UK SPACE AGENCY

# Review and Evaluation of the National Space Technology Programme

An evaluation of the funding programme portfolio against delivering support for growth of the space sector.

November 2014

# Contents



The UK Space Agency accepts the recommendations made in this evaluation and will implement them in the delivery of future National Space Technology Programmes. The UK Space Agency takes an active role in Horizon Scanning activities and will continue to evaluate the projects and portfolio as a whole.

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## Executive Summary

In 2011, the UK Space Agency allocated £10 million to the National Space Technology Programme (NSTP). The purpose was to complement existing funding streams to progress products up the technology readiness ladder, positioning them for ESA funding or into a more commercially viable position. This implemented a core recommendation of the Innovation and Growth Strategy. The first round of the programme was delivered through a wide ranging portfolio of funding elements and through the combination of co-funding with industry and public sector initiatives. It has directly created a programme worth in excess of £30 million. The awards were made in 2012 and the majority of the projects have now been completed.

The Panel reviewed the current European-level technology programmes and how NSTP could be used to leverage and add effectively to UK industry's space capability.

The Review Panel found the Programme had met all its original objectives raising Technology Readiness Levels (TRL) by 1 to 4. As a result companies have secured strong roles in key European Space Agency (ESA) programmes that are developing commercial telecommunication and meteorological platforms. Plans are in place to fly some of the technologies on commercial platforms. New partnerships have been forged which have particularly helped SMEs to capture new business and give them insight into ESA and prime contractors for future requirements. NSTP has also enabled established companies to move into the space sector.

The evidence gathered through questionnaires and individual interviews has given the Panel confidence in recommending that NSTP becomes a central funding stream within the UK Space Agency's programme. The Agency and industry would gain great benefit from having a long-term programme with annual funding calls at the very least. This would provide a stable platform allowing better forward-planning of technology development but also would improve the Agency's ability to align activities with ESA programmes or nationally with other public sector funders.

Although overall the programme is deemed to have been very successful, the report covers detailed recommendations for areas which can be improved.

# 1. Introduction

The National Space Technology Programme (NSTP) is the national capability-building programme for the space sector and was formulated to implement Recommendation 3 of the Space IGS Report; Space Innovation and Growth Strategy 2014-2030 – Space Growth Action Plan:

*"Increase the UK's returns from Europe by continuing to grow the UK's contributions to European Space Agency (ESA) programmes and securing greater influence in large European-funded programmes."*

NSTP targeted space technologies focussed on the commercial sector and provided seed-corn funding for low technology readiness level projects; providing vital positioning that allows industry and researchers to enter both institutional (ESA, EU, EUMETSAT) and commercial space markets. NSTP was expected to bridge the gap between pre-commercial early stage ideas and their commercial, scientific or societal exploitation. A central aim of the programme was to de-risk technologies sufficiently to become commercially attractive propositions. Moreover it was designed to be complementary to the technology development activities offered by EU or ESA programmes. Potential future investors include the European Space Agency, the European Community, private investors or Government. The end markets foreseen could be commercial, scientific or institutional, to develop networking amongst UK space stakeholders by stimulating collaboration.

The initial round was funded in 2012 with the majority of projects now complete or near completion. This timely Review has taken place to determine the success of the programme and how the scheme could be improved. The UK Space Agency set up an independent panel to review the programme in March 2014 and this is their report. The Terms of Reference and Panel membership is provided in Annexe A.

The Panel's recommendations are based on input provided by the UK Space Agency's Head of Space Technology Strategy and Head of Technology Innovation and Standards, the final reports from the projects, responses from a questionnaire sent to project leads and follow up interviews on specific issues.

The main characteristics of the scheme were to:

- Raise technology levels and de-risk strategic UK projects to make them more attractive for further investment or facilitate the demonstration of products
- Complement existing funding schemes
- Bridge gaps of existing funding schemes
- Use government funding effectively through working with other funding agencies
- Encourage strategic partnerships in industry and between industry and academia that enhance UK capabilities
- Be as "light touch" as possible as well as keeping administration costs to a minimum using existing grant awarding systems such as through Innovate UK (formerly Technology Strategy Board – TSB) and CEOI

The NSTP has to be seen in the context of other funding routes and particularly the European Space Agency (ESA), the European Union Horizon 2020 (formerly Framework Programme) and national research programmes such as those of UK Research Councils.

European level technology development is carried out through a number of programmes as described below:

## 1.1 European Space Agency (ESA) TRP/GSP

The ESA Technology Research Programme (TRP) is funded from the general budget of the Agency and is open to any Member State at 100% funding. It is driven by a mix of priorities around the Agency's perceived interest and is thus linked to future Agency programmes. All ESA Member States contribute to the TRP on a mandatory basis. A three-year work plan is organised according to technology themes and is drafted by

senior ESA experts [Technical Network (TECNET)] with reference to the 10-point roadmap represented by the ESA Long Term Plan. TRP does allocate a third of its effort to Generic Technologies, either of use to multiple missions or else advanced basic technologies of common interest to all applications, such as component design, spacecraft propulsion, or power generation.

Ideas can be also proposed to open initiatives. Calls for StarTiger exercises (co-located groups of researchers in a particular area to look at a specific technical challenge) are made yearly – the success of a StarTiger programme at Harwell some years ago was one basis for the colocation based CITI element in NSTP1. Overall, a weakness is the tendency for a generic output, results being openly available and further from market than NSTP. Indeed, TRP work can be picked up in NSTP and moved closer to specifically commercial use.

The ESA General Studies Programme (GSP) is also 100% funding but more "blue sky" and is largely advanced concept study money. The ESA mandatory Science Programme uses the programme for early feasibility studies that are identified through its external science advisory groups. Content in all other areas (Earth Observation, Telecoms, Navigation, Human Spaceflight, Launchers, etc.) is determined by an internal ESA annual call. There has long been resistance to opening the specification of programme content to delegations. The 3 major lines of activity are:

1. Mission feasibility studies, typically up to Phase-A level. The GSP also performs internal mission concept assessment via its Concurrent Design Facility (CDF).
2. Interdisciplinary activities; inter-directorate work - views and suggestions of industry gathered through workshops, visits and hearings.
3. Strategy studies; analysis of trends and identifying potential issues for the Agency.

GSP is run by an advanced concepts group, contracting (100% funding) study work with European industry.

NSTP could usefully have a similar element but one focused specifically on national interest and need.

### 1.2 ESA GSTP/Prodex

GSTP (and Prodex) are ESA optional programmes. The virtue of buying into these for technological development is for the funding agency to get direct access to the technical oversight capacity of ESA. Because the programmes are à la carte, they are a good way of ensuring that invested money is directed to national industry. They are probably best viewed as an adjunct to the NSTP to be used for projects where access to specific ESA technical skills and knowledge are important. The panel considered that by using a small proportion of the NSTP funding to take projects forward through ESA's GSTP programme there had been a clear benefit. The nature of GSTP allows direct oversight of programme content whilst providing access to ESA background technical expertise. Key technologies to progress included activities to develop mission on-board planning system, real time Earth Observation data management, development of GaN H-FET and a digital sun sensor on a chip. GSTP provides a route to use when a technology can be taken forward in collaboration with other countries, whereas the National Programme is more suitable for prepositioning companies for European bids or where the UK wishes a technology to remain solely within the UK.

