests and crops, as well as offering faster crisis response, monitoring the maritime environment and airspace, telecommunications, and asset management.[287]
	Robinson Research Institute at Victoria University of Wellington	Together with partner company HTS-110 Ltd gained international commercial funding for superconducting magnet systems for satellite thrusters.[288]

279 Australian Government (2020).
280 New Zealand Ministry of Business Innovation & Employment (2021b).
281 New Zealand Ministry of Business Innovation & Employment (2021b).
282 New Zealand Ministry of Business Innovation & Employment (2021b).
283 Long (2019).
284 New Zealand Ministry of Business Innovation & Employment (2021a).
285 New Zealand Ministry of Business Innovation & Employment (2021b).
286 Leo Labs (2021b).
287 Long (2019).
288 Long (2019).

Capability	Type	Detail
	University of Auckland	With University of Canterbury developing thrusters and ADAC (attitude determination and control) systems.[289] Hosts the Space Institute- centre for space science and engineering, including a capability to execute space missions and develop applications and home to the Warkworth Radio Astronomical Observatory. Recently partnered with NASA to install next-generation Global Navigation Satellite System (GNSS) reflectometry receivers on passenger aircraft.[290]
Other	Geolocation	New Zealand's geographical location is an advantage, with relatively low levels of air traffic, as well as some of the largest selection of launch angles (azimuths) for rocket launches.[291]
	Regulatory environment	One of the first countries to develop laws covering non-rocket propelled activity in high altitudes, such as balloons, New Zealand's regulatory regime encourages space activity, while minimising risks to public safety and the environment.[292]

Source: RAND Europe analysis of open source data

B.7. United Arab Emirates

B.7.1. Stated ambitions

The UAE established its Space Agency when it announced intentions to participate in international Mars exploration programmes, using the first UAE, Arab and Islamic probe.[293] The UAE has plans to invest in innovative solutions and applications in space.[294] R&D and satellites manufacturing capabilities are the main area of focus.[295] The UAE has seen an impressive journey from no space capabilities in the late 2000s to the successful launch of the Hope Mars Mission in July 2020, which saw the spacecraft enter first orbit of Mars on 10 February 2021.[296]

The UAE plans to deploy the satellite 813 Project (2019-2022) which will have a lifespan of five years and will monitor the Earth, measuring the environmental and climatic developments in several Arab countries.[297] It also focuses on the Mars Scientific City (2117) programme which will aim to build the first

289 Long (2019).
290 NASA (2020).
291 New Zealand Ministry of Business Innovation & Employment (2021b).
292 New Zealand Ministry of Business Innovation & Employment (2021b).
293 UAE Government (2016).
294 UAE Government (2021b).
295 UAE Government (2021b).
296 Emirates Mission (2021).
297 Arabian Business (2019).

settlement on Mars as part of Mars Science City.[298]

B.7.2. Resources and capabilities

The UAE's national space investment has exceeded Dh22b ($6b), consisting of government as well as private funding.[299] Three UAE universities offer five dedicated space programmes, with the UAE Space investing more than Dh160m in space projects at these universities.[300] The EMM Graduation Project Grant is supported by the National Space Science and Technology Center (NSSTC) to support faculty and students in exploring the science, technical and/or social objectives of the Emirates Mars Mission. In 2015, the UAE became a member of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). The UAE signed a memorandum of understanding with the UN Office of Outer Space Affairs (UNOOSA) in 2017 'to work on capacity-building initiatives on both the technical and legal aspects of the peaceful uses of outer space.' Another agreement was signed with UNOOSA in 2020 for cooperating in space sustainability.[301]

Some of UAE's space capabilities are highlighted in Table B.7, based on open-source information.

Table B.7. Highlighted space capabilities: UAE

Capability	Type	Detail
Satellites	EO	MeznSat (2020-unknown) is a 3U CubeSat to detect Greenhouse Gas concentrations.[302] KhalifaSat (DubaiSat-3) (2018-2023) was developed in the UAE,[303] aiming to monitor environmental changes on Earth, as well as urban management and disaster relief.[304] Nayif-1 (2017-unknown) will provide environmental data from space with a UHF to VHF linear transponder.[305]
	SATCOM	Al Yah 3 (2018-unknown) satellite will expand Yahsat's coverage to an additional 19 markets in Africa and Brazil.[306]

298 UAE Government (2021a).
299 Space Watch (2021).
300 Gokulan (2020).
301 SPARC (2020).
302 UAE Space Agency (2021a).
303 MBRSC (2021a).
304 MBRSC (2021b).
305 AMSAT-UK (2021).
306 Gunter's Space Page (2021a).

Capability	Type	Detail
Space organisations	Mohammed bin Rashid Space Centre (MBRSC)	Is home to the UAE National Space Programme. The Centre builds and operates earth observation satellites, launching DubaiSat-1, DubaiSat-2, and KhalifaSat.[307] The Centre is responsible for the Emirates Mars Mission and the Mars Hope Probe.[308]
	Al Yah Satellite Communications Company (Yahsat)	Offers integrated satellite communications solutions to over 150 countries across the world.[309] In terms of revenue, it has become the sixth largest satellite operator in the world.[310]
	UAE Astronaut Programme	Initiated in April 2017 to prepare an Emirati astronaut corps for scientific space exploration missions.[311]
Other	STEM and skills programmes	For example, a STEM-oriented contest called 'UAE Mini Satellite Challenge: Design, Build, Launch' was developed by the UAE Space Agency and Khalifa University. The competition provides the opportunity for university students to develop space technology applications and experiments. The winning team will test their project on a 2U CubeSat platform launched from the International Space Station.[312]

Source: RAND Europe analysis of open source data

B.8. United States

B.8.1. Stated ambitions and wider trends

The United States is the world leader in space, with the largest space budget in the world (see Chapter 3), a long heritage of space exploration and using space to enable military and civil activities over the last 70 years. It is beyond the scope of this short overview to comprehensively map out the vast number of United States capabilities and strengths. Instead, this overview highlights some of the most recent influential developments and stated ambitions in defence, commercial and civil space.

