SCEPTRE

Final Report

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Executive Summary

The SCEPTRE project is a commercially-focussed project which investigated the challenges associated with the introduction and operation of commercially viable small-satellite launch services from the UK. The UK Space Innovation and Growth Strategy (IGS) sets out ambitious targets for the growth of the UK space sector, with 'Access to Space' being a key IGS theme. The UK has clearly stated its ambition to become a launching state, with the long term goal of being able to support suborbital operations and orbital delivery of small satellites.

The UK is geographically well situated for launch to Polar and Sun-Synchronous Orbits (SSO), which are in high demand from the growing communications and Earth Observation markets respectively. For reasons of flight safety, the North of Scotland is the only feasible launch region in the British Isles. The SCEPTRE project focuses on one particular model of operation: vertical launch of an imported (US) launch vehicle carrying payloads of up to 300 kg.

Commercial launch is driven by two questions: which orbits are accessible, and what payload mass can be delivered to those orbits at an attractive price? For any given launch site the optimal trajectory is a 'direct launch' without manoeuvres to avoid overflying populated areas. However, for many combinations of launch site and desired orbit it may be necessary to perform manoeuvres to ensure the safety of people located north of Scotland, notably in the Faroe Islands and Iceland, effectively flying around the populated area. Any manoeuvre will reduce the payload that can be placed in a given orbit, consequently, launch sites that require significant manoeuvres will have a lower maximum satellite mass that can be launched into the desired orbits.

In SCEPTRE we have used the Quantitative Risk Assessment method specified by the US authorities (the FAA-AST) to assess the risk to the public of different trajectories. The fundamental approach to assessing risk from a vehicle failure is commonly termed an Expected casualty (Ec) analysis, as it estimates (in a probabilistic sense) the number of casualties resulting from all hazards related to the launch. The FAA-AST require that the expected number of casualties from a launch is less than 10^{-4}.

The site offering the maximum payload mass to orbit is Saxa Vord in the Shetlands, from where direct launch is possible to both SSO and Polar orbits. A site in the Orkney Islands would be next best, followed by the north coast of the mainland. Launch sites in the Hebrides have the highest mass penalty.

Some parameters of the Ec methodology are overly pessimistic, and we have shown that using a more realistic model could allow improved payload performance without compromising safety. Such a 'challenge case' approach would increase the commercial attractiveness of any UK launch site, and may be required to reach a competitive launch price.

Commercial launch is highly driven by cost and availability of launch slots. The market analysis clearly showed that a significant market could exist for a UK launch service. However, there is uncertainty surrounding the future market, as many of the programmes are novel and not yet fully funded. Additionally, the market is largely underpinned by replenishment of the communications 'mega constellations' that a number of organisations, such as OneWeb, are developing. The market is likely to evolve with the proportion of demand for Polar, SSO and other (miscellaneous) high inclination orbit launches changing over time.

SCEPTRE's costs analysis focussed primarily on the indirect costs associated with launch, given that the direct costs (mainly consisting of launch vehicle production) would not be a variable in the analysis. Indirect costs also included all of the personnel (labour) costs associated with planning and preparation activities and also the costs of the launch campaign, considering the costs for both the launch service provider and the payload provider. Our analysis showed that main cost drivers for a UK based operation were likely to be range, export and customs, and compliance with the UK-US Technical Safeguards Agreement (TSA) currently being developed. Range costs are largely driven by the extent of the range capabilities required; a highly significant cost saving can be made by use of autonomous flight termination vs. the 'traditional' approach of radar tracking and remotely-activated flight termination. TSA compliance costs are dominated by the recovery of depleted stages, which will potentially be required. It is clear that the content of the two main UK regulatory and legal frameworks being developed (the launch

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regulatory framework and the TSA) could have a major impact on the potential competitiveness of a UK based launch service.

A number of business case scenarios were developed based on the addressable market forecast and the outputs of the costs analysis. The analysed scenarios combined influential and driving factors in different ways to illustrate how a UK based launch business would probably need to be shaped in order to be competitive in the market, and also allow all parties involved to be profitable in the long term. The competitive benchmarking we performed further confirmed the criticality and negative effect of unfavourable and expensive solutions for the main cost driving factors on the potential competitiveness of a UK based launch service. However, we did conclude that the business case did close for some of the possible launch sites, with the assumption that a launch price equivalent to $35k-$40k/kg needs to be achieved in order to offer a commercially attractive offering to the market.

Conclusions drawn about the most promising sites include:

- The Shetland Isles has the best orbital access, but the remote site means it is logistically the most challenging.
- The Moine peninsula is a large uninhabited area on the north coast of the UK mainland. As a mainland site it has advantages in terms of logistics, but the populations downrange in the Faroes and Iceland constrain the available trajectories and reduce the mass that can be delivered to orbit.
- Scolpaig on North Uist could benefit from MOD Hebrides range infrastructure, but it is not possible to launch to Sun-Synchronous Orbits while meeting the FAA-AST casualty rate requirement (using their parameters for a 'small' launch vehicle), and the trajectories to polar orbit are highly constrained resulting in lower payload mass.

Feasible trajectories with lower mass penalties to both SSO and polar orbit from all sites are achievable with no reduction in safety if the future UK regulatory regime explicitly includes a new class of 'micro' launcher, more closely representative of the size of vehicle proposed for UK operations.

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1. INTRODUCTION

The SCEPTRE project is a commercially-focussed industrial research project to investigate the challenges associated with the introduction and operation of commercially viable small-satellite launch services from the UK.

The UK Space Innovation and Growth Strategy (IGS) sets out ambitious targets for the growth of the UK space sector, with 'Access to Space' being a key IGS theme. The UK has clearly stated its ambition to become a launching state, with the long term goal of being able to support suborbital operations and orbital delivery of small satellites. Previous UK studies have established top level feasibility of vertical launch from northern Scotland. The SCEPTRE project focuses on one particular model of operation: vertical launch of an imported US launch vehicle carrying payloads of up to 500 kg. Within the project we have used the Firefly Alpha as our 'reference vehicle', as it is an example of the vehicle class that could operate from the UK by 2020.

The objective of the SCEPTRE project was to address various topics and issues that have been identified as being in need of further investigation and analysis before committing to a UK launch facility, including:

- Accessible orbits and trajectories: Which orbits can be accessed from a UK launch site? What trajectory must the launcher fly to reach them? What constraints are put on the trajectory by the presence of populated areas downrange? How does this affect the maximum payload delivered to orbit?
- Commercial analysis: What is the market that a UK launch operation could address? What price could be targeted? What are the main cost drivers? Is there a viable business case?
- Site assessment and trade-off: Where should the launch site be located? What are the Strengths, Weaknesses, Opportunities and Threats for different sites?
- Range Facilities, Termination and Abort: What facilities does a UK launch range need? What relevant facilities already exist? How should the UK handle processes including protection of population along the launcher track, and the termination and abort of a malfunctioning flight?
- Inputs to Regulatory Framework: Ensuring that launch activity is performed safely is critical, but the approach taken will directly affect not just the potential success of UK launch operations, but even the feasibility from some locations. The UK needs to take an approach which is streamlined, safe and effective. We make recommendations to the future regulators for how this can be achieved.
- Development: How can a launch site be developed in a way that maximises the benefits brought to the local, regional and national economy?
- Roadmap: What are the steps to be taken to lead to a successful UK launch operation?
- Recommendations
- Conclusions

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1.1. Acronyms and abbreviations

The following acronyms and abbreviations are used in this document:

Table 1: Acronyms and abbreviations

Acronym	Meaning
CFR	(US) Code of Federal Regulations
Ec	Expected number of casualties
EDRS	European Data Relay System
FAA-AST	(US) Federal Aviation Administration Office of Commercial Space Transportation
FTS	Flight Termination System
GNSS	Global Navigation Satellite System
HIE	Highlands and Islands Enterprise
IGS	(Space) Innovation and Growth Strategy
LV	Launch Vehicle
LSP	Launch Service Provider
MOD	(UK) Ministry of Defence
MPA	Marine Protected Area
NSA	National Scenic Area
PO	Polar Orbit
QRA	Quantitative Risk Assessment
SAC	Special Area of Conservation
SLC	Space Launch Complex
SNH	Scottish Natural Heritage
SPA	Special Protection Area
SSO	Sun-Synchronous Orbit
SSSI	Site of Special Scientific Interest
SWOT	Strengths, Weaknesses, Opportunities and Threats
TSA	Technical Safeguards Agreement

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2. PROJECT OUTPUTS

The following table shows the technical documents delivered by the project.