Prodex has not been used by the UK. Its original use was for the development of instruments under national support to fly on ESA spacecraft (particularly in Science Programme and on ISS). Its use has expanded with time but still is probably not a useful vehicle for UK.

TRP and GSTP programmes are subject to the oversight of the relevant ESA delegate body, the Industrial Policy Committee (IPC). It is in this group that national representatives can participate in developing and

reviewing ESA's overall technology policy and bring national interest to bear.

In addition, many ESA programmes have technological preparation lines [e.g Core Technology Programme (Science Programme) or some ARTES lines (Telecom) or EO preparation elements within EOEP]. These are normally focused for use on specific identified missions in the programme. They have the virtue that a successful response is quite likely to lead to an eventual flight, but often the specific nature of the technology target may not open a large potential market elsewhere.

### 1.3 European Union "Horizon 2020" – previously Framework Programme

The overt aims are to enable competitiveness, non-dependence, and innovation of the European space sector, advances in space technologies, exploitation of space data or European Research Technological Development (RTD) in support of international space partnerships. In practice, there is a bias towards EU programmes: European Global Navigation Satellite System (EGNSS (previously, Galileo), divided into research and innovation grants and procurement funding), Earth Observation (GMES), Protection of European assets in and from space (Space Situation Awareness). The European Commission manage the programme and select projects through review by expert panels drawn from outside. There is less direct opportunity for oversight from the national side than in the case of ESA programmes.

### 1.4 The relationship between NSTP and European level programmes

None of the above programmes replace the national need for NSTP. NSTP should exploit the existence of the programmes. However, a national programme allows matching the specific long term national priorities of the National Growth for Space strategy and more potential control over intellectual property rights. Moreover it can also be used to increase competitiveness by facilitating national industry to take a lead in future European programmes, and also by bringing the output from programmes closer to market.

It seems clear that there are advantages to entering the other systems with a level of development already achieved. The intention should be that wherever possible investment in NSTP should leverage European programmes which appears to be the case in many situations. Evidently moving programmes from NSTP to European programmes is an important route for much of the institutional market and for parts of the commercial market.

Table 1 provides a simplistic overview which shows how NSTP filled a number of key gaps in funding opportunities, allowing bids for projects that fell into TRL gaps in other funding lines.

**Table 1**

| | TRL Steps | TRL 1 | TRL 2 | TRL 3 | TRL 4 | TRL 5 | TRL 6 | TRL 7 | TRL 8 |
|---|---|---|---|---|---|---|---|---|---|
| Research Council | 1-2x | ■ | ■ | | | | | | |
| GSP | 1-2x | ■ | ■ | ■ | | | | | |
| TRP | 1-2x | | ■ | ■ | ■ | | | | |
| GSTP | 1-2x | | ■ | ■ | ■ | | | | |
| Pathfinder | 1x | ■ | ■ | | | ■ | ■ | | |
| Core Programme | 2-3x | | | ■ | ■ | ■ | ■ | | |
| Mission / Industry | 1-2x | | | | | | ■ | ■ | ■ |

## 2. Original programme elements

The £10m programme was divided into a number of elements defined by the type of activity rather than the particular technology. The advantage being that this increased the level of competition and allowed maximum flexibility. It also minimised administration costs. The planned division of funding can be seen in Table 2 (p7).

### 2.1 Core Programme

A core programme will provide grant aid to cover all areas of technology, both large (£1million plus) and smaller projects - all funded at 50%. The aim is to provide a balanced funding mechanism covering all the areas of technology and in particular the technology roadmaps.

### 2.2 Pathfinder Programme

This component targeted studies of future technologies. Breakthrough technologies and other innovations often threaten the existing commercial status quo – this element of the programme ensured that such possibly disruptive commercial opportunities are investigated, alongside those closer to market technologies. This would support the Agency's future programme and would feed into further NSTP funding.

### 2.3 Demonstration Programme

This was to support companies to demonstrate technologies likely to radically improve the economics or capabilities of space products and services, providing a bridge to full commercial acceptance. It was anticipated that some resource would be required to underpin some existing technology development programmes.

### 2.4 Contribution to GSTP

This was a short-term tactical necessity to ensure that the development of important time-critical UK technological capabilities continued within a European context, and ensure that these are not 'locked out' of future large-scale ESA exploitation opportunities.

### 2.5 Collaboration with other Funding Partners

The purpose of this activity was to encourage industrial collaboration to increase the resources available for research, to promote mutual understanding with the partner organisations, to promote technology spin-in and spin-out through other industrial sectors, and to allow partners to explore the relevance of space to their business.

### 2.6 Space Collaborative Innovation Team Initiative (Space CITI)

The Space CITI programme was designed to investigate the benefits undertaken in co-research in that it should progress the development of new technology and services more rapidly, and build new business relationships with the establishment of long-term collaboration or the establishment of new companies. Projects were encouraged to exploit the new facilities at the International Space Innovation Centre (ISIC) Harwell, which is now integrated within the Space Applications Catapult.

### 2.7 Horizon Scanning

The purpose of this activity was to explore methodologies that could be used to identify emerging trends, threats and opportunities that will affect the UK space sector acknowledging scientific, industrial and commercial factors both within and beyond the space sector, ensuring that technical and socio-economic

drivers are identified as well as framework, regulatory and governmental issues. In any circumstance, the UK Space Agency needs a view of how space technology could evolve in the long-term perspective. However, at a time where the priority has been set to establish growth knowledge, the possible social and economic impact of technological evolutions is very important.

## 3. Implementation of NSTP

In this section the implementation of the programme is discussed. Table 2 below shows how the resources were finally allocated against the each programme element.

The number of proposals submitted and the consequent success rate shows that there is demand from the community. Although the Panel considered that there must have been a number of quality proposals unfunded, a record had not been kept of the proposals categorised as unfunded but fundable. This should be done in future rounds. The exception in success rate was Space CITI where all proposals submitted were funded. This is discussed in section 3.6.

**Table 2**

| | % of bids funded | Panel assessment of Successfully Achieved Aims | UK SPACE AGENCY / NSTP Funding | Inervention Rate | INNOVATE UK/ Partner* | Company Investment |
|---|---|---|---|---|---|---|
| **1. Core Programme** | 45% | 100%* | 6000** | 50% | 2500 | 8500 |
| **2. Pathfinder Programmes** | 20% | 100%*** | 500 | 90% | | 50 |
| **3. Demonstration Programmes** | N/A | 100% | | 100% | 310**** | |
| TDS | | | 385 | | | |
| SABRE | | | 200 | | | |
| CubeSat studies | | | 282 | | | |
| **4. GSTP Additional Funds** | N/A | N/A | 1,000 | 50% or 100% | | |
| **5. Collaboration with other Public Funding Providers** | N/A | N/A | | As Required | | |
| DSTL | | | 250 | | 250 | |
| STEAM-R | | | 250 | | 250 | |
| BA | | | 50 | | 20 | |
| EPSRC | | | 250 | | 6272 | 3352 |
| **6. Space CITI** | 100% | 100% | 614 | 65%-80% | | 308 |
| **7. Horizon Scanning Studies** | N/A | N/A | 50 | n/a | 0 | 0 |
| **TOTAL** | | | **9831** | | **9602** | **12210** |