Ongoing and planned NASA missions

Congress allocated $22.6b to NASA in 2020.[313] NASA's key missions include:

- **Mars Perseverance (2020):** NASA's Perseverance rover landed on Mars on 18 February 2021.[314]

307 MBRSC (2021a).
308 MBRSC (2021a).
309 YahSat (2021).
310 Thuraya (2021).
311 MBRSC (2021c).
312 UAE Space Agency (2021b).
313 Markovich et al. (2021).
314 NASA (2021a).

- **Space Launch System Missions (Artemis):** NASA is collaborating with the private sector (Space-X, Blue Origin, Dynetics) towards goals to put astronauts on the moon by 2024.
- **Lunar Orbital Platform-Gateway:** NASA and other space agencies, including the ESA and Russia's Roscosmos will cooperate to replace the International Space Station (ISS).[315]
- **James Webb Space Telescope (2021):** The James Webb Space Telescope is an orbiting infrared observatory that will complement and extend discoveries of the Hubble Space Telescope.[316]
- **Humans on Mars Exploration Campaign (2030s):** The Exploration Campaign focuses on three core domains: low Earth orbit; lunar orbit and surface; and Mars and other deep space objectives.[317]

Growing capabilities in large commercial players and their collaboration with NASA

Large commercial space industries are growing both their space ambitions and capabilities. The technological advances achieved by commercial space companies have resulted in civil-commercial partnerships for delivery of space missions. Illustrative examples of these are included in the tables overleaf.

Table B.8. Illustrative examples of complex commercial space missions

Company	Ambitions and capabilities
Blue Origin	• New Shepard: Blue Origin has been developing New Shepard to carry people and payloads to suborbital space and back.[318] • New Glenn: rocket (loaded with satellites). New Glenn's first flight is scheduled for 2021.[319] • Blue Moon: a flexible lander delivering payloads to the lunar surface. It could enable a sustained human presence on the Moon.[320]
Boeing	• United Launch Alliance (2006), a joint venture between Boeing and Lockheed Martin serving as national launch services provider with its Delta IV and Atlas V rockets.[321] • Boeing Commercial Satellite Services: satellite communications to partners operating on land, sea, and in air.
Breakthrough Starshot (2036)	• Ambitions to send spacecraft to Alpha Centauri, our neighbouring star system. Breakthrough Starshot aims to develop a fleet of 'nanocraft' probes, to reach the nearest star within 20 years and return images to Earth.[322]

315 NASA (2021d).
316 NASA (2021c.).
317 NASA (2018).
318 Makwana (2021).
319 Dent (2020).
320 Blue Origin (2021).
321 Boeing (2021a).
322 Future Timeline (2021).

Company	Ambitions and capabilities
Space X	• In May 2020, SpaceX became the first private company to transport two NASA astronauts to the ISS, using its Falcon 9 rocket and Dragon capsule.[323] • Construction of Dragon spacecraft, capable of carrying up to seven passengers to and from Earth orbit.[324] • Starship spacecraft and Super Heavy rocket represent a system designed to carry both crew and cargo. Starship will be the world's most powerful launch vehicle.[325] • September 2021: SpaceX plans to send three space tourists to the ISS. • 2022: Aims to launch the first uncrewed test missions to Mars, and if successful, a potential crewed Starship in 2024.[326] • 2023: Hopes to fly the first private lunar mission. • Longer term visions include plans to create a colony on Mars, starting with Mars Base Alpha, the first Mars habitat.[327]

Source: RAND Europe analysis of open source data

Table B.9. Illustrative examples of NASA collaboration with private space companies

Company	Details
Advanced Space	Developing a navigation system between Earth and the Moon to supplement NASA's Deep Space Network and support future exploration missions.[328]
Bigelow Aerospace	Is building a demonstrator for human spaceflight missions in and beyond cislunar space.[329]
Blue Origin	Collaborating with NASA on a navigation and guidance system for safe and precise landing on the Moon. Blue Origin will partner with Glenn and Johnson, working on a fuel cell power system for the Blue Moon lander.[330] Blue Origin, Marshall and Langley will cooperate on high-temperature materials for liquid rocket engine nozzles to be used on lunar landers.[331]

323 Markovich et al. (2021).
324 Space X (2021a).
325 Space X (2021b).
326 Bartels (2020).
327 Weitering (2020).
328 NASA (2019a).
329 NASA (2019a).
330 NASA (2019a).
331 NASA (2019a).