Table 2: Delivered documents from the project

Reference	Code	Title	Issue	Date
[TN-01]	SCEPTRE-DMU-TN-01	Accessible Orbits and Trajectory Analysis	2.2	17 Feb 2017
[TN-02]	SCEPTRE-DMU-TN-02	Range Facilities, Termination and Abort	2.0	08 Feb 2017
[TN-03]	BRDOC-SCP-01	Commercial Report	3	13 Feb 2017
[TN-04]	BRDOC-SCP-02	Roadmap	3	14 Feb 2017
[TN-05]	SCEPTRE-DMU-TN-05	Site Assessment Report	1.2	10 Feb 2017
[TN-06]	SCEPTRE-DMU-TN-06	Inputs to Regulatory Framework	2.0	09 Feb 2017
[TN-07]	SCEPTRE-HIE-TN-07	Development Report	1.0	02 Feb 2017

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3. ACCESSIBLE ORBITS AND TRAJECTORIES

Commercial launch is driven by two questions: which ***orbits*** are accessible, and what payload mass can be delivered to those orbits. In order to compare the desirability of different proposed launch sites, the Accessible Orbits Technical Note [TN-01] considers the maximum payload that could be placed in Polar and Sun-Synchronous orbits (SSO) by a reference Launch Vehicle (LV), from a number of proposed launch sites in the north of Scotland, while ensuring public safety. This is achieved by optimizing the launch ***trajectory***, the route taken from the ground to orbit.

The first part of [TN-01] considers the requirements of different regulatory frameworks that need to be met to ensure that a launch is conducted safely, both in terms of the LV itself as well as site operations. We have used the Quantitative Risk Assessment (QRA) method specified by the US authorities (the FAA-AST) to assess the risk to the public of different trajectories in this project. The fundamental approach to assessing risk from a vehicle failure is commonly termed an Expected casualty (Ec) analysis, as it estimates (in a probabilistic sense) the number of casualties resulting from all hazards related to the launch. The FAA-AST require that the expected number of casualties (Ec) from a launch is less than 10^{-4}, and we have used this value as the limit of acceptable trajectories.

In order to ensure the safety of the populations located north of Scotland, notably the Faroe Islands and Iceland, some launch trajectories require the LV to perform a 'dog-leg' manoeuvre, effectively flying around the population as illustrated in Figure 1 and Figure 2. Any manoeuvre will reduce the payload that can be placed in a given orbit. Consequently, launch sites that require significant manoeuvres will be compromised in terms of the maximum mass of satellites that can be launched in to the most desired orbits. Sites which offer direct trajectories (without manoeuvres) therefore offer maximum market access potential.

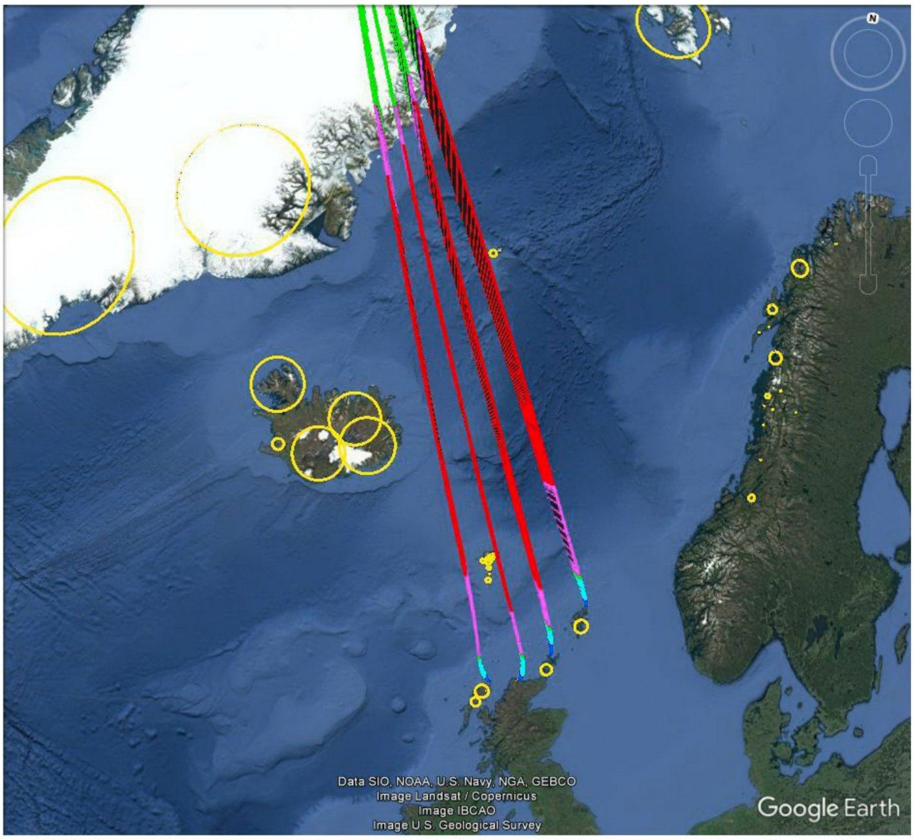

Figure 1: Trajectories from different locations to SSO using dog-leg manoeuvres to reduce risk where required

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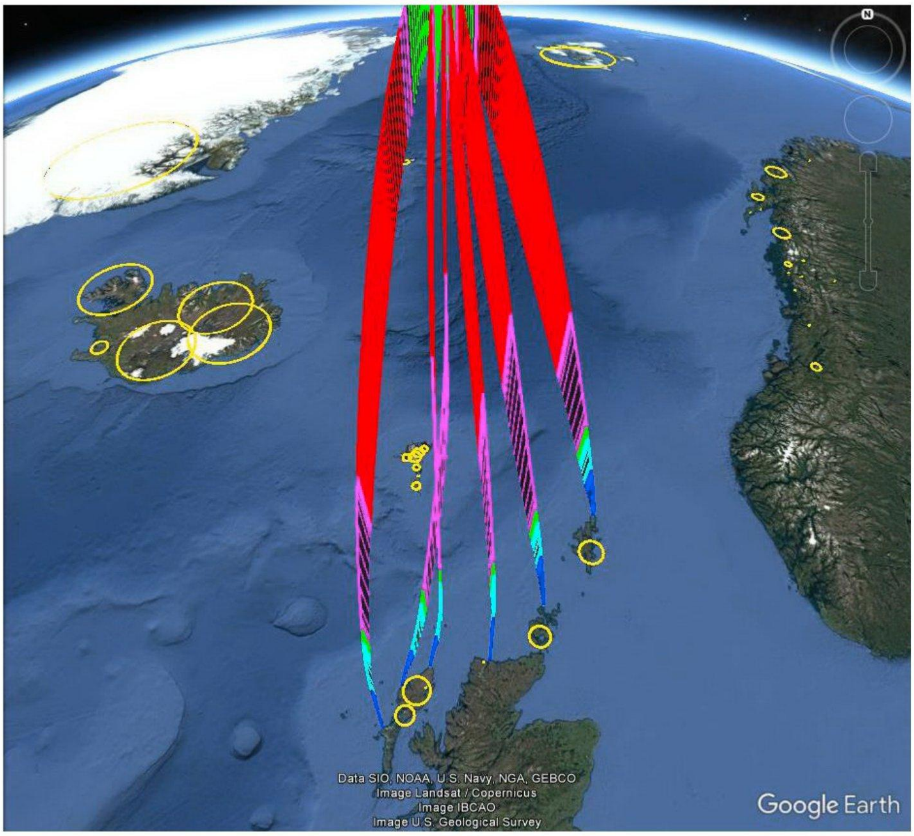

Figure 2: Trajectories from different locations to polar orbit using dog-leg manoeuvres to reduce risk where required

The analysis shows that, in general, launches can be directly into the desired orbits from the sites further to the east, and so they have higher achievable payloads. From the more westerly sites, the presence of populated areas downrange, particularly the Faroe Islands and Iceland, means that manoeuvres are required to meet maximum risk levels. Furthermore, there no trajectories to one or more of the target orbits which are compliant with the FAA requirements from the most westerly launch sites. Figure 3 presents a top-level summary of the payload that could safely be placed in SSO and polar orbit by the study reference vehicle from six candidate launch sites compared with the direct trajectories. Where no trajectory is able to meet the FAA expected casualty rate requirement, zero payload is shown.