* This number denotes the Fast-Tracks. A number of Flagships are still on-going so the final success rate has yet to be determined.
** In addition £2500 INNOVATE UK/SEEDA Support
*** This line covers various elements of support for demonstration programmes delivered through NSTP
**** Includes contributions from other UK Space Agency programme areas

The Panel considered that the division of the programme into categories defined by size of awards and TRL levels and not technology areas was an effective approach. This provides the advantage of a structure that supports technology progression through the TRLs, and allows the best proposals at each technology level to be funded with a clear route for progression. A consequence of this might be a loss of balance between technology areas, but an assessment of the technical areas supported showed that all but one area in the technology road map had been supported, and this area had received funding through other routes. This initial round was considered successful in matching the technology road maps. It follows that the Agency should consider developing the technology roadmaps further with a greater element of prioritisation to assist with targeting funding in future rounds.

A generic problem was the slow start on projects caused by the time taken to put the collaboration agreements in place. This is not unique to the space sector. As such, alliances between industrial companies and/or academia are good and the UK Space Agency's financial planning needs to take this into account. The introduction of reliably regular calls would enable applicants, particularly industry to prepare the collaboration agreements before applying. Alternatively the UK Space Agency might consider having the call open for a longer period and insisting the collaborative agreement is part of the proposal package. Projects would have benefitted from greater interaction and guidance; however the Agency worked effectively with the resources available.

In general the resource allocation was in line with the original plan however the management support provided by Innovate UK meant that the planned appointment of a fixed term programme manager did not proceed. Instead, the funding for demonstration programmes and Space CITI was increased. With the hindsight provided by the review and comments of users, the returns from projects might have been even greater with some expenditure on external expertise for management.

### 3.1 Core Programme

The delivery of this element was managed by the Technology Strategy Board (Innovate UK) under the Space for Growth competition. It was divided into two components: Flagship projects (a maximum of £2M per award); and Fast-Track projects (£50k-100k per project).

Four Flagship projects and 28 Fast-Track projects were awarded. Projects were supported across all five Technology Roadmap areas; satellite telecommunications; sensing; position, navigation and timing; robotics and exploration; and access to space.

The Flagship projects typically raised their TRL by 2-4 levels and the Fast-Tracks predominantly by 1-2 levels. The Flagships mainly started at a higher TRL and progress up the TRL ladder is inherently more expensive. The Panel agreed this element had achieved its objective.

The Innovate UK system for assessing proposals and managing the awards was used under the Innovate UK terms and conditions. These awards required the companies to provide a 50% contribution and the project had to be led by a company. The Innovate UK rules have now changed so if this scheme was to be used in the future there are more favourable terms if an academic partner was to be involved.

There were major benefits in collaborating with Innovate UK for NSTP. These were:

- Doubling the size of that programme element
- Quicker release of funding because the programme used a procedure already in place
- The new UK Space Agency did not have the manpower to develop its own bespoke mechanism

Collaboration with Innovate UK enables far more activity to be funded than could have been done by the UK Space Agency alone and produces a more cohesive programme. However, by collaborating with Innovate UK, the UK Space Agency had to make compromises. Innovate UK has been set up to support industry to undertake research that will ultimately result in commercial products. The UK Space Agency has a different remit and may support technological development for science or society applications that provide an environment for growth. Innovate UK only appear to be able to collaborate on the basis that they run the schemes under their rules. It is quite understandable that if Innovate UK run a scheme that their rules apply and as a new organisation the UK Space Agency did not have the processes in place or the manpower to run the competition. There may be occasions in the future where the UK Space Agency provides more than 50% of the funding and, depending on the Innovate UK /UK Space Agency split, it might be inappropriate to for Innovate UK to run the scheme.

The Panel concluded overall that it is sensible for the UK Space Agency to make use of existing grant award mechanisms and management. This does not abrogate the UK Space Agency from a management role and there are benefits of the UK Space Agency taking a greater role in the projects as they progress. As noted elsewhere, the reallocation of all the originally allocated project management resource into projects was probably unwise. In future, project management must be an element of the programme.

Specific issues arising from partnering with Innovate UK included:

- Universities should not be the lead partner under Innovate UK rules. The Panel agreed that as the programme was aimed at developing commercial products this is an appropriate policy
- Innovate UK projects have to be undertaken as partnerships and not as sole company schemes. The Panel identified that there were potential instances when positioning the UK for involvement in an international project, there could be a case for a single company project. The UK Space Agency needs to consider how it would deal with this situation as it would be ineligible for an Innovate UK scheme
- Although Innovate UK make every effort to acknowledge the UK Space Agency contribution to projects e.g. success stories on the Innovate UK site identify the UK Space Agency as the funder, there is an inevitable loss of branding. This has been exacerbated by the low level of UK Space Agency support in project management
- The lack of clarity in the Memorandum of Understanding (MoU) between Innovate UK and the UK Space Agency appears to have resulted in some misunderstandings and sometimes friction between the two organisations

The Agency was over-optimistic in its financial planning and should assume a proportion of projects will start late or request extensions. This is normal business. Both the UK Space Agency and Innovate UK come under the Department for Business, Innovation and Skills (BIS). In the future, when bidding to BIS, more realistic estimated schedules and expenditure profiles need to be provided. Recently, the accruals accounting system within the BIS family has been tightened up and it should not be assumed cash flow can always be dealt with through one of the partners. Furthermore, the UK Space Agency may not always have the opportunity to partner with Innovate UK and therefore needs to consider preparing a process for awarding its own grants.

### 3.2 Pathfinder Programme

This programme was managed by the Centre for Earth Observation Instrumentation (CEOI) who were responsible for the proposal assessment placement of grants and project monitoring. Ten awards were made involving 19 academic and industrial organisations. Most projects built or tested new hardware or implemented a new manufacturing technique or process. These £50k awards allowed the projects to raise the TRL by at least one level and were considered excellent value for money. An indication of the success of the programme is that it resulted in six patent applications. Another clear benefit is the fostering of partnerships at an early stage of development.

### 3.3 Demonstration Programme

The major element of this programme was to provide support to the Technology Demonstration Satellite (TDS) putting in place the planning tools at the operations centre at Harwell. This was procured and managed by ISIC (now merged with the Space Applications Catapult). Additional support was provided for payloads on TDS-1. Further funds were used to hold a competition for the use of CubeSats for technology demonstrations. Finally, £200k was used to purchase independent expertise from ESA in advanced propulsion technology to monitor the progress of the SABRE engine development and test.

The TDS-1 and the UKube programmes had already been initiated by Innovate UK and the Science and Technologies Facilities Council (STFC) prior to the formation of the UK Space Agency. Resource was used to complete later phases of the programme, and to provide an operation facility. A ground test of the SABRE engine was supported; a proof of concept was required before considering further funding.