Company	Details
Boeing	Space Launch System Missions (Artemis) In partnership with the NASA Artemis program.[332] 2021: Boeing Starliner in collaboration with NASA to accommodate seven passengers, or a combination of crew and cargo, for missions to low-Earth orbit.[333]
Masten Space Systems	Developing an engine to provide a lower-cost reusable launch services for the cubesat and smallsat launch market.[334]
Lockheed Martin	Will test materials made from metal powders using solid-state processing to improve the design of spacecraft.[335] Mars Base Camp (late 2020s): a crewed laboratory orbiter concept commissioned by NASA. Orion : A deep-space crew spacecraft, built for long duration deep space flight.[336]
Orbital Sciences Corporation	Will incorporate advanced materials for dampening into flight structures to reduce dynamic loads during flight.[337]
Sierra Nevada Corporation	Will work with NASA on two entry, descent and landing projects. SNC is also working on its Large Inflatable Fabric Environment (LIFE) habitat, designed to launch in a compact, 'deflated' configuration, then inflate once it's in space. [338]
SpaceX	Will work with NASA's Kennedy Space Center in Florida to advance their technology to vertically land large rockets on the Moon. SpaceX will work with Glenn and Marshall to advance technology needed to transfer propellant in orbit, an important step in the development of the company's Starship space vehicle.[339]
UP Aerospace	A suborbital mission will demonstrate several subsystems for a launch vehicle currently under development.[340]
Sierra Nevada Corporation	Will work with NASA on two entry, descent and landing projects. SNC is also working on its Large Inflatable Fabric Environment (LIFE) habitat, designed to launch in a compact, 'deflated' configuration, then inflate once it is in space.[341]

Source: RAND Europe analysis of open source data

332 Boeing (2021c).
333 Boeing (2021b).
334 Russell (2017).
335 NASA (2019a).
336 Cichan et al. (2016).
337 Russell (2017).
338 NASA (2019a).
339 NASA (2019a).
340 Russell (2017).
341 NASA (2019a).

Continued investment in academic/ scientific capabilities

Many of the world's top space science universities are in the United States, including California Institute of Technology, Harvard University, the University of California (Berkeley, Princeton University, Stanford University, University of California), Santa Cruz and the University of Chicago.[342] Also, the Mars oxygen experiment (MOXIE) is a joint experiment between MIT and NASA's Jet Propulsion Lab.[343] It went to Mars on the 2020 Rover. Several university teams were selected by NASA to develop deep space exploration systems prototypes in 2019. Some of the teams and their research are outlined below.

Establishment of the United States Space Force (USSF)

The United States Space Force (USSF) was established in December 2019, with the goal to organise, train, and equip space forces to protect United States and allied interests in space and to provide space capabilities to the joint force.[344] The 2021 budget proposal directs $15.4b to the USSF, of which $1.6b is earmarked for launches, $1.8b for Global Positioning System projects and $2.5b for space-based overhead persistent infrared systems.[345]

Table B.10. Illustrative examples of deep space mission collaborations with academic institutions

Area of expertise	University	Detail
Habitation	University of Maryland, College Park	The design of minimal cabin volumes for near-term exploration missions.[346]
Life Support	Iowa State University, Ames	Design of a two-stage heat exchanger to separate air from carbon dioxide and volatile organics.[347]
In-Space Manufacturing	Rice University, Houston, Texas	Development of a practical tool for basic and everyday repair and maintenance needs in space.[348]
NASA Platform for Autonomous Systems (NPAS)	University of Michigan, Ann Arbor	Design of user interfaces for Gateway and other autonomous spacecraft.[349]
Space Life Sciences	Auburn University, Alabama	Electromechanical plant growth chamber to maintain growth during a long duration Mars mission.[350]

Source: RAND Europe analysis of open source data

342 US News (2021).
343 Owens (2017).
344 United States Space Force (2021).
345 Wall (2020).
346 NASA (2019b).
347 NASA (2019b).
348 NASA (2019b).
349 NASA (2019b).
350 NASA (2019b).

Annex C. Decision support tool

This annex provides additional guidance and suggestions on how the MOD Space Directorate and joint Space Command might navigate the capability management choices discussed in this report. This builds on both Chapter 4 of this final report, as well as the more detailed analysis contained in the Interim Report (PR-A1186-1) dated 11 May 2021.

C.1. RAND has developed a decision support tool to help frame and guide Defence's upcoming choices on space capability development

The annex presents a combination of narrative and visual elements (heavily inspired by flow chart symbology) that are intended as a 'decision support tool' for thinking through the various options open to the Defence space enterprise as it makes future choices about space capability.

It is important to bear in mind several caveats when reading and making use of the tool:

- The tool is focused primarily on the choices faced by Defence space decisionmakers, though there are multiple places when it explicitly addresses interdependencies across the rest of UK government.
- This tool is intended to inform and enhance, rather than supplant, existing processes within MOD, such as ways of identifying capability requirements, or conducting investment appraisals.[351]
- The tool and accompanying guidance are intended for transferrable applicability across all areas of space capability; this would require tailoring to the context of a given capability area during delivery of a specific real-world programme.
- While it is beyond the scope of this unclassified RAND study to assess or recommend what the MOD's priorities should be in future – for example when weighing up different types of benefit, cost and risk – this tool is intended to help frame the MOD's evolving thinking in the space domain and increase its understanding of the trade-offs inherent in different potential approaches to capability development under the framework of 'own-collaborate-access'.[352]

351 This includes the existing guidance available on topics such as Combined Operational Effectiveness Investment Appraisals (COEIAs), or on cost-benefit analyses and public sector investment appraisals and evaluation more broadly. See HM Treasury (2020); MOD (2014, 2020a).