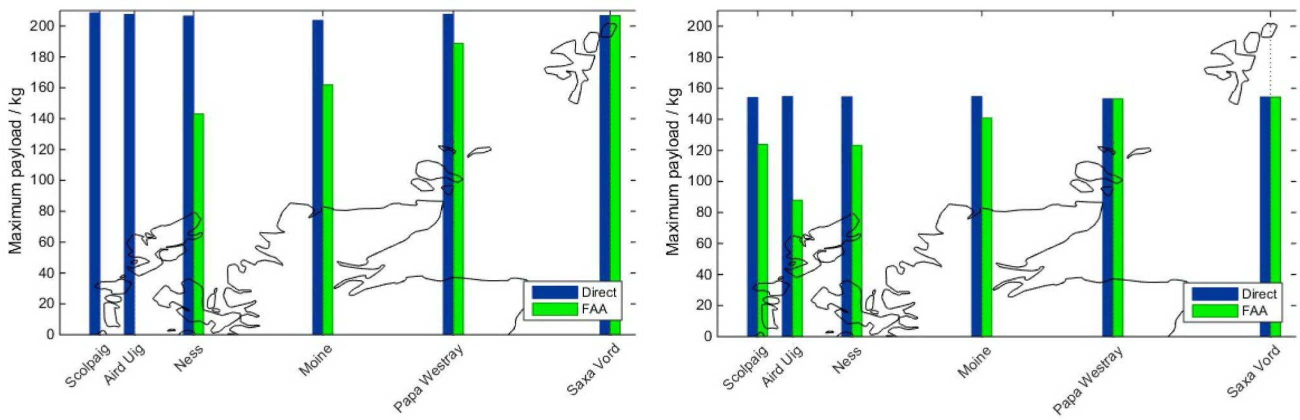

Figure 3: Maximum payloads before and after manoeuvres from candidate launch sites for launch to 500 km SSO (left) and 1000 km Polar orbits (right)

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The site offering the maximum payload mass to orbit is Saxa Vord in the Shetlands, from where direct launch is possible to both SSO and Polar orbits. A site in the Orkney Islands would be next best, followed by the north coast of the mainland. Launch sites in the Hebrides have the highest mass penalty.

Some parameters of the Quantitative Risk Assessment methodology used to model expected casualty rates could be challenged. The method parameterizes vehicle characteristics according to the class of the vehicle, which is defined by payload size. Using characteristics of the actual launch vehicle will result in a less pessimistic model that potentially is able to increase the payload performance of the vehicle without increasing the risk to downrange populations. Performing a sensitivity analysis on some of the vehicle parameters demonstrates how the regulatory framework could increase the commercial attractiveness, or even viability, of vertical launch from any of the candidate sites, but especially those in the Hebrides.

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4. COMMERCIAL ANALYSIS

The commercial analysis carried out as part of the SCEPTRE project is described in detail in [TN-03]. Four main commercial elements were addressed:

- **Market Assessment and Forecasting**: Analysing the potential market for the type of service which was project was target at, and determining how much of that market could be addressable and captured by a UK based operation
- **Costs Analysis**: Capturing and, as far as possible, quantifying all of the costs associated with a launch service and operation, for both US and UK based operations, whilst also identifying key cost drivers and differentiators between US and UK environments
- **Business Case Analysis**: Defining and analysing multiple scenarios to determine what a commercially successful UK based launch service would need to look like, with different solutions to the key cost drivers and business case 'make or break' factors considered and analysed.
- **Competitive Analysis**: Considering how a UK based launch operation would need be shaped in order to be competitive against other current and future global launch offerings, taking bench marks in to consideration

4.1. Market assessment and forecast

The global market forecast for small satellites of the size and mass applicable was determined by considering multiple sources, including SSTL and Firefly Space System's own actual prospect lists. The potential addressable market was then determined by considering orbit inclinations accessible from the regions considered, political and market factors, and also the performance capabilities of the reference vehicle. Figure 4 shows the global market forecast and Table 3 shows how this was translated in to an addressable market forecast in terms of launches per year for UK based service.

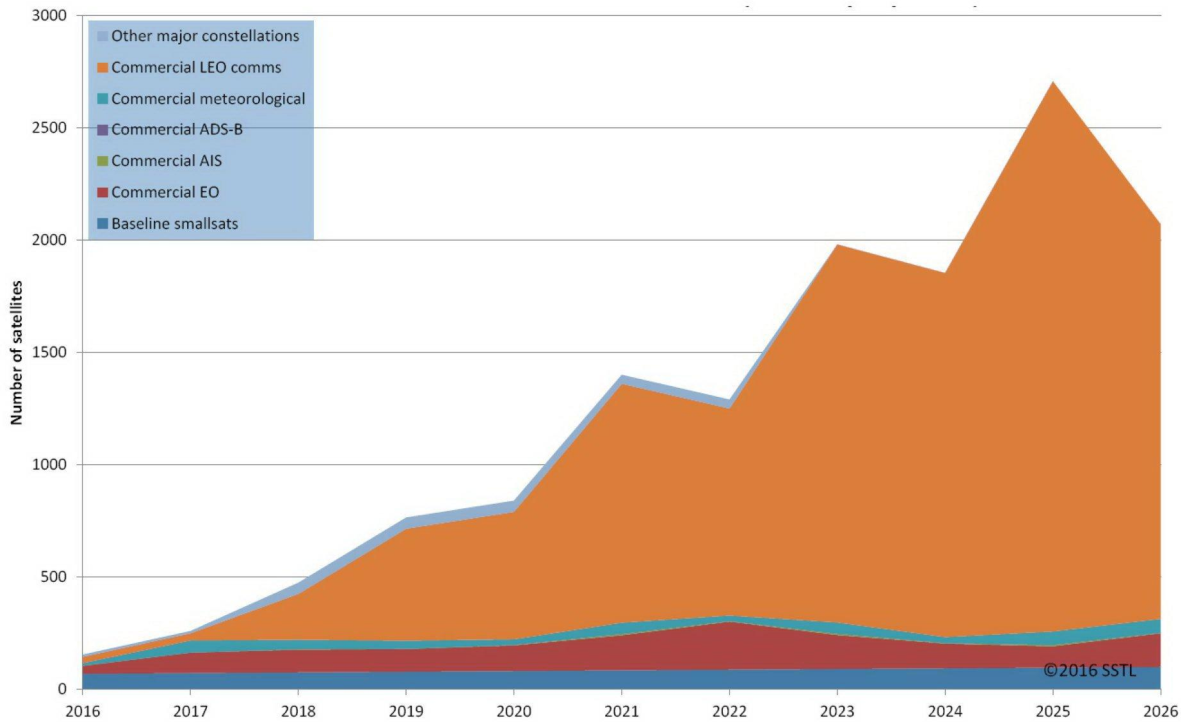

Figure 4: SSTL's global market forecast for small satellites (known proposals)

Table 3: Addressable market forecast for a UK based launch service

	2019			2020			2021			2022			2023			2024			2025			2026			2027		
	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified	Polar	SSO	Unspecified
	2	5	5	2	5	5	2	5	5	2	5	5	11	5	1	11	4	1	41	4	1	41	4	1	41	4	1
Total launches	12			12			12			12			17			16			45			45			45		

The market analysis clearly showed that a significant market could exist for a UK launch service. However, there is significant uncertainty surrounding the future market, as many of the programmes and initiatives which constitute the future markets are novel, and/or not yet fully funded. Additionally, the market is largely underpinned by one of the 'sub markets' identified, being the replenishment of satellites constituting the communications 'mega constellations' that a number of organisations, such as OneWeb, are proposing and/or developing. Failure of this market, or the lack of its emergence, could significantly impact the addressable market potential for a UK based launch service.

The market analysis also showed that the market is likely to evolve with the proportion of demand for Polar, SSO and other (miscellaneous) high inclination orbit launches changing over time. This is illustrated in Figure 5, and again is heavily influenced by the overall dominance of the 'mega constellation' replenishment launch demand which is expected to emerge in ~2023, if the associated programmes and projects go ahead. This split in orbit market demand is significant, as the accessible orbits and trajectories work (summarised in section 3) has clearly shown that some potential sites are better suited to SSO launch than polar launch, due to the likely manoeuvres associated with each. Should the market develop significantly in 'best case' scenario, there could well be a case for developing multiple launch sites to service the SSO and Polar orbits respectively (separately).