The Panel discussed the future need for both a TDS and CubeSat programme. In the long run the Panel considered TDS more appropriate as a vehicle for demonstrating commercial space technology. The CubeSat's strength at this point lay in its ability to be used in educational and training programmes. A thorough assessment should be undertaken of the technologies that need a flight demonstration and how they can be best achieved before starting a new activity.

In future, the UK Space Agency may have the need to invest in national facilities for demonstration and testing which can be used by multiple companies. An example is a national propulsion test facility (there are now several UK-based space propulsion companies). Another would be Phase 2 of the Climate and Environmental Monitoring System at the Satellite Applications Catapult Centre (a powerful computing system designed to process the myriad data now provided by Earth observation spacecraft and make it useable to small and medium enterprises (SME) and start-up applications companies). It would be appropriate to use a proportion of NSTP funding to support this activity through requirement studies for the construction of lower cost facilities. Major investments of this kind should be undertaken as a specific bid to Government. For all facility investments, they have to demonstrate they satisfy the need of the broader community, do not unnecessarily duplicate facilities, and are sensibly located.

### 3.4 Collaboration with other Funding Partners

This programme supported collaborative work with DSTL, EPSRC and STFC. When space technology is being increasingly driven by very diverse potential uses, such collaborations are inherently useful. A wide range of work was supported including; investigating scene based co-phasing techniques for small satellite systems, infrared limb-sounder for future EO programmes, underpinning generic technology for autonomous intelligent systems. This has delivered cost effective research. However, the panel suggests that the UK Space Agency might have gained even more if it had more staff effort available to take a more active role in the project reviews. In addition to the research these collaborative programmes have developed links with other research funders which could be of long-term benefit to the UK Space Agency.

### 3.5 Space Collaborative Innovation Team Initiative (Space CITI)

Four projects applied for funding under this scheme which were all funded. This was for activities at the low end of the TRL scale and on average the TRL level was raised by 1-2 levels. Work undertaken through this programme has fed into the developing strategy on possible national launch capabilities and a British spaceport, the ground work was completed for setting up a marine data service, and a standard avionics test bed facility is being planned for national use at the Satellite Applications Catapult Centre.

The programme was successful in that the projects achieved their research objectives but the added benefits from the long-period of co-location were not as clear as the earlier StarTiger project funded in 2006 by ESA which provided a model. Co-location for short periods is very effective at critical points in many

projects. However a move to long duration of six months is more problematic as indicated by the low number of applications. The analysis by the panel showed that such a time is problematic for companies who may be unable to release technical people to concentrate on one project for so long. Moreover, for individuals relocation is often difficult due to family commitments. Nevertheless, the benefits reported from StarTiger were huge. After investigation, the panel concluded this was partially due to the make-up of the team who were drawn from all over Europe and were almost uniformly in early career states, often in institutional employment rather than industry and so able to take leave of their home institution and immerse themselves in the project for six months. Co-location should be an option available for projects in future but should not be singled out.

### 3.6 Horizon Scanning

A nine month contract was awarded to the University of Strathclyde Advanced Space Concepts Laboratory to assess methodologies for identifying game changing technologies on a 15-25 year timescale. The procedure largely came from specifying a particular game changing step (e.g. substantial reduction in launch cost or green regulation of propellants) and analysis of what markets would expand and which would atrophy.

The Panel agreed that although the horizon scanning was imprecise it could provide important insights that might give UK industry an edge and at some level was a necessity within the UK Space Agency in preserving programme balance and assessing long term risk. It should be by nature a rolling process, and is worth continuing at a small level (~1-2%) of the total programme activity.

## 4. Impact

The initial round of NSTP has been a success, and is universally regarded with satisfaction by its users. The review panel found evidence of raised TRL of a wide range of technologies all of which were on industry's technology road map. On average the Fast-Track and Pathfinder projects have raised TRL by 1-2 levels and the flagships by 2-3 levels. Substantial advancements have been made in the areas of reduced hazard clean combustion propellants, the next generation telecommunication platforms, pulsed plasma thrusters, and advanced GNSS receivers.

An objective of the scheme was to de-risk technology to make it attractive for further investment by ESA or industry. The NSTP has delivered on this front. Firstly the work on the next generation platform activity is now being funded through ESA, the E3000 spacecraft delivered a Return of Investment (RoI) of 30 and it is expected that this new platform will deliver at least a similar return. Similarly the work on the Microwave Limb Sounder has now been included in the MetOp-SG programme. MetOP-SG will become part of the operational instruments serving the needs of meteorologists for at least the next 20 years and is expected to give a minimum return on investment of 4:1.

The development of an innovative, low cost synthetic aperture radar (NovaSAR) has been accelerated opening up the possibility of commercial funding. The expected return will be 6-12Bn in sales between 2018 and 2030. The Advanced GNSS receiver for positioning and timing in space is being planned to be used on three satellites.

For SMEs, NSTP has been invaluable providing them with a track record and contacts that have enabled them to win contracts. One respondent commented that "we are about to start a major project...and without this project [NSTP funded] we probably would not have been considered". Another stated, "[NSTP] has been a real help in bringing us as an SME into the space sector".

Other benefits and comments gathered through the stakeholder questionnaires include:

- Many companies particularly SMEs and new entrants into the space sector commented that involvement in NSTP had improved their recruitment and retention of staff
- Defining detailed road-maps for future development
- Increasing customer base
- Companies have found that the collaborations fostered through the programme has improved their competitiveness; e.g. a more effective supply chain and development of new manufacturing techniques by the Telecom Satellite Mechanical Platform consortium (Fast-track)
- Allowing the UK to access growing markets; e.g. SSTL & Airbus Defence and Space being the first to exploit to the SAR market with significantly lower costs than offered elsewhere (Japan and Italy still being in the conceptual stage)
- Providing a platform that enabled long term self-financed R&D work; e.g. one of the projects included the development of a test-bed that has allowed the company to undertake more of its own R&D work
- Increasing visibility for SMEs of the ESA and prime contractor future requirements
- Developing state-of-the-art MMIC chip for space applications
- Showing the potential for delivering output power in an ITAR-free solution
- Practical demonstrations; execution and independence of applications
- Encouraging and developing more strategic goals
- Developing prototypes of experimental hardware
- Developing Europe's most advanced TRL5 thruster for Green Propulsion
- Allowed progression from a low TRL concept into a working prototype

# 5. Conclusion and recommendations

## 5.1 Overall Conclusions

The programme was effective and met its objectives.

- It raised the TRL between 1 to 4 levels for a wide range of technologies identified in the industries technology road map
- It complemented the existing funding streams and has bridged gaps between European funding streams supporting projects across the TRL 5-6 funding gap and by supporting at national level very early ideas specific to the space sector, nationally important projects at the TRL level 2 to 3
- Government funding was used effectively by working with other partners. Working with Innovate UK ensured that there was no duplication and reduced the management costs to a minimum. Similarly by working with other partners the UK Space Agency kept management costs down whilst gaining benefit from a larger pool of research. The total research investment was about £27M compared with £10M allocated by the UK Space Agency
- The results of the panel's survey confirm that participants did develop new partnerships that have continued and resulted in further work, it has been particularly beneficial for SMEs
- There is good evidence of de-risking technologies thereby rendering them competitive, able to secure follow on funding or being considered for use on future satellites

It will take several years for the full benefits of the programme to finally become apparent as it will take time for the technologies to be fully embedded in commercial activity but, the results to date already justify the expenditure.