352 MOD (2021a).

As noted in Chapter 4, the following definitions were used, drawing on the Integrated Review:[353]

- **Own:** where the UK has leadership and ownership of new developments, from discovery to large-scale manufacture and commercialisation. This will always involve elements of collaboration and access.
- **Collaborate:** where the UK can provide unique contributions that allow us to collaborate with others to achieve our goals.
- **Access:** where the UK will seek to acquire critical S&T from elsewhere, through options, deals and relationships. This will always be conducted within the bounds of the Assured Capability Framework, cognisant of the fact that there will be differing national levels of assured access requirements.

C.2. The tool is built around three main elements, with Defence weighing its different options based on their benefits, costs, risks and trade-offs

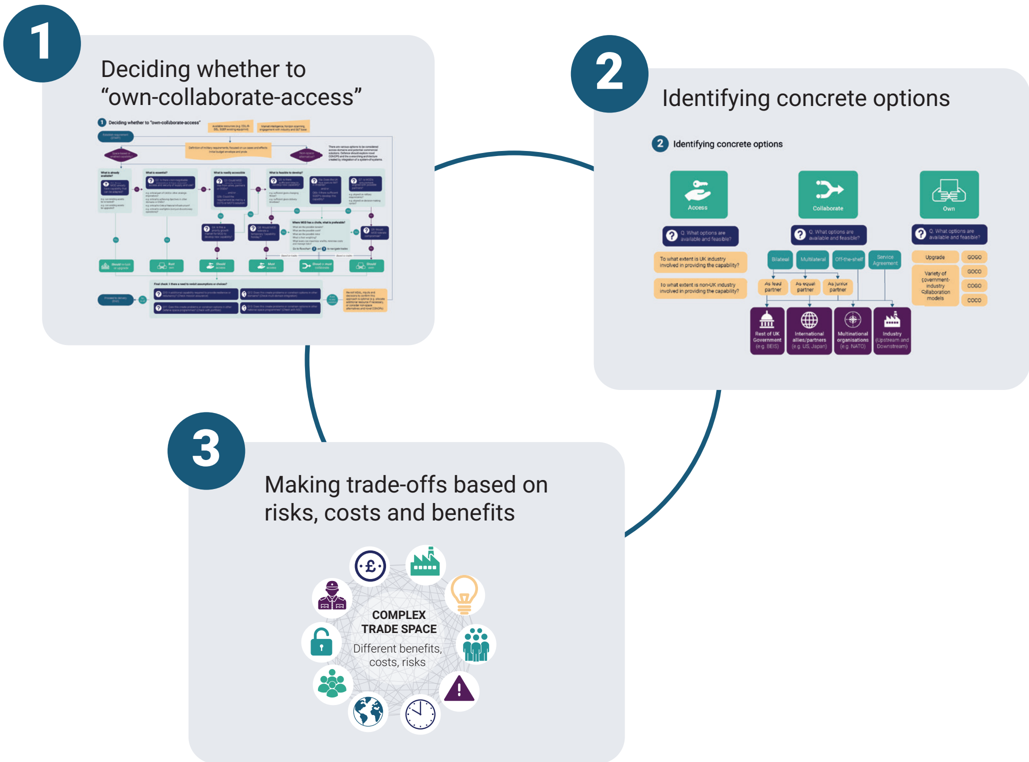
There is no straightforward or optimal solution to the complex trade-offs that exist between the different types of benefits, costs and risks inherent in sovereign, collaborative and COTS/MOTS capability programmes. These can be partially de-risked through the various commercial and other levers available to the MOD. This is true in all domains, but the MOD faces an unusual set of conditions as it goes about implementing the *Defence Space Strategy*, given the lack of legacy structures, capabilities, or decisions to work around – as well as a relatively unfamiliar space market.

The decision support tool in this annex sits nested within the concept and assessment phase of the 'High-level framework for managing defence acquisition' (see Figure 4.2) introduced in Chapter 4. As such, it focuses in on the MOD's choices between 'own-collaborate-access' options and is not intended to cover the other phases of activity that would follow, such as contracting or programme delivery. It is built around three interlinked elements, as depicted in Figure C.1 and described below:

- **Step 1:** The main visual, derived from flow chart symbology, which is intended to help guide the MOD through its decisions as to whether it should (willingly) or must (by necessity) either 'own', 'collaborate' on or 'access' a given Defence space capability.
- **Step 2:** The second visual, which is intended to help guide the MOD through selection of specific approaches and combinations of partner(s) (if applicable), on the basis of choices made in Step 1.
- **Step 3:** The third visual, which is intended to help guide the MOD through an assessment of different types of benefit, cost and risk, and to make informed trades between them, depending on its weighting of different factors on a given Defence space capability programme.

353 Cabinet Office (2021).

Figure C.1. Principal elements of the decision support tool



Source: RAND Europe analysis.

C.3. The first step is to identify which options for 'own-collaborate-access' are available and worth considering, based on MOD's requirements

In the first step, Defence has already initiated the process of identifying a new military requirement – one that could potentially be met through either space-based or space-enabled capability, or non-space alternatives. The focus of this, the main element of the decision support tool, is to help guide thinking about whether 'own', 'collaborate' and 'access' are feasible and realistic options, or necessities, given the nature of that requirement as well as a mix of both internal factors (e.g. the MOD's priorities, resources, etc.) and external conditions (e.g. a changing threat environment, technology landscape and global space market).

Specifically, this element of the tool is presented as a visual heavily inspired by flow chart symbology,[354] which contains a series of decision points. This is to be interpreted and applied as follows:

- **The user should begin at the top left,** 'Establish requirement (START') (see Figure C.2).

