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An International Comparison of Approaches to Space Cluster Development

18TH MAY 2021

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RED KITE
MANAGEMENT CONSULTING

International Comparison of Approaches to Space Cluster Development

Prepared for the Satellite Applications Catapult and the UK Space Agency by Red Kite Management Consulting

March 2021

This report is the output of a project to provide an independent review of international space clusters, the types and magnitude of public support for them, and lessons for the public policy to accelerate their economic development.

Introduction and summary

In this report, we examine space clusters around the world with a view to understanding how public policy has catalysed space sector development. The purpose of the research is to benchmark UK performance against its peers, check how UK approaches to sector development are performing; and begin to deliver insights into how public policy could be improved to drive growth in the nation's space clusters and in the national UK cluster.

The space sector is both growing and changing quickly. In much of the world, historic models of space cluster development driven by previously by government facilities or research is giving way to a commercial model.

In our research we explored eight international clusters of activity and compared these to three clusters in the UK. Through these case studies we found a wide range of cluster origin stories and reasons for recent success. Public policy and government interventions appear to have had the most profound effects through the following mechanisms:

- **Skills are sticky**: Skills often remain in place when research programmes end – resulting in talented and educated people looking for opportunities and setting up companies. This can take time and is not fool proof but is a major characteristic of long term and sustained space sector growth.

- **Scale matters:** Reaching scale helps to develop a space sector brand, signals success and the availability of talent. It also helps to attract resources, companies and nationally and internationally, and mitigates risk for individual workers or companies.

- **Individual space customers can be fickle:** Whether it is a research programme, a single project or a high-profile mission, relying on an individual space customer is risky. In some cases, single organisations can be larger than moderately sized clusters, and can be successful. However, in a rapidly changing industry, technologies and markets have provided many examples of clusters struggling when single customer relationships end.

- **Business environment and success culture is critical:** 'Business friendly' environments do not necessarily mean low taxes. We found that more important were: being 'open' to skills migration and company formation, having a strong 'how can we help' style dialogue with the business community, supportive regulation, and developing a narrative of success.

- **Public facilities and business support are not significant differentiators:** Some clusters examined provide a supportive public function for companies to start projects or develop technologies whilst they prepare for market. Other jurisdictions offer very little or nothing. While the success of support mechanisms, such as access to finance, startup space, or business incubation is mainly anecdotal, there is evidence – particularly in the European clusters – that this support can make a big difference to some companies. Some unicorns have benefited from this support, but it isn't always clear where it was an essential component of success.

Some implications for the UK are clear – for example, the value of developing a long-term skills pipeline for the space sector. However, some other implications are more nuanced. In many ways, the UK functions as a single cluster. We found evidence of strong connections between the three UK clusters that we examined which included research, industrial collaborations, movement of personnel and distributed functions of companies. This tends to support the current UK strategy of supporting individual clusters with different functions as part of a national cluster policy.

Throughout our work we have also sought ways that public policy making, to support economic development in the space sector, could be improved. Presently, data is weak and inconsistent, and evaluation of public interventions is very limited. Going forward, to better understand how government can support the development of the space economy, we recommend:

- **Deep dives into specific programmes:** Our cluster case study approach was not suited to unravelling information on the economic returns of particular policy interventions. to achieve this, we recommend a series of evaluation studies of specific elements of expenditure such as grant funds, business support programmes, UKSA and ESA programmes etc. The objectives of some programmes may also not be specifically directed to economic development, but it may proof beneficial to understand how these programmes contribute through focused research.

- **Data improvement for cluster comparison:** Our study was relatively limited in scope and was not able to develop new quantitative information on clusters of economic activity in the space sector. Existing information is weak, partly due to issues of defining the sector or cluster, and because only some jurisdictions have invested in developing quantified views of their space economies. A priority in the future should be to develop consistent measures of cluster size and growth. This approach would concentrate on valuable economic measures, such as economic output or jobs, rather than more easily available data such as the number of companies operating in a particular location.

- **Scaling up to increase robustness:** Larger cross-cluster assessment could provide quantitative findings and challenge our case study results to see if they hold up.

- **A circular approach to learning:** We recommend that the space sector develops a more scientific approach to economic development where post project evaluation is the norm and this is shared across the community. A cycle of intervention experiment, evaluation, learning, and further intervention experiments would build insight into how economic development interventions work best in the space sector.

The report is structured in three chapters:

1. Chapter 1 sets out the broad scale and pattern of international space sector activity, including the main thrust of policy in the major space-faring nations;
2. Chapter 2 examines eight case studies of international space cluster development and compare these with three clusters in the UK – focussing on the role of public intervention in driving cluster growth; and
3. Chapter 3 draws lessons for the UK about how public intervention has been most effectively targeted to grow the space economy.

Over the course of the report, we also set out the challenges for conducting the analysis effectively, weaknesses of the approach and lessons for developing a future methodology.

1. The international space economy and clusters of activity

In this section we set out some important features of the international space economy to provide the background for our subsequent assessment of international space clusters, public support for them, and the effectiveness of different public policy approaches.

We first examine the overall characteristics of the global market by function, examining 'upstream' space which designs, builds, launches and manages spacecraft, and 'downstream space' which provides space derived services. Where possible, we split these into commercial and government funded and concentrate on civilian space expenditure, although military expenditure is also considerable. We then examine the geographical breakdown of the space economy across the major space-faring countries to provide context for scale of the clusters examined and the scale of public interventions. In the second part of this chapter, we briefly examine geographic patterns of space sector activity within countries and set out some of the reasons for the formation and growth of space clusters.

Analysis in this chapter draws on a number of existing published sources (most of which are publicly available) and does not draw on any new primary research. The assessment is therefore somewhat limited due to data availability and differences in definitions. Downstream space activity is particularly difficult to quantify because it is often integrated into products and services which offer other services (e.g. PNT chips and services are embedded in smartphones).

1.1 The international space economy

Space sector activities

The global space economy is estimated to have a turnover of around $400 billion in 2020, depending on the source[1]. However, some care needs to be taken over this because some countries (notably China) do not publish this information and the definition of the space sector varies across countries and across studies so estimates can vary considerably.

Although the data is not consistent or complete, some key elements are clear:

- Downstream space is around three times the size of upstream space activity;
- The major components of downstream space are direct to home broadcasting and services which rely on PNT signals – although satellite communications are also sizeable and earth observation products remain small but are growing quickly;

[1] The Space Report 2018 put turnover at $383bn in 2017.

- Upstream space is dominated by hardware for the ground segment – particularly when devices that receive and interpret PNT data are included (driven mainly by smartphone demand);
- The value of satellites launched is around five times larger than the cost of launch services used to launch them;
- Most of the value in manufactured satellites remains in government and military applications, although this balance is changing.

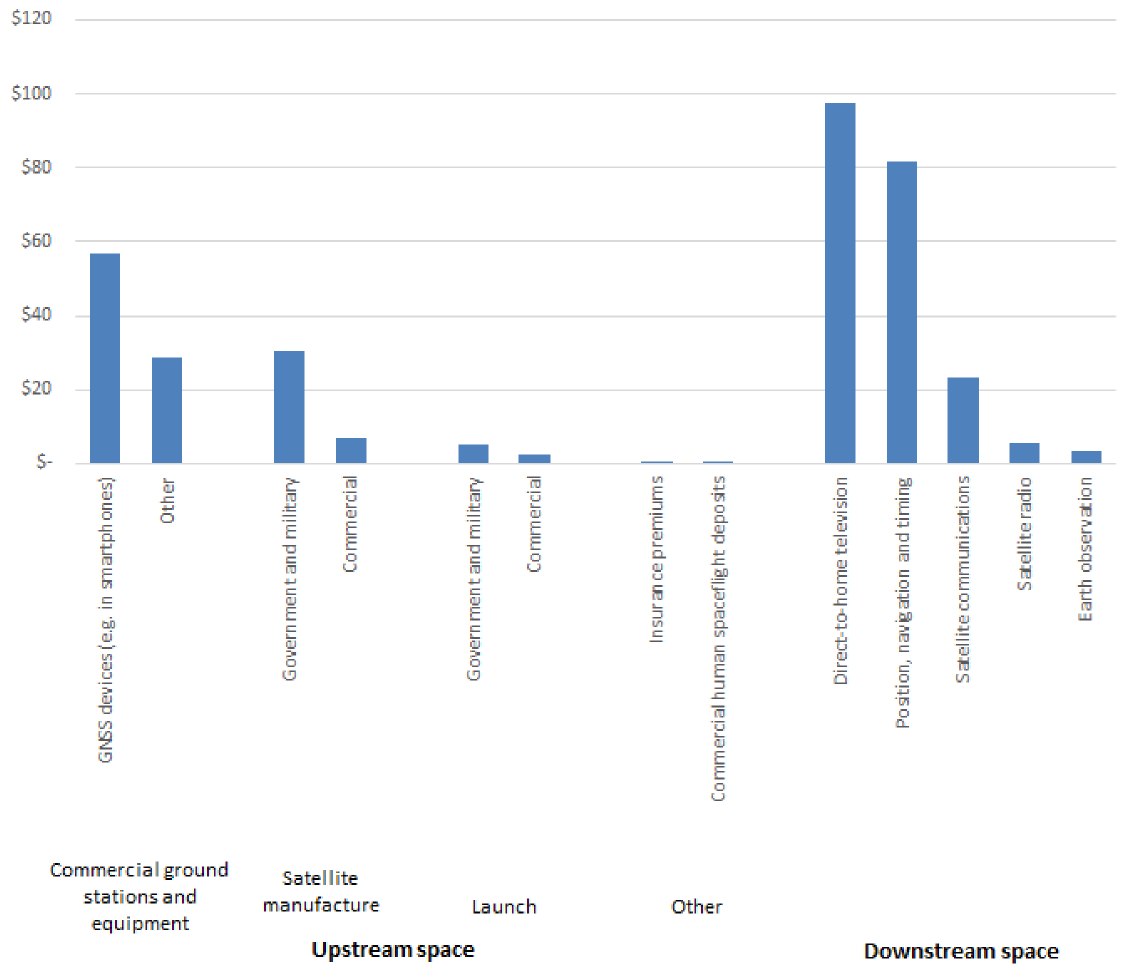

Figure 1: Key elements of space sector global turnover, 2017, US$

In 2017, only 26 out of 91 launch attempts were for commercial satellites with the remainder launching government satellites and missions.

The upstream space market is highly consolidated. In Europe, four companies (and their subsidiaries and JVs) make up over half of upstream space employment (Airbus, Thales, Safran and Leonardo)[2], and SMEs make up less than 10% of space manufacturing employment.

[2] https://eurospace.org//wp-content/uploads/2018/05/eurospace_facts_and_figures_data2018_oct-2019-release.pdf

However, this is changing as access to space becomes cheaper and satellites become smaller and more efficient, enabling the emergence of a more diversified space manufacturing industry.

While military space expenditure is often classified or unreported, in the USA military budgets are a similar size or slightly smaller than civilian space turnover, while across other countries, military space expenditure is around 25% of civilian space expenditures. In Germany and France these figures are around 21% and 14% respectively. Although no data is available for the UK, military expenditure is rising. The founding of UK Space Command and the renewal of the Skynet military communications satellite constellation are two immediate indicators of this.

Public sector space budgets

Figure 2 shows national public sector space budgets across the world. The US public sector civilian space budget of around $23 billion is dominated by NASA but also includes other agencies such as the National Science Foundation. This eclipses other national space budgets and may comprise around half of global government civilian space spending. China is likely to be the next largest, although data is scarce and the Space Foundation estimate China's expenditure at between $8bn and $30bn including military expenditure. Outside of Europe, three further countries have annual public sector space budgets of over $1bn: Japan; Russia; and India.

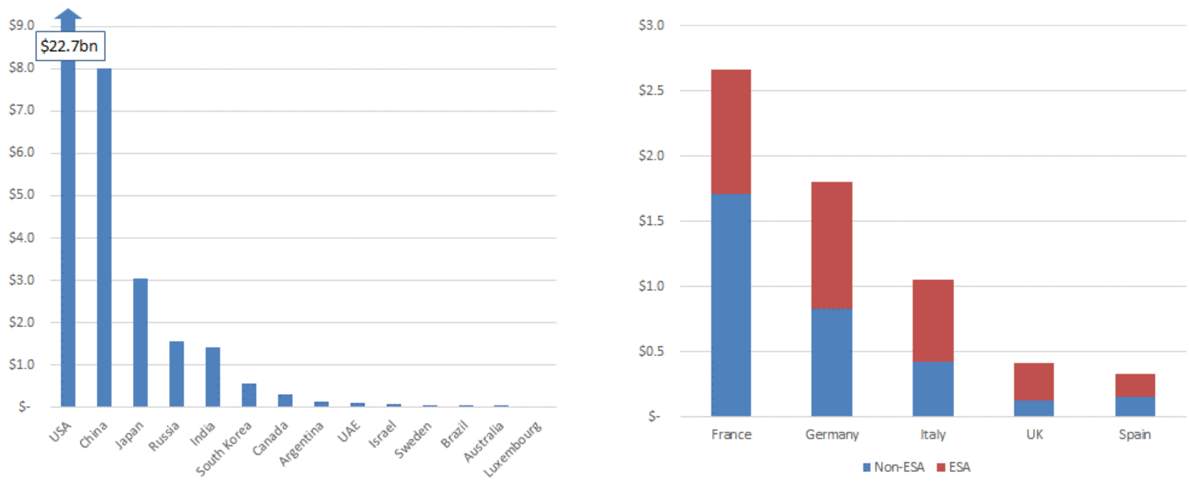

Figure 2: National civilian space budgets ($bn), 2017[3]

In Europe, budgets are split between contributions to ESA and national space programmes. France is the largest space economy in Europe by some margin with public budgets of around $2.7 billion per annum, followed by Germany at around $1.8 billion. France and Germany's ESA contributions are similar size, but France's domestic space expenditure is around 50% larger than Germany's. The UK's space budget in 2017 was around $0.4 billion with more than two thirds

[3] Chinese expenditure is uncertain. Civilian Chinese space expenditure is shown as the lower end of the Space Foundation's estimates for total Chinese expenditure.

of this channelled through ESA. While the data presented is now somewhat old to allow international comparisons, the UK government space budget has been growing substantially by a compound annual growth rate of 10.5% per annum over the last 5 years. The budget for 2020/21 is £569.5 million.

Major market trends

In this section, we briefly set out some of the major market trends that are changing the shape of the global space industry and influencing where and how it grows. A more detail survey of these trends is provided in Appendix 3. The space industry has seen radical change in the last 10-15 years, both in the upstream and downstream markets. These changes have been brought on by technological advancements, newly emerging threats, shifting government policies, substantial private investments and societal changes.

Commercial launch was perceived as one of the main bottlenecks to sector growth. Until 15 years ago all launch vehicles were operated by large government contractors and were designed to launch large government satellites weighing several tons. High price tags led to a shift towards commercial launch pioneered by NASA and SpaceX. Meanwhile, as satellite technology became miniaturised, small sat payloads suffered from the drawbacks of ridesharing – prompting a flood of new small launch systems. Since the cancellation of Falcon 1 there have been over 160 small launch vehicle projects emerging around the world, almost all with the commercial small satellite launch market in their sights – perhaps 10% of these have the means to make it to market. So far, US Company Rocket Lab is the only private small launch provider to make it to market after SpaceX.

Commercial provision to government has accelerated as governments aim to drive the best value from their space programmes. Agencies have started turning to new private companies through fixed price contacts and seed corn investments.

PNT has seen the lion's share of recent investment in applications. Commercial growth is almost entirely application and software driven, because the most expensive hardware component, the global navigation satellite system (GNSS), is developed and deployed by national programs. Governments then retain the higher resolution GNSS signals for defence applications while supplying lower resolution signals for free to commercial users.

Data communications – ever increasing demand for communications has driven expansion of terrestrial and satellite communications markets. Sat comms are becoming increasingly dominated by large constellations of smaller satellites (e.g. Starlink, OneWeb and Kuiper) which are responding to lower launch and satellite build costs and greater satellite functionality.

The global market for commercial **earth observation** (EO) data and services has been projected to reach $8 billion by 2029, growing from $4.6 billion in 2019.[4] Historically, the main customer has been the defence sector, but the customer base is widening quickly. The commercial landscape is changing as downstream businesses are developing to process, interpret and deliver new products from the massive volumes of data being delivered. Crossovers with software, data warehousing, AI and data processing are proliferating.

Internet of Things – Utilising similar advancements in AI and machine learning to those mentioned in the EO section above, NewSpace IoT companies are able to benefit from low cost and low power satellite platforms, such as CubeSats, to deliver services based on the networking and transfer of low-bandwidth data from a varying array of sensors. Investment in this sector has been comparatively humble so far, but that's arguably because hardware costs for satellites and sensors, as well as launch costs, can be kept low. This means that the deployment and business case of such systems should be demonstrated soon (in the next 1-2 years), which is especially fast when compared to larger satellite businesses.

Communications security – As society's dependence on communications and data increases so does the demand for security against tampering or sabotage. Protection against signal spoofing, physical interception and other techniques include advancements in optical communications (where information is transferred via laser), quantum key distribution research, Blockchain and other novel encryption methods.

A proliferation of orbiting objects has led to a growth market in **space situational awareness** – the capability of detecting and tracking man-made and natural in-orbit debris, predicting and assessing the risks involved, and providing services enabling the implementation of appropriate mitigation measures.[5] Tightening international and national regulations are leading to new markets for miniaturised satellite propulsion and manoeuvring systems, passive de-orbiting systems like deployable sails, 'active debris removal' services and 'end of life' services.

Lunar economy – Every major space-faring nation (with Europe included as one under ESA) has a lunar program, with overlaps in their respective timelines over the next 2 to 9 years. This has opened opportunities for the private sector, firstly to hitch a ride on government launches to the moon and to supply communications, monitoring and mapping services to support the development and operation of the infrastructure expected from these national programs.

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[4] (2020) Earth Observation Data and Services Market, Euroconsult

[5] Space Situational Awareness, PWC

Demand for **satellite broadcast television** has been falling (at least in developed markets) as viewing habits have shifted to streaming services like Netflix and Amazon Prime. This has put pressure on the Geostationary Orbit (GEO) Communications market, one of the largest providers of space derived services. This could jeopardise space sector growth targets if this decline can't be overcome by growth in new emerging markets. A consequence of uncertainty in the GEO Communications market is an emerging potential market for **in-orbit servicing** missions, which extend the life of satellites already in-orbit through refuelling or supplemented propulsion.

All of these market trends point to some key conclusions that will affect the emergence of new clusters and markets:

Lower barriers to entry are enabling an explosion of space applications pointing to the critical role for entrepreneurialism and continual innovation in space clusters.

- The space sector is far from mature and technologies and developments are dynamic and often unexpected. Potentially large new industries (such as lunar exploration, on-orbit manufacturing) may be emerging, but it is not clear yet which will have sound markets over the coming decades.
- Downstream commercial markets are developing quickly which may not have the strong geographic links to upstream space and their location may be more closely aligned to customers or to ancillary industries such as software and computing.
- Competition is fierce and is driving down costs. Growth in markets will therefore need to offer substantial and protected sources of value or will need to be prepared for a more competitive and commoditised high-volume future. Volume growth in upstream space could favour locations with lower manufacturing costs rather than high-cost high-innovation environments.

National space policies and approaches

In this section, we briefly review the national space policies and approaches of the major spacefaring nations. This is intended to provide the 'big picture' and help to set the scene for more geographically localised public policy interventions in clusters which we examine in the next chapter. More detailed assessment of the approaches of major nations is provided in Appendix 4.

China – While China has the second largest civil space budget after the US, its space industry – especially launch – has been almost entirely isolated from international trade because of international restrictions. The space programme centres on high profile pride projects such as the Chinese Large Modular Space Station and activities are enabled by a new family of small to heavy lift vehicles.

Most apparently commercial space companies (e.g. LandSpace, Head Aerospace) are quasi private companies with strong links to government. Due to international restrictions (e.g. IRAT) and concern over use of intellectual property, these companies have not been given the opportunity to compete internationally.

Russia has a shrinking international presence in space, failing to build on its rich heritage and with new projects plagued by schedule delays. Annual cuts to the Federal Space Budget have been consistent since 2014 and international revenues are under pressure as new entrants like SpaceX outcompete older Russian technologies. Rather than focusing on expansion, Russia's main efforts have been on preserving the space infrastructure they already have such as GLONASS (navigation). New facilities and potential future clusters of state sponsored activity such as Russia's development of a new launch site in the far-East, Vostochny, have been delayed.

The tech hub of SkolkovoTech is Russia's attempt to recreate a Western style academia-led research hub that creates spin out businesses. It was set up with $4bn of funding some years ago but has been plagued by corruption scandals and seen little commercial success. Russia does not have a culture of university graduates using their learning to create companies. Instead there is a history of graduates joining research state institutions. There remains very heavy state involvement across the space value chain (satellite and rocket manufacturing, operations sites, etc) and the government is usually a shareholder.