As with any activity improvements can be made, and the Panel made the following recommendations:

- A stable funding line with annual calls would enable better planning and improve alignment with activities funded by ESA or nationally, with other public sector providers in science and technology

domains. It would minimise the number of opportunistic projects that are currently dealt with under urgent procedures. A technology funding line is a core element of the UK Space Agency and every effort should be made to secure a long-term programme. This would allow companies and the Agency to plan technology development through the TRL, allowing the Agency to plan strategic partnerships with other funders with the knowledge that there will be some funding available even if the exact level is not known

- Co-location for short or long periods can bring about enormous benefits for the right project and applicants should be allowed to work in this way if they consider it is the most effective way of implementing their project. This should be a tool within schemes not a separate element within the NSTP
- A small fund for very small awards in the region of £25k should be created for TRL-1 projects. This may encourage companies to spin in to the space sector more easily at low risk
- Although the Agency succeeded in keeping the management cost down to a minimum there would be benefit in a greater involvement in the proposal reviews and progress meetings. In some instances this may require the use of expert consultants
- The Agency should undertake an in depth review of the best way of delivering flight demonstrations to meet industry's needs
- The demonstration package can also include national facilities, but careful mapping should be done so that these are beneficial to a large portion of the community. There is already huge investment in this area, so this should be seen as a lower priority than a TDS project
- The Agency needs to be more realistic in its financial planning for new programmes taking into account the time required to instigate the programme, review the proposals and for industry to set up formal collaboration agreements
- For future activities with Innovate UK, a more detailed MoU is required providing greater clarity on the role and responsibilities of both organisations
- The Agency should keep easily accessible records of the success rates for rounds including identifying fundable but un-funded proposals
- The Agency should consider refining the technology road map to give managers and review panels more guidance on priorities
- Although it is good to have a balanced portfolio of investments the first differentiator of proposals should be the quality of the proposals against the assessment criteria. However, the UK Space Agency should retain the ability to adjust awards to take account of balance across technology areas but this should only be between proposals that have reasonably close marks. However, this flexibility must be a fully transparent process

For mid-range TRLs (three, four and five) collaboration with Innovate UK has been appropriate and a cost effective way of working.

For this first round of the NSTP, the balance of funding between the elements was appropriate, and the balance of projects within those levels looked correct. It should be noted that some flexibility should be retained to adjust the balance to allow funding for projects that closely match the assessment criteria.

The UK Space Agency needs to develop its own standard process for funding industry so that if there is a requirement for sole funding a process is available. State-Aid clearance takes considerable time and hence needs to be developed before a specific need is identified. The Agency also needs to maximise support from expert bodies to ensure that NSTP objectives are met year on year.

## Acknowledgement

The Panel wished to acknowledge the excellent support provided by Charles McCausland and Timothy Hudson from the UK Space Agency.

# Appendix A – NSTP Review Terms of Reference

## Objectives

The Review will:

- To review and critically evaluate all aspects of NSTP which were run by the UK Space Agency between 2011 and 2014
- To inform the design of future National Space Technology Programmes
- To provide evidence that can be used in requesting funding for future programmes
- To produce a publication highlighting the benefits that have accrued from participating in NSTP
- To determine what processes were used by both the UK Space Agency and its delivery partners and in particular whether they worked well
- To determine what the key successes and failures were including the impacts that have been achieved and how they should be maintained in future programmes

## Membership

Membership of the NSTP1 Review panel is made up of:

- UK Space Agency Steering Board member and NSTP1 Review Chair – David Southwood; Former President of the Royal Astronomical Society
- Industrial Member (UK Space Agency Technology Advisor) – Chris Ward; Head of R&D Airbus Defence and Space
- SME Member – Andy Bowyer; Director Magna Parva Ltd
- UK Space Agency member with knowledge, but not direct involvement in technology delivery – Sue Horne; Head of Space Exploration UK Space Agency
- NSTP1 Programme Managers – Nick Cox & Major Chahal

## Appendix B – Core Programme – Flagship Projects

| Project Title | **Telecoms satellite mechanical platform** |
|---|---|
| Lead | Astrium Ltd |
| Partner Organisations | Thermacore Europe Ltd Qioptiq Ltd TISICS Ltd Moog Isp Ltd ABSL Power Solutions Ltd QinetiQ Ltd Surrey Space Centre |
| Background | This project is the first stage of the development of the mechanical platform for European telecommunications satellites in the three to six-tonne range. The mechanical platform comprises the satellite structure, propulsion and thermal control system. The project will study and trade-off new architectures for the mechanical platform that better address the requirements of the communications payload and optimise the propulsive efficiency. The collaboration is intended to encourage technological innovation and enhance the competitiveness of the UK supply chain. This project forms part of the wider European development of the next-generation platform. |
| Outcomes | Obtaining a competitive edge by developing the technology of the satellite mechanical platform, its architecture, subsystems and equipment. By advancing the technology, a lower mass and cost is achieved, shorter assembly schedules and higher performance. Development of green propellant chemical thrusters and new evolutions of electric propulsion plasma thrusters is ongoing with Moog, QinetiQ and Surrey Space Centre. The use of silicon carbide fibre reinforced titanium material is being characterised for possible use in propellant tank manufacture with TISICS Ltd, and, with the University of Bath, we are investigating different satellite assembly techniques. |

| Project Title | **LYNX – Ruggedised and portable Ka-Band satcom suitcase terminal** |
|---|---|
| Lead | Avanti Communications Ltd |
| Partner Organisations | BAPCO Alcatel-Lucent Nottingham Scientific Ltd Cobham |
| Background | LYNX builds on a previously completed feasibility study for Innovation in Space: KA Satcom on the Move (KASM), and a European Space Agency integrated application programme project on civil protection. It aims to develop a more rugged and light-weight portable Ka-Band satcom terminal, which is lacking in the current market, fitted and operable in a compact suitcase for nomadic use in both military and civilian markets. |
| Outcomes | An all-in-one rugged Ka-Band suitcase terminal with flexible module insertion for global navigation satellite system (GNSS) or small cell boards, catered to specific user requirements. The targeted market will be primarily military, with the potential to extend into new markets including broadcast, aviation, news-gathering, emergency and planned events. |

| Project Title | **High resolution for commercial carbon stock and flux measurement** |
|---|---|
| Lead | DMC International Imaging Ltd |
| Partner Organisations | Rezatec |
| Background | This project applies the developing science of land carbon stock and flux measurement techniques to deliver global high-resolution products at regional and local scales. An important differentiator for this project is that the team is conducting rigorous scientific analysis of the carbon intelligence from the data sources (satellite image and ground samples). This will take place throughout the processing chain and uses carbon models to quantify the uncertainties involved, supplying users with valuable quality assurance information. The developed system will be automated for online processing and delivery. |
| Outcomes | This initiative will build on established carbon modelling and satellite remote sensing techniques. This will provide scientifically validated carbon market intelligence and an automated monitoring, verification and reporting (MRV) system to help organisations in their efforts to reduce deforestation and degradation. This system is designed for use in supporting REDD+ (reducing emissions from deforestation and degradation) initiatives and aims to significantly reduce the transaction costs incurred in trading forest based carbon. |