354 The main deviation from standard symbology is that the various decision points, or questions, are not shown as diamonds; these have been shown as dark blue rectangular boxes as a concession to legibility.

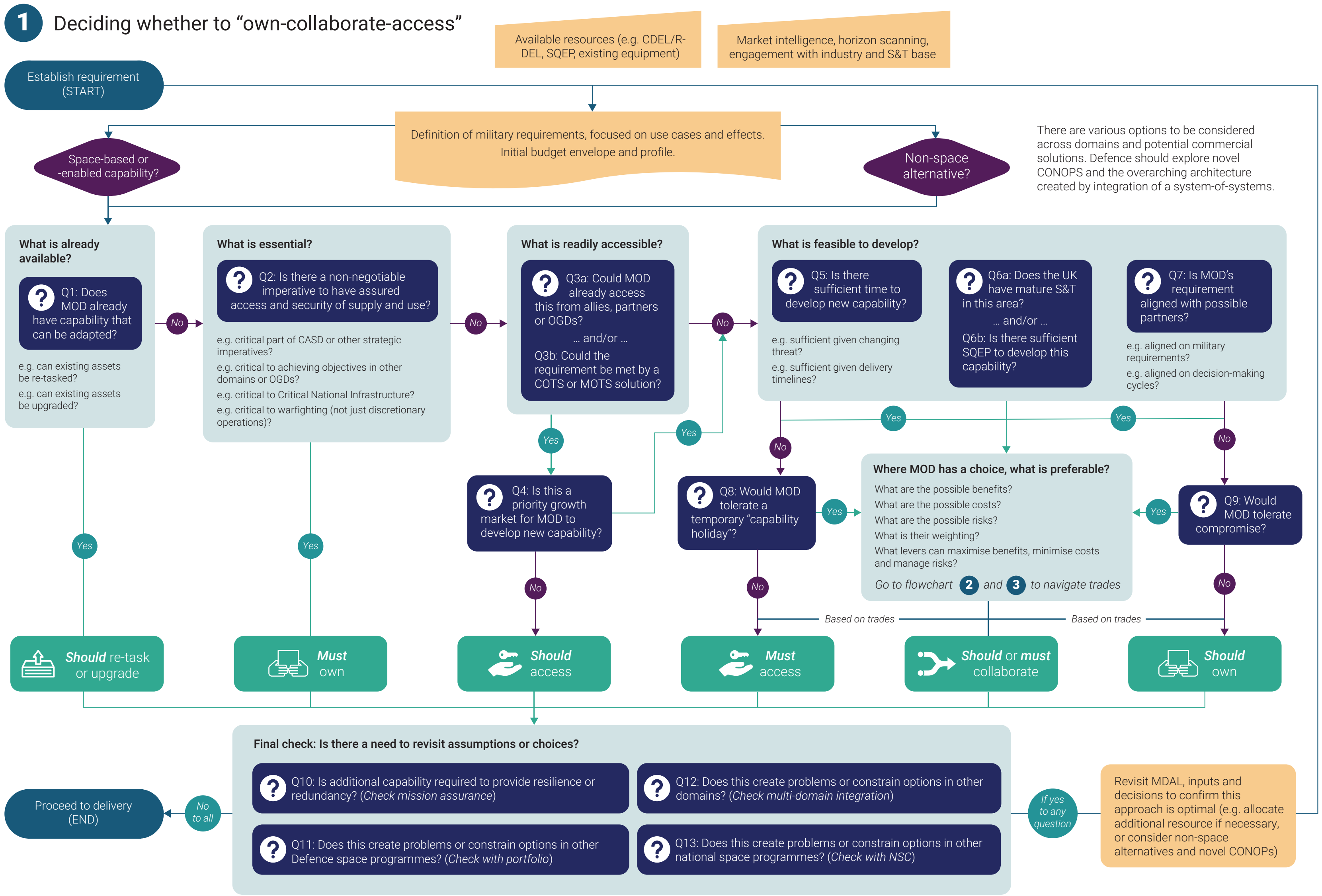
- **The user should next come to definition of military requirements,** along with the input of various resources and information (e.g. budget,[355] relevant personnel and market intelligence). Based on this the user then begins consideration of possible solutions and CONOPS for addressing those requirements, to include capabilities in the space domain or terrestrial alternatives.
- **The user then proceeds to consider what is already available**, since it may be possible to avoid the need to develop new capability altogether by instead re-tasking or upgrading existing assets (Q1). This may trigger a decision: 'Should re-task or upgrade'.
- **If existing assets cannot meet the requirements**, the user will need to begin investigating options to develop and field new capability. The user proceeds to consider what is essential in terms of operational advantage and independence, focusing on whether having sovereign capability is imperative, given factors such as security of supply, access, and use (Q2). This may trigger a decision: 'Must own'.
- **If sovereignty is negotiable**, the user will need to consider if it can expeditiously access the necessary bandwidth, data or service through allies, partners, other government departments or existing COTS/MOTS solutions available on the market (Q3-4). Here, the focus is on determining whether there is any reason not to proceed with this ready-made solution (e.g. due to a lack of available commercial solutions, or a policy preference for the UK to develop a new competing offer in the extant market), given it has already been established that security concerns are not a critical 'red line' (Q1). This may trigger a decision: 'Should access'.
- **If no solution is readily-accessible**, the user will need to consider what is feasible and realistic if seeking to develop an entirely new capability, given constrains such as time to delivery, technology, SQEP, and levels of alignment or divergence with prospective partners. These factors should be considered in parallel (Q5-7) and the outcomes of these deliberations will drive the user either towards two follow-up questions (Q8-9) or the more complex trade-space elaborated upon through Steps 2 and 3 of the decision support tool (see sections below).
- **If there is no time to develop new capability**, the user proceeds to consider whether it would tolerate a temporary 'capability holiday' (i.e. a capability gap while a new programme takes time to deliver) or instead opt for a sub-optimal COTS/MOTS solution that can be rushed into service to meet urgent requirements (Q8). This may trigger a decision: 'Must access'.
- **If requirements are not aligned with those of allies and partners**, the user proceeds to consider when it would tolerate revising its requirements as the basis for a possible collaborative programme, or whether it is unwilling to compromise and therefore must embark on a sovereign programme (Q9). This may trigger a decision: 'Should own'.
- **If there is room for discretion**, the user proceeds to consider the complex trade-space that exists between different options