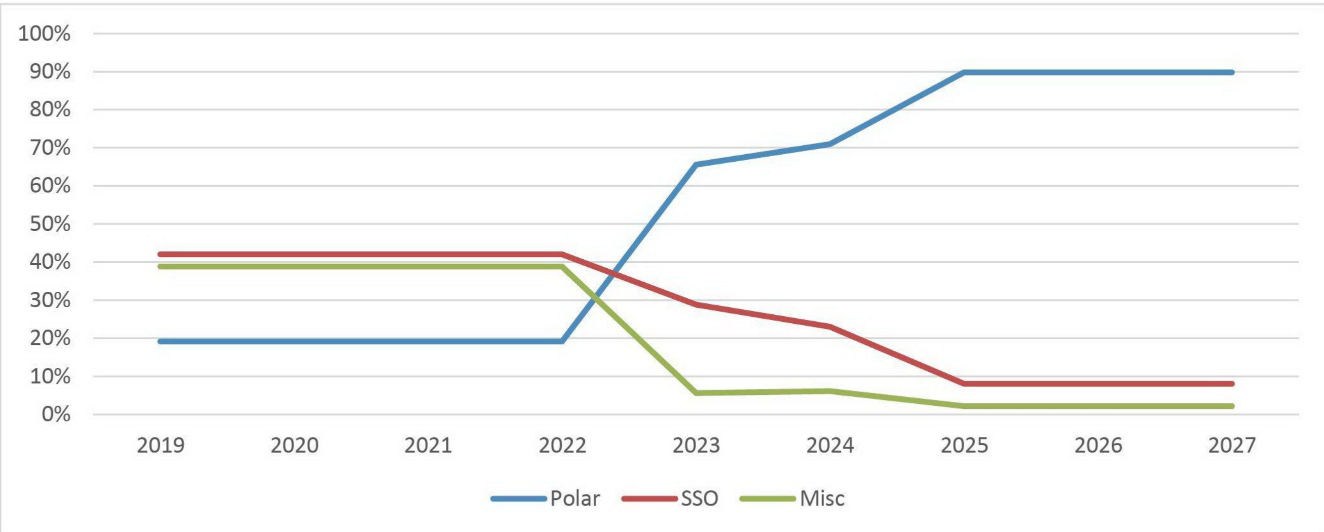

Figure 5: Evolution of dominant launch sub-markets from SSO to Polar orbits

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4.2. Costs analysis

A detailed analysis of launch and launch related costs was performed, with the aim of capturing, understanding and reliably quantifying all costs associated with launch. This included the costs borne by all parties involved, including the Launch Service Provider (LSP), Launch Site Operator, and payload (satellite) provider.

Firefly Space Systems and SSTL provided the majority of the information to support the costs analysis, with SSTL providing historical information based on their actual costs associated with launching over 45 satellites from various locations and with various vehicles over a 30 year period. Firefly Space Systems were the main source of costs associated with the launch vehicle and service. For other indirect costs such as the provision of range capabilities and also the provision of propellants, providers of those items (e.g. QinetiQ for range) were consulted directly.

The costs analysis focussed primarily on the indirect costs associated with launch, as (a) the direct costs (mainly consisting of launch vehicle production) would not be a variable in the analysis, and (b) the indirect costs are often less considered and less obvious, whilst in fact likely contributing most to the price competitiveness of a UK based service versus and equivalent service based in the US, or any other country. Indirect costs also included all of the personnel (labour) costs associated with planning and preparation activities and also the costs of the launch campaign, considering the costs for both LSP and payload provider.

The cost analysis considered a number of cases, which analysed different combinations of key factors such as:

- Where the launch service was based (UK or US)
- Where the payload supplier was based (UK or non UK)
- Which approach was adopted to Tracking, Termination and Abort (FTS - either a traditional ground/radar based solution or a more advanced autonomous & space based solution)

The cases showed clearly which combination of variables would likely result in the most attractive option for a customer. A summary of the cases and costs calculated is shown in Table 4.

Table 4: Summary of indirect launch costs

Payload	Launch site	FTS	LSP indirect costs	Payload provider indirect costs	Total indirect costs
UK	US	Traditional	£816,150	£425,500	£1,241,650
UK	US	Autonomous	£572,400	£425,500	£997,900
UK	UK	Traditional	£1,189,511	£317,500	£1,507,011
UK	UK	Autonomous	£953,511	£317,500	£1,271,011
Non-UK/US	UK	Traditional	£1,189,511	£342,000	£1,531,511
Non-UK/US	UK	Autonomous	£822,511	£342,000	£1,164,511

Further analysis was performed to determine cost drivers for a UK and US based launch service. The results are shown in Figure 6. Equivalent cost categories for LSP and payload provider are combined, for example the costs for shipping include the cost of shipping the satellite (and all supporting equipment) from the UK to the US in the first two cases, and the cost of shipping the launcher from the US to the UK in the last two cases.

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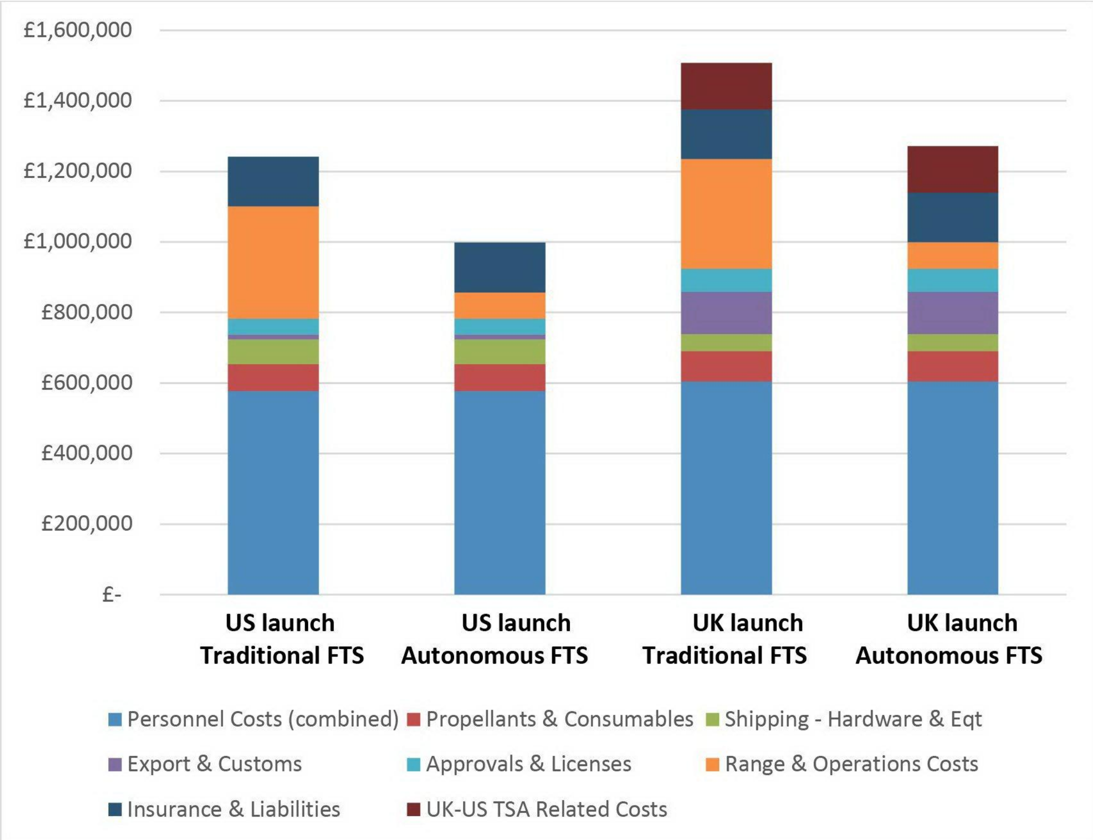

Figure 6: Cost drivers for each of the analysed launch cases with UK payloads

The analysis showed clearly that main cost drivers for a UK based operation were likely to be:

- Range costs, driven by the nature of the approach taken (traditional or autonomous/space based), and the extent of the range capabilities required
- Export and Customs costs, and those associated with compliance to the assumed requirements of the UK-US Technical Safeguards Agreement, dominated by the recovery of depleted stages. (These are the most significant extra costs in launching from the UK compared to launching from the US.)

It was therefore clear that the content of the two main UK regulatory and legal frameworks being developed (the launch regulatory framework and the TSA) could have a major impact on the potential competitiveness of a UK based launch service.

4.3. Business case analysis and modelling

A number of business case scenarios were developed based on the addressable market forecast and the outputs of the costs analysis. The analysed scenarios combined different influential and driving factors in different ways to illustrated how a UK based launch business would probably need to be shaped in order to be competitive in the market, and also allow all parties involved to be profitable in the long term.

The main variables applied in the different scenarios included:

- Maturity of the LSP at time of UK service introduction – affecting the direct costs per launch, which directly impacts LSP gross profit per launch
- Amortisation of LSP (vehicle) development costs – whether from UK launches only or from LSP global launch operations
- Launch price, taking market expectations and competing services in to account

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- Range costs, driven by approach taken
- Market size – driven by different outcomes of market evolution as described in 4.1
- Approach taken to amortisation of up front development costs for the UK parties

Nominal Cases considered scenarios where the driving costs (indirect and direct) were favourable overall with minimal amortisation of development costs charged to the LSP/Launch Site Operator. A 'best case' was modelled which assumed high level of market access, and low indirect and direct costs allowing the LSP to charge a very competitive launch price. Two 'worst' cases were also modelled, which considered scenarios where very high indirect costs were charged by the site and operator, amortisation of site and infrastructure development costs were charged, and a very high cost traditional range infrastructure was utilised. These cases also considered the impact of high pricing (resulting from the high indirect costs) and its negative effects on market capture. Figure 7 and Figure 8 show cashflow projections for the analysed scenarios, for both the LSP and Service/Site Operator.