| Project Title | **NovaSAR innovative imaging chain critical element qualification** |
|---|---|
| Lead | Surrey Satellite Technology Ltd |
| Partner Organisations | Astrium Ltd Spur Electron Ltd |
| Background | This collaborative project will accelerate the technology development of an innovative S-Band synthetic aperture radar (SAR) instrument. This low-cost, yet extremely capable instrument is the key enabler for a SAR satellite (NovaSAR) that completely changes the economics of the radar remote sensing market and SAR satellite ownership. Once developed and proven, SSTL and Astrium plan to bring this product to market ahead of potential competitors and achieve a '1st mover' position. This would place the UK at the forefront of a new and exploitable global market generating income through export sales, service provision and applications development. Economic benefit in the UK is expected from jobs in upstream space infrastructure industry and supply chain, and from the creation of business opportunities in downstream service sectors. |
| Outcomes | Progress on this project has allowed SSTL to kick-off work on the first NovaSAR satellite, planned for launch as early as 2015, and engage in serious marketing activities with potential customers. SSTL is now working with a variety of interested parties who would like to have a NovaSAR satellite as part of a national programme or who want access to data for specific services. |

# Appendix C – Core Programme – Fast Track Projects

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|---|---|
| Project Title | **Innovative green propulsion systems** |
| Lead | Astrium Ltd |
| Partner Organisations | Surrey Satellite Technology Ltd MOOG ISP Ltd DELTACAT Ltd |
| Background | Develop alternative 'green' propulsion technologies to access UK, European and global markets. This is in response to the increased legislation that is likely to force the banning of high toxicity systems. Development of propulsion technology in combination with mechanical satellite/spacecraft platforms is a strong UK strategic asset for both telecommunication missions and for earth observation, navigation and science missions. These include Rapideye, GAIA, LISA Pathfinder and BEPI Colombo. The propellant and propulsion technologies necessary have been highlighted by universities and SMEs, but a lever for the involvement of primes, such as the banning of current propellants and funding has not previously been available. This application brings all entities together with funding for the development of new technologies and UK intellectual property. |
| Outcomes | The primary development of the project is to drive the design, manufacture and test of a UK hydrogen peroxide monopropellant 10N thruster to technology readiness level 5 by testing of the mature design in a high altitude test facility. In doing so, the project's technology will achieve a European first. Review of the current state-of-the-art technologies with alternative green propellants will be completed, harmonising the work with other ongoing EU developments. This will allow maximum return of the UK investment into the technology development.<br><br>The project should act as a lever to successfully bidding for further development studies with the Technology Strategy Board, UK Space Agency and European Space Agency with a target of incorporating the technology into future satellite propulsion systems. |

| | |
|---|---|
| Project Title | **Development of a quasi-optics system for the MetOp-SG microwave sounder 183/229 GHz channels** |
| Lead | Astrium Ltd |
| Partner Organisations | RAL Space Systems Engineering & Assessment Ltd |
| Background | This project draws together experts in the UK space industry, mm-wave research, development and manufacturing to address the design challenges in the MetOp-SG microwave sounder (MWS) instrument. The work develops new analysis techniques for microwave radiometer systems using non-sequential ray tracing techniques and beam propagation synthesis, inviting improved radiometer design and performance. In addition, the new instrument scan requirements for MWS are reviewed and the opportunities for torque and momentum compensation investigated. |
| Outcomes | Improvement of UK quasi-optical design capability by the application of new ideas in the analysis of complex ray-tracing to be applied to microwave systems, and the development of improved field-probing techniques |

| Project Title | **Next-generation onboard software environment** |
|---|---|
| Lead | CGI |
| Partner Organisations | Surrey Satellite Technology Ltd |
| Background | CGI and SSTL are working on a new platform that will support the next-generation on-board software (NGOBS) that is more accessible than the traditional software that exists today. The aim is to make it far easier to write, test, maintain, deploy, and operate on-board software. By adopting Java, a proven open-source software, we are creating a platform that enables developers to write flight software applications that integrate other hardware and software subsystems. |
| Outcomes | Ability to interface with the satellite test-bed, including monitoring and controlling over a very efficient wire protocol developed specifically for the prototype. A CAN-bus simulator is part of the test-bed, and is accessed through the on-board software. As a next step, we would like to take our platform from the virtual into the physical world and install it on a representative flight computer system, complete with a few sensors and actuators. We would then develop drivers for each hardware subsystem and build a few prototype flight software applications. These will use both the drivers and common functionality provided by the platform, such as communications link services, to form a fully-functional demonstrator using real hardware. |

| Project Title | **HiVaCroM – High-value crop monitoring** |
|---|---|
| Lead | CGI Logica |
| Partner Organisations | University of Leicester |
| Background | The HiVaCroM project is focused on the development of high-resolution datasets (<20m) to support the production of high-value crops, particularly sugar beet and potatoes. The routine production of datasets related to the crop geophysical variables, for example chlorophyll content (an indicator of crop health) and crop canopy cover (an indicator of crop development), will be of great importance to farmers, agronomists and producers alike. HiVaCroM will be developed to be hosted within the Climate for Environmental Monitoring from Space (CEMS) facility at Harwell, with the ultimate aim of these tools/ datasets being used to provide a commercial crop management service. |
| Outcomes | CGI Logica intends to access potentially significant markets. HiVaCroM allows for scaleability; such an approach means global monitoring for environment and security (GMES) data can be used to provide services to overseas markets. Significant potential market across Europe, as well as globally, for the service.<br><br>As an illustration, if HiVaCroM was to achieve 10% penetration of the European potato market and data was charged at the nominal fee of £1 per hectare, throughout the growing season turnover would be £3.5m per year. |

| Project Title | **SATellite Structures – Novel AdVanced composites (SATNAV)** |
|---|---|
| Lead | Cytec Industrial Materials (Derby) Ltd |
| Partner Organisations | Surrey Satellite Technology Ltd |
| Background | As proven in terrestrial applications, the use of composite materials can result in significant cost reduction of component development and manufacture. A limiting factor in the application of these approaches in space applications is requirement for multi-function capability. Working with Surrey Satellite Technology Limited (SSTL), Advanced Composites Group (ACG) intends to develop an affordable high conductivity carbon fibre pre-impregnated thermoset material exhibiting the enhanced thermal and electrical conductivity functions required by typical satellite applications. The enhanced material, in combination with the development of application techniques, will enable the design and manufacture of composites more akin to those found in lower cost terrestrial applications, leveraging significant cost reductions. This proposal is to provide validation of enhanced multi-functional composite capabilities via testing of a demonstrative structural component. |
| Outcomes | The main expected outcome of this project is a pre-impregnated material with increased electrical and thermal conductivities compared to standard cyanate ester prepregs. This material could be used in satellite applications, offering, for example, the opportunity for satellite manufacturers to decrease the weight of the overall component by replacing metallic parts. |