The shape of the space sector in the **USA** is likewise a legacy of cold war programmes such as Apollo and the Shuttle programme. This led to large scale public investment and politically driven investment decisions which favoured widely distributing NASA facilities to create the broadest national political coalition. While the commercial cargo and commercial crew programmes have begun to reshape NASA, its footprint and activities today still largely reflect this history – for example with major NASA facilities and clusters developed around Florida (launch), Huntsville AL (propellant and rocketry), Colorado (defence applications), and many more centres of excellence. The newly established US Space Force will support a cluster of geographic space activity and political tussles continue over where it will find a permanent base.

The shift towards commercial provision goes alongside two other main trends in the USA: the emergence of billionaire space investors (such as Paul Allen, Elon Musk and Jeff Bezos); and Silicon Valley style space startups in downstream space – with PlanetLabs as the posterchild.

In national policy, the Artemis project (to establish a permanent presence on the moon) looms large alongside the development of the Space Launch System and a rise in unclassified Department of Defense spending, primarily to meet new perceived threats from China and Russia.

Europe – With the space interests of several independent nations partly represented under the banner of the European Space Agency (ESA) and the European Union, there is less of a centralised and connected space programme to speak of for Europe. France, Germany and Italy have sizable national space programs while the UK, as the other major contributor to ESA, does not have a large domestic space programme. These difficulties of strategic coordination and direction mean that European programmes (under ESA especially) tend to be 'neatly packaged' one-off science missions where budgets, although sizable, can be feasibly drawn from the contributions of member states (e.g. the Gaia astronomy mission to identify exoplanets). A high frequency of high-profile science missions means that support often skews to the academic community and project roles are distributed according to national contributions, supporting national clusters of academic and engineering excellence.

India – The majority of India's space activities emanate from the Indian Space Research Organisation (ISRO), which falls directly under the Department of Space. The program involves a series of robotic missions and probes to the Moon, Mars, Venus and the Sun, as well as in-orbit astronomy missions and human spaceflight. India has also found success in commercialising the outcomes of its space agency through a separate government-owned company (Antrix) which was established to commercialise the space products and services developed in ISRO. State owned companies also provide several downstream commercial services, including TV broadcasting, telecoms and direct to home services - predominantly to India's growing domestic market. Another agency will be responsible for commercialising the usage of spacecraft data and rolling out of space-based services, such as the marketing, sharing and dissemination of remote sensing data. Some ISRO employees are starting to form independent commercial companies, such as Skyroot Aerospace Ltd., a small launch vehicle developer, and Dhruva Space Ltd., a small satellite manufacturer – both are winners of India's National Startup Awards 2020 (run by India's Department for the Promotion of Industry and Internal Trade).

Japan – The Japanese space industry is heavily dominated by prime contractors such as Mitsubishi Heavy Industries and IHI Corporation, who have worked closely with the national space agency, JAXA (Japan Aerospace Exploration Agency) to deliver several high profile national and internationally-partnered missions. JAXA has an active space science and exploration program, as well as contributing modules, supplies and astronauts to the ISS. Due to budgetary constraints, Japan's space budget is forecast to grow modestly (2% per year), with stable civil growth and sharper defence fluctuations as military program cycles begin and end.[6]

A complacent dominance by heavy industry has led to high price tags for Japanese space products and services and JAXA is under pressure to change this trend. The JAXA Space Innovation through Partnership and Co-creation (J-SPARC) initiative was thus formed in 2018, to encourage the formation of private space business. Through J-SPARC, Japanese startups can receive support from JAXA via joint research, technology development, technology demonstration, human resources, and assets. The J-SPARC initiative also supports cooperation with public-private funds such as Development Bank of Japan, access to co-working space and helps companies promote their brand.

Conclusions – The national space programmes of the US, Russia and China are all partly reactive to one another. The outcome is the emergence of a new race to the moon between the US and China. Meanwhile, Russia's space industry appears to be stagnating after losing commercial ground to the US on launch, as well as lucrative US contracts. Russia's space capabilities are at risk with three effects: skills are leaving to join clusters elsewhere; ex-Soviet era facilities are being partly repurposed for commercial use; and startups are emerging to use skills and facilities left by public programmes.

The Indian and Japanese space programs both appear to have a growing interest in commercialising the successes of their respective space programs while continuing their ambitious science, exploration and human spaceflight goals, leading to small emerging clusters of private sector activity (e.g. in Bengaluru).

Although Europe has a combined space budget to rival most of the world's space faring nations, aligning the priorities of separate countries into a programme is challenging. This pushes ESA into discrete missions and partnerships.

National Space Programs in their nature are focused on strategic or high-profile upstream activities that capture the public's imagination and yield immediate and obvious results. The consequential advancements in science and technology that eventually sink into our everyday lives, however, often go unnoticed, and the routes towards eventual downstream services are hard to predict – but the transformative potential is indisputable when they do. For example, all the smartphone applications that have resulted from GPS, or Google maps and other geospatial applications from US Landsat and EU Copernicus remote sensing data. The continuation of

[6] 6 Simon Seminari (2019) Op-ed | Global government space budgets continues multiyear rebound, Space News

national space programs, and the emergence of newer ambitious programs from China and India, will ultimately see further transformative outcomes in society. With a stronger emphasis on commercial partnership for almost all the major national space programs, these outcomes are likely to reach society faster than ever before. In doing so they will drive growth in global clusters of activity which the UK will participate in and compete with.

1.2 Clusters of space sector activity

The space industry has historically been an extension of the defence sector which has migrated in civil and scientific directions. This has meant that a number of the global hubs for space activity have emerged from government facilities, such as the launch sites of Baikonur, Russia and Cape Canaveral, USA, both of which were products of the cold war space race. There are also clusters of space activity around civil space agencies, such as Toulouse, France and Cologne, Germany.

This model for the space industry remained largely unchanged, with the inclusion of a few "prime" spacecraft builders whose main business centred on government contracts, such as Airbus Defence and Space, with one of their main manufacturing facilities located near the French Space Agency (CNES) in Toulouse. However, this ecosystem has been changing with the advent of 'NewSpace' and the rapid increase in privately owned and financed companies. Several of these companies are focused on delivering services and applications to the general public, continually iterating their satellite hardware, products and services based on fast-moving consumer habits (e.g. streaming services like Netflix and Amazon Prime overtaking satellite and cable TV), emerging markets (e.g. Internet of Things) and the latest commercial off-the-shelf technologies.

In the same way the business models for space are changing, so are the priorities of where to locate. Some of these NewSpace companies are clustering close to high-risk high-reward investors and technology hubs in adjacent sectors offering specialised suppliers and distributors, such as those in Silicon Valley, California and Denver, Colorado. Meanwhile, others seek more of a balance with government support and facilities, such as the Harwell Space Cluster in the UK. There are also space clusters forming around universities with world leading research in space technology, such as TU Delft in the Netherlands, offering companies access to a highly skilled and motivated workforce.

Lessons from economics provide three main commercial forces driving clustering of activities in particular locations – once natural geographic advantages (such as isolated east facing coastlines for launch activities), random clumping and government fiat have been taken into account. These are:

- Sharing: of large facilities
- Matching: of customers with suppliers and of workers with jobs
- Learning: both by individuals learning from their peers close by and companies learning from close associations with each other.

While the origins of space clusters tend to reflect their histories as part of defence or government programmes, NewSpace is developing in ways more closely aligned to the economic model. In particular, downstream space activities are clustered around concentrations of skills and business ecosystems rather than hard space facilities.

The geographic and functional reach of space clusters is undefined, and so individual clusters can be difficult to identify and to separate from one another. In the UK for example, the Upstream Space Science and Innovation Audit identifies UK space activities as a 'national cluster'. However, distinct geographic concentrations certainly exist within this (e.g. at Harwell, or around the Solent and M3 corridor) although they interact, and some areas of the country host very little space activity.

Due to limitations of budget and timescale, and a pragmatic approach to problems of definition, we defined a long list of space clusters that were not based on a rigid definition (see Appendix 1 for the full list). Instead, we drew on third party evidence and the expertise of the project and client team and identified the following international space clusters.

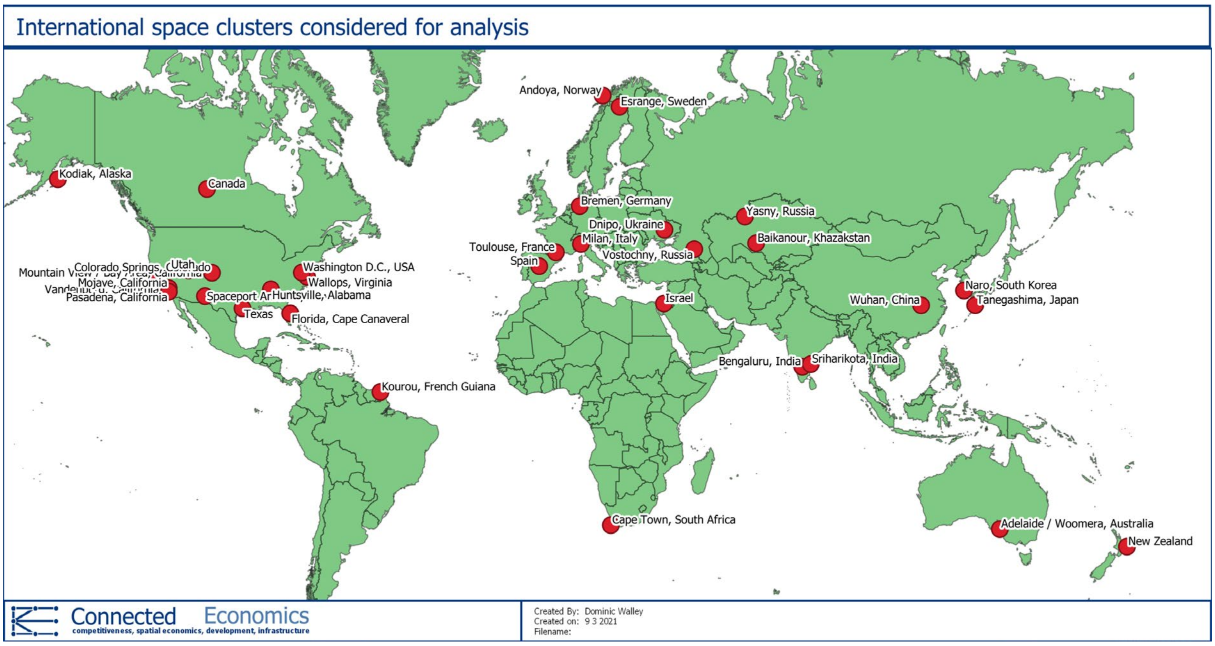

Figure 3: Map of international space clusters

Some general points flow immediately from this:

- It is easier to identify clusters of activity related to upstream space activity due to the obvious location of launch sites and major manufacturers;
- Most of the clusters identified are associated with significant government activity, at least historically; and
- Where we attempted to identify clusters of NewSpace activity, these are also primarily based around upstream space because downstream space activities tend to be less geographically concentrated and therefore less easy to group into clusters.

2. Cluster case studies

In this section we examine eight international space clusters and three UK clusters in detail. The eight clusters shortlisted for detailed analysis were:

- Toulouse, France
- Bremen, Germany
- Esrange, Sweden
- Luxembourg
- Mojave, California, USA
- Colorado, USA
- Adelaide, Australia
- Cape Town, South Africa

These eight clusters and compared to the space clusters in the UK at Harwell, around Leicester and in Scotland based on published sources and interviews with cluster representatives.

The international space clusters were selected from a long list identified by the study team (described in the Appendix 1). Brief assessment of the longlisted clusters was followed by prioritisation for analysis based on the following criteria before approval by the client:

- A spread of different jurisdictions (in order to capture a range of national or subnational policy approaches)
- Relevance and potential transferability to the UK policy environment (i.e. significant commercial space sector activity)
- A range of different main functions including launch, upstream space manufacturing, space-derived services and growing areas of NewSpace.

Due to limitations of scope and resources, this approach does have some weaknesses. The main weakness is that the analysis is limited to 8 clusters. However, it would also have been beneficial to examine a wider policy landscape including, for example, how commercial markets are emerging in areas of the ex-Soviet Union or how smaller states (such as UAE and Singapore) are developing their space economies.

In the following sections, for each of the identified clusters we briefly set out:

- The origins and history of the cluster;
- Its recent economic performance and main features today; and
- The nature and scale of public engagement in it.

2.1 Toulouse, France

Cluster origins

The Toulouse aerospace cluster has origins stretching back to 1917 when the French government installed the aeronautics firm, Latécoère in southwestern France. After World War II, Toulouse consolidated its position as a centre for aviation research and this supported the nucleus of emerging French space research with CNES' Toulouse Space Centre completing in 1968. The cluster became a major European aerospace hub when Airbus established its headquarters here in 1974.

The cluster is now known by the name Aerospace Valley after a programme cluster initiated by the governments of Aquitaine and Midi-Pyrénées regions in 2005. It stretches some 80km from Bordeaux along the Garonne river valley to Toulouse and surrounding areas (roughly the distance from London to Birmingham).

How is the cluster performing today?

The official boundaries of Aerospace Valley are the boundaries of Midi Pyrenees and Aquitaine – approximately 50x50 km in area and incorporating 25 French départements. The cluster self-consciously reflects all of the aerospace sector, so information on space activity alone can be difficult to extract (and indeed to define). The wider functional cluster grew from 550 to 830 members between 2011 and 2017. Over this time, the number of SMEs grew from 271 SMEs to 500. Now there are 869 companies and over 120 000 employees. The cluster's stated aim is to create 40,000 to 45,000 new jobs by 2026.

The member roster of Aerospace Valley is composed of three different domains of activities (in French, "filières"): Aeronautics, Space and Embedded Systems. Firms in the cluster take place in almost all parts of the space value chain (upstream, downstream, manufacturing, services, R&D/testing, military, etc. – although there is no launch site there) and a wide range of facilities are available to support upstream space.

The main space organisations are:

- CNES at the Toulouse's Space Center on a campus to the southeast of the city
- Airbus Defense & Space's Bordeaux facility specialising in launchers and orbital infrastructure;
- Airbus Defense & Space's Toulouse facility specialising in design and development of satellites and spatial systems;

- Airbus-Safran: European leader in solid propellant propulsion in ballistic missiles and spatial launchers; and
- Thales Alenia Space: one of the world's leaders in design and development of satellites and spatial systems.

As of October 2019, Aerospace Valley has obtained funding for 619 R&D projects representing an accumulated value of 1.6 billion Euro.

With such a concentration of activities, the cluster also hosts various support centres, public and regional bodies, economic development organisations, trade associations and related partners.

Public support and effectiveness

Public support in the cluster is widespread:

- **Coordination, marketing and events:** The Aerospace valley brand was established by the public partners working with the trade association. Aerospace Valley hosts and participates in Technoday (a conference focussing on innovative products in aeronautics, space, and embedded systems), the Toulouse Space Show, Technical forum and Blue Talks.
- **Direct public sector activity:** This is widespread through the presence of CNES, ESA and many other public and quasi-public organisations that employ significant numbers of staff in the cluster. Public customers and contracts support much of the cluster activity.
- **Education and pure research:** With the grouping on a single site of 3 major French aerospace schools (Supaero, Ensica, Enac) near the universities and other engineering schools, more than 1,000 researchers from the ONERA, EADS CCR, the CNRS and the CNES. Since its inception in 2005, the cluster has initiated some 220 research projects with a total budget of 460 million euros, including 204 million euros in government funding – a pipeline of around £10m per year in public funding for research projects.
- **Business support:** The ESA Business Incubation Centre (BIC) Sud France opened in 2013 and is managed by Aerospace Valley. The centre is located in three regions (Nouvelle Aquitaine, Occitanie and Provence-Alpes-Côte d'Azur) in the south of France, offering startup support and technical expertise to the creation of innovative companies. ESA BIC Sud France is composed of the following members providing the best support to business creators: Six support structure: ESTIA Entreprendre, Bordeaux Technowest, CEEI Théogone, Midi-Pyrénées Incubator, PACA-Est Incubator and BIC Montpellier.
- **Spatial planning:** Public sector spatial planning has deliberately focussed on attracting and developing clusters of aerospace activity with different functions. These include, for example: clustering aerospace related higher education facilities at the Toulouse

Aerospace Campus which incorporates three major aerospace schools (Supaero, Ensica, Enac) and other engineering schools, are hosts more than 1,000 researchers; and developing aerospace industry parks (e.g. Turbomeca).

Large scale public investment is matched by a range of other public interventions across a wide range of fronts. Together, directed public programmes, development funding and location of public facilities and institutions have resulted in a very large and growing space cluster.

Summary and conclusions

France has the largest government space budget in Europe, and it is perhaps no surprise that the Toulouse space cluster is therefore Europe's largest. However, as no economic accounts are available for the French space sector, so we simply do not know whether France gets economic output per Euro of public expenditure on space than elsewhere.

A major activity in the Toulouse space cluster is servicing government space programmes (e.g. developing and manufacturing the Ariane 6 launch system), so raw public expenditure appears to be the main driver of economic activity. Aside from this, it has also not been possible to isolate the impact of different forms of industry support.

It is not the stated intention of the French government to develop a self-supporting commercial cluster to compete internationally. The economic development push and drive for clustering is driven by local government.

2.2 Bremen, Germany

Cluster origins

Flight history in Bremen began over a hundred years ago with the aviation pioneer Henrich Focke and aviation capability developed there in the form of the Weserflug and Focke-Wulf companies. A partnership with Fleuzeugbau in Hamburg created the Northern Development Circle (ERNO) in 1961 as a joint venture to develop parts for rockets and other space activities. Since then the cluster has grown into a centre for aerospace research and the aerospace industry.

How is the cluster performing today?

Germany's federal system has 12 states of which Bremen is the smallest – comprised of two small and geographically separate parts which encompass Bremen city and the smaller port of Bremerhaven. The cluster is geographically located mainly at Bremen Technology Park in the northern suburbs and at Bremen Airport-Stadt to the south. Both of these have a high density of space and other aerospace companies alongside other technology companies such as Siemens.

The space cluster's economic scale comes from upstream space manufacturing and research and development. According to the local industry body Avia Space, "approximately 40 percent of the aeronautics and space sector are dedicated to Research and Development (R&D)". Within the wider aerospace cluster more than 140 companies and 20 institutes, a workforce of about 12,000 employees, generate more than 4 billion euros per year in a city with a population of around 540,000 – the highest employment density in the aerospace sector in Germany. While it is difficult to identify the space cluster, specific size within this, it makes up a large share with around 80 identifiable businesses and organisations with strong space sector capabilities. Key companies are:

- Airbus Safran Launchers – the Franco German launch alliance which will build the upper stage of Ariane 6 in Bremen;
- Airbus DS – integrating the European parts of the Orion programme in Bremen;
- OHB – the German company focussed on launch and space payloads including human space flight systems. It manufactured the first generation of Galileo satellites.
- Rheinmetall Defence Electronics

Through these and other capabilities, Bremen is also the European centre of competence for human space flight and space robotics.

The Bremen cluster is also a university and research cluster with the university close to and linked to other research institutes such as the DLR, DFKI, Max Planck and Fraunhofer Institutes.

Downstream space activities include, for example, the activities of OHB in the provision of software solutions for IT security, cryptography and the provision of global ship positioning data.