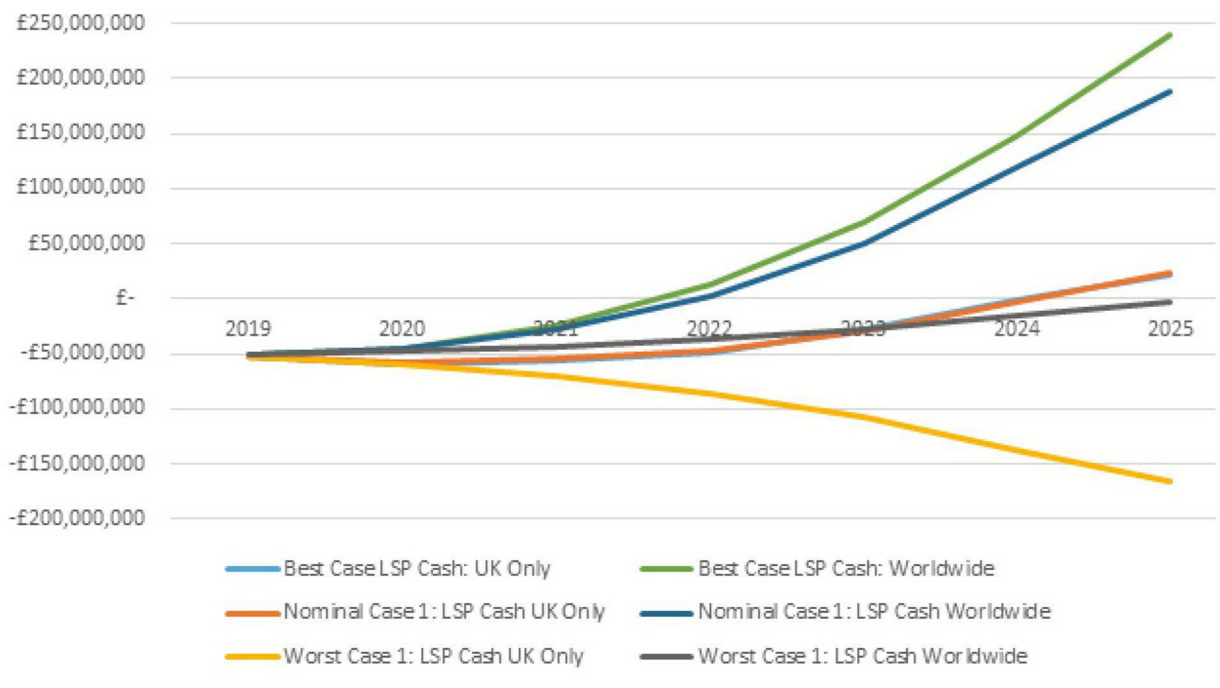

Figure 7: Cash position for LSP for analysed scenarios (LSP UK and worldwide cashflow)

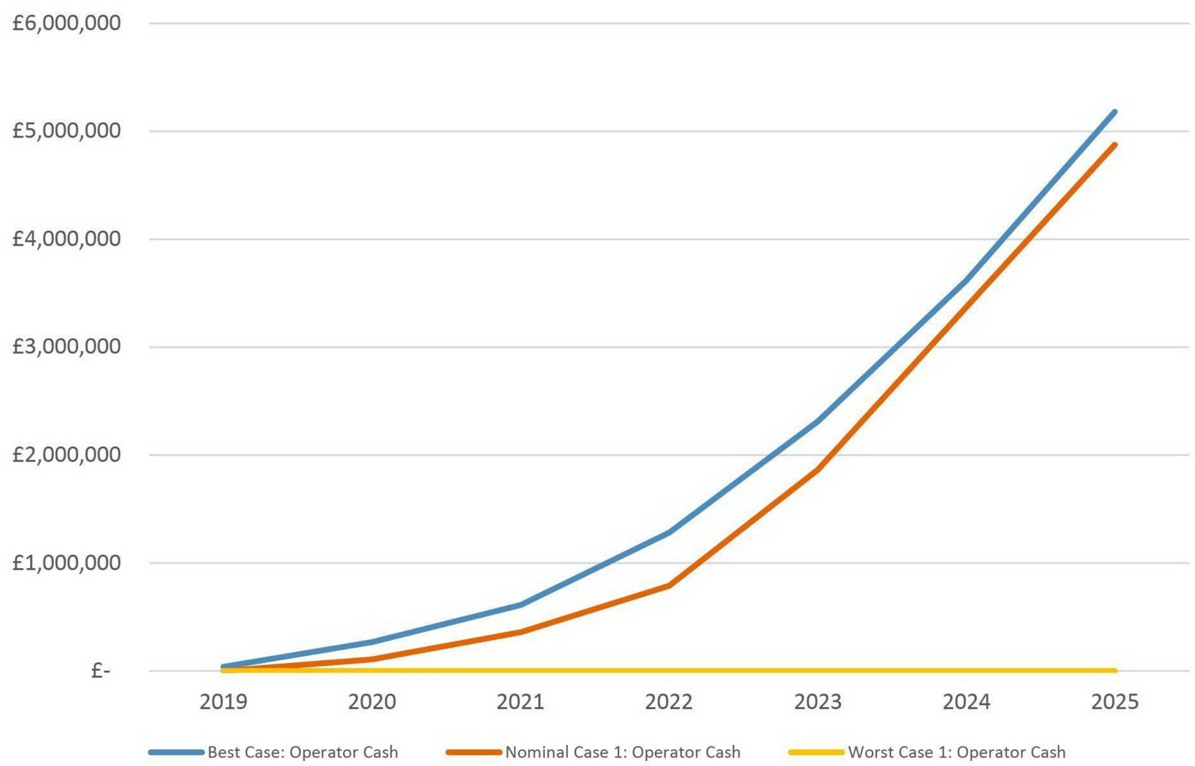

Figure 8: Cash position for Spaceport Operator over 7 years for analysed scenarios

The business case analysis clearly showed which factors were most influential in determining whether a business case could close for all parties or not. The most dominant variable was LSP maturity, which was essentially a measure of (a) how many launches an LSP had conducted successfully prior to starting UK operations, and (b) if, and how well economies of scale in launch vehicle production costs had been achieved at time of UK service introduction. ***Amongst the factors and associated costs driven entirely by the UK parties, the site and range development amortisation and per launch range costs dominate.*** For an immature LSP whose direct costs were still constituting a major proportion of the launch selling price, high indirect costs associated with range and amortisation costs could easily make or break a business case. The most attractive and long term commercially successful business for all parties (including the local economy and wider beneficiaries), would feature a mature LSP and lowest possible indirect costs, consistent with minimal or zero direct amortisation costs passed to the LSP/operator, and an autonomous/space based range approach and architecture. This combination of factors would allow low launch pricing and therefore high contract win success, fast economic growth for all concerned and good profitability for all entities in the value chain.

4.4. Market competitiveness and benchmarking

Outputs from the cost analysis and business case analysis were used to determine the likely competitiveness of potential UK based launch service offerings to the market, considering:

- Launch price benchmarks from the small satellite industry (declared/published launch prices of competitors and known historical prices paid),
- The mass deliverable to the orbits required by the market by the reference launch vehicle from the different potential sites considered,
- The cost drivers identified and how they may be influenced by different factors such as LSP maturity, approach to development costs amortisation and range solutions.

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It was possible to calculate a 'break even' launch price corresponding to different combinations of the factors considered and the associated costs. The launch price for each scenario could then be compared with the market rate for an equivalent service. The combinations are detailed in [TN-03]. Scenario 1 corresponds to highest possible indirect costs of range, high TSA compliance costs, low LV maturity and inclusion of amortisation of all development costs. Scenario 16 assumes the opposite. Other scenarios include some favourable and some not so favourable conditions. Table 5 shows the selected results for the sites downselected. A traffic light colour coding key is applied to indicate which combinations would be competitive in the market or not.