355 If desired, this can be further broken into day-to-day and capital spending, or Resource Departmental Expenditure Limits (RDEL) and Capital Departmental Expenditure Limits (CDEL).

based on its preferred weighting between different types of possible benefits, costs and risks, along with an understanding of the levers of influence it has for maximising those benefits, minimising those costs and mitigating those risks. This redirects the user to the additional nuance provided in the visuals in Steps 2 and 3 of the tool (see sections below). This may trigger several different decisions: 'Should own', 'Collaborate' or 'Must access'.

- **Final checks are then required**, to ensure that the option selected does not introduce problematic dependencies or constrain other parts of the Defence space portfolio, other domains, or other parts of government from achieving strategy and policy objectives. These factors should be considered in parallel (Q10-13). The outcomes of these deliberations will drive the user either to revisit their assumptions and choices (e.g. by allocating additional resource if necessary, or considering different trades that may appear sub-optimal in space but support broader multi-domain integration), or allow them to proceed to delivery of this new capability programme.
- **Upon determining a preferred option ('own-collaborate-access')** that fulfils the various conditions set out in Q10-13, the user then exits via 'Proceed to delivery (END)'.

Figure C.2. Decision support tool #1: deciding whether to 'own-collaborate-access'



Source: RAND Europe analysis.

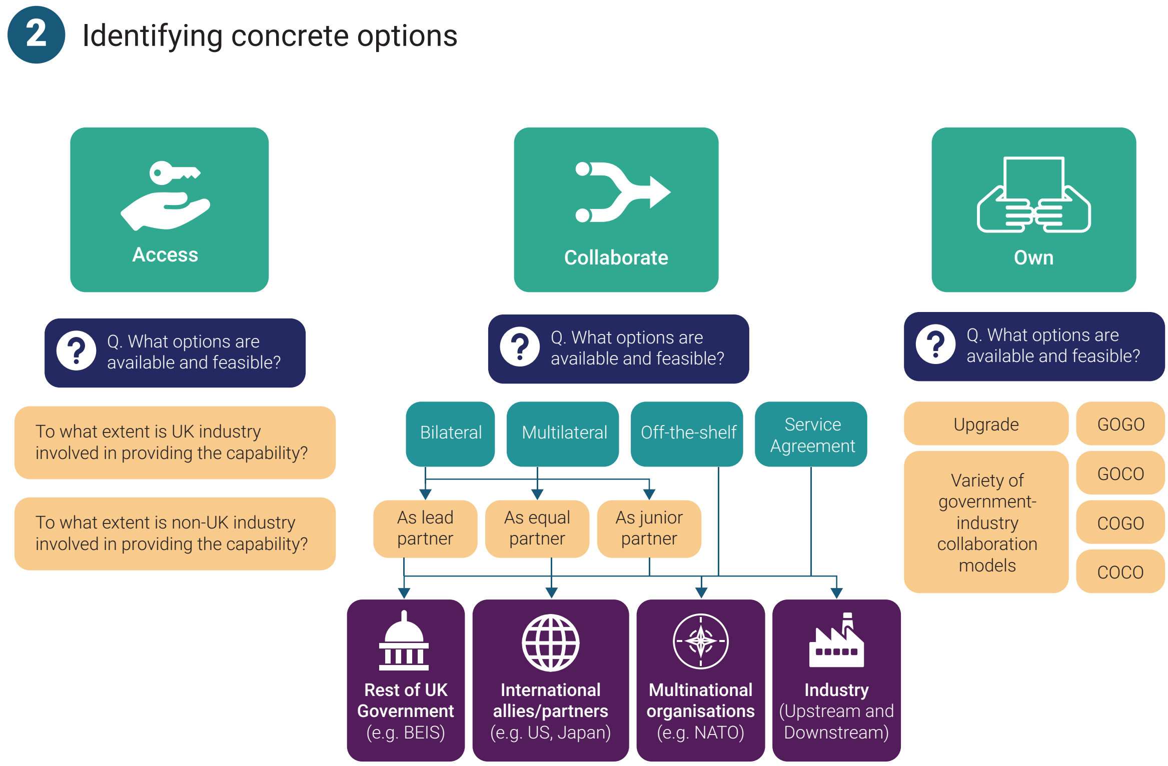
C.4. The second step is to identify concrete options for delivery based on the preferred approach to 'own-collaborate-access'