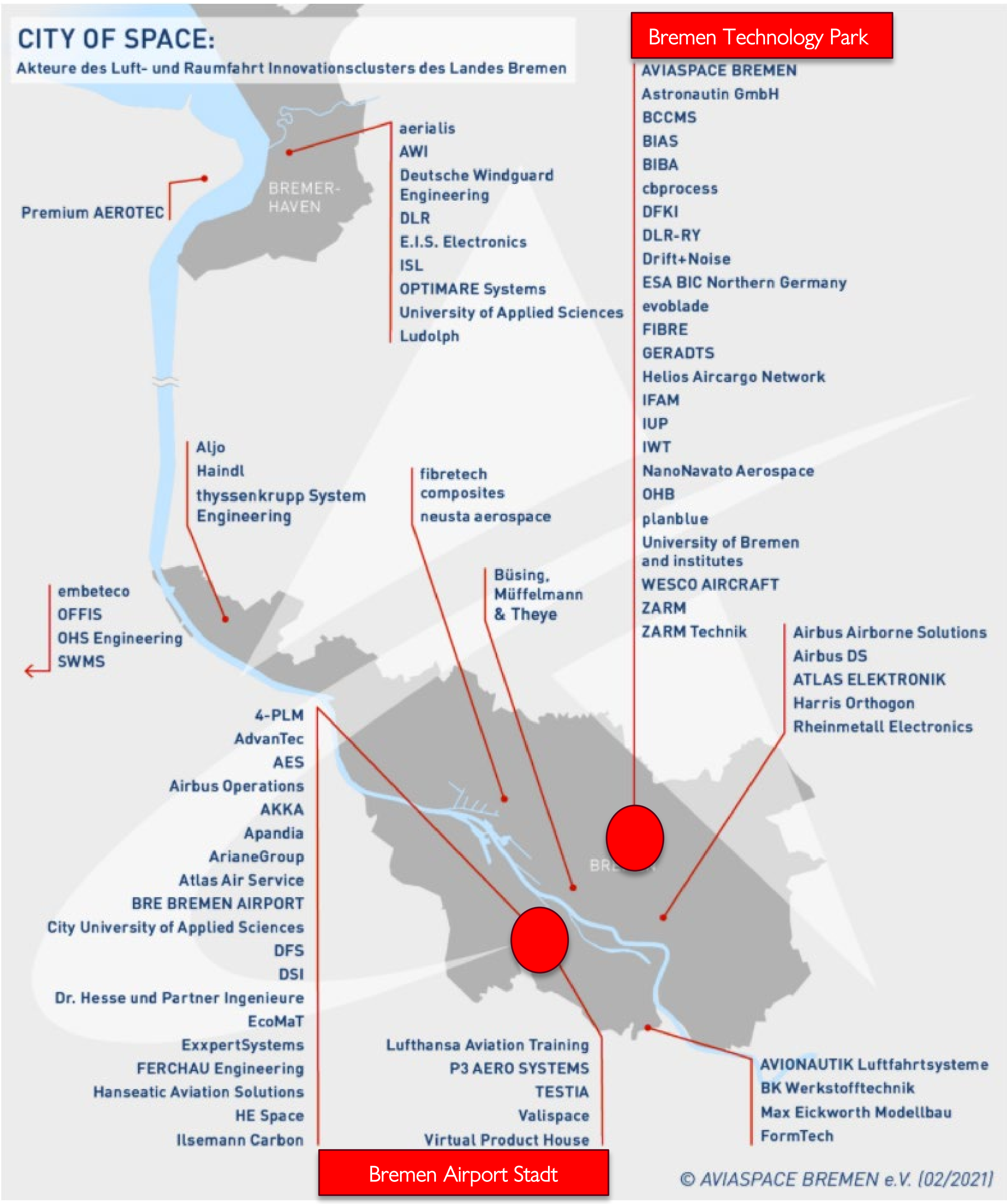

Figure 4: Map of the Bremen space cluster, 2021

Public support and effectiveness

Public support is widespread, driven by the State of Bremen and focussed on the Bremen Innovation Cluster Strategy or which the is part. Avia Space (an industry body) has been set up to implement this strategy and a space manager appointed (Siegfried Monser, previously of Airbus DS).

Public support takes seven main forms:

- **Coordination, marketing and branding:** The State of Bremen is instrumental in developing and coordinating public sector space activities including driving the 'Space City' brand and funding BremenInvest (the inward investment organisation).
- **Events:** The International Astronautical Congress (IAC) was hosted in Bremen, in 2019. This conference is one of the largest international space conferences, attracting around 10,000 delegates. Different countries and locations compete to host the event each year. The Bremen IAC was sponsored and organised by a consortium of German industry and public bodies, namely: Airbus, ArianeGroup, OHB, DLR, BremenInvest, DLR and ZARM. Bremen also hosts the Space Tech Expo each year, a space event that is gaining in popularity, attracting more than 400 exhibitors and more than 4,500 delegates each year.
- **Direct public involvement:** Public agencies such as DLR Institute for Space Systems are located in the cluster and the State of Bremen through BremenInvest has provided funding for the new lightweight materials centre (ECOMAT) which has anchor tenants from industry academia and government;
- **Universities and research collaborations:** The Bremen Aerospace Research Program 2020 (funded through ERDF) has supported various research projects such as '5GSatOpt' which examined 5G satellite swarms and was a partnership of ZARM Technik AG, DSI Aerospace Technologie, OHB System AG, the Institute for Telecommunications and High Frequency Technology, the Center of Applied Space Technology and Microgravity, and the Center for Industrial Mathematics at the University of Bremen.
- **Skills:** Bremen is developing a pipeline of space skills through targeted programmes with schools as well as developing university courses at Bremen University and the three local universities of applied sciences;
- **Startup support:** Startup support is based around the ESA Business Incubation Centre (BIC) Northern Germany which is headquartered within the BITZ, Bremen's largest business and technology centre for high-tech companies and startups. ESA BIC Northern Germany brings new opportunities to the region by strengthening Bremen's aeronautics and space sector. It complements the existing aeronautics and space innovation cluster association AVIASPACE BREMEN e.V. and is supported by "Starthaus", the institution responsible for implementing the financing of new businesses and startups in the Federal

State of Bremen. Since 2015 there are Startup Weekends in Bremen and since 2016 they are organized by bremen-startups.de.

- **Spatial planning:** Bremen set up the Bremen Technology park in 1988 – a 174 hectare site surrounding the University of Bremen. It forms the nucleus for a large part of the space cluster including OHB, ZARM (the Center of Applied Space Technology and Microgravity which includes a 146m drop tower for zero gravity research), Cosmos Space Systems, Avia Space and others. Alongside this, Bremen Airport Stadt has been developed into a space and technology cluster hosting Airbus Defence and Space (developing human spaceflight programmes), DSI Aerospace Technologies, ArianeGroup, HE Space Operations (providing HR and managed services to the space sector), and others.

Summary and conclusions

The Bremen space cluster is founded on a history of aviation research and strongly tied into the aerospace sector. The space sector has grown out of a combination of major research universities and institutes combined with large primes delivering publicly funded programmes and supported by a wider business ecosystem that has grown out of the aviation sector.

In practical terms the main public support remains the substantial spending through ESA and DLR programmes and through research and institutional funding. However, a newer strand of public support is now aimed at developing a more broad-based commercial space cluster. It is doing this mainly through nurturing startups, providing coordination and support, and supporting limited facilities (such as the drop tower).

2.3 The European Space Range (Esrange), Sweden

Cluster origins

Esrange is remote research facility near Kiruna in Northern Sweden centred on sounding rockets. Its origins lie in European politics. Although not exactly a cluster of space businesses, it does provide some interesting lessons in space cluster formation and the impacts of space policy.

It began in 1957 with the establishment of the Kiruna Geophysical Observatory (KGO) which became a base for sounding rockets in 1961. Located 40 km from the town of Kiruna in the very north of Sweden, above the Arctic Circle, Esrange Space Center has access to a vast, unpopulated impact and recovery land area covering 5200 square kilometres. The development of the facility was a major bargaining chip in Sweden's entry to ISRO (the forerunner to ESA) and provided a centre for European collaboration in sounding rocket and microgravity research.

In the beginning the launches took place from Kronogård, which originally was a hunting post for royal foresters and hunters and the launch site was very primitive. Construction of Esrange started in 1964 when ESRO decided to expand sounding rocketry research. The facility has been operational since 1966. In 1972 ESRO pulled out and the Swedish Space Corporation (SSC, then "Rymdbolaget") was founded to take ownership. Esrange Space Centre was born funded by a special project of 8 countries to continue sounding rocket research.

How is the cluster performing today?

Esrange Space Centre remains operated by SSC which is owned by the Swedish Government. The site now acts as a facilitator for a number of international research programmes. Commercial companies on the site are temporary, entering and leaving on a mission basis. However, SSC has since grown well beyond Esrange to become a leading global provider of space services.

The site incorporates test firing facilities for solid motors (horizontally) and liquid engines (vertically) as well as dedicated test facilities for reusable rockets, including tethered stage tests, hover tests and controlled landings. The facility is used by the international community for suborbital and near-space operations with suborbital rockets and high-altitude balloons for scientific, technical and commercial applications, as well as for tests of aerospace vehicles such as UAVs and high-altitude drop bodies. Rocket Factory Auchsberb and Isar Aerospace have begun testing there relatively recently.

SSC's main satellite station with around 30 large communication antennas is also located here. To support this, Esrange is equipped with large and modern facilities for preparation, integration and testing of payloads and all levels of flight systems such as integration halls, clean room facilities, laboratories, workshop, offices and meeting rooms, as well as on premises hotel and restaurant facilities for up to 100 persons. Esrange Space Center caters to all users, e.g. agencies, universities, institutes and commercial customers.

The facility has grown in size, facilities and capabilities over the years (particularly through a modernisation investment programme in 2000), but its central role remains the same and it remains relatively small. There are plans to develop a future orbital launch capability.

Public support and effectiveness

The site does not get general operations funding from the Swedish Government but is funded by the original eight countries. Its funding is tied with Andoya under the Esrange Andoya Special Project agreement (EASP) which is refreshed every 5 years.

The Swedish government is investing around £8million to enable orbital launches from the site. ESA has invested in a station 5km outside of the Esrange boundary which is operated under contract by SSC.

It is used by many student programmes. ESA and DLR (the German space agency) sponsor microgravity and other missions there. A range of government space agencies are regular users of the site (JAXA, NASA, CSA, ESA, CNES, DLR). The ESA BIC in Sweden opened in 2015 with branches at Upsalla and Umea.

The Lulea University of Technology Space Campus is based at Kiruna split between the Onboard Space Systems group and the Atmospheric Science Group. The Swedish Institute of Space Physics is also based in Kiruna and there are strong links with Umea University and with the Ångström Space Technology Centre at Uppsala University.

Together the universities and the ESA BIC has spun out various space companies including, for example, Per Aspera Space Qualification which is based at Kiruna and offers independent space qualification to satellite equipment suppliers and integrators.

The Swedish Space Corporation is another spin off success, now with revenues of around £850m and approaching 600 employees. SSC's ground station has grown because of popularity in polar orbits (telecoms, EO (predominantly), navigation, etc.).

Esrange provides employment in the North of Sweden where there is otherwise very little economic activity. The only other (and most major) industry is extraction of Iron Ore where the largest reserve in Europe is located. The only other employer is the ice hotel.

Summary and conclusions

Not a typical commercial space cluster, Esrange was developed in large part to build diplomatic links. It now serves to facilitate research and support regional economic development. Economic benefits have been modest, but so has investment. A nascent cluster of space startups (around Umea and Lulea universities and the ESA BIC centre in Umea) although small, owes much to the activities on the site.

Esrange points to how collaboration agreements and facilities can drive a small but active space cluster. Benefits are partly local economic development in remote region and partly diplomatic.

2.4 Luxembourg

Cluster origins

Luxembourg's space cluster is young and largely based on publicly backed corporations. In 1985 Luxembourg created SES as a national champion in sat comms and it has grown into a global communications giant. The Luxembourg government retains a large shareholding.

In 2005, Luxembourg joined the European Space Agency (ESA) as a full member, laying the foundation for participation by its companies in ESA R&D programmes and space exploration projects. At the same time it founded the non-profit GLAE (Groupement Luxembourgeois de l'Aéronautique et de l'Espace) as a trade organisation to drive space sector growth and development. Luxembourg's second largest space company, LuxSpace, began just after this big push for space sector growth (in 2006) as a joint venture of SES and Germany's OHB and is now a subsidiary of OHB.

How is the cluster performing today?

The Luxembourg cluster is countrywide, although the whole country is approximately the size of Greater London. It is home to approximately 50 companies and research labs in the space sector, employing more than 800 people. The space sector's share of GDP is now among the highest in Europe.

Today, Luxembourg space community remains dominated by large space corporations (mainly SES and LuxSpace) which have been born from public origins but operate commercially. SES delivers TV and radio broadcasts, communications and data traffic around the globe, and LuxSpace develops high-tech components for satellites, advanced materials and equipment for space travel, with significant roles delivering ESA projects and missions.

The cluster is growing relatively quickly. In 2017 it was 32 companies and research labs employing about 700 people. Growth in companies has been much faster than growth in employees, reflecting smaller new companies being formed or moving to the jurisdiction.

Public support and effectiveness

Part of the cluster's success is because the government has been proactive in seeking new opportunities in the space sector. In 2016 Luxembourg launched the SpaceResources.lu initiative to make the country the best place in the world to develop space mining businesses. Luxembourg was the world's first country to adopt space legislation at the end of 2017 to give researchers and investors legal certainty about the ownership of materials from outer space.

It is hoped that this 'big bet' will generate attractive opportunities in Luxembourg and worldwide for established and startup players in fields including materials science, additive manufacturing, remote sensing, communications, robotics, data analytics and artificial intelligence. Note that the big bet has not actually involved a lot of cost as it has mainly been through policy and legal mechanisms rather than financial support.

The Luxembourg Space Cluster is managed by Luxinnovation which was originally formed as an economic department of the Ministry of the Economy and Small and Medium-sized Businesses. Luxinnovation has grown into a partnership of various government departments and the Chamber of Commerce into and innovation support and inward investment group. It is part funded by ERDF funding.

Luxembourg offers incentives for private sector companies seeking to develop space mining opportunities and startups investing capital to support their growth. Luxembourg's financial regulatory systems fully support venture capital and private equity investment within a wider European framework.

The Luxembourg Space Agency was set up in 2015 and notes that "Contrary to many other space agencies, the LSA will not directly conduct research or launch its own space mission, but focus on business development and the creation of economic value and jobs." Today Luxembourg is one of the top five per capita contributors to ESA. ESA membership and contributions have been used to drive commercial success in LuxSpace and others, create a narrative of space sector activity and provide the foundations and critical mass to attract private sector companies and startups.

Luxembourg's presence has been growing rapidly at international space conferences.

However, beware that the narrative regarding business environment is a perception which is not supported by some of the key measures of competitiveness. Luxembourg corporate tax rates are well above the EU and European and global average and it ranks 68th in the World Bank's ease of doing business index (compared to the UK in eight position) – although it ranks first for the ease of doing business across borders.

Summary and conclusions

Luxembourg has prospered through strategic corporate interventions and a canny approach to positioning itself and crafting a narrative of being a business friendly environment for space companies to move, start and grow.

Its role as a liberalised institutional centre for finance and telecoms is now being carried forwards into the space age. The supportive regulatory regime and international outlook has mainly attracted global space startups rather than developing home grown ones. Marco Fuchs, CEO of OHB says of Luxembourg "We have constantly expanded our activities there, because the underlying local conditions have always been advantageous." It could be considered an institutional rather than industrial cluster and points to some ways that the UK may shape its role in the global commercial space marketplace, building on its previous success as a centre for the global maritime and financial markets.

2.5 Mojave, California, USA

Cluster origins

The relatively small Mojave space cluster is based at Mojave Air and Space Port. It grew out of an airport established in 1935 to serve the gold and silver mining industry which was expanded as Marine Corps Auxiliary Air Station in World War II and then transferred to the county authorities when it was decommissioned in 1961. Since then it has been a general purpose airport developing capabilities in flight testing in the early 1970's alongside aircraft heavy maintenance and storage. Space industry development began in the mid-1990s with the development of the Rotary Rocket and picked up again in earnest in 2004 when it was certified as a spaceport by the Federal Aviation Administration – the first facility to be licensed in the United States for horizontal launches of reusable spacecraft. This was driven by the culmination of the Ansari XPRIZE for reusable private spacecraft, which was won in October 2004 by Mojave Aerospace Ventures led by Burt Rutan. The site was licensed in July 2004 and the XPRIZE was awarded in October 2004. Site characteristics are ideal for space launch vehicle and aircraft testing with around 300 days of sunshine per year, and its remoteness is conducive to rocket engine testing.

How is the cluster performing today?

Today the cluster remains based on the old airport site. Space activities remain focussed on testing and development of rockets and spaceplanes. The number of space companies based there has ebbed and flowed over the years. In the mid-1990s there were two space companies on site (Rotary Rocket Company and Scaled Composites which was an aerospace design and development company that was also building the fuselages for the Rotary Rocket). Since then, some have closed (Rotary Rockets, XCOR, Orbital Sciences Corporation) and others have joined the cluster (e.g. Masten Space Systems, Stratolaunch). The cluster now houses six pure space companies (Scaled Composites, Stratolaunch Systems, Masten Space Systems, The Spaceship Company, Firestar Technologies and Interorbital Systems) and represents other aerospace companies such as Northrop Grumman and BAE Systems.

Cluster performance depends on the fortunes of its small number of companies and their development programmes. Virgin Galactic will be moving operations from Mojave to Spaceport America after its test campaign is complete and commercial operation commence, although The Spaceship Company (a venture that was set up to develop Spaceship II and White Knight) will continue to manufacture vehicles there. In 2020 Masten Space Systems won a $67m contract from NASA to develop a lunar lander enabling its operations to scale up substantially over the next few years.

The wider air and spaceport facility provides employment for around 2,000 permanent employees. While the fortunes of the space sector at Mojave have been variable, the wider aerospace cluster has prospered, growing from 14 companies in 2002 to over 70 today.

Public support and effectiveness

Mojave is a good example of laissez faire economic development approaches to space. Although the airport site is owned by Kern County, there is no development plan for the space cluster and little public coordination of economic development activities in the space sector. The spaceport does offers cut-rate rents to startup companies and has recently refurbished the small on-site events and conference centre. There is no NASA presence, although NASA officials scout Mojave for technology and commercial space partners.

What Mojave does have is a sympathetic approach to the issues of experimental testing and licencing. This is aided by large open area of the Mojave desert that it backs onto (124,000 km2). The arid conditions also favour storage, hence the aircraft graveyard "the boneyard". Kern County was an early mover in the NewSpace environment licensing the spaceport in 2004. Test facilities are located around 30 miles northeast at the Mojave Test Area which is equipped with several static test stands, launch towers, two steel reinforced concrete block houses, observation bunkers, and a rocket assembly building. This site is privately owned and operated by The Reaction Research Society.

Companies in the cluster are well networked together through their design and testing activities. Scaled Composites, for example, have designed and built Stratolaunch and designed the Tier One spacecraft that won the Ansari XPRIZE and was then licensed to Virgin Galactic – as well as building its own experimental aircraft and the fuselages for the original Rotary Rocket. Firestar Technologies offers flexible drop in workspace as well as consultancy and design support to companies in the cluster. The public sector plays little or no role in this.

Government sponsored prize funds and R&D contracts have played a major role in the fortunes of firms within the cluster (e.g. Masten Space Systems participated in NASA's lunar lander prize and subsequently won a contract to develop and deliver a lunar lander). Private/philanthropic development goals have arguably been just as valuable – the XPRIZE led to the development of Interorbital Systems' technologies and to the formation of Virgin Galactic. Prize based approaches and one-off major development contracts have led to periods of feast and famine in the space cluster with little follow through. After companies complete their development phase they move on, leaving companies in the cluster to compete for future development challenges, or invent their own.

XCOR died because it was wating on a big contract with Aerojet Rocketdyne. Stratolaunch appears to be in its death throes after losing direction after the death of its founder Paul Allen (also co-founder of Microsoft).

Conclusions

Mojave has experienced success at times but has never achieved sufficient critical mass to continue a path of growth, and the departure of individual large businesses has set it back more than once. However, it offers some hard-to-find facilities and it does not require a high amount of support. As such, it is likely to continue as a second tier of cluster, resilient enough to survive with few resources in the desert heat.

2.6 Colorado, USA

Cluster origins

Colorado's place in the global space sector stems from its historic role at the centre of America's military industrial complex, and the sheer scale that this brought about in engineering and aerospace companies and skills. Critical mass now makes it the natural home for many US and global companies in aerospace and defence.

During World War II, Colorado's Lowry and Peterson Army air bases developed competencies in photographic intelligence which were later transferred to space applications to monitor and manage surveillance and communication satellites. The Glenn L. Martin Company (now Lockheed Martin Space Systems) established a plant in Waterton Canyon in 1955 to build the Titan intercontinental ballistic missile. The site was considered a highly strategic central-U.S. location. In 1957, the North American Air Defense Command (NORAD) was established and activated at the Ent Air Force Base in Colorado Springs. In the late 1950s, a plan was developed to construct a command and control centre in a hardened facility (Cheyenne Mountain) as a cold war defence. This wider aerospace and defence cluster developed continually and by the end of the century a core part of it was the second largest space cluster in the USA.

The Colorado economy has historically been one of boom and bust tied to specific industries (e.g. silver or oil) and, following the recession in the early 2000s, the Colorado business community took a more proactive approach to developing a broad based and resilient economy, setting up the MetroDenver Economic Development Corporation in 2003 to help plan for development of key high-tech sectors, including aerospace. The Colorado Space Coalition was set up at the same time to spearhead this in the space sector.

How is the cluster performing today?

The Colorado aerospace cluster is comprehensive and incorporates upstream and downstream space including R&D, testing, military, manufacturing, services and applications – all of the value chain. Nine of the top ten aerospace contractors in the USA have major operations there: Ball Aerospace & Technologies; Boeing; Harris; Lockheed Martin; Northrop Grumman; Maxar Technologies; Raytheon; SNC; and ULA. The cluster boasts over 500 space related companies and suppliers. Other major notable companies include Sierra Nevada Corp., Digital Globe, ViaSat, Raytheon, Up Aerospace (sounding rockets), Reaction Engines (the US office that support testing), L3, Blue Canyon (CubeSat builders), Braxton (positioning) and many other.