Table 5: Break-even launch prices corresponding to different combinations of cost driving factors under a regulatory framework designed to support 'micro' launchers

Scenario	Site	SSO (Challenge Case Applied)				Polar (Challenge Case Applied)			
		Mass to orbit	Break Even Price	$/kg achieved	SSO Market Delta	Mass to orbit	Break Even Price	$/kg achieved	Polar Market Delta
1	Scolpaig	204	£9,250,001	$60,368	180%	130	£9,250,001	$95,133	204%
1	Aird Uig	202	£9,250,001	$61,015	182%	116	£9,250,001	$106,699	229%
1	Ness	183	£9,250,001	$67,440	201%	127	£9,250,001	$97,170	209%
1	Moine	173	£9,250,001	$71,145	212%	147	£9,250,001	$84,163	181%
1	Papa Westray	189	£9,250,001	$65,354	195%	153	£9,250,001	$80,526	173%
1	Saxa Vord	207	£9,250,001	$59,658	178%	154	£9,250,001	$79,928	172%
8	Scolpaig	204	£6,070,816	$39,620	118%	130	£6,070,816	$62,436	134%
8	Aird Uig	202	£6,070,816	$40,045	120%	116	£6,070,816	$70,027	151%
8	Ness	183	£6,070,816	$44,261	132%	127	£6,070,816	$63,773	137%
8	Moine	173	£6,070,816	$46,693	139%	147	£6,070,816	$55,236	119%
8	Papa Westray	189	£6,070,816	$42,892	128%	153	£6,070,816	$52,849	114%
8	Saxa Vord	207	£6,070,816	$39,154	117%	154	£6,070,816	$52,457	113%
12	Scolpaig	204	£5,320,816	$34,725	104%	130	£5,320,816	$54,723	118%
12	Aird Uig	202	£5,320,816	$35,098	105%	116	£5,320,816	$61,375	132%
12	Ness	183	£5,320,816	$38,793	116%	127	£5,320,816	$55,894	120%
12	Moine	173	£5,320,816	$40,924	122%	147	£5,320,816	$48,412	104%
12	Papa Westray	189	£5,320,816	$37,593	112%	153	£5,320,816	$46,320	100%
12	Saxa Vord	207	£5,320,816	$34,317	102%	154	£5,320,816	$45,976	99%
16	Scolpaig	204	£4,320,816	$28,199	84%	130	£4,320,816	$44,438	96%
16	Aird Uig	202	£4,320,816	$28,501	85%	116	£4,320,816	$49,840	107%
16	Ness	183	£4,320,816	$31,502	94%	127	£4,320,816	$45,390	98%
16	Moine	173	£4,320,816	$33,233	99%	147	£4,320,816	$39,314	84%
16	Papa Westray	189	£4,320,816	$30,528	91%	153	£4,320,816	$37,615	81%
16	Saxa Vord	207	£4,320,816	$27,867	83%	154	£4,320,816	$37,336	80%

Table 5 considered the 'challenge case' for flight safety and flight corridor definitions, as defined and analysis in the orbits and trajectories work. The fully compliant case (according to FAA definitions for launch vehicles larger than the reference vehicle) was also analysed – this showed that most sites would find it even more difficult to support a market competitive launch service if those regulations were applied 'as is'.

The competitive benchmarking summarised above further confirmed the criticality and negative effect of unfavourable and expensive solutions for the main cost driving factors on the potential competitiveness of a UK based launch service.

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5. SITE ASSESSMENT AND TRADE-OFF

Developing a UK site for satellite launch will require down-selecting to one or more specific location(s) before detailed design and construction work can start. One of the objectives of the SCEPTRE project was to support the selection process by analysing the different possible locations with a trade-off covering all relevant criteria.

Given that launch vehicles cannot overfly populated areas, and considering the geography of the UK and its surroundings, together with the physics of spaceflight, it is clear that a UK launch site would have to be at a coastal location in northern Scotland, either on the mainland or an island.

In [TN-05] a trade-off and assessment of different sites was performed, considering a number of important criteria:

- Site geography: What coastal sites are available with a large enough area of relatively flat land to host a launch site?
- Accessible orbits: Which orbits could be accessed from each site, considering orbital mechanics and safety aspects?
- Population: Who would be impacted by the launch site? We consider population resident within the launch site itself, who would have to be moved, and people in the wider area who could suffer occasional disruption.
- Environmental considerations: The north of Scotland is home to many wonderful plants, animals and birds, some of which are rare, endangered or vulnerable. We consider whether launch sites may affect protected areas including Sites of Special Scientific Interest, Special Areas of Conservation (SACs) and Special Protection Areas (SPAs).
- Access and infrastructure: Accessibility issues considered include such as transport of the launch vehicle, payload and personnel by road, sea and air. We also look at infrastructure matters such as the availability of electricity and water at the sites, and the local amenities which could support a launch campaign.
- Weather: The north of Scotland can be windy and wet. Could the conditions have an impact on the viability of a launch site?
- Development potential: Which spaceport locations would bring the most economic benefit? What are the local political considerations regarding locating a spaceport in different areas?

To make the assessment more concrete, we picked a number of sites roughly equally spaced across northern Scotland (including the north coast of the Outer Hebrides, mainland Scotland and the Orkney and Shetland Islands) and assessed their viability as launch sites through a formal trade-off process. To the largest extent possible we have picked ‘plausible’ launch sites, i.e. north-facing coastal locations which are an acceptable distance from any settlements. The different sites considered are shown in Figure 9.

The objective of looking at a large number of sites is to show how the different criteria vary along the coast. While this is relatively straightforward for ‘continuous’ quantities like mass to orbit, it is, of course, more challenging for discrete ones like environmental impact and development potential. However, the exercise as a whole forms a picture of various strengths and issues that is likely to be important in those considering development of any such site.

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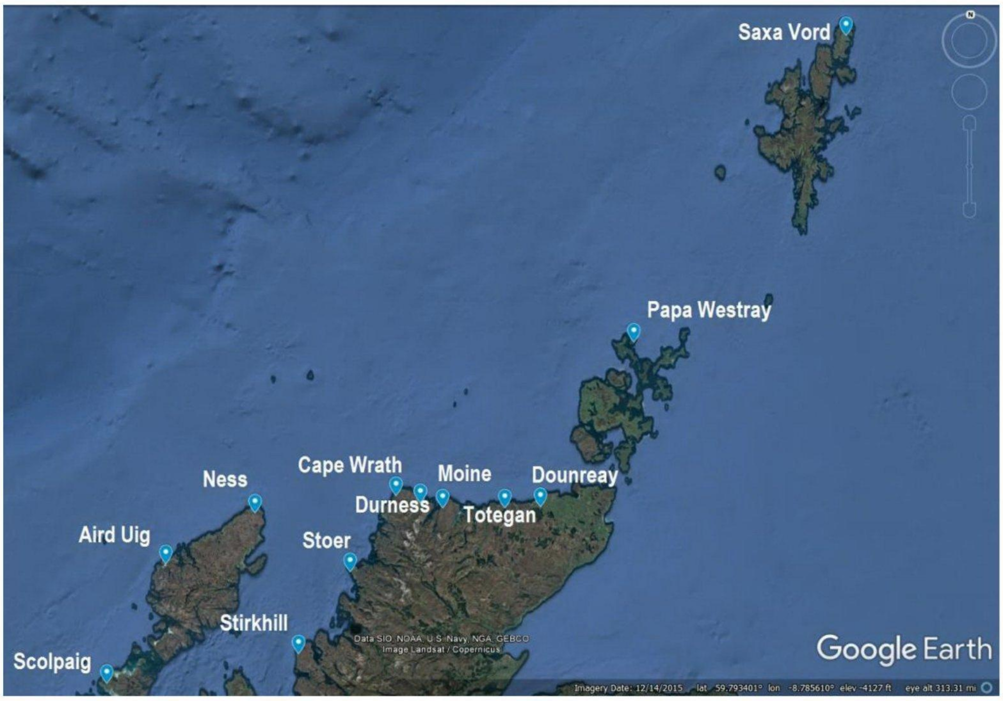

Figure 9: Example launch sites

Conclusions drawn about the most promising sites include:

- The Shetland Isles has the best orbital access, but the remote site means it is logistically the most challenging.
- The Moine peninsula is a large uninhabited area on the north coast of the UK mainland. As a mainland site it has advantages in terms of logistics, but the populations downrange in the Faroes and Iceland constrain the available trajectories and reduce the mass that can be delivered to orbit.
- Scolpaig on North Uist could benefit from MOD Hebrides range infrastructure, but it is not possible to launch to Sun-Synchronous Orbits while meeting the FAA-AST casualty rate requirement, and the trajectories to polar orbit are highly constrained resulting in lower payload mass.
- Other sites could be considered, including the island of Lewis in the Hebrides, mainland sites such as Totegan, Durness or Cape Wrath, or a site in the Orkney Isles. Although these each have their advantages, none appear so favourable as the first three.

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6. RANGE FACILITIES, TERMINATION AND ABORT

A launch range needs to have the infrastructure and facilities to fulfil five critical functions:

1. Tracking: determining the position of the vehicle during flight, which can be done by radar tracking from the ground, satellite navigation (GNSS) signals received on board, or by inertial navigation on board
2. Telemetry and telecommand: getting data from the vehicle to the ground, and (if necessary) commands from the ground to the vehicle
3. Termination of a malfunctioning flight before it endangers the population
4. Monitoring sea- and airspace to ensure that it is empty before launch
5. Management of the entire process

The overall architecture required for a system to address all of these requirements is discussed in [TN-02], looking at two approaches:

- Conventional architecture used on existing launch ranges, using land- or sea-based radar stations to track the LV, ground-based antennae to communicate with it, and a man-in-the-loop flight termination system.
- Space-based range architecture enabled by modern navigation and communications technology, using GNSS for tracking and satellite communication such as EDRS.