Once the user has made an initial decision on whether to 'own-collaborate-access', a range of concrete options are likely to become available for consideration, as shown in Figure C.3. It is beyond the scope of a simple visual tool to identify the full variety – and many potential combinations – of different options; rather, this second element of the tool seeks to highlight the key differentiating factors that will set apart the concrete options and partner(s) that may be available. These factors will then shape the analysis of trade-offs, risk, benefits, and costs presented in the third element of the tool (see Figure C.4). A fulsome appreciation of options will have to be informed by both an understanding and clear articulation of the UK's unique selling point (or value proposition) and an understanding of strengths and weaknesses of potential partners, as discussed in Chapter 3. These key differentiating factors include:

- For 'accessing' capability, the principal differentiating factor for the analysis of trade-offs is the **extent of involvement of UK industry** (or where relevant also academia and other stakeholders) in delivery of the commercial solution. This differentiating factor will have a bearing on a range of trade-offs, most notably on considerations around security of supply, wider prosperity benefits, industrial and commercial impact, innovation, IP and spillovers as well as the nature of risk.
- For 'collaboration', two differentiating factors are especially important for shaping trade-offs: the **UK's workshare** in any collaborative programme (i.e. whether the UK is a lead partner, equal partner or junior partner) which will influence a range of factors. These include: affordability, the UK's ability to exercise influence over requirements and other decisions, the degree of involvement of UK industry and the corresponding prosperity, innovation and spillover benefits as well as the degree to which the MOD is able to understand and manage risk. The second key consideration is **with whom the UK decides to partner** and to what degree there is established collaboration to build upon versus an empty drawing board in an untested relationship. If the latter is the case, the MOD would naturally need to invest more into learning about and understanding the partner(s)'s acquisition processes, dynamics and culture, ambitions and motivations, as well as potential constraints and barriers, in order to mitigate risk and ensure a successful collaboration (as discussed in Chapter 4).
- For 'owning' capabilities, the principal differentiating factors shaping trade-offs will be related to the **acquisition and commercial strategy and corresponding delivery model** that will be implemented for the delivery of capability. These will shape not only affordability and value for money assessments but also the understanding, allocation and management of risk, considerations of operational independence and wider prosperity benefits. Different constructs and models are available for acquisition of defence capability, including the use of alliances, joint industry- MOD teams as well as different commercial operating models combining government and contractor ownership and operation (e.g. GOGO, GOCO, COGO, COCO).[356]

356 'Government-owned, government-operated' (GOGO), 'government-owned, contractor operated' (GOCO), 'contractor-owned, government operated' (COGO) and 'contractor-owner, contractor operated' (COCO) models.

Figure C.3. Decision support tool #2: identifying concrete options



Source: RAND Europe analysis.

C.5. The third step is to determine the preferred weighting and trades between different benefits, costs, and risks in the discretionary cases

In those cases where the first element of the tool has not directed the user towards those comparatively straightforward and unambiguous cases (i.e. where it 'Must own', or where there is no reason not to simply 'access' a readily-available COTS/MOTS solution), it is then necessary to consider the possible benefits, costs, risks, and trade-offs associated with the concrete options identified in the second element of the tool.

As discussed in Chapter 4, this involves considering a range of different factors, with no common metric between them. In this situation, it would be for the user to determine what weighting they wish to ascribe to individual factors (as occurs when specifying evaluation criteria for appraisals or industry proposals). In this regard, the 2021 *DSIS* provides updated guidance. For example, it mandates a requirement for MOD to give considerations of wider prosperity and net social value a minimum weighting of 10 per cent to any procurements launched under the Defence & Security Public Contract Regulations after 1 June 2021. At the same time, there is still considerable room for discretion by decision-makers within the Defence space enterprise, who are likely to apply a different weighting based on whether they are opting to 'own', 'collaborate' on or 'access' a given space capability.

The figure overleaf provides examples of the sorts of questions that the user should consider when seeking to understand the trades it might need to make among these different factors on a given programme.

To inform its assessment of each of these different factors, the user can draw on a variety of different data sources, analysis, and other inputs, some highlighted in Figure C.4 and slightly expanded in the table below. The resources that the user devotes to generating an evidence base to inform its ultimate decision over whether to proceed with a given option will depend on the nature of the capability in question, the costs and risks associated with this specific programme, and the type of investment appraisal being undertaken.

Table C.1. Illustrative examples of sources for information input into analysis of trade-offs

Factors for consideration	Example inputs to inform assessment
Affordability and value for money	For example, cost estimation and modelling, red-teaming and assurance.
Operational advantage	For example, wargaming, modelling, simulation, net assessment vis-à-vis competitors, intelligence on hostile capabilities, doctrine, intent.
Security of supply and access	For example, supply chain mapping, supplier risk assessment, analysis of relevant regulatory frameworks.
Interoperability	For example, information on partners' technical requirements, interfaces, standards (e.g. NATO STANAGS).
International influence and engagement	For example, engagement cross-Whitehall (especially FCDO), industry, diplomatic missions.
Industrial and commercial impact	For example, market intelligence, industrial skills data (e.g. the MOD's new JEDHub), supply chain mapping.
Innovation, IPR and spillovers	For example, comparative analysis of similar programmes (e.g. done by partners and allies), horizon scanning and technology watch.
Wider prosperity benefits (net social value)	For example, comparative analysis and evaluations of similar programmes.
Risk (and opportunities)	For example, risk analysis, assumptions-based planning.
Time and learning	For example, analysis of good practice from allies and partners/other domains/private sector.

Source: RAND Europe analysis.