Space activity in Colorado is geographically spread. The state is around 600km from east to west and 400km north to south, but most is sparsely populated. Interstate 25 runs north to south and is the main spine connecting centres of activity in Colorado Springs in the south with the Denver metro area and up to Boulder and Fort Collins in the north. North to south is a drive of around 2½ hours. In the US, distance does little to discourage travel and space activities extend from Colorado Springs to Boulder in a coherent cluster. There are, however, clusters within clusters such as Littleton (near Lockheed), by Colorado Springs (near the Airforce Academy and other Air Force bases and facilities) and at Boulder.

Today the cluster is growing relatively quickly. It is one of the few clusters for which quantitative analysis is available through the tracking work of the MetroDenver EDC whose geographical reach covers around 80% of Colorado's space sector companies. They track the size of the space cluster using public data for aerospace related standard industrial classifications and, by this measure, employment in the cluster has grown by 4.5% per annum over the last five years (strongly from 2016 to 2019, but static from 2014 to 2016).

For nearly 70 years, the combination of Air Force presence, open space, high altitude, space-related science, and community boosterism made Colorado "A Mile Closer to Space." It is the second-largest space economy in the USA, directly employs around 30,000 workers directly in private aerospace industries and supports around 200,000 Colorado space-related jobs across the value chain (including downstream space).

Public support and effectiveness

Economic development in the Colorado cluster is managed by industry through the Metro Denver Economic Development Corporation and other trade associations such as the Colorado Space Coalition. The state does not support these organisations financially, but instead provides collaborative public support through championing a supportive business environment, for example by:

- Appointing an aerospace and Defence Industry Champion in 2013 partly with a remit to support state legislative activity in support of the aerospace sector;
- The formation of a bipartisan Aerospace and Defense Caucus in the legislature in 2015;
- The state Lt Governor serving as vice chair of the CFC; and
- State support and promotion of industry events such as Aerospace Day which is now held annually at the state Capitol.

Colorado state government does not spend much on financial incentives to locate in the state, although it does provide some tax credits linked to new employment generation. Counties can also sometime provide corporate incentives (e.g. through reduced property taxes) but, like state incentives, these are not specific to the space sector. The state does provide small amounts of research funding through the Advanced Industry Accelerator Grant programme for technology startups at from state universities. This has been very successful in leveraging wider investment – and also had the spin off benefit of generating regular information and insight into the technology landscape which is useful for the economic development community.

Colorado is the largest state without a major NASA facility, although the state's space sector is very successful at winning NASA commercial contracts. However, there continues to be a large military presence with a strong focus on space (e.g. Norad) and other large military customers such as Buckley Air Force Base. Various USAF activities have now been transferred to the Space Force such as Schriever Air Force Base outside Colorado Springs which is the master control station for the US GPS system[7], the largest of the PNT constellations. In addition, significant National Science Foundation and NOAA contracts go to Colorado businesses and the state hosts and NOAA research lab.

Wider economic issues related to public policy do exist but are less relevant to the sector's fortunes. For example, housing in Denver has become increasingly expensive and traffic has increased. Housing development is more permissive than in the UK, but development is somewhat constrained by increasing regulation of housing quality and some counties have introduced housing ordinances limiting new housing growth. However, these have not significantly impeded the industry's ability to attract talent. Likewise, skills are critical to the sectors growth, but only part of these are indigenous and Colorado draws from a national and international talent pool. The cost of living remains lower that coastal competitors such as California.

Conclusions

Colorado's primary driver of space sector growth is its scale. This provides businesses with access to a huge pool of talent and is attractive to prospective employees and thicker labour markets limit the risks of losing your job. Likewise, thick markets, links through the value chain and proximity to customers all provide advantages. This market access is attractive to downstream businesses which also cluster along the 'Front Range corridor' to the east of the Rockies.

Part of the cluster's success appears to be due to the collaboration between businesses as seen in the overlapping trade associations in the space and other sectors. These provide a forum for

[7] https://www.gps.gov/multimedia/images/GPS-control-segment-map.pdf

the sector to speak with a common voice to the legislature and federal authorities, to build an international brand and to network. The recent approach of more focussed market and clusters-based approach to economic development comes from the business community. It was partly in response to the early 2000s recession and partly a reflection of a changing technology landscape where different sectors (such as computing, space and advanced manufacturing) are interdependent and mutually reinforcing. This sector led economic development activity manifests in a wide range of events and conferences which give the sector a 'buzz' (e.g. the National Space Symposium in Colorado Springs which is one of the largest space conferences in the world).

2.7 Adelaide, Australia

Cluster origins

In 1947 the Woomera Rocket Range was established in South Australia on the Arcoona plateau as part of an agreement between the British and Australian governments under the Anglo-Australian joint project. This relationship reached a crescendo of activity in 1971 with the launch of Prospero on the Black Arrow launch vehicle (the first and only time a UK satellite was launched on a UK vehicle). The Woomera site also operated a tracking station from 1957 to 1972, to support NASA's Mercury human spaceflight program, as well as deep space missions. From its inception, Woomera has remained a military site, operated by the Royal Australian Air Force (RAAF). It has supported hundreds of civil and defence sub-orbital research rocket launches, as well as the testing of long-range weapons. Woomera was also used as a landing site for spacecraft, starting a relationship with the Japanese Aerospace Exploration Agency (JAXA) in 2003 that continues to present day with the return of Japans Hayabusa2 asteroid sample-return spacecraft.

Local skills and supply chains in Adelaide itself are strong and dispersed across sectors such as Advanced Manufacturing and Aerospace, to feed the defence and civil activities in Woomera, as well as RAAF Base Edinburgh. This clustering of defence customers and activities has attracted prime contractors, such as BAE Systems Australia (head office) and Airbus Group, located next to the air force base, as well as Lockheed Martin, based close-by in Technology Park Adelaide (alongside telecom supplier SpeedCast). The city also hosts the University of Adelaide and the University of South Australia, both run space science and engineering courses and have built and operated satellites (such as for the global QB50 initiative). The latter is also partnered with the International Space University and spun out Myriota in 2015 from its telecommunications research. Myriota raised A$50 million by 2020 to develop and launch a constellation of IoT Cube Satellites (CubeSats). A few other NewSpace start-ups, like Fleet Space Systems, another space IoT company, and Inovor Technologies, a satellite platform manufacturer, were also drawn to the area because of the rich supply chain and defence markets that they both have services specifically pointed towards.

How is the cluster performing today?

2017 was an active year for the Australian space Industry and Adelaide. The foundation of the Australian Space Agency (ASA) was announced at the International Astronautical Congress that was hosted in Adelaide in 2017. The South Australian Government also created the South Australian Space Industry Centre (SASIC) the same year. The latter is a pan-departmental organisation to connect local industry and international companies and organisations with Defence SA, Department for Trade and Investment, and Department for Innovation and Skills. Such a department could prove powerful considering the concentration of government stakeholders in Adelaide, such as the Department of Environment, Water and Natural Resources, Bureau of Meteorology, Department of Education and Child Development and the Department of Defence. SASIC is also aimed at coordinating and implementing industry and workforce development through initiatives, events, scholarships and an incubator program.

The ASA received A$41 million over four years from 2018-19 in the federal budget to "grow the Australian space industry," including A$26 million to help launch the agency which will "coordinate domestic space activities for Australia". According to Australia's Prime Minister, Scott Morrison, founding the ASA is to "act as a launching pad to triple Australia's space economy to A$12 billion and create up to 20,000 jobs by 2030". The ASA is housed in the Central Business District of Adelaide at 'Lot Fourteen', a former hospital site that has been transformed into a seven-hectare entrepreneur and defence hub, which falls within the Australian government's City Deal scheme to drive long-term investment in the city. The site is also located near Boeing Defence Australia, University of Adelaide and University of South Australia campuses, and the South Australian Space Industry Centre, which is located approximately 1km SE.

Lot Fourteen is also host to the Defence Landing Pad and the Aurora Space Start-up Cluster. The former is run by Defence SA, a "single point of contact for all defence stakeholders, streamlining their interaction across the South Australian Government." Defence SA chief executive Richard Price said "Landing Pad would provide companies assistance with local regulations, migration, business establishment and real estate, as well as information on workforce availability and skilling opportunities." Meanwhile, Aurora is a new company set up and fully owned by SmarSat Corporate Research Centre, which is a consortium of universities and other research organisations, partnered with industry that has been funded by the Australian Government to develop working knowledge and technologies in advanced telecommunications and IoT, satellite systems and EO data services. Aurora is already supporting over sixty-five member companies representing every part of the space supply chain – from rocket launch services, through to satellite technology, operations and data applications.

Figure 5: Lot Fourteen – 23,000m2 of space situated in the Central Business District of Adelaide, aimed at incubating several high-tech start-ups. The Defence Landing Pad being situated in the Margaret Graham Building and the Mission Control Centre and Australian Space Discovery Centre in the McEwin Building

Australia's Space Infrastructure Fund has also released a Mission Control Centre (MCC) grant opportunity that will award a single grant of $6 million over 3 years, to establish a mission control centre on the ground floor of the McEwin Building at Lot Fourteen. The mission control centre will provide facilities for space businesses and researchers to control satellite and space missions. The MCC will also connect to the Australian Space Discovery Centre, which will showcase interactive space exhibits and a careers hub to the public, promoting STEM and outreach.

As of March 2020 there were nearly 80 space businesses and organisations in South Australia. These includes at least 20 businesses which started in the last five years, among them Myriota, Inovor Technologies and Neumann Space – all based at Lot Fourteen. This sits within a community of 50 start-ups and 39 established businesses on the Lot Fourteen site, totalling 995 people.

At this stage Lot 14 appears to be mostly office and networking space (650 workspaces), as well as conference facilities. There is, however, a plan under the Modern Manufacturing Initiative of the Australian Federal Government to support the construction of manufacturing and test facilities for space hardware in Lot Fourteen. This is an open tender and the deadline for the first phase of applications will be on 22nd March 2021. Funding for the facilities will be split into thirds from State and Federal budgets, as well as some of the companies in Lot Fourteen.

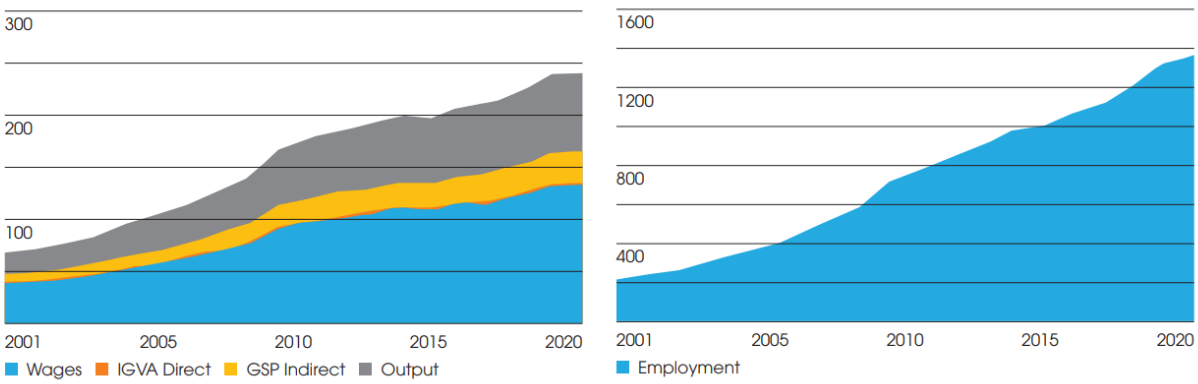

Figure 6: South Australian Space Economy in A$(left), Number of South Australian Space Employees (right)

Australia's NewSpace industry is relatively young, with the Australian Space Agency founded only in 2018. The South Australian space ecosystem has grown in recent years, with international collaborations, such as NASA and JAXA, as well as the presence of defence sectors and numerous successful start-ups such as Myriota, Lux Aerobot, and ResearchSat. The graphs above demonstrate the space sector in South Australia has been consistently growing, with Adelaide at the centre. The gradients of the graphs above should start increasing if government efforts in areas like Lot Fourteen are successful.

Public support and effectiveness

- Government Organisations at Lot Fourteen: the roles of the organisations listed below are described in the previous section. Together they represent the Australian government's efforts towards setting up a space incubation hub that networks across the entire space supply chain, as well as encouraging discussion and innovation with adjacent sectors and academia. They are also connecting industry to civil and defence customers, as well as primes, to develop products and services that meet their needs, as well as having wide commercial applications. The hub also supports STEM and outreach.
    - Australian Space Agency
    - SmartSat CRC and the Aurora Space Startup Cluster
    - Mission Control Centre and Australian Space Discovery Centre
    - South Australian Space Industry Centre
    - Defence Landing Pad
    - Australian Institute of Machine learning
- Academia: The campuses of the University of Adelaide and the University of South Australia overlap in the city centre – within walking distance of Lot Fourteen. Both universities have internationally recognised and respected space science and engineering courses that have spun out satellite projects and notable space start-ups.
- Funding: Australian Government is contributing almost $700 million into the space sector. This money has been dispersed across a range of activities; include grants and other funding initiative made available through government organisations at Lot Fourteen.
- Events: Adelaide hosted the International Astronautical Congress in 2017 and used the international conference as a platform to announce the formation of the Australian Space Agency. The IAC was supported by the Space Industry Association of Australia, an industry trade group similar to the UK Space Trade Association. There are also a number of events hosted at Lot Fourteen, including the Australian Space Forum every 6 months.

Summary and conclusions

Since the foundation of the Australian Space Agency, the government has been very proactive in supporting their space industry, especially in the State of South Australia, building mainly on existing skills and infrastructure in Adelaide and Woomera. Although funding is humble compared to other space agencies, support has been directed to cultivating the start-up community through several government organisations working together to engage with local universities and defence partners – encouraging the space community to solve Australia's big challenges, such as wildfires and water resources. These efforts are seeing particularly positive growth of IoT NewSpace companies, who require minimal financial support to quickly develop and roll out low-cost solutions. IoT is also well placed to service the Australian market because the technology is capable of supplying low-cost services to large areas of land. Mature supply chains and strong support from local academia and rich telecoms skills (possibly because of the regions history in ground stations) has also aided the emergence of space IoT start-ups in Adelaide, although the business case for them is yet to be proven.

Public funding streams are distributed across different agencies and can be perceived as working towards different objectives with coordination of these happening unofficially. Likewise, civil and defence budgets are distinct. Coordination of these government activities is improving.

There are several parallels between Australian and UK aspirations for space, albeit with a difference in maturity. There appears to be a strong focus on the Lot Fourteen space hub in the Central Business District of Adelaide. If the Modern Manufacturing Initiative successfully brings government subsidised manufacturing and test facilities to Lot Fourteen, it could have a similar positive presence as Harwell in the South East of England. However, after only three years it is too early to tell how effective the concentrated efforts of the Australian government will be for the space industry in and around Adelaide.

2.8 Cape Town, South Africa

Cluster origins

Having been involved in the space sector since the early 1960's, South Africa has a rich legacy of participation in space activities. It partnered with Israel to convert the Jericho missile into an orbital launch vehicle (its successor, Shavit-2, is still launched by Israel to this day) and has, as of 2020, launched 6 locally built satellites. The Western Cape had Overberg missile test range (involved in developing Jericho) and the Houwteq facilities for developing, testing and integrating satellites (established by 1990).

The end of Apartheid in 1994 was a reset for the industry. The country's Overberg rocket facilities were destroyed, while the satellite facilities were abandoned and now lie derelict. The skills, however, remained and mostly gravitated to Stellenbosch University, on the outskirts of Cape Town. The University successfully built and launched Sunsat-1 in 1999. A group then left the university and formed Sun Space, to develop small and medium satellites. In collaboration with Stellenbosch, the company built and launched SumbandilaSat in 2009 before dissolving shortly after. Former Sun Space employees formed separate startups, while Stellenbosch University's space courses received a boost from the success of Sunsat-1 and SumbandilaSat. This resulted in a further enrichment and dispersal of skills in the local area and the beginnings of the commercial space industry in Cape Town.

How is the cluster performing today?

There are 15 NewSpace companies in or close to Cape Town, they are mostly clustered around or close to three universities: Stellenbosch University, Cape Town University, and the Cape Peninsula University of Technology, all offering specialized space engineering & policy related courses. Most of these companies operate in the upstream space market, which is a result of the skills originating from pre-1994 government programs and an academic focus on engineering and satellite hardware from the surrounding universities.

Five NewSpace companies are clustered around Stellenbosch University campus and the affiliated Techno Park, most notably CubeSpace and Dragonfly Aerospace. The former is a Cube Satellite component and subsystem manufacturer, while the latter was founded in 2019 and has already grown to 30 people, having emerged from SCS Aerospace Group to build optical payloads for Small Satellites, with an aspiration to build full small satellites in the future. The Park hosts around 30 technology, engineering and software companies, as well as companies that could provide ancillary support services such as legal and finance.

There is also a cluster of space, aerospace and advanced technology companies based on an Industrial estate in the Town of Somerset West, Cape Town. Two notable satellite component and systems manufacturers on the estate are Simera Group and New Space Systems, numbering 60 and 30 employees respectively. The estate is located just 20km South of Stellenbosch University and the Techno Park – it is a favourable location for these space companies because of the cheaper real estate, while still being a commutable distance from the University.

Government investment in the industry is limited, which partly explains the long gaps between government sponsored missions like Sunsat-1 and SumbandilaSat 10 years later. The imbalance towards upstream, along with minimal government orders has meant that the space companies in Cape Town have been forced to rely on exports. The South African National Space Agency (SANSA) is trying to address this imbalance and refocus the industry on downstream. SANSA has a considerable repository of EO data (SAR and optical) and one of its biggest data streams is data analytics to government, which it is now trying to spin-out. However, the Agency's influence in the Western Cape is limited because its main presence is in country's capital of Pretoria, where this spin-out activity is underway.

Companies like NewSpace Systems (founded by a UK national) were attracted to Cape Town because of the balance of highly technical skills with comparatively low wage rates. Another attraction is the quality and maturity of the supply chain – a pre-1994 legacy that includes industries in adjacent sectors, such as precision engineering, testing and analysis. There is also a lot of radar capability out of Simon's Town Naval Base (SA's main naval based just outside of Cape Town), as well as potential defence markets.

Public support and effectiveness

Public support to South Africa's space industry is minimal. The country's economic challenges mean that budget priorities lie elsewhere. The government announced funding of R4.47 billion (approximately $300 million) in 2020 for SANSA to develop a Space Infrastructure Hub, but the location and details of this hub are still unclear. Public support takes three main forms:

- **Universities and research collaborations:** Stellenbosch University has been instrumental in maintaining and growing the skills base in South Africa, with companies like Simera Group building the majority of its team from the University's graduates. Space expertise in the region has further improved as Cape Town University, and the Cape Peninsula University of Technology, have also started space engineering courses and feeding graduates into the workforce.
- **SANSA:** The agency's remit is currently focused on science rather than cluster growth. It's only presence in the Western Cape is its Space Science Facility in Hermanus,

approximately 70km south of Cape Town. Although the facility doesn't closely interact with the local industry, it promotes awareness and interest in STEM subjects through the SANSA Space Lab, an 'interactive mobile laboratory'. The activities are specifically aimed at educators and learners with an emphasis on practical learning programmes.

- Events: The International Astronautical Congress (IAC) was hosted in Cape Town, in 2011, supported by SANSA and the Department for Trade and Industry (DTI). The country has also had a consistently strong presence at other IACs around the world, with DTI often funding a national stand that hosts and promotes private industry.

Summary and Conclusions

Several of the clusters on this list can trace their origins as far back as WWII, or beyond. By comparison, South Africa's Industry is still fledging since the country's reset in 1994, when most government activities in space abruptly ended. A foundation of heritage and high-quality graduate skills are now growing a new industry, but it will be a few years until new government interventions filter through to distinguishable outcomes.

The principals of NewSpace around affordability and flexibility has governed the technology development of the sector and most of the companies are focused on delivering products to CubeSat and Small Satellite platforms. Despite minimal government investment, the cluster of NewSpace companies in Cape Town is successful and growing. This growth is also competitive, because it is reliant on international trade and exports rather than an internal market.

Without government missions or funding, growth of the sector is slow and is struggling to reach a 'critical mass' where it can become more sustainable – with examples of larger space companies in Cape Town, like Sun Space and (possibly) SSC failing after they reach a certain size. Government plans for the new Space Infrastructure Hub could alleviate this problem, if based in Cape Town. Another potential route for support could be to encourage the uptake of space services from the local naval base.