Existing infrastructure in the UK is reviewed. Some existing equipment could partially fulfil these requirements, particularly for launch sites near to the MOD Hebrides range, but no site in the UK already has all of the capability required.

The range infrastructure is one of the cost drivers for a launch system. The capital costs required to put in place different range systems are estimated, as shown in Table 6.

Table 6: Total capital cost estimates for different range configuration options

Option	Lower bound	Upper bound
Basic capability, conventional architecture, close to the MOD Hebrides range	£3M	£9.5M
Higher capability, conventional architecture, close to the MOD Hebrides range	£5.75M	£15M
Basic capability, conventional architecture, distant from the Hebrides	£4.5M	£15M
Higher capability, conventional architecture, distant from the Hebrides	£7.75M	£21.5M
Higher capability, conventional architecture, including new ship-based radar	£36.5M	
Space-based architecture, close to the MOD Hebrides range	0	£0.5M
Space-based architecture, distant from the Hebrides	£0.25M	£3.5M

The ground-based range would also be more expensive to operate, requiring more manpower for each launch. The operational costs are estimated at £300k per launch for a traditional ground-based range, and £75k per launch for a space-based range.

Using in-space assets and modern technologies has the potential to be a more cost effective approach than that used on existing launch sites, without compromising safety. For this reason, all new launch vehicles being developed are intending to make use of them. With little existing capability, the UK has the opportunity to develop a world class range, taking advantages of the best-practise developments being made in space based infrastructure.

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7. INPUTS TO REGULATORY FRAMEWORK

The regulatory framework that ensures that space launch activity in the UK is performed safely will directly affect not just the potential success of such operations, but even the feasibility from some locations. One of the outputs from the SCEPTRE project was a set of inputs to the process of developing the regulatory framework to be used for UK launch, presented in [TN-06]. Our key conclusion is that the UK must develop a regulatory framework which is streamlined, safe and effective.

The first part of [TN-06] reviews the key aspects of contemporary space legislative frameworks from other countries around the world, considering how they could be best applied to the UK. A general framework that would be suitable for the UK is proposed, as shown in Figure 10.

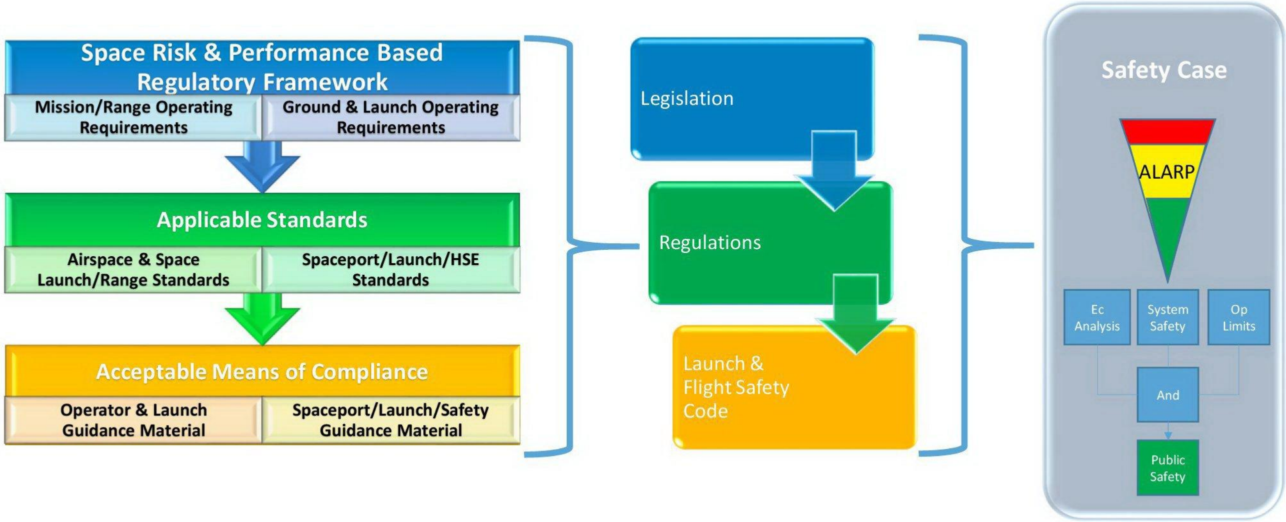

Figure 10: Proposed UK regulatory framework architecture with parallel streams for spaceport and launch regulations

The impacts of regulatory decisions on launch costs are discussed. Additional requirements of operating a non-UK vehicle from the UK would include import/export controls and any technical safeguards required by agreements such as the UK-US TSA. A particular concern is a potential requirement to retrieve spent stages from the Norwegian Sea. The key finding of this section is that, based on the model of importing a US launch vehicle, the cost of export controls and additional technical safeguards is expected to significantly increase the cost of a UK launch operation compared with an American launch of the same vehicle.

Aspects relating to the regulation of the launch itself are then discussed. The regulations which determine how the risk to downrange populations must be calculated are shown to have a large impact on the commercial competitiveness of different potential launch sites. Existing regulations are all written for much larger launch vehicles than those being considered for UK operation; some suggestions as to how a UK regulatory framework could be designed to support 'micro' launchers (with payloads up to 500 kg) are made. Furthermore, it is strongly recommended that further detailed analysis of the expected casualty rate calculation is undertaken.

Finally, an overview of the regulations pertaining to the operation and infrastructure required by any future spaceport is discussed. The range costs are strongly driven by the required infrastructure used to assure the safe operation of a vehicle during launch. It is shown that these costs have a large impact on the commercial competitiveness of different sites. Depending on the form of future regulation relating to the range architecture, the commercial feasibility of potential sites could be jeopardised. Modern range architectures using space-based positioning and autonomous flight safety systems have the potential to be the most cost effective approach without compromising safety and are being adopted by US ranges to reduce costs. Therefore, another key recommendation is that the regulatory framework should enable the adoption of modern space-based range architectures.

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8. DEVELOPMENT

Building a launch site in the north of Scotland would be a significant commercial undertaking, bringing welcome jobs and visitors as well as significant knock-on benefits. The factors affecting the establishment and development of such a facility are discussed in [TN-07].

The first part of [TN-07] addresses the regional variations from issues around the different legislative powers that are developed to Scotland and down to the various levels of government bodies that are likely to be encountered in establishing a successful vertical launch facility.

The report notes that while the UK Parliament leads on the legislation to enable space transport to be used in the United Kingdom, there are significant powers that are devolved to the Scottish Parliament. These specifically include the matters of Environment and Land use planning (led in Scotland by the relevant local authority). It suggests that while UK legislation will be taken forward through the Modern Transport Bill it would not be expected that the UK Parliament would legislate on these matters that affected Scotland without the consent of the Scottish Parliament. It is noted that both Scottish Natural Heritage and Scottish Environmental Protection Agency will need to be consulted prior to any application being considered. Thought should be given to how any licensing arrangement with UK Space Agency would engage with these relevant bodies.

The mood and appetite of the local community can have a significant impact on the success of a project and the report notes that the vertical launch facility would be no exception. The acceptance of any local community cannot be assumed and considerable effort and care should be taken to make sure that a transparent and honest discussion is undertaken with both the local community and particularly any crofting interest that may have an impact on the project.

The second part of [TN-07] considers the development potential of the various areas considered to be able to host suitable launch facilities. It is increasingly recognised that the region has hosted many different leading technology developments and that there is a strong tradition of the local economic and community development agency working to develop supply chain companies and communities alongside new initiatives.

The report summaries the demographic and economic base for each of the four main geographies (Western Isles, Highland, Orkney and Shetland) considered and notes the opportunities for economic and community development in each of the areas. This includes the low unemployment rates in many parts of the region and the issue of finding a local workforce in some areas. It notes the benefit of having the MOD base in Benbecula both in terms of the existing skills that could be transferred and also the significant impact that a modest increase in jobs would have in the community. The rundown of the nuclear facility in Caithness is also shown to both increase the potential labour available for such a project but also to emphasise the significant impact that such a project there could also bring to the community.

The report notes that the engagement of relevant UK bodies with the Scottish, Highlands and Islands bodies and local communities will determine a significant element of the success of vertical launch in the UK.