| Project Title | **Space based interference & detection (IDG)** |
|---|---|
| Lead | Exemplar Associates Ltd |
| Partner Organisations | Surrey Satellite Technology Ltd Astrium Ltd SES B.V. |
| Background | The aim of this project is to design a simple, accurate and affordable system to detect and locate sources of radio frequency interference which affect commercial satellite services. Instances of interference are growing due to the rapid increase in numbers of users of satellite spectrum both for terrestrial applications and other satellite systems. The new technology will be a space-based detector which can measure ground-based sources of radiation in any commercial satellite frequency band, combined with the ground-based processing, to localise the source of interference on Earth. The main outputs of the project will be a demonstration based on simulation and a business plan for either a manufacturing or service export. These will be used to show the accuracy obtainable, the cost and the operational requirements. |
| Outcomes | The project has successfully demonstrated the feasibility of a space-based interference and detection system. In collaboration with our partners, different system architectures and implementations have been traded off with preferred solutions being identified. The consortium has engaged with potential key equipment suppliers and a rough order of magnitude costing exercise is being completed for the delivery of the system. |

| Project Title | **ORTHOWEB** |
|---|---|
| Lead | Magellium Ltd |
| Partner Organisations | Astrium |
| Background | ORTHOWEB provides a low-cost, easy-to access web service that removes distortion from satellite and airborne images. This process, known as orthorectification, is performed to project image pixels from the sensor's output into a geographically accurate location on a digital map, adjusting the topographic displacement. A key feature of ORTHOWEB is that a full image upload is not required. Only a small percentage of pixels, 'the essential image', are needed to perform the image adjustment. This saves bandwidth, preserves confidentiality and reduces the processing required on the client side. High-performance graphics processing unit computing on the server allows fast processing and quick results. The system supports most satellite sensors, such as optical, radar and infrared and is very effective for low-cost images which come from less accurate satellite platforms. |
| Outcomes | A prototype ORTHOWEB system has been developed and tested to both prove the concept and provide the basis for the development of a commercial service. A roadmap for further refinement has been established, including the addition of a log-in/payment system, a web map viewer and a quality assessment service. Testing will continue with a range of satellite image types, together with performance evaluations using different reference databases. |

| Project Title | **Extension of the lifetime of pulsed plasma thrusters for CubeSat application** |
|---|---|
| Lead | Mars Space Ltd |
| Partner Organisations | Clyde Space Ltd |
| Background | The first electric propulsion subsystem for CubeSats' station-keeping has been developed by the consortium under European Space Agency funding in 2010. The project aim was to double the orbit lifetime of a CubeSat. The propulsive subsystem (named PPTCUP) showed to outperform the mission requirements in terms of propulsive performance, but at the same time was unable to deliver the required lifetime. The main life-limiting factor has been identified as carbonisation of the thruster surfaces and of the spark plug, preventing the possibility of igniting the thruster. The aim of this project will be to study the main parameters affecting carbonisation and to reduce it to a level that will allow the thruster to achieve the required lifetime. After the successful completion of the project, PPTCUP will be ready to be flight qualified and will be the first electric propulsion subsystem for CubeSat on the market. |
| Outcomes | A new PPTCUP design has been produced. This new design has been able to demonstrate the full lifetime needed to use all the propellant onboard (1,000,000 shots), while at the same time showing performances that are in excess of those measured previously. At present, PPTCUP is undergoing a full flight qualification programme that is expected to be completed by the end of 2013. The first thruster flight is scheduled for mid-2014. |

| | |
|---|---|
| Project Title | **High thrust apogee engine test – fast-track boost to satellite propulsion** |
| Lead | Moog ISP Westcott Ltd |
| Partner Organisations | Airborne Engineering Ltd |
| Background | Moog ISP Westcott is developing a high-performance chemical rocket engine, the high-thrust apogee engine (HTAE) for future spacecraft, building on its experience with the extremely successful Leros product line. Feeding directly into a European Space Agency (ESA) development programme, Moog ISP and Airborne Engineering Ltd have collaborated to produce the hardware test rig necessary to conduct a series of rapid hot-firing tests to test critical items for this engine. Data from the proposed firings will verify performance predictions and, as well as supporting the ESA programme, will be shared with spacecraft bus manufacturers in Europe to highlight availability for the commercial market. These comprehensive test firings will start in July 2013 with a final review at ESA of all results due before the end of the year. |
| Outcomes | The immediate next step is the conclusion of the test programme which will identify new valve, injector and combustion chamber technology for space exploration. This technology's design will be further refined in order to prepare for a preliminary design review in mid-2014. This design will then be taken to critical design review by end of 2015. It is intended for inclusion on future European planetary exploration missions in the years that follow, along with commercial exploitation where suitable.<br><br>The Technology Strategy Board programme has enabled us to assemble a test rig to the satisfaction of ESA and to perform the tests to support detailed technology selection for the next generation of high-performance satellite rocket engines. |

| Project Title | **Compact electronics for space deployable quantum cascade lasers** |
|---|---|
| Lead | M Squared Lasers |
| Partner Organisations | RAL Space |
| Background | Focussing on the development of highly compact and ruggedised electronics that can be employed on spacecrafts and used in the context of environmental sensing using laser technology, specifically laser heterodyne radiometers. The quantum cascade laser is a laser source that is ideal for this application; however, so far no appropriate drive electronics that qualify for space missions have been developed. This project will address this issue by combining the world-leading capabilities in the design of electronics for laser systems of M Squared with the experience in space-born sensing applications at RAL Space. |
| Outcomes | Demonstration of a compact, power efficient, and highly stable quantum cascade laser controller for space applications, looking to advance the technology further to allow for an airborne demonstrator to be flown. Miniaturisation is a key enabler to benefit from small mission opportunities, and favours technology demonstration through deployment on small, possibly autonomous, airborne platforms. A direct next step will be a similar development on the acquisition – processing electronics of quantum cascade laser heterodyne systems, which would deliver a fully miniaturised solution. This, in combination with the optical miniaturisation undertaken in the framework of the centre of Earth observation instrumentation, will deliver laser heterodyne instruments ready to be flown to demonstrate their relevance in atmospheric remote sensing for air quality and emission monitoring services. |

| Project Title | **Optical cavity for next-generation timing and navigation** |
|---|---|
| Lead | National Physical Laboratory |
| Partner Organisations | Astrium |
| Background | The aim of this project was to adapt one of our existing cubic cavity designs to develop a new system – in particular, the support mechanism for the cavity, with the aim of increasing its technology readiness level. Astrium's role was to advise on how we should upgrade the design and development approach towards producing a flight unit. The challenges faced are to move from a lab-based cavity system to a space-qualified system capable of withstanding launch conditions, and that can operate for years. The project has successfully started this process, and will feed into future European Space Agency funded projects to continue this. The project has also involved a successful collaboration with Astrium, which will continue into a follow-on project. |
| Outcomes | The next-generation vacuum design and mounting has been detailed, together with supporting finite element analysis. Experimental data was obtained on the existing cubic cavity, including thermal expansion and frequency stability measured using both a fibre laser and YAG laser. Key cavity design improvements for a future system need to include ultra low expansion glass for operation at zero linear co-efficient of thermal expansion. Tests indicate that pointing and power stabilities are sufficient to achieve target stabilities. Lock monitoring and auto re-locking hardware and software will be tested and evaluated to provide a 'system OK' signal. Cavity mounting tests include work using Cerroseal solder, and future work will involve tests of hydroxyl bonding methods. The outcomes of this project will be used within two new projects. The first is a European Space Agency elegant breadboard high stability laser for next-generation gravity mission. The second, an optical reference cavities for space deployment (ORCS) project with Astrium, which has recently started. |