2.9 Harwell, Oxfordshire, UK

Cluster origins

The Harwell science cluster grew from a WW2 airbase (RAF Harwell) which was transferred after the war to the Ministry of Supply which set up the Atomic Energy Research establishment there in 1946. Over the years, public science facilities clustered there including the Rutherford Appleton Laboratory in 1957 which was established to study high energy physics. The cluster remains centred on the old RAF Harwell site which is now owned by the UK Atomic Energy Authority (UKAEA) and the Science and Technology Funding Council (STFC) and operated as a joint venture through the Harwell management company.

How is the cluster performing today?

Today, the Harwell space cluster is part of the 700 acre science and technology campus which is the epicentre for the UK's large scale public scientific activities. The space cluster within this now employs around 1,100 people in around 100 organisations[8] and has an ambition to grow to 5,000 jobs by 2030.

The cluster is growing rapidly and has seen compound annual growth in employment of around 15% over the last three years[9]. The number of companies and organisations has also seen a meteoric rise, moving from 'a couple of organisations' ten years ago to over 100 today[10]. There have been several announcements over recent years of high-profile space organisations developing a presence at Harwell (e.g. Lockheed Martin recently set up a space technology office on site). However, while larger commercial organisations are represented, this is often through small research offices and not major facilities (e.g. Airbus Defence and Space, Lockheed Martin).

The cluster is focussed on research and development activities and does not, for example, host any large-scale space manufacturing or military presences. The space R&D focus is part of a wider R&D ecosystem centred around major science facilities including the Central Laser Facility, the ISIS neutron and muon source, the Diamond Light Source, and the Scientific Computing Department at RAL Space.

One of the key strengths of the cluster is the range of space related testing facilities that are available on site (e.g. clean rooms, vacuum chambers, vibration testing). This further cements the key activities of R&D, rapid testing and prototyping.

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[8] https://www.harwellcampus.com/space-cluster/
[9] https://www.harwellcampus.com/wp-content/uploads/HAR5024-Space_Cluster_Brochure-v18.pdf
[10] https://www.harwellcampus.com/news/harwell-space-cluster-10-year-strategy/

In addition to the upstream space activities, there are three main activities:

- Downstream space technology development and company spinouts, for example in earth observation (AgSpace, Rezatec), communications and connected sensors/Internet of Things (e.g. Lacuna Space).
- A wider ecosystem of business support services both on site and nearby such as business advice, access to finance, and business incubation services;
- Many research partnerships with universities

Public support and effectiveness

There is widespread public intervention in developing the space cluster at Harwell including:

- RALSpace with around 300 employees at Harwell and a wide range of engineering and test facilities including the new National Satellite Test Facility;
- ESA with the European Centre for Space Applications and Telecommunications (ECSAT), the headquarters for ESA's applications and telecommunications programmes, in addition to a successful ESA Business Incubation Centre;
- The Satellite Applications Catapult – an innovation company partly supported by government grants and contracts;
- Space testing facilities on site which are publicly funded and are available for private sector rental and usage; and
- Public sector hosted events (e.g. conferences and smaller scale industry meet ups such as 'Satuccino') and coordinates industry and government activities. These communicate the latest funding programmes from UK and European sources (which are not Harwell specific) and encourage collaboration building.

Summary and Conclusions

Public support has been effective in attracting companies to the cluster and its recent growth has been remarkable. The larger space companies have set up touchdown offices there to benefit from the range of events, activities and networking opportunities (e.g. Airbus DS and Thales Alenia). Incubation and business support services have supported several new companies to develop and grow there.

2.10 Leicester

Cluster origins

The Leicester space cluster has been developed almost entirely by the University of Leicester.

The university was founded in 1957 and space science began there in 1960 when national government instituted a space programme and set up research groups around the UK. Leicester's group concentrated on solar and x-ray astronomy and rocketry. In the 1980's the university's research capabilities moved into different wavelength observations and into satellites, but another big change came in the late 1980's – again based on a central government strategic decision. This time the government decided to rapidly grow earth observation capabilities and Leicester hosted one of several research groups that was set up to do this.

In response to declining numbers of students in STEM courses in the 1990s, the university began a massive outreach programme using space as one of the hooks to drive interest in these subjects and courses. This included the creation of a very successful course in 'physics with space science and technology' at the University which was followed by many further undergraduate and then masters courses. When the Millennium Commission put out calls for ideas for new national museums at the end of the century, Leicester jumped on the opportunity and proposed hosting the National Space Centre as both a museum and a centrepiece for continued science outreach. This opened in 2001.

Throughout this time the University itself was taking a very active role in space science, proposing and leading missions or parts of missions with NASA and ESA such as XMM Newton, NASA's Chandra x-ray observatory, Gaia, James Webb, ESA's BepiColumbo mission to Mercury and many others. In 1995 the XMM Survey Science Centre was established at university and in 1998 the first phase of Space Research Centre (SRC) was completed including offices, labs and workshops, followed in 2003 by a large cleanroom and further labs and offices, with further expansion in 2011.

How is the cluster performing today?

Today the University of Leicester has eight active missions in space and a further five waiting to launch. Most of this programme comes from proposing missions or being part of consortia who do. Mainly through the University's activities, a network of local relationships and links with larger international industrial partners has developed.

A commercial cluster of space activity is developing in the area. It is currently small but appears to be growing, although little data is available to quantify this. Almost all of the activity still revolves around or is connected to the university. A small number of pure space companies have been set up or spun out locally (e.g. Magna Parva, a small space engineering company founded in 2005 and located in Pioneer Park next to the National Space Centre) and graduates from space related courses at the university have founded other startups locally in related disciplines such as software.

The university, local government and industrial partners have big plans for space. The Local Industrial Strategy Prospectus includes goals to develop 20,000m^2 of new R&D and manufacturing workspace for the space industry, to create a space technology cluster and support development of a low-cost satellite manufacturing facility and assemble land and deliver infrastructure required for the next phase of Space Park Leicester.

Space Park Leicester is currently in development. This is co-located with the National Space Centre (featuring galleries of exhibits of space hardware, a planetarium and other attractions) and will be a space science and business park with an end-to-end capability, from satellite design and engineering, through to downstream data and its applications. Space Park will be supported by programmes of research in advanced manufacturing, digital intelligent systems, and novel Earth observation technologies. In the longer term, plans for LoCAS (Low-Cost Access to Space) would take this a stage further with a larger centre providing full satellite manufacturing facilities.

Space Park marks the next phase of development in the university sponsored ecosystem of relationships and facilities. This builds on years of organic growth in space activities at the university. In 2014 the university began to host the National Centre for Earth Observation and hence began coordinating a distributed set of researchers and capabilities including the Centre for Environmental Data Analysis (CEDA) and JASMIN computing infrastructure at Harwell, the Field Spectroscopy Facility at the University of Edinburgh and others. Today the university has around 300 staff involved in space – from research and engineering to downstream applications, related fields (such as AI) being applied to space, and business development staff supporting SMEs.

Leicester's position with good transport links and relatively inexpensive labour, housing and commercial premises are particularly attractive to some companies.

Public support and effectiveness

The university has the been the driving force behind the development of the local space sector and its investments and facilities. Public support (including from the university) today takes four main forms:

- **University teaching research and mission involvement:** This appears to remain the hearth of the cluster and its continual success has provided the nucleus for cluster development. Space related courses have proliferated, and mission involvement has grown – although opportunities for further growth here may be limited due to public research and mission budgets.
- **Funding for Space Park:** Overall this is approximately a £50m capital programme and a £100m programme overall. The university has provided around £25 of direct capital funding, while £8m has come from the Local Growth Fund, Research England's 'Research Partnership Investment Fund' has provided around £14m and smaller contributions have been made by NERC (which will use space at the new facility) and philanthropically from the Wolfson Foundation.
- **Local government support through planning and economic development funding:** In addition to the Local Growth Fund contribution for Space Park, the LEP and City Council have been supportive of development proposals and included Space Park as a centrepiece of the Local Industrial Strategy. Council land by the river Soar next to the National Space Centre was made available for the Space Park site.
- **Continual promotion and development planning:** Other forms of public support have enabled the university to maintain a more-or-less continuous stream of events over a decade to publicise Leicester's space capabilities, and to take a lead role in planning space related development activities. One example is the ERDF G-STEP programme which was secured to promote the use of EO data to improve regional competitiveness.

There is currently little evidence of clustering of commercial activities in Leicester in the Space Capabilities Catalogue and the Knowledge Transfer Network's Space Landscape map. Compared with other clusters we have examined, the local presence is small. However, university activities have spurred sustainable development of research partnerships with some associated commercial development. Industrial support for Space ark is an indicator that, while large pure space businesses have not collocated their operations at Leicester, there is an appetite for greater commercial links with university research.

Summary and Conclusions

University research activity and mission participation is high and there is a shared drive between the university and local authorities to develop this into a local commercial space cluster essentially from scratch. The university has been noisy about its role in space and this enthusiasm and drive has propelled the cluster so far. However, the university fundamentally sees itself as part of a national space endeavour whether delivering research or growing STEM skills and more advanced space and science educations. Future investment in Space Park is at its early stage and there is little evidence yet to judge whether this approach will have in developing a spatially localised commercial cluster or whether it will build industrial-academic links that payoff nationally.

2.11 Scotland

Cluster origins

Scotland's position as a major space cluster is relatively new. Its origin story derives from two main sources: the universities; and successful growth in the early days of NewSpace.

Four universities in Scotland have a prominent role is the space sector: University of Edinburgh, University of Glasgow, University of Dundee and University of Strathclyde. Edinburgh University has a long history in astronomy and the discipline has been taught in the city since 1583 with the opening of the college. The Calton Observatory was founded and later became the Royal Observatory Edinburgh in 1822. Today it is still the focus of much of Edinburgh's space sector and has cemented the University's role in this. The University of Glasgow has a space systems course at its James Watt School of Engineering and a cross-disciplinary 'Space Glasgow' research cluster. Scotland's only satellite ground station – Dundee Satellite Receiving Station – was founded at Dundee University in 1979 and the university, through its Space and Technology Centre, is today involved in data handling onboard of spacecraft, planetary lander technology, and satellite data reception. The University of Strathclyde has formed the multi-disciplinary Strathclyde Space Institute of which the Centre for Space Science and Applications is a part.

The second part of this story is best told through the creation and growth of Clyde Space. In 2005 Craig Clark left Surrey Satellite Technologies to found Clyde Space. Craig was a graduate of Glasgow University who gained his masters at Surrey University – highlighting the link between the university driven skills pipeline and the future success of space clusters. The partnership between Clyde Space and Strathclyde University went deeper though. In 2008 they signed a knowledge sharing agreement and together they designed Scotland's first satellite (UKube-1) which launched in 2014. Clyde Space was foundational in the NewSpace movement and the development of cube sats. With support from the Satellite Applications Catapult, Clyde Space has gone on to be one of the world's largest satellite manufacturers by volume.

In little more than a decade, Scotland's emerging space capabilities have mushroomed into a true cluster of activity which is being internationally recognised and attracting inward investment.

How is the cluster performing today?

Today the Scottish space cluster has built effectively on its long tradition of university science and its very recent success in NewSpace and the cluster reflects these two growth poles.

- **Glasgow** focusses on space manufacturing – particularly of satellites by homegrown companies such as AAC Clyde Space (founded in 2005) and Alba Orbital (founded in 2012) as well as inward investors such as Spire Global (opening in Glasgow in 2015).
- **Edinburgh** focusses on astronomy and data science. The UK Astronomy Technology Centre is an STFC centre of excellence at the Royal Observatory in Edinburgh, focussing on camera, spectroscope and telescope systems and the Higgs Centre for Innovation concentrates on space and data intensive activities. Data hungry earth observation startups in Edinburgh include companies like Global Surface Intelligence (GSI) and Ecometrica. The International Centre for Earth data is good example of Edinburgh's specialisation paying dividends. It is a commercial project by Orbital Micro Systems in partnership with the University of Edinburgh and University of Colorado at Boulder and based at the University of Edinburgh.
- **A dispersed launch sector** is developing at different rates in five sites: Sutherland, Shetland, North Uist, Prestwick and Machrihanish. Access to polar and Sun-Synchronous Orbits (SSO) are unimpeded from Scotland.

Although this pattern is a useful summary, geographical divisions of capability are not quite as neat. Sykrora, for example, is an Edinburgh based launch company with facilities outside Glasgow – although their R&D facilities are mainly located in Dnipro in Ukraine. Scotland also has a wide base of companies and activities outside of these centres such as Orbex at Forres in Moray and significant activity at Dundee University for example. A dispersed launch sector is developing at different rates in five sites across the country: Sutherland, Shetland, North Uist, Prestwick and Machrihanish. Access to polar and Sun-Synchronous Orbits (SSO) are unimpeded from Scotland.

Scotland is unique amongst the space clusters we have examined in that its space economy has recently been studied and quantified in some detail[11]. London Economics estimate that in 2017/18 the cluster had a total economic output of £880m – around 14% of total UK space sector output. Of the 133 companies that make up the cluster, around half were involved in space manufacturing while 43% were engaged in provision of downstream space derive services. The upstream segment of the value chain delivered higher economic output per employee and was responsible for 60% of the sector's economic output. Overall, the sector employs around 8,000 people, although a large majority of these (78%) were engaged in direct-to-home broadcasting activities. Glasgow builds more satellites than anywhere else outside of California.

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[11] The Scottish Space Cluster - Progress now and in the future, May 2020, London Economics (https://londoneconomics.co.uk/wp-content/uploads/2020/05/LE-SE-Scottish-Space-Cluster-EXECUTIVE-SUMMARY-FINAL-Issue-4-S2C110520.pdf)

Growth in the sector has been rapid. Between 2012/13 and 2017/18, Oxford Economics estimate that industry income grew from £144m to £254m between 2012/13 and 2017/18 – compound growth of 12% per year. Almost all of this growth came from new entrants to the sector – a strong indication that Scotland is benefiting from NewSpace startups. The sector plans to have a £4 billion space industry by 2030.

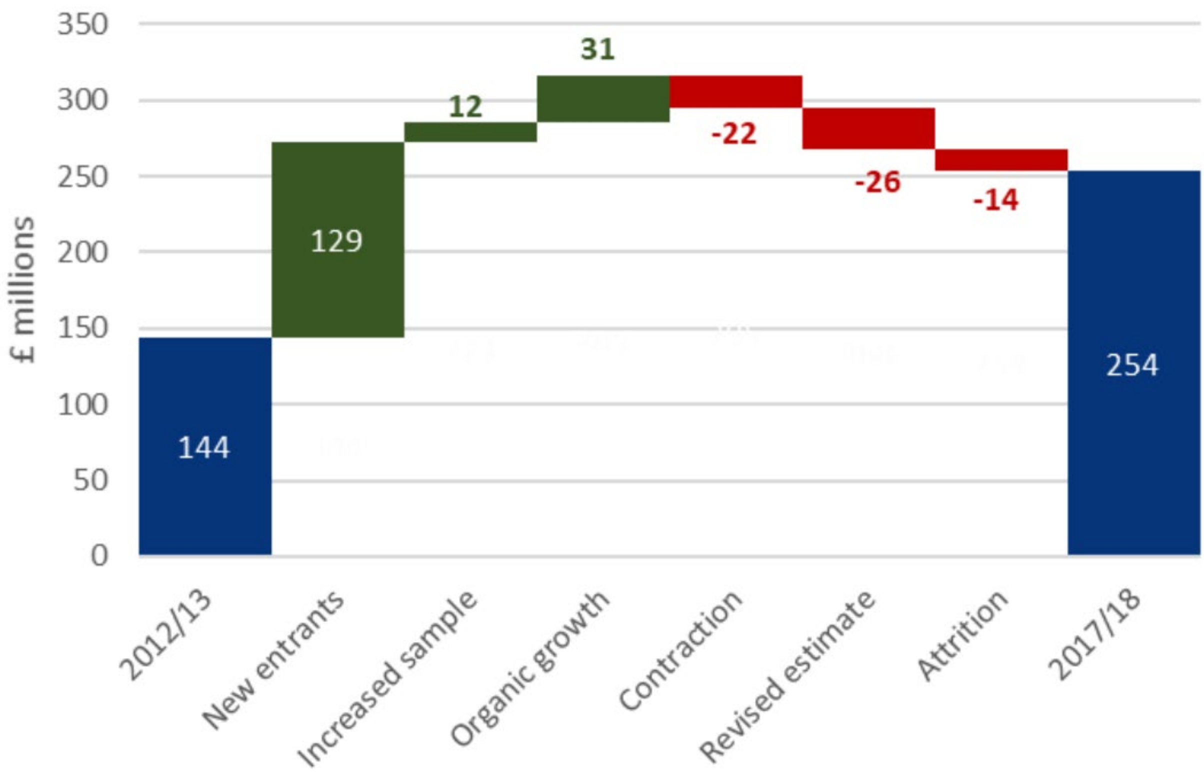

Figure 7: Scottish space sector income growth 2012/13 to 2017/18

Public support and effectiveness

The Scottish approach to space sector development is focusses on three areas.

- **The skills pipeline:** The space skills pipeline in Scotland is strong and continuing. As well as bespoke space related courses and PhD opportunities, the Scottish Space School at the University of Strathclyde takes around 100 school children per year for a week to get involved in space related projects.
- **Collaborative environment:** Scottish Space Leadership Council was formed in 2017 to bring together commercial organisations, universities and the public sector. Formed the Spaceports Alliance as a working group in September 2020. Partnerships between universities and industry work well with Clyde Space and University of Strathclyde's partnership as the stand-out success.
- **Launch:** Enthusiastic and proactive development of indigenous launch capability

- **Business incubation:** Various space related centres for business incubation have been begun relatively recently including the Scottish Centre of Excellence in Space Applications (SoXSA) jointly funded by UKSA and Scottish Enterprise, and the Higgs Centre for Innovation at the University of Edinburgh.
- **Big investments:** The £45 million Bayes Centre for artificial intelligence and data science in Edinburgh is related to its space growth strategy while other large investments such as the Higgs Centre for Innovation

Summary and Conclusions

Scotland's commercial success in the space sector has come from playing the odds. Continued investments in STEM education, university capabilities and space sector skills have produced a pipeline of talent. In this environment the chances are that a few individuals would emerge with great ideas and commercial acumen. In the context of a relatively small overall population and economy, this approach appears to have paid dividends with leading space companies developing which have been foundational in the NewSpace revolution – and deeply connected with the Universities as incubators, supporters and research partners.

Early success and growth potential in the 2000s was nurtured though a collaborative approach with industry and supportive policy. These other aspects of public policy also appear to have been important in smoothing the path to success for Scotland's emerging NewSpace companies.

Future strategy appears to be to do more of the same, leveraging universities to develop talent, technologies and projects supported by upgraded facilities and a stronger ecosystem of peer-to-peer and public sector startup support. The development of the launch market is another important strand, although it is not yet clear how closely it is related to Scotland's wider success or how this will fare.

3. Effective public support for the space sector

3.1 Introduction

Most of the international clusters that we have studied are growing relatively quickly, in line with the global space economy. However, success metrics differ and data is inconsistent so our assessment is somewhat subjective – based on quantitative data but also on interviews and anecdote. All of the largest clusters (Toulouse, Bremen, Colorado) have grown recently, although none as strongly as Harwell. Growth rates are more difficult to determine for smaller clusters because data is scarcer, but it appears that Esrange, Cape Town and Adelaide are growing rapidly from a low base while Mojave has declined somewhat recently.

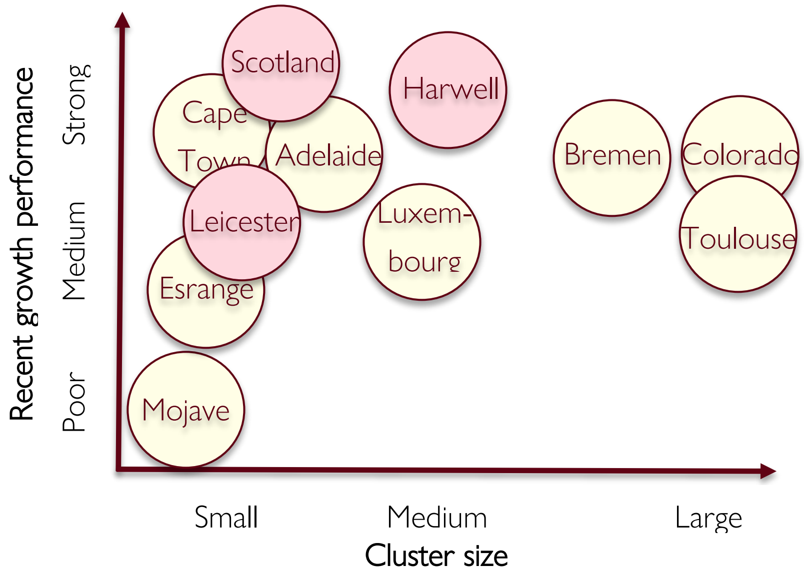

Figure 8: Cluster performance summary

The clusters have a wide range of origin stories, but most grew from public expenditure or research programmes, whether civilian and military. While direct public investment still plays a major role in driving some clusters, the balance of forces is shifting. We have identified the following key lessons from our work:

- Skills are 'sticky' and drive the space economy in the long term;
- Scale matters;
- Individual space customers can be fickle;
- Business environment and success culture is critical; and
- Public facilities and business support are not significant differentiators.