Figure C.4. Decision support tool #3: understanding trade-offs, cost, benefits, and risks

3 Making trade-offs based on risks, costs and benefits

MOD's determination of the weighting assigned to each factor (likely to be different for "own", "collaborate" and "access" options)

Analysis of alternatives to determine costs, benefits, trade-offs

Affordability and value for money

What are the likely acquisition and through-life costs?

How can MOD spread upfront cost?

Could MOD spending incentivise match funding by others (e.g. OGDs, allies and partners, or private industry investment)?

Could capability generate additional income? (e.g. selling bandwidth)

Example inputs: cost estimation and parametric modelling, red-teaming and assurance (e.g. through CAAS)

Operational advantage

How will the new capability be integrated with the rest of the Joint Force (space and cross domain)?

What are the relevant CONOPS?

How does the capability contribute to BLUE operations in the space domain/in other domains?

What are RED's possible counter-measures?

How will vulnerabilities and countermeasures be mitigated?

Example inputs: wargaming, modelling, simulation, net assessment vis-à-vis competitors, intelligence on hostile capabilities, doctrine, intent

Security of supply and access, freedom of action

What are the vulnerabilities in the supply chain (reliability, security risks, cyber risks)?

Are there any regulatory/legal restrictions that could affect availability?

Will MOD have full control over operational use, through-life support, underlying software and code etc?

What are the redundancies and reversionary modes?

Example inputs: supply chain mapping, supplier risk assessment, analysis of relevant regulations

Interoperability

What are the requirements for data links across Defence (e.g. with end users in land/air/maritime/cyber)?

What are the requirements with OGDs, allies and partners?

Are common CONOPS in place?

What is the systems architecture

Could a modular open systems architecture (MOSA) be used?

Are there set standards in place or are new ones needed?

Example inputs: info on partners' technical requirements, interfaces, standards (e.g. NATO STANAGS)

International influence and engagement

What levers of influence are likely to become available to the UK? (e.g. diplomatic, industrial collaboration, technology transfer, training, development…)

How might this programme be integrated within a broader international engagement strategy with allies and partners involved?

How might this programme contribute to broader strategic and policy objectives in the region/country of interest?

Example inputs: engagement cross-Whitehall (especially FCDO), industry, diplomatic missions and DA network

Innovation, IPR and spillovers

What is the state-of-the-art based on the latest S&T advances?

Could S&T for a particular capability have wider applications and bring expertise to the UK?

What are the potential spillovers into other sectors of the economy?

Could high profile companies (e.g. UK equivalent to SpaceX) generate public interest in space?

Example inputs: comparative analysis of similar programmes (e.g. done by partners and allies); technology watch

Industrial and commercial impact

What is the capacity of the UK defence industrial base to deliver this programme (including skills, facilities, order book)?

What is the broader global market for this area (export potential)?

What would be impact on SMEs and lower tiers of supply chain?

Does the programme bring together private companies and HMG towards unifying the UK space sector?

Example inputs: market intelligence, industrial skills data (e.g. MOD's new JEDHub), supply chain mapping

Wider prosperity benefits (net social value)

What are the impacts of this capability on civilian infrastructure? (e.g. internet coverage, weather monitoring)

Could this capability bring industry to remote/rural areas of the UK?

How does this programme deliver social value (e.g. contributing to tackling climate change, improving community cohesion, etc.)

Could this capability generate increased public interest in space, leading to more STEM skills in the wider economy?

Example inputs: comparative analysis and evaluations of similar programmes

Risk

What is the programme risk (cost, schedule, performance)?

What is the technical risk?

What is the political risk?

Could sovereign capabilities drive a wedge between allies/partners?

Does the capability duplicate efforts elsewhere?

Could the capability be seen as 'provocative' and generate risk in other areas from adversaries?

Is there sufficient public understanding and support for spending on space?

How can risks be mitigated?

Example inputs: risk analysis

Time and learning

Does MOD yet have sufficient experience to act as an intelligent customer (or sufficient time to acquire the SQEP) in space?

Are there applicable lessons to be learned from allies or other domains or the private sector?

Is there a sound learning infrastructure (e.g. logging, applying and reflecting on lessons learnt, organisational culture)?

Example inputs: analysis of good practice from other allies, sectors etc

Based on these trade-offs, do any of these options fulfil the MOD requirement and provide value for money?

Yes → *Proceed with procurement*

No → *Go to flowchart* 1

Source: RAND Europe analysis.

Having gathered the necessary evidence and formulated an assessment of these different factors, based on a given weighting, the user can then make an informed decision as to whether the selected option has met all the minimum 'critical success factors' for proceeding with the acquisition.[357] Alternatively, if the likely benefits associated with a preferred 'own-collaborate-access' option do not seem to merit the costs, risks and trade-offs, the user should return to the first and second elements of the tool to re-evaluate their options. In this way, the interlinked elements of the decision support tool are intended to form a feedback loop, with the user revisiting and, if needed, changing its assumptions and choices as trade-offs become more apparent through evidence-gathering and analysis. While this should be done at the programme level, the best long-term results are likely to arise from a portfolio approach that balances different types of benefits, costs, and risks – and different 'own-collaborate-access' options – across multiple programmes. The relatively 'blank slate' of UK Defence in space, outside of SATCOM, presents a unique opportunity to instigate such a portfolio approach as it goes about implementing the *Defence Space Strategy* in the 2020s.

357 The *DSIS* lists 'strategic fit' and value for money as critical success factors and emphasises considering other issues such as supplier capacity and capability, potential achievability, and potential affordability. See MOD (2021b).