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|---|---|
| Project Title | **TruDat – Trustable data for carbon, science and finance** |
| Lead | National Physical Laboratory |
| Partner Organisations | CGI IT UK Ltd University of Sheffield |
| Background | The TruDat project aims to address and understand how to propagate uncertainties in, and define suitable quality metrics for, satellite data used for forest carbon estimation. Earth observation (EO) datasets play a major role in understanding the Earth and are increasingly being relied on for a wide range of operational monitoring services and applications related to the science of climate change. Since the establishment of the carbon market and the ascribing of a notional monetary value to carbon, the accuracy of EO data has risen in importance. TruDat explores the data processing chains implemented to derive forest carbon information from both radar and optical satellite sensors. Tools to assess data quality and associated uncertainties throughout the processing steps are being developed. These tools and accompanying documentation will be incorporated into the UK's facility for Climate and Environmental Monitoring from Space (CEMS) operational architecture. |
| Outcomes | TruDat will provide two user-friendly tools within the climate and observation monitoring from space facility. The first will derive uncertainties through the processing of synthetic aperture radar data to produce quantified estimates of above-ground biomass. The second tool will enable users to explore and quantify differences between bottom-of-atmosphere reflectance values derived from an array of optical satellites. This will enable sensor data to be used inter-changeably, which is important in tropical forested regions where clouds and aerosols are persistent and affect data collection. It will also permit the temporal analysis period to be extended beyond the life of a single sensor, improving the evaluation of climate change studies. Although using forest carbon trading as a case study, TruDat will seek to generalise the principles in readiness for broader applications and services, such as those related to essential climate variables, positioning the UK for a leadership role in conjunction with the European Space Agency's Harwell facility. |

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|---|---|
| Project Title | **Rapid assessment, characterisation and localisation of GNSS denial of service attacks (RASCAL)** |
| Lead | NSL |
| Partner Organisations | Association of Chief Police Officers (ACPO) CGI |
| Background | The aim of the RASCAL project is to benefit police forces, emergency services and frequency regulators to pinpoint the type and location of an emitter that is causing interference to global navigation satellite system (GNSS) services. The approach will enable a wide variety of GNSS interference sources to be detected, characterised and isolated in order to locate and ultimately remove the source of the interference. RASCAL will be suitable for handheld deployment, as well as for installation and operation within patrols cars or dedicated vehicles. It will provide protection to open services, safety of life services, such as the European geostationary navigation overlay service (EGNOS) and government such as the Public Regulated Service. RASCAL will also address a gap within existing capabilities, by focusing on a cost-effective portable interference analysis system capable of being used by multiple user communities. |
| Outcomes | A real-time prototype has been developed to demonstrate the capabilities to potential customers. It has been tested in controlled jamming trials to validate its functionality and performance and in field trials to assess its robustness and usability. Plans are underway to trial the device with the authorities in operational scenarios. The next stage will see the novel algorithms being patented. Joint venture opportunities are also being explored to identify how to best migrate the solution from a prototype to a commercial product. |

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|---|---|
| Project Title | **Fundamental analysis and design study of integration of pre-coolers into advanced air-breathing propulsion systems for reusable launch vehicles** |
| Lead | Reaction Engines |
| Partner Organisations | Cranfield University |
| Background | This project investigates the installation aerodynamics of pre-coolers in advanced hybrid air-breathing and rocket engines. Pre-cooled hydrogen-fuelled hypersonic engines offer the capability to achieve Mach 5 terrestrial transport and enable reusable single-stage launch vehicles to orbit. This concept is set to revolutionise access to space, potentially delivering a ten-fold cost reduction compared to the current launch systems. The key to propulsion efficiency is a unique pre-cooler developed by Reaction Engines. There is very little experience globally in the integration of such devices into hypersonic propulsion systems. |
| Outcomes | Overall, 48 prototype pre-cooler engine runs were conducted and approximately 80 computational fluid dynamics (CFD) simulations were run to support the experimental activity and facilitate the design process. CFD models for the pre-cooler modules were derived, calibrated and implemented; CFD and experimental campaigns served to greatly increase the understanding of fundamental flow physics through the pre-cooler installation; and guide vanes and centre bodies were designed using CFD tools and empirical rules. These were manufactured and tested, demonstrating a great improvement in overall flow behaviour through the installation. These project outcomes will directly feed into future work at Reaction Engines, developing the installation aerodynamics of the SABRE engine and de-risking the future Skylon project (the reusable space plane). The multiple validation cases have improved the robustness of Cranfield's CFD algorithms, which are now used in other applications associated with UK-based organisations. |

| Project Title | **Next-generation reaction wheel development** |
|---|---|
| Lead | SSBV Space & Ground Systems |
| Partner Organisations | University of Southampton Roame Systems Ltd Panmure Instruments Ltd Universal Balancing Ltd Stevenage Circuits |
| Background | SSBV Space & Ground Systems, in collaboration with Southampton University, investigated and developed a new generation of reaction wheel for agile Earth observation small-satellite application. This included investigation of novel methods for restraining the flywheel mass during the launch phase, enabling higher reliability and longer life of the mechanism. |
| Outcomes | The project concluded with the delivery of a space-flight-ready reaction wheel assembly and its associated electronics control module to the University of Madrid. This has been accepted for integration into a small satellite currently being built by the university. It is planned to piggy back onto the launch of the Spanish spacecraft, the 'Ingenio' in late 2014. |

| Project Title | **Advanced GNSS receiver for positioning and timing for space** |
|---|---|
| Lead | Surrey Satellite Technology Ltd (SSTL) |
| Partner Organisations | Chronos Technology Ltd |
| Background | In this study, SSTL has developed the prototype for a new generation of advanced space GNSS receiver, called the SGR-Axio. The Axio has been designed to replace its predecessor, the SGR-10, and can track all GPS L1 signals in view on two antennas. Beyond this, it carries reprogrammable front-ends and can support up to four dual-frequency antennas. It has reconfigurable correlator channels that will support Galileo and Glonass and other signals. During the course of the project, the new in-orbit validation Galileo signals have been tracked as a demonstration. Furthermore, we have been collaborating with timing expert Chronos to evaluate the utility of the chip-scale atomic clock (CSAC) to the space GNSS receiver. The timing performance and robustness of the space receiver can be enhanced to generate a non-interruptable timing pulse for the satellite, and as a receiver timing source has applications in low and high orbits. |
| Outcomes | The Technology Strategy Board support for this project has provided a significant lever through acceleration of development, cost contribution, and encouragement of new technology adoption. Further work would explore the advanced potential of the product. The adoption of Galileo open service in space needs further implementation and investigations, including dual-frequency testing. The CSAC is unlikely to be adopted until it is known how robust it is under energetic radiation particles, such as accelerated proton testing. The SGR-Axio could demonstrate SSTL/University of Surrey's