3.2 Skills are 'sticky' and drive the space economy in the long term

The most common and consistent finding from the case studies is that, in the long term, the most important driver of space clusters is the workforce. In smaller clusters (Esrange, Mojave, Cape Town) a few key individuals or project teams have anchored growth while in larger clusters (Colorado, Bremen) the wider pool of space engineering and related skills maintains a cluster critical mass.

Our research has found that skills are 'sticky' – often they persist even after their original role disappears. For example, in Colorado the early cluster development was partly driven by ex-Air Force personnel with skills in engineering and electronics spreading their entrepreneurial wings in the technology revolution of the 1970s. In Cape Town, skills retained from historic programmes have sought new outlets and driven the emerging NewSpace cluster around Cape Town. A similar story emerges in some of the ex-Soviet centres of space activity where state activity has withered (e.g. Dniepro).

Looking forward, almost all of the clusters we examined are associated with the large-scale development of indigenous skills in physics, space and engineering disciplines which ensure continued space sector activities into the future. The exception was Mojave which has experienced fickle economic fortunes.

Skills can be imported (Colorado does this very effectively) but this relies on a large pool of people within a national labour market with few barriers to movement or cultural barriers – and the ability to offer a great quality of life. Great if these factors are in place, but it may be easier to develop locally if local universities and businesses are already in place and can be leveraged.

In Bremen, a pipeline of skills honed at the local technology universities has been a critical factor driving the success of the cluster. Toulouse is seeking to follow Bremen and augment its skills base with a pipeline of homegrown talent through deliberate colocation of aerospace technology higher education. In Esrange, for example, despite being a small cluster, space activities anchor university campuses and institutes which will continue to drive local space sector activity for many years and have spun out several private businesses. In Cape Town energetic university courses are generating a pipeline of graduates keen to set up in NewSpace, which looks set to drive activity in the industry even if wider market conditions become difficult.

Meanwhile, NASA is in danger of a skills shortage as it fights a relentless process of aging in its workforce after the highs of the Apollo programme. In Mojave, the handful of businesses are often led by an older generation of engineers and – if it had a few bad years – it may suffer a demographic fate as these businesses close down.

The long-term importance of skills in the local community argues for a rapid expansion of space programmes through the UK's universities. In the light of potential growth in the size of the sector a conveyor belt of ever-expanding space skills is required. These skills will be put to good use whether in space or related fields such as computing, engineering or materials.

3.3 Scale matters

We found that larger clusters have four critical inherent advantages:

- Talent pooling: A large cluster attracts companies that can be confident that they can attract the talent that they are looking for. The interaction of demand and supply of skills can be complicated though. In Colorado and Toulouse, for example, there is some evidence that the success of the cluster may have generated a wage premium but this does not seem to have slowed down their growth. However, in Cape Town, some firms set up there precisely because of a high skill low wage environment.
- Risk sharing: In larger clusters, economic performance relies less on the success of a particular product or the continuation of a particular programme. Workers can move there confident that if they lose one job they stand a good chance of getting another that will be a good match for their skills. In Mojave, the lack of risk pooling has posed the greatest threat to the cluster and resulted in boom and bust cycles as projects have ebbed and flowed with no base load of project work and without a critical mass of local skills to coalesce into new companies and projects. Cape Town's cluster is emerging despite this lack of critical mass due to its historic pool of skills and continual generation of a pipeline of new space skills.
- Collaborations: Larger clusters saw a wide range of collaborations between different parts of the space industry and with other industries. Larger clusters both have the scale to support trade associations and multiple large events, but also have the depth and range so that the matchmaking works well. In Bremen, universities, research institutes larger companies and SME's have a deep and rich set of interactions – the two dense physical/spatial clusters there also create a 'coffee shop effect' writ large. In Colorado, similarity of outlook (due perhaps to a certain cultural similarity) helps build trust and enable collaborations. Dense spatial clusters are not a prerequisite for successful collaboration (Esrange develops collaborations across the world, Colorado works despite 100 mile scale), but they definitely help.
- Profile raising: As clusters grow they also gain a fourth benefit in raising their own profile and the profile of companies based in them. In addition from collaboration benefits, the cluster as a whole is more effective at promoting space enterprise than the sum of its parts, and they also gain from association with success. Being able to say 'We are based

in the XYZ space cluster' becomes an advantage, and companies want to base in a cluster to gain that advantage.

In some ways, critical mass depends on where you are and the local competition. In Southern Africa, the Cape Town cluster is relatively small but it is still the natural place to go as a space sector worker or business.

3.3 Individual space customers can be fickle

Large individual space sector customers have played a central role in cluster development. Our scope is limited to the consequences for developing successful clusters, rather than the value of research, exploration or military outcomes per se – so we restrict our comments to this. In Toulouse and Bremen, the major customers are ESA programmes, government supported research activities and national space programmes. In Colorado the original public sector impetus was military. Esrange continues to be supported largely by a public research community. However, this can be a fickle basis for long term cluster development (see the Cape Town experience) unless it is both sustained and leads to a sticky pool of skills (and possibly facilities) which remain when public spending priorities change.

In Europe, Toulouse takes more government expenditure than Bremen and is a larger cluster. It has not been possible within the scope of this project to tease out how far these public budgets are 'multiplied' into wider economic gains for the region. Both clusters support significant numbers of other companies (particularly NewSpace startups and wider engineering and technology firms) that are not involved or only peripherally involved in government programmes. It is not clear, if public programmes wound down, whether these clusters would continue to grow as their skills and expertise was put to other uses chasing global private sector space opportunities. Perhaps Colorado provides some insights. Without direct grant funded NASA programmes or military programmes, the Colorado cluster is very successful at bidding for a wide range of public and private contracts alike. It benefits from public funding only in the sense that this grows the overall size of the space market.

Luxembourg took a different path. It won a 'big bet' with targeted public investment in satellite communications in the 1980s. This did not result in a depth or breadth of space activity that generated a more general cluster, a critical mass or a pipeline of skills. However, it did have major commercial success. There are as many stories of big bets being lost as won, so this is a high-risk strategy. Now Luxembourg's public investment strategy is based on its ESA contributions which along with a benign policy environment is used to create a narrative of success in the space sector and attract footloose activity.

For public support to be effective at delivering sustained commercial space sector success, it must generate skills, build a critical cluster mass and be withdrawn incrementally to enable the cluster to reorient. Alternatively, public authorities need to be prepared to provide support in pursuit of aims which are not fundamentally about economic development (such as exploration or military objectives).

3.4 Business environment and success culture is critical

We found that the wider business environment and culture played a large part in the success of space clusters. Public authorities have levers in this area but may have limited influence on business culture.

A ‘business friendly’ environment does not have to be a low tax environment or one that offers cash incentives. Luxembourg has relatively high rates of corporate tax and Colorado provides few cash incentives for businesses starting up or relocating. However, these jurisdictions do benefit from being open and having a strong ‘how can we help’ style dialogue with the business community, mainly focussed on supportive regulation. In Colorado, much of the economic development function is taken on by the business community through trade associations such as the MetroDenver EDC, highlighting the role of an active, engaged and collaborative business community.

Some clusters have managed to generate a somewhat self-sustaining narrative of success. This is related to, but slightly different from the critical mass effect. Success stories drive enthusiasm and visions of shared success. In Luxembourg, that national space narrative of a successful and growing economy may be exaggerated but is successful in raising the country’s profile and attracting investors. In other clusters, high profile events such as conferences and industry days support awareness of the sector, raise its profile and help generate a shared success narrative. In Europe these are often supported by the state and quasi-governmental institutions while in the USA they tend to be entirely business driven. Either way, they seem to play a role in communicating success and brand development.

Hard metrics of success are nowhere stronger than in the UK space cluster and particularly at Harwell. However, the narrative of commercial success that flows from this could be louder and it could be clearer.

3.5 Public facilities and business support are not significant differentiators

We found that in the eight foreign clusters that we studied in detail, public provision of facilities and busines support mechanisms did not seem to be a differentiator of cluster success.

Some smaller clusters are built around facilities which dictate where they are (Esrange, Mojave) but we did not find these clusters to be the most successful at driving economic development. In some of the other clusters (Bremen, Toulouse, Cape Town), public facilities do seem to play a significant role (e.g. the drop tower at Bremen Technology Park). However, in others, similar facilities were privately owned and operated (Colorado, Mojave) and the development of upstream businesses was not noticeably affected by the ownership or funding structure of facilities.

However, facilities differ very substantially and it is difficult to draw general conclusions from this. In Harwell the world class range of scientific facilities anchor a wider cluster of publicly supported science and a density of research that enables cross-fertilisation of cutting-edge ideas. None of the clusters we examine boasted this level or density of scientific or research facility.

At a cluster level it was difficult to identify the effect of incubation facilities for startups. ESA BICs were prevalent in all of the European clusters but there is no comparable support in the US case studies or in Cape Town. The more successful 'low support' clusters are successful for other reasons: Colorado due to it scale driven by wider aerospace and defence activities, Luxembourg from its regulatory environment). Cape Town has had relatively meagre public support so far but SANSA recognise the potential for this and are scaling up funding in this area.

It would require a focussed analysis of their efficacy to establish the value for money that incubation facilities provides and we are not able to do this within the study scope. While they are not essential for cluster growth, without them a cluster has to have other strengths.

3.6 What does this mean for the UK?

The development of UK space will have military and research goals, but the industry is united behind a growth objective: reach 10% of the global space market by 2030. The UK's future path is therefore more likely to be like that of Colorado or Luxembourg where business success is a key driver of policy rather than other interests. Toulouse and Bremen for example, are not designed and managed to deliver commercial spin outs and the French sector, in particular, is more based on national prestige, exceptionalism and national security. If this is correct, then a focus on economic growth suggests the following lessons:

Sticky skills: The UK must build an accelerating supply of indigenous skills in the space sector. These will outlast any specific project or programme and many are likely to stick geographically and deliver long term space sector growth. It must build itself into an attractive destination for skilled international workers post Brexit.

Critical mass: Directed public investment can help to deliver critical mass in the space sector, but must not unbalance development. Government markets must either be sustained or a phased exit strategy put in place to transition skills into ventures serving private customers as the market grows and matures.

Business environment: A supportive business environment will need continual review of legislation and policy. This applies at the space sector level (for example in air traffic control, hazardous goods, international trade in technology, etc.) and more generally (e.g. in migration and skills, ease of doing business, etc.). It must support a collaborative business culture where possible – although this is already a strength in the UK space sector. And it must develop its narrative of success and shout about this – both to raise its profile and attract businesses and skills in the short term and also to build energy and feed the indigenous pipeline of sills in the longer term.

Public facilities and business support: Public facilities can be drivers of cluster formation and early growth, but beware of building an economic development strategy around major public facilities. The evidence for long term cluster growth based on facilities is limited in our research. Facilities either need sustained investment to support a growing cluster, or should be pursued for objectives other than economic development (such as pure science research). Facilities differ, but more generic facilities have been successfully provided elsewhere by collaborative business activity or private developers where strong clusters are already thriving on the strength of their innovation and skills. Business support through public sector grants, tax reliefs and incubation programmes are not fundamental ingredients for cluster growth. Where they provide strong independent business cases, they should be made available to those that need them and should be well signposted.

As a final word, we note two things:

- The space sector is unique in many respects, but perhaps not from an economic development point of view. The critical factors of skills, scale and business environment are common to most industries. Twists in the space sector include the rapid emergence and development of new technologies and close links to pure research, and large role for public customers (e.g. in defence), but the innovation environment is as much about improving the regulatory environment (e.g. by clarifying responsibilities for space traffic and debris, or clarifying rights over non-earth assets) as it is about financial commitments.
- Harwell has been more successful recently than almost all of the clusters that we examined – so beware of importing new models.

3.6 Study weaknesses and recommendations for improvement

Our analysis has provided an assessment of the growth of space clusters, the factors which appear to be responsible for their success and the role of public policy within this. However, the analysis does have some weaknesses which should be considered in future research:

- **Defining a geographic space cluster:** For the purpose of this study we aimed to cover clusters across a range of sizes, functions, features and jurisdictions. We took a pragmatic approach to defining space clusters based on the project teams' experience – but we may have missed something important. Future research would benefit from a more comprehensive and robust identification procedure which aims to reduce individual biases. This might include a formal definition of cluster sizes or functions and a robust search procedure for identifying and sifting them.
- **Quantitative data:** Due partly to time and budget constraints we have not been able to develop consistent and quantified metrics for cluster size or growth. Consistency issues mean that, for example, currencies and years of analysis are not necessarily aligned – although these issues perhaps have a limited impact on the reader's understanding. However, a basic lack of available data means that for most clusters we do have comparable measures of scale such as employment or the number of companies involved in a cluster. The Catapult's work on a taxonomy for the sector and approaches to company data gathering could provide an opportunity to improve this in future.
- **Suitable measures of success:** Given the lack of available data, it is not surprising that some of the metrics that we have had to employ are not ideal for establishing economic success. Ideally, the success of cluster would be defined by its economic value added or by its productivity. However, we have often had to rely on other less revealing measures such as turnover or the number of companies identifying as being in the cluster.
- **Distinguishing the impact of different interventions:** Our case study approach provides a qualitative assessment of success factors but does not provide the range of examples to enable statistical techniques to be employed. This means that the assessment of public policy success factors is necessarily a matter of judgement. It may be valuable in future studies to combine a case study based approach with one that delivers a larger sample size and statistical techniques to extract information about the impact of different policies.
- **Anglo-centric approach:** The approach we took was somewhat Anglo-centric in terms of both the language used for the research and the cultural and policy landscapes that we examined. For future work, it would be worth considering a wider set of clusters in different jurisdictions to avoid any Anglo-centric bias (e.g. USSR, Ukraine, China, India, South Korea, Israel, etc.).

Appendix 1: Longlist of clusters considered for inclusion as case studies

No	Cluster	Notes
Europe		
1	Toulouse, France	Likely Europe's largest space cluster – focussed around CNES (space agency) and Airbus Defence and Space
2	Bremen, Germany	German sector is distributed across the county, but concentration in Bremen with large companies such as OHB and the DLR (space agency)
3	Milan, Italy	The industrial areas of northern Italy have a strong space manufacturing and services concentration, for example OHB Italy, Leonardo, Thales Alenia Space Italy and Leaf Space.
4	Spain	Three new Spanish small sat launch companies are positioning Spain as serious NewSpace contender (PLD Space, Zero2Infinity and Celestia), with launch sites considered at Zaragoza, Teruel and elsewhere. AN interesting but still small European cluster which has not yet coalesced into a physical location.
5	Esrange, Sweden	Dynamic recent development with the construction of an orbital launch complex, private sector activity and academic collaborations (with Swedish Institute of Space Physics). A history of sounding rocket research since the 60s. Engine testing facilities. Small site but with recent growth and interesting and potentially transferable features.
6	Andoya, Norway	Andoya is similar to Esrange but has seen progress on launch facilities paused while funding arrangements are worked out. Outside the EU, funding and policy considerations may be more similar to the post-Brexit UK experience.
North America		
7	Mojave, California	The Civilian Aerospace Test Center and associated industrial facilities host around 60 companies, many in the space sector, including Virgin Galactic, BAE Systems, Orbital ATK, Scaled Composites and ASB Avionics, and successfully launched SpaceShipOne. Close to Edwards Air Force Base.
8	Colorado Springs, Colorado	Significant and diverse space and aerospace cluster centred on the Colorado Springs area. This is interesting because it has a significant overlap between space and aerospace and is predominantly commercial (although the cluster's origin story is also associated with Peterson Air Force Base nearby). It is also not based around a major NASA facility.
9	Mountain View / Bay Area, California	Interesting because of the location of the Ames Space Flight Centre in in Silicon Valley and the commercial spin offs that have come from this.
10	Texas	The legendary Johnson Space Centre and Rice University form the nucleus of 'OldSpace' in Texas. Meanwhile, billionaire backed startups SpaceX and Blue Origin have chosen Texas for significant new facilities: SpaceX' Boca Chica launch complex; SpaceX' McGregor engine development and testing facility; and BlueOrigin's launch facility at Van Horn. Large and diverse space sector, but with potentially few parallels for development of UK clusters.
11	Huntsville, Alabama	A large and diverse space cluster which grew from roots in army rocket programmes, built the Saturn V rocket and hosts the Marshall Space Flight Centre. It has recently seen dynamic growth as Blue Origin has established a plant for manufacturing BE4 engines, and Aerojet Rocketdyne and Boing have expanded private space operations.

12	Florida, Cape Canaveral	America's (and the world's) largest space cluster based around the Kennedy Space Centre and Space Coast. The cluster continues to commercialise and is widening access to facilities once used exclusively by NASA.
13	Utah	Space Dynamics Lab and Shuttle programme
14	Kodiak, Alaska	A military site which has developed a civilian space launch offer and is home to emerging NewSpace companies. Maybe too small to draw significant insight from?
15	Wallops, Virginia	Built around the NASA Goddard Space Flight Centre and Wallops Flight Facility, this is the centre of the USA's sub-orbital space research capability, including sounding rockets, balloons and high-altitude flight. Offers commercial launch facilities (e.g. to Orbital's Antares rocket) alongside a heavy, multi-agency government and defence presence.
16	Washington D.C., USA	A cluster of space related companies and agencies focussing on research, policy and lobbying ('Beltway Bandits'), including Bryce and Rand Corporation.
17	Vandenburg, California	Another launch centred cluster with Vandenburg Airforce Base at its heart, the cluster hosts commercial space activities, including SpaceX launches.
18	Pasadena, California	Another major NASA facility and associated space cluster hosting around 6,000 employees, the Jet Propulsion Lab focuses on construction and operation of planetary robotic spacecraft. JPL is managed by Caltech and there is very deep NASA/university partnership. However, there is limited ancillary space cluster activity nearby.
19	Spaceport America, New Mexico	Experiment in developing a commercial space cluster from scratch based around a civilian spaceport and with significant public investment. It has attracted startups and testing activities including Virgin Galactic as anchor tenant.
20	Canada	The national space sector has a strong focus on space robotics (including development of the famous 'Canada Arm' on the ISS). Potentially interesting for developing a specialist space niche.
Asia		
21	Wuhan, China	The centre of China's large and impressive space programme including launch facilities. Although large, this cluster offers limited transferability to a UK context.
22	Japan	The space industry in Japan is very hierarchical and dominated by JAXA and a small number of large conglomerates (e.g. Mitsubishi Heavy Industries). Clusters tend to be centred around JAXA facilities. The Tanegashima cluster centres on the Space Centre run by JAXA and hosts nearby several large industrial companies' space divisions (e.g. Mitsubishi Heavy Industries). It is focussed on upstream space including launch, testing and assembly. Other clusters could also be viable candidates for analysis (e.g. Tsukuba Space Centre), although we are relatively unfamiliar with these and would need further research to determine the most suitable approach to Japanese space cluster development.
23	Naro, South Korea	The Naro Space Centre is operated by the state-run Korea Aerospace Research Institute and includes test facilities for satellites and rocket motors.
24	Bengaluru, India	The heart of India's space sector and hosting various space related agencies and function, Bengaluru is poised to become the centre of the brand newly emerging Indian space sector, following a decision to open up the sector to private industry at the end of 2020. May be too soon to learn lessons about private space sector development.

25	Sriharikota, India	Launch site and space centre in Andhra Pradesh which is a key part of India’s launch capability. It launched India's lunar orbiter Chandrayaan-1 and is expected to host India’s manned space programme.
Australasia		
26	Adelaide / Woomera, Australia	Australia has been very active in the space sector over recent years, establishing a space agency and developing space policy. Its universities have been active in space research for many years. Now a NewSpace cluster is developing in Adelaide, the closest gateway to the launch facilities at Woomera in the Australian outback.
27	New Zealand	RocketLab is a joint USA/NZ company that is successfully leading the NewSpace small sat launch sector, launching from the Mahia Peninsula on North Island. However, the sector development is really the story on this one company with limited parallels for the UK.

Appendix 2: Interviewees and acknowledgments

We would like to thank the following people who, through interviews and discussions, helped us to understand the space cluster landscape. Any errors are our own.