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9. ROADMAP

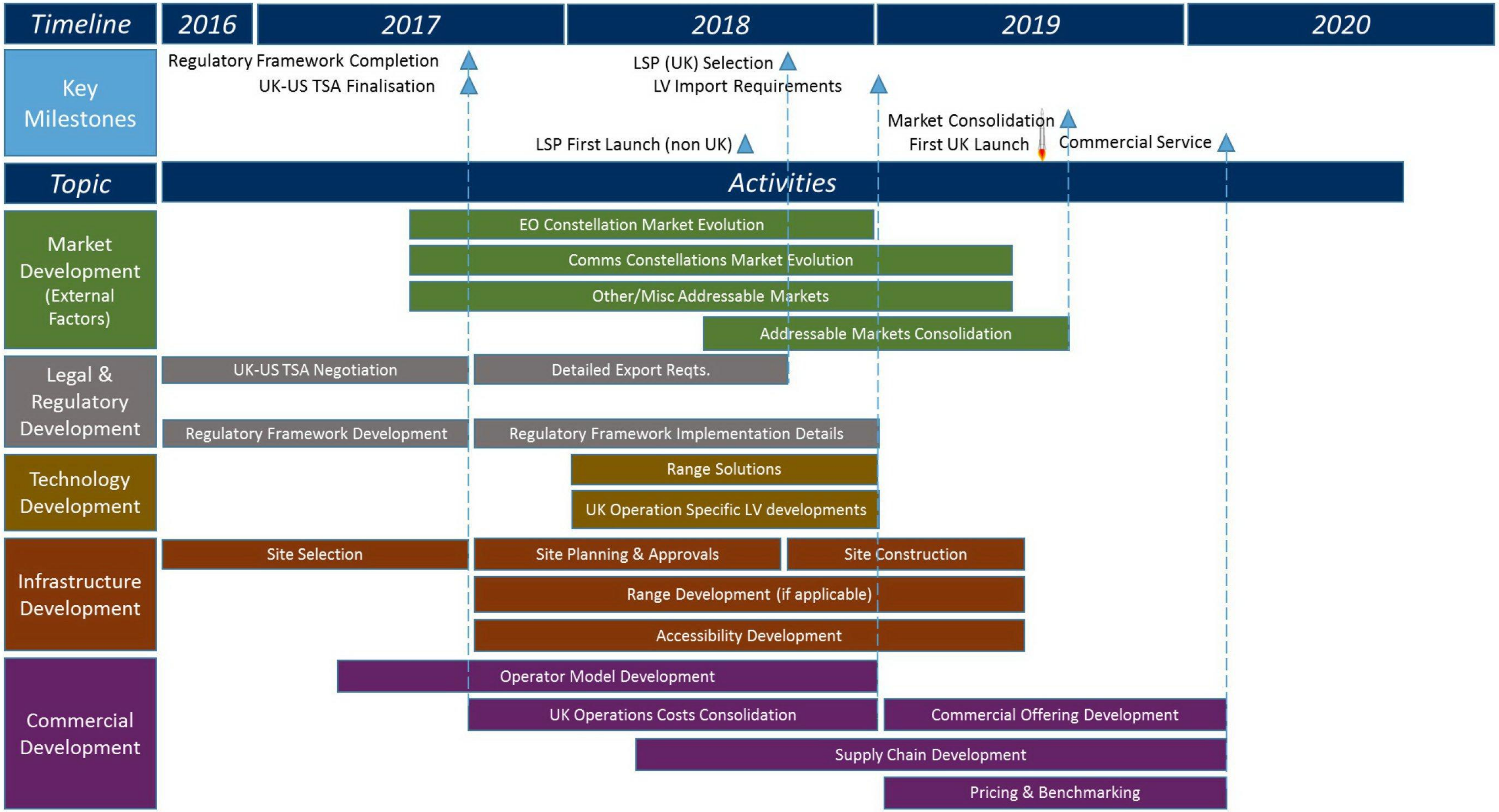

Figure 11: Roadmap for UK launch site development

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10. RECOMMENDATIONS

This section captures the most significant requirements made across the project.

- Funding approaches for the development of UK launch infrastructure should be considered very carefully, as the requirement to amortise development of launch infrastructure development costs from launch service revenues may not allow a competitively priced launch service business case to close.

- The weather conditions at a launch site determine when launches can take place. In northern Scotland, the limiting factor is wind. There is little data currently available to assess how significantly the wind will limit operations: the Met Office only has one radiosonde station in the area, at Lerwick (Shetland). Follow up work should be commissioned which looks in more detail at the weather conditions around northern Scotland, focussing especially on the characterisation of wind shear in that region.

- Given that there is no site in the UK which already has all of the range facilities required to run a space launch, the UK has a choice between making significant investment to create a traditional ground-based range infrastructure, or taking advantage of newer developments in satellite-based tracking and communications to create a space-based range. The UK should take advantage of the greater flexibility and lower cost of a space-based architecture, so as to develop a world class range following current best practice.

- Detailed research in to how autonomous tracking, abort and termination architectures for a UK based launch operation should be undertaken, specifically considering how European in-space assets could be utilised and how the UK supply chain could develop and/or contribute any of the required elements.

- The regulatory framework will play a crucial role in determining the commercial viability of launch from some UK sites. The UK must develop a regulatory framework which is streamlined, safe and effective. This will best be achieved if potential launcher operators and launch site operators are involved in the discussions which develop the regulatory framework, rather than having to respond afterwards.

- Should the UK regulatory framework be based heavily on current FAA regulations, especially those for defining flight corridors and safety cases, then a new class of launch vehicle (e.g. 'micro class') should be established, with associated characteristics defined which allow more representative and accurate (but no less safe) flight corridors and safety cases be defined. This would allow the 'challenge case' identified in this study (or something similar) to be adopted, which would significantly increase the commercial competitiveness of any launch service operating from a UK launch site.

- Seemingly minor requirements in high level international agreements, such as a requirement to recover spent stages which may stem from the UK-US TSA, can have a large influence on costs. It is important that treaty negotiations are carried out with a clear understanding of the consequences of particular requirements.

- Community engagement is a significant element of any successful project in the north of Scotland. Working with the community can be the major factor in ensuring the long term success of any project, and so it is important that a transparent and honest discussion is undertaken with the local community.

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11. CONCLUSIONS

We have assessed a number of technical and commercial aspects of vertical launch from the UK. There is a significant opportunity for commercially successful UK based launch operation to be established. Success is likely to be heavily dependent on how some key cost driving factors are approached.

We have shown that launch to commercially-desirable orbits can be achieved from a number of sites in the north of Scotland, both on the mainland and the islands. Trajectories compliant with FAA's requirements to protect the public are available to Polar Orbit from sites on the mainland, Outer Hebrides, Orkneys and Shetland. Compliant trajectories to Sun-Synchronous orbits are available from sites on the mainland, Orkneys and Shetland, but not from the western most locations (in the Hebrides). Depending on the launch site and desired orbit, 'dog leg' manoeuvres may be required to meet FAA casualty rate requirements, at a cost of reducing the maximum payload mass deliverable to orbit.

Considering only the payload mass deliverable to orbit, a site in the Shetland Isles is the best location in the UK to launch from as the trajectory avoids the populations in the Faroe Islands and Iceland. However, a remote island location would be logistically much more challenging than a mainland site such as the Moine peninsula.

We have identified the range infrastructure needed, and assessed what is currently available at different possible launch sites. No site has all of the required capabilities in place already; some existing facilities could be repurposed for range support, particularly for launch from sites close to MOD's Hebrides range, but some investment would be needed at any launch site. We have recommended that the UK should develop a space-based range.

The overall market forecast and the resulting addressable market forecast is healthy and could enable a very successful business from the UK. However, it must be noted that the addressable market forecast is heavily underpinned by the emergence of the communications mega-constellation replenishment market. These constellations are currently looking promising, but are both novel and currently under-funded. If this market does not emerge, there may not be enough launches per year accessible to close any business case.

The market assessments show that the accessible market is expected to evolve significantly over the assumed years of UK launch operations, with early years likely being dominated by (low cadence) SSO launches, and later years primarily featuring Polar launches. Some launch sites are better suited to SSO than Polar launches or vice versa, hence the possibility for multiple sites, being phased in to suit market evolution, should be seriously considered.

There is a clear opportunity for a launch service and vehicle capable of delivering around 175 kg or more to a 1000 km polar orbit. Lower performance vehicles are likely to struggle to capture any part of the communications constellation replenishment market. This should be noted when considering UK indigenous launch vehicle developments.

We have shown that there is a clear business case for launching an imported vehicle of the Firefly Alpha class in the UK, but that a number of decisions made by the UK government, its funding bodies and its launch regulatory bodies will determine whether the launch operation would be commercially viable. We have emphasised the importance of developing a regulatory framework which is streamlined, safe and effective in order to make the UK a commercially competitive site for launch. We have provided detailed inputs and recommendations to the development of the regulatory framework.

A launch site would be a significant development in many of the areas considered, bringing welcome jobs and money, but also noise and potentially disruption to very long-standing land use such as crofting. A launch site would have support from Highlands and Islands Enterprise and local government.

Overall, the UK *can* meet its target of commercial launch by 2020 using an imported launch vehicle, but there are a number of significant challenges to overcome, and much work remains to be done.

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