- Vicky Lea, Director of Aerospace and Aviation, Metro Denver EDC
- John Paffett, Managing Director, KISPE Limited (previously CEO at SSTL US in Denver)
- Professor Martin Barstow, Professor of Astrophysics and Space Science, Department of Physics and Astronomy, University of Leicester (and former President of the Royal Astronomical Society)
- John Stuart, Senior Vice President of Sales and Marketing, Swedish Space Corporation
- Darin Lovett, Director Space, South Australian Space Industry Centre
- James-Barrington Brown, CEO and Founder, NewSpace Systems

Appendix 3: Major Space Market Trends

The space industry has seen radical change in the last 10-15 years, both in the upstream and downstream markets. These changes have been brought on by technological advancements, newly emerging threats, shifting government policies, substantial private investments and societal changes. The following subsections will identify and asses these emerging trends and growth markets.

Commercial launch – was perceived as one of the main bottlenecks, and a significant obstacle to anyone looking to start a business in the space industry. Up until 15 years ago, all launch vehicles on the global stage were operated by large government contractors such as Lockheed Martin, Arianespace and International Launch Services (ILS). The vehicles themselves could all trace their heritage back to civil and/or military programs that were designed to launch large government satellites weighing several tons, with reliability taking priority over cost. Companies like Surrey Satellite Technology Ltd. in the UK began capitalising on advancements in microelectronics and building satellites with off-the-shelf (OTS) components – weighing hundreds of kilograms rather than tons. The NewSpace market emerged as the barriers to building spacecraft began to fall. The philosophy of small satellites was to come close to the capabilities of large satellites, but at a fraction of the cost. Despite the advancements in spacecraft technology, larger satellites that could afford to purchase full vehicles remained the priority for launch providers. Small satellite companies were therefore limited to rideshare missions where they launch alongside larger 'primary' payloads. Rideshare brought the price down for small satellite launch, but remained highly inconvenient as compromises on orbit and schedule had to be made in favour of the primary payload. Any alternative smaller vehicles at the time were variants of Intercontinental Ballistic Missiles (IcBMs), which were more convenient and cost-effective in some ways, but involved an incongruous interaction between commercial and military that brought its own challenges.

SpaceX was the first private company to break this trend and develop a small vehicle, the Falcon 1, dedicated to the small satellite market. The Falcon 1 was partly backed by US Defence Advanced Research Projects Agency (DARPA), but also involved heavy private investment – something unprecedented for the launch industry at the time. After two successful launches the Falcon 1 was cancelled, and SpaceX moved on to developing the medium lift Falcon 9 launch vehicle after winning the NASA Commercial Orbital Transportation Services contract. However, the potential to develop a small launch vehicle with private investment had been proven and since the cancellation of Falcon 1 there has been over 160 small launch vehicle projects emerging around the world, almost all with the commercial small satellite launch market in their sights. Developing a launch vehicle is still a costly and technically challenging endeavour. Elon Musk confessed that the Falcon 1 nearly bankrupted him, and most of these projects will likely suffer this fate. Based on technical achievements and successful investments, perhaps 10% of these launch vehicle projects have the means to make it to market. Some notable mentions include:

- Virgin Orbit (US) – that raised around $700 million by the 4th quarter of 2020 and recently celebrated its first successful launch[12]
- Relativity Space (US) – that raised $500 million USD in November 2020, on top of an additional $160 million raised in series C the year before.[13]
- Firefly – (US) won a resent NASA lunar launch contract of $93.3 million, combined with $200 million in investment over the last few years from Noosphere Ventures[14]
- Astra Aerospace (US) – has had $100 million of announced investment so far and will soon go public with a valuation of $2.1 billion.[15]
- Isar Aerospace (Germany) – recently raised $91 million in series B funding at the end of 2020, building on a $16million series A investment the year before.[16]

Developing new launch systems takes time and, so far, US Company Rocket Lab is the only private small launch provider to make it to market after SpaceX. However, with the recent announcement that Rocket Lab (like SpaceX before it) will be moving to a medium lift launch vehicle, after only two years of commercial operations, a shadow of doubt has been placed over the commercial viability of small launchers. This is further exacerbated by the downwards pressure on launch prices from the SpaceX Rideshare Program, which offers $5000 per kg compared to the ~$35,000 per kg offered by Rocket Lab with Electron. SpaceX are able to offer such aggressive pricing because of the revolutionary first stage recovery technology the company has pioneered, combined with the consistency of launches the company is guaranteed from the launch of its Starlink internet broadband constellation. The trend for aggressively priced rideshare is likely to continue as rival medium and heavy launch vehicles enter the scene over the next 2-4 years – one of the most anticipated being the Blue Origin's New Glenn heavy launcher, which is sponsored by rival tech billionaire Jeff Bezos. The Amazon chief is also developing a rival broadband constellation, called Kuiper, which was authorised to launch of 3,236 satellites US Federal Communications Commission (FCC).[17]

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[12] David Dawkins (2020) Virgin Orbit Seeking Over $100 Million As 'Jaw Dropping' Costs Mount And Small Satellite Market Narrows, Forbes

[13] Jeff Foust (2020) Relativity Space raises $500 million, Space News

[14] Jeff Foust (2021) Firefly Aerospace seeking to raise $350 million, Space News

[15] Michael Sheetz (2021) Rocket builder Astra to go public via SPAC at $2.1 billion valuation after reaching space last month, Space News

[16] Ingrid Lunden (2020) Germany's Isar Aerospace raises $91M to get its satellite launch vehicle off the ground, Tech Crunch

[17] Michael Koziol (2020) Amazon's Project Kuiper is More Than the Company's response to SpaceX, Spectrum.iee.org

With the abundance of launch options in the market, the last major barrier for NewSpace companies is lowering. When combined with the very public space race unfolding between two of America's most prominent tech billionaires, public and private investment in the space industry has significantly increased – with an emphasis on satellite technology and downstream applications to match the increasing demands of the "Information Age". This ultimately opens further opportunities for the launch market, that will be more definable once some of the 'megaconstellations', such as Starlink and Kuiper, have begun operations and the subsequent dust has settled.

New investments and PNT services – The spending strategy of space agencies and defence departments have changed in recent years. Following years of using the same established government contractors, space agencies, such as NASA, have started turning to new private companies, seeking the best value for their dollar through fixed price contacts and seed corn investments. By supporting companies to deliver products and services that serve the strategy of civil and military programs, while also having dual-use in the commercial sector (such as launch), these companies are encouraged to think competitively. Such projects are therefore more likely to be delivered on time and to budget, while also being able to point to government confidence to raise further private investment. An example of the antithesis of this is the NASA contract to Northrup Grumman for the James Webb Telescope. The contract is uncapped, partly because Northrup Grumman will not be left with a saleable product at the end of the project, which has led to delays and overspend of several billion dollars.

The change in government support to the private sector, success stories like SpaceX and the resulting easing of barriers to business, such as the prohibitive launch practices and prices mentioned earlier, have amounted to growing space investment. Despite the economic slow-down from Covid-19, 2020 has been a good year for global investments in the space industry, totalling $25.6 billion invested across 359 rounds (surpassed only by 2016 and 2018), amounting to $177.7 billion of equity investment into 1,343 space companies over the past 10 years. Of this $30.9 billion has been invested into 'infrastructure' (the majority split between $18.8 billion for launch and $10.7 billion for satellite manufacture) and the lion's share of $141.6 billion in applications, 87% of which was in the Position Navigation and Timing (PNT) sector (especially around Location-Based-Services such as on-demand delivery and ride-hailing services).[18]

[18] (2021) Space Investment Quarterly: Q4 2020, Space Capital

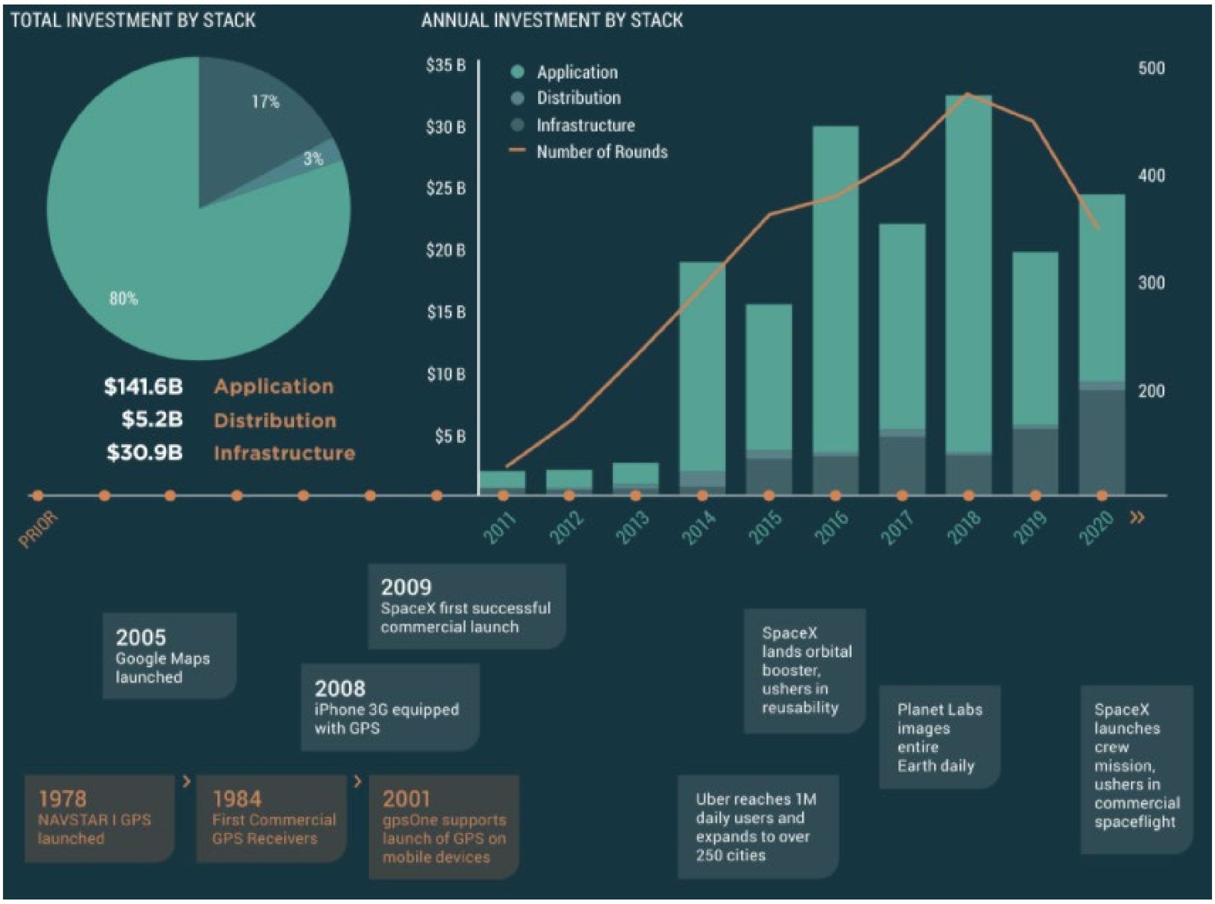

Figure A3.1: Cumulative Equity Investment from 2011 to Q4 2020[10]

The commercial growth and investment in the PNT sector is almost entirely application and software driven, because the most expensive hardware component, the global navigation satellite system (GNSS), is developed and deployed by national programs. Governments then retain the higher resolution GNSS data for defence applications while supplying lower resolution data for free to commercial users.

Data communications – the emergence and continued investment in small satellite data constellations in low and medium Earth orbits (LEO and MEO) such as Starlink, OneWeb, and Amazon's Kuiper project demonstrates the demand for data communications. It can be argued that this is a response to the ever increasing societal demand for higher bandwidth connectivity to support streaming services, general smartphone applications, video conferencing (especially following Covid-19) and more.

Teledesic LLC in the late 90s early 2000s attempted to corner the same market with ambitious plans for a $9 billion program to provide global broadband internet coverage with 840 small satellites. Despite gaining early notoriety with high profile investors like Bill Gates, Teledesic only launch two demonstration satellites before closing down, because demand was not yet there and on-ground fibre networks were quickly closing the gap in terms of speed and affordability. In the meantime, satellite delivered internet has remained isolated to specialised applications, such as pricy subscription services on commercial airlines that are delivered by large GEO satellites operated by companies like Intelsat. A combination of similar GEO satellite operators and efficient ground networks brought competition which limited the appeal of satellite phone companies Iridum and Globalstar (that launched around the same time as Teledesic) and consigned them to niche markets.

The new generation of satellite data constellations mentioned above are relying on a trade-off of factors to work in their favour in order to succeed where Teledesic failed 20 years before. Barriers to entry such as high launch and satellite build costs are now lowered, while the functionality that can be packed into the same volume and mass of a satellite has increased. All of this means that more satellites could potentially be launched to LEO/MEO for a similar price to larger GEO satellites, with the added advantage that launching into lower altitudes would reduce signal latency. The market for internet broadband has also considerably improved since the days of Teledesic. However, will this be enough to compete with existing ground networks, which have also improved in the past 20 years?

While Starlink, OneWeb and Kuiper are currently relying on selling receiving terminals to its users, a competing alternative is being proposed by AST SpaceMobile, based in Texas. The US company is developing a satellite constellation designed to instead deliver 2G/3G/4G LTE/5G and NB-IoT (Internet of Things) connectivity direct to smartphones and IoT devices. It is planning to deploy 243 large satellites to LEO and has secured up to US$462 million in financing from investors such as American Tower, Rakuten and Vodafone. AST SpaceMobile is also going public via a merger with a special purpose acquisition company (SPAC). The combined enterprise is valued at $1.4 billion and when the merger is completed it will become a publicly traded company listed on the NASDAQ.[19]

If unsuccessful, these emerging megaconstellations will either disappear entirely or be forced to downsize and cater to niche markets, suffering a similar fate to Iridium and Globalstar. However, if successful, they would further expand the applications potential of the internet and handheld devices like smartphones.

Earth Observation data – The global market for commercial Earth observation (EO) data and services has been projected to reach $8 billion by 2029, growing from $4.6 billion in 2019.[20] One of the first NewSpace satellite companies to receive unicorn status was Planet Labs Inc. The San Francisco based company was also one of the first to introduce the concept of

[19] Martyn Warwick (2020) New 243-strong satellite system will bring 4G and 5G to equatorial regions, Telecom TV
[20] (2020) Earth Observation Data and Services Market, Euroconsult

megaconstellations, utilising the affordability and efficiencies of production of the CubeSatellite platform to operate more than 200 satellites, which provide daily imagery of the Earth. Planet Labs continue to receive investment 10 year on, having secured $168 million in Series D funding in 2019 to further develop their business, as well as core data analytics products. One prominent commercial customer is Google, who signed a multi-year data contract with Planet Labs in 2019.

Despite attracting increased commercial and civil interest, the EO sector has always been dominated by national defence interests – accounting for 64% of the market in 2019.[12] For example, Planet Labs created the subsidiary, Federal Planet, to address the US Federal Government market and signed a contract with the National Reconnaissance Office (NRO), a member of the US Intelligence Community. This defence market is shared by long standing government contractors, such as Airbus Defence and Space, L3 Harris Technologies Inc., PlanetIQ, etc.

There is currently more EO data being produced than most can process. The value of EO data is in the analysis, meaning that end users are interested in what the images mean rather than the images themselves. Moving large volumes of raw EO data between nodes places strain on data networks, there is therefore demand for on-site processing of EO data (either on board the satellite or at major distribution hubs on the ground) before sending lower bandwidth processed data onto intermediaries and end users. This need has led to the development of applications and services that use Artificial Intelligence (AI) and machine learning to process data and relay meaningful information to end users on the status of environments, crop yields and other commodities, transport networks, weather systems, etc. There is also a move to data processing in the cloud.

As processing methods improve, popularity is gaining for Synthetic Aperture Radar (SAR) satellites to work in tandem with, or instead of, multispectral optical satellites. SAR satellites image the Earth using radar rather than the light from the sun. One of the main benefits of SAR over optical EO is it can view the surface of the Earth (or even slightly below) through storms, fog and general cloud cover. SAR spacecraft have traditionally been large because of sizable antennas and the high power demands of the payload. However, with advancements in battery technology and deployable structures, SAR satellites have started becoming miniaturised to the level of small or even cube satellites. For example, ICEYE (Finland) and CapellaSpace (US) have raised $152 million and $82 million respectively to develop small satellite based SAR constellations.

As with other space sectors, such as IoT, there is potential for Unmanned Aerial Vehicles (UAV) to complement EO satellite services. While satellites can give a good general overview of a situation by covering a wide area of land with longer revisit times, UAVs have a narrower field of view, but can be deployed to monitor specific areas more consistently in greater detail.

Internet of Things – Utilising similar advancements in AI and machine learning to those mentioned in the EO section above, NewSpace IoT companies are able to benefit from low cost and low power satellite platforms, such as CubeSatellites, to deliver services based on the networking and transfer of low-bandwidth data from a varying array local and global of sensors. Potential applications include environmental monitoring, agriculture, public infrastructure management and anything related to wide area remote sensing.

Investment in this sector has been comparatively humble, but that's arguably because hardware costs for satellites and sensors, as well as launch costs, can be kept low. This means that the deployment and business case of such systems should be demonstrated soon (in the next 1-2 years), which is especially fast when compared to some of the larger satellite businesses discussed in this section. With applications mainly limited to one's imagination of where to place a sensor, the transformative potential of this industry is considerable.

Communications security – As society's dependence on communications and data increases so does the demand for security against tampering or sabotage. While space-based nodes are away from physical tampering, signals can still be sent to satellites from the ground to interfere with their operations. For example, someone can use a radio transmitter to send a counterfeit GPS signal to a receiver antenna to counter a legitimate GPS satellite signal, in a technique called 'spoofing'. Radio signals can also be used to mask (or jam) a satellite signal with noise. Efforts to protect against and detect these attacks have led to advancements in certain data transfer and encryption technologies, with contributions from public and private research organisations (mostly supported by public investment). Optical communications, where information is transferred via a laser beam as opposed to a radio signal, is a partial solution because most forms of interference would require physically intercepting the beam, which could most likely be detected. Further advancements to this technology have involved quantum key distribution research (QKD) – predominantly pioneered in China, who invested $100 million in their latest QKD Satellite called QUESS.[21] There are also opportunities currently being explored by private companies and agencies like ESA for Blockchain to partner with space to improve security through novel encryption methods.

Space situational awareness – Space Situational Awareness (SSA) refers to the capability of detecting and tracking man-made and natural in-orbit debris, predicting and assessing the risks involved, and providing services enabling the implementation of appropriate mitigation

[21] (2019) Quantum Communications in Space, Commercial Space Technologies

measures.[22] Space debris is a growing concern for the international space community, especially with the advent of megaconstellations like Starlink. The Starlink system currently has 1,200 satellites in orbit, with a potential 30,000 still to go. For context, from 2019 fewer than 9,000 objects had been launched since Sputnik-1 in 1957.[23]

To mitigate the risk of Kessler Syndrome (a worst case scenario where space debris collides and causes more debris in an uncontrolled chain reaction that renders the space environment around the Earth unusable), international and national regulations have been tightening. Most nations now agree to only issue licences to satellites that have a maximum 25 year lifetime and can demonstrate a strategy to either de-orbit of move their satellite into an unused orbit within this time. Meanwhile, nations like the UK require satellites to have active collision avoidance means (like thrusters) when operating above the ISS altitude of ~400km. These regulations are generating new markets for miniaturised satellite propulsion and manoeuvring systems, passive de-orbiting systems like deployable sails, 'active debris removal' services and 'end of life' services. For example, Astroscale Ltd. is developing a satellite service that docks with satellites at the end of their mission life, or with debris, and uses its on-board propulsion to actively de-orbit the object. The company received $51 million in series E funding in 2020[24] and will launch its first demonstrator in March 2021. Astroscale has already started securing contracts from private industry for its end-of-life service, as well as from space agencies like JAXA to remove debris already in orbit. Another example is LeoLabs, that recently announced a commercial partnership with SpaceX to help track their Starlink satellites during their initial deployment and orbital travel with ground-based radar stations.

Lunar economy – Every space faring nation (with Europe included as one under ESA) has a lunar program, with overlaps in their respective timelines over the next 2 to 9 years. This has opened opportunities for the private sector, firstly to hitch a ride on government launches to the moon and to supply communications, monitoring and mapping services to support the development and operation of the infrastructure expected from these national programs. Companies such as Astrobotic and Firefly have won $75.9 million and $93.3 million respectively from NASA contracts to develop landers and deliver NASA payloads to the lunar surface. Both companies, along with others, like PartTime Scientists from Germany, are looking to part fund their projects with commercial revenue and are offering rideshare opportunities to the moon alongside their government customers. Meanwhile, companies like Surrey Satellite Technology Ltd. are developing satellite based lunar communication constellations to enable communications between bases on the moon or between the Earth and the moon.

[22] Space Situational Awareness, PWC
[23] Caleb Henry (2019) SpaceX submits paperwork for 30,000 more Starlink satellites, Space News
[24] (2021) Space Investment Quarterly: Q4 2020, Space Capital

Decline of broadcast television & the rise of in-orbit servicing – Demand for satellite television has been falling (at least in developed markets) as viewing habits have shifted to streaming services like Netflix and Amazon Prime. This change in viewing habits is generational and is therefore likely to intensity. This has put pressure on the Geostationary Orbit (GEO) Communications market that is one of the most commercially prolific sectors of the space industry. In 2010 the Size and Health report estimated that satellite broadcasting made up 68% of downstream space revenues. In the 2018 study this had fallen to 48%. This decline in revenues could prove problematic if Satellite Television services continue to slip, while other emerging markets are still too far in their infancy to fill the gap and maintain growth in the sector.

Uncertainty in areas of the GEO Communications market resulted in a reduction in GEO satellite orders in 2017 and 2018. However, 2019 saw a bounce-back in orders, although with a greater variance in satellite sizes from large high throughput satellites like ViaSat-3 at 6,500kg to small geostationary satellites weighing 2,000 to 3,000 kilograms that emphasize lightweight design and reprogrammability (possibly as a response to changing demands).[25] It is clear that commercial GEO communications operators are still uncertain on the future direction of the market and are pausing or placing different kinds of GEO satellite orders as a consequence. This is understandable considering commitment to a new GEO satellite could range from hundreds of millions to over a billion dollars. Meanwhile, the viability of satellite megaconstellations in low and medium Earth orbits is still to be proven.

The emerging conservative instincts of commercial GEO operators is opening a new potential market for 'in-orbit servicing' missions, which extend the life of satellites already in-orbit through refuelling or supplemented propulsion, thus removing the immediate need to have them replaced. With this in mind, Astroscale acquired Effective Space Solutions (ESS) in 2020. ESS's Space Drone program was focused on servicing the GEO satellite life extension market, which Astroscale is now pursuing, with independent valuations estimating the market will generate more than $4 billion in revenues by 2028.[26]

Terrestrial competition – Roll out of fibre networks and 4G and 5G are providing competition for satellite communications – except in niche markets such as rural areas, on-board commercial airlines and in isolated or challenging regions like the Arctic. Competition for EO, IoT, weather and communications data is also arising from advancements in drone technology and 'high altitude platforms' (HAPs) such as the TAO-Group's Sky Dragon. Drones, however, may prove complementary to satellites in some instances and may even rely on connectivity supplied from

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[25] Caleb Henry (2020) Geostationary satellite orders bouncing back, Space News

[26] Press release (2020) Astroscale U.S. Enters the GEO Satellite Life Extension Market, Astroscale website

satellites to operate. Meanwhile, HAPs are still to convincingly overcome technical issues from high-altitude wind shear and, in the case of high-altitude solar powered UAVs like the Airbus Zephyr, meaningful payload capabilities.

Appendix 4: National space programmes, policies and approaches

China – China's space industry, especially launch, has been almost entirely isolated from international trade because of international restrictions (mainly the US International Traffic in Arms Regulations) and customer concerns around IP infringement. This, however, has not restricted China's aspirations in space. With the second largest civil space budget after the US, China's National Program centres on high profile pride projects such as the Chinese Large Modular Space Station, human lunar missions and a Martian robotics program (its first in-house Mars mission – a combined orbiter, lander and rover, called Tianwen-1 – successfully landed on Mars on 10th February 2021). China's space activities are being enabled by a new family of small to heavy lift Long March launch vehicles, powered by highly advanced Liquid Oxygen/Hydrogen propellant engines. China is now the second most prolific launching nation after the US.

China's increased activities in cyberspace are well recognised by the international community, as are the tight domestic regulations it imposes for internet access, commonly referred to as the 'Great Firewall of China'. It has therefore embraced space both as a means of enhancing and controlling connectivity, taking a global lead in 5G technology and quantum key distribution communications from space. The country has also developed, launched and is now operating an upgraded constellation navigation satellites called BeiDou-3. The 55th satellite that completed the latest constellation was launched in 2020,

Russia – has a shrinking international presence in space. As the primary inheritor of highly advanced launch vehicle technology from the Soviet Union, Russia has failed to build on this heritage. The entry of its new Angara A5 launch vehicle has been plagued by schedule delays, and after almost 20 years in development it only had its second orbital test launch in 2020. With the US now cornering the commercial launch market, Russia has dropped from 1st to 3rd (behind China) in terms of number of annual launches. Further revenue streams from rocket engine sales and exclusive astronaut transit to the International Space Station (ISS) are also slowing and will soon dry up – the latter was costing the American taxpayer an estimated $400 million USD a year. A lot of this has resulted from the US steadily gaining independence on launching national security missions with US built engines (they were previously reliant on the Russian made RD180 engine) and regaining human launch capability to the ISS (previously lost after the retirement of the Shuttle in 2011) through SpaceX and the NASA Commercial Crew Program.

Annual cuts to the Federal Space Budget have also been consistent from 2014 as Russia's economy has suffered from falling oil prices. This has resulted in a number of projects being cancelled, while others have been slowed, such as Russia's development of a new launch site in the far-East, called Vostochny – an effort to remove dependence on human launch from Baikonur spaceport, which is leased from Kazakhstan.

Rather than focusing on expansion, Russia's main efforts have been on preserving the space infrastructure they already have. Ongoing civil and military satellite programs such as, GLONASS (navigation), Elektro-L (meteorology), Gonets (communications) are being replenished, and a few new constellations, such as Arktika (monitoring and communications for the Arctic regions), are being cautiously introduced to protect emerging strategic interests.

USA – before the introduction of the SpaceX Flacon 9, US launch options were limited to a select few long-established government contactors, primarily United Launch Alliance (ULA is a collaboration of Boeing and Lockheed Martin) and Orbital Sciences Corp. (now part of Northrup Grumman). This monopoly on launch resulted in inflated prices for government missions, as well as the US being priced out of the international commercial launch market. This issue was further exacerbated by the conflict between Russia and Ukraine in 2014, which led to the US imposing sanctions on Russia, as well as certain space officials like Dimity Rogozin, head of Roscosmos. Deteriorating diplomatic relations between the US and Russia led to questions over the US dependence on Russian rocket engines to power vehicles such as ULA's Atlas V, which were essential for the launch of US national security missions (such as GPS). This resulted in SpaceX being certified to launch national security missions from 2015.

Meanwhile, SpaceX had had its development and operation of the Falcon 9 launch vehicle partly supported from successive NASA contracts, starting in 2006 with the Commercial Orbital Transportation Services (COTS) contract for $369 million USD. This marked a change in tactics from NASA to pose challenges and award contracts to the private sector, potentially as a result of a steadily decreasing budget and the pricy monopoly on launch mentioned earlier. NASA's commercial contracts have led to the emergence of several new, innovative and competitively priced launch vehicles and ISS crew capsules. Downwards pressure from SpaceX competitive pricing has also resulted in ULA developing a new vehicle called Vulcan, which is aiming to be more cost effective. NASA is now using this broader selection of launch vehicles as a backbone for research support programmes such as the Educational Launch of NanoSatellites (ELaNa), which is an initiative to attract and retain students in STEM subjects.

Other US Department of Defence (DoD) entities, such as the National Reconnaissance Office, the US Air Force and Defence Advanced Research Projects Agency, are also using the opportunity to launch more technology demonstration and research missions on small satellite platforms.

Like China, the US also has strong ambitions for the Moon – not just to return, but to establish a more permanent presence from 2024, as a stepping stone to Mars. These plans are being orchestrated through NASA's Artemis program, with the most sizable budget going towards the state development of a new launch vehicle (despite the success of COTS) and a new lunar crew capsule. Based partly on shuttle technology, this new vehicle is called the Space Launch System and had approximately $2.6 billion assigned to its development in 2020. Meanwhile the new Orion crew capsule had approximately 1.4 $billion assigned to it last year.

The top level breakdown of NASA's $22.6 billion budget for 2020 is in the table below[27]:

General Category	Sub-category	2020 Budget (millions USD)
Deep Space Exploration Systems	Exploration Systems Development Exploration Research & Development	6,017.6
Exploration Technology		1,100.0
LEO and Spaceflight Operations	International Space Station Space Transportation Space and Flight Support (SFS) Commercial LEO Development	4,140.2
Science	Earth Planetary Science James Webb Space Telescope Astrophysics Heliophysics	7,138.9
Aeronautics		783.9
STEM Engagement		120.0
Safety, Security and Mission Services	Mission Services & Capabilities Engineering, Safety, & Operations	2,913.3
Construction and Environmental Compliance and Restoration	Construction of Facilities Environmental Compliance and Restoration	373.4

While NASA's budget has been stagnating, or arguably slipping as a percentage of US GDP, unclassified DoD spending on space is rising, primarily to meet new perceived threats from China and Russia. From $11.8 billion USD in 2019, $15.2 billion was enacted in 2020 for the newly established US Space Forces, which includes $2.4 billion for operations and maintenance, $2.3 billion for procurement and $10.5 billion for RDT&E (research, development, testing and

[27] NASA FY 2021 Budget Estimates

evaluation).[28] US military space budget priorities broadly include research and development of next generation GPS technology, satellite communications, National Security Space Launch (constituting a series of public-private partnerships with commercial launch suppliers, such as Blue Origin, Northrup Grumman and ULA), Enterprise Ground Services (ground systems, missile warning and experimental satellites) and the Space Development Agency (research into new military space capabilities).[29]

Europe – With the space interests of several independent nations partly represented under the banner of the European Space Agency (ESA) and the European Union, there is less of a centralised and connected space programme to speak of for Europe. France; Germany and Italy have sizable unconnected national space programs while is the other major contributor to ESA and does not have a large domestic space programme. While the other national programmes discussed in this list tend to work around a central theme or grand goal, such as human spaceflight to the Moon, Europe's interests remain fragmented by the varying priorities of its member states. For instance, ESA has laid out a vision for a "Moon Village", but the details backing the plan and sources of funding are less clear. This means that larger European ambitions, such as the Moon Village, often have to seek partnerships with other space fairing nations. European programmes (under ESA especially) are otherwise presented as more 'neatly packaged' one-off science missions where budgets, although sizable, can be feasibly drawn from the contributions of member states. One of many examples is the Gaia astronomy mission, a €740 million contribution from ESA members that was launched in 2013 to identify exoplanets, which is still operating today.

This emphasis on near term goals means that ESA spins out a high frequency of big-profile science missions, resulting in prioritising support to the academic community. Its need to fill budget gaps on some of its larger missions also means it encourages and facilitates its member states to collaborate with international partners, which supports both academia and industry. The strategic and defence interests of Europe are meanwhile represented by individual EU programmes, such as Galileo for navigation and Copernicus for remote sensing.

With combined national, ESA and Eumetsat (European Organisation for the Exploitation of Meteorological Satellites, responsible for Copernicus) spending of $3.2 billion, France is the world's fourth-highest space spender and currently tops European national spending. Space situational awareness (SSA) is the priority of the new defence strategy, while completion of the Ariane 6 launcher development in 2020 should put an end to the growth cycle in ESA spending.

[28] Sandra Erwin (2020) Omnibus spending bill gives Space Force its first separate budget, Space News
[29] Sandra Erwin (2019) Military space gets big boost in Pentagon's $750 billion budget plan, Space News

The civil budget is then expected to grow slowly while defence spending should be maintained at current levels before decreasing in the mid-2020s.[30]

India – The majority of India's space activities emanate from the Indian Space Research Organisation (ISRO), which falls directly under the Department of Space. Like several other nations in this list, the Indian Space Program has been used to boost the nation's pride and international profile. The program involves a series of robotic missions and probes to the Moon, Mars, Venus and the Sun, as well as in-orbit astronomy missions and human spaceflight. India has and is developing a range of launch vehicles and advanced cryogenic engine technology to support these ambitions.

India has also found success in commercialising the outcomes of its space agency. A separate government-owned company, called Antrix, was established to commercialise the space products and services developed in ISRO. Through the marketing efforts of Antrix, India's medium lift vehicle, the Polar Satellite Launch Vehicle, has become an internationally respected option for commercial small satellite rideshare launches. There is currently a hand-over of some responsibilities from Antrix to a newly established government-owned company called NewSpace India Ltd (NSIL). This new entity also offers several downstream commercial services, including: TV broadcasting; telecoms and direct to home services - predominantly to India's growing domestic market. Another state sponsored entity, the Indian National Space Promotion and Authorisation Centre (INSPACe) is also in the process of being established, following its announcement in June 2020. As well as commercialising some of the upstream skills and outputs of ISRO, INSPACe will also be responsible for commercialising the usage of spacecraft data and rolling out of space-based services, such as the marketing, sharing and dissemination of remote sensing data.

[30] Simon Seminari (2019) Op-ed | Global government space budgets continues multiyear rebound, Space News

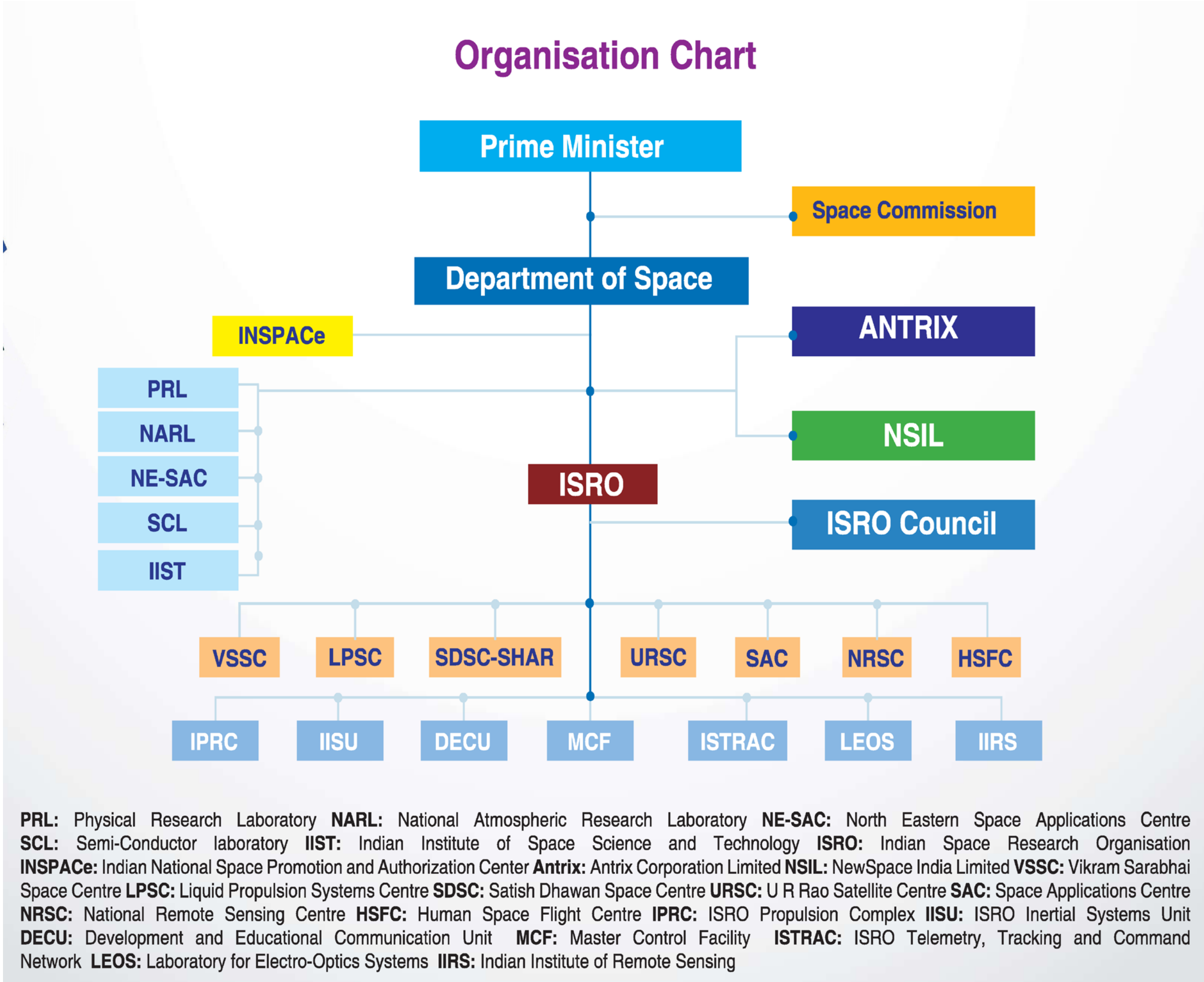

Figure A3.2: Organogram of Indian national space entities[31]

As ISRO and its partnering organisations continue to grow and find success, some employees are starting to form independent commercial companies, such as Skyroot Aerospace Ltd., a small launch vehicle developer, and Dhruva Space Ltd., a small satellite manufacturer – both are winners of India's National Startup Awards 2020 (run by India's Department for the Promotion of Industry and Internal Trade).

Japan – The Japanese space industry is heavily dominated by prime contractors such as Mitsubishi Heavy Industries and IHI Corporation, who have worked closely with the national space agency, JAXA (Japan Aerospace Exploration Agency) to deliver several high profile national and internationally-partnered missions. JAXA has an active space science and exploration program, as well as contributing modules, supplies and astronauts to the ISS.

Despite yielding several science, research and technology advancements, Japan's space industry has remained dominated by heavy industry that has become complacent with the steady stream

[31] Indian Space Research Organisation website – www.isro.gov.in

of projects supplied by JAXA. This has led to high price tags for Japanese space products and services, for example the Japanese HII-A, HII-B and Epsilon launch vehicles rarely launch foreign commercial satellites, despite having a good track record of reliability. Epsilon in particular is well sized to service emerging small satellite markets, but its price remains prohibitive. With mounting stresses on the Japanese economy, JAXA is now under pressure to change this trend and deliver commercial results. The JAXA Space Innovation through Partnership and Co-creation (J-SPARC) initiative was thus formed in 2018, to encourage the formation of private space business. Through J-SPARC, Japanese startups can receive support from JAXA via joint research, technology development, technology demonstration, human resources such as engineers and researchers, and assets such as spacecraft, equipment and/or data. The J-SPARC initiative also supports cooperation with public-private funds such as Development Bank of Japan, access to co-working space and helps companies promote their brand through partners such as PR TIMES Co., Ltd. Notable companies from the initiative include Space BD (working towards commercialising satellite deployment from the Japanese module of the ISS), ALE (looking to commercialise a space debris prevention device) and Gree Inc. (a new business in the VR / AR field using space-related data).

Japan's space expenditures totalled $3.1 billion in 2019, as the budget steadily downsized from 2012's peak of $3.62 billion. However, as programs renew their replenishment cycles, new programs are announced (for example the next-gen High Throughput communications satellite, ETS-3), and existing programs are expanded (Japan's QZSS regional satnav system expanding from four satellites to seven), budget growth is returning. Japan's defence budget is dominated by its Information Gathering Satellite reconnaissance program, representing 72% of its defence space investments. Due to budgetary constraints, Japan's space budget is forecast to grow modestly (2% per year), with stable civil growth and sharper defence fluctuations as military program cycles begin and end.[32]

Conclusions – The national space programmes of the US, Russia and China are all partly reactive to one another. The outcome is the emergence of a new race to the moon between the US and China. Meanwhile, Russia's space industry appears to be stagnating after losing commercial ground to the US on launch, as well as lucrative US contracts. When combined with successive budget cuts from a weakened economy, Russia's national space priorities are mostly focused on preserving and replenishing existing satellite assets. Russia still has valuable space technology and experience, so as its relationship with the West deteriorates it may collaborate more with China on joint space projects.

[32] 32 Simon Seminari (2019) Op-ed | Global government space budgets continues multiyear rebound, Space News

The Indian and Japanese space programs both appear to have a growing interest in commercialising the successes of their respective space programs while continuing their ambitious science, exploration and human spaceflight goals.

Although Europe has a combined space budget to rival most of the world's space faring nations, aligning the priorities of separate countries will always lack the cohesion and focus of a single space program from a single nation, like the US or China. This therefore forces ESA to seek partnerships for grander projects and programs. For example, ESA are already collaborating with Russia, the US, Japan and others on moon missions, all of which are stepping stones towards its aspirations for a Moon Village.

National Space Programs in their nature are focused on strategic or high-profile upstream activities that capture the public's imagination and yield immediate and obvious results. The consequential advancements in science and technology that eventually sink into our everyday lives, however, often go unnoticed, and the routes towards eventual downstream services are hard to predict – but the transformative potential is indisputable when they do. For example, all the smartphone applications that have resulted from GPS, or Google maps and other geospatial applications from US Landsat and EU Copernicus remote sensing data. The continuation of national space programs, and the emergence of newer ambitious programs from China and India, will ultimately see further transformative outcomes in society. With a stronger emphasis on commercial partnership for almost all the major national space programs, these outcomes are likely to reach society faster than ever before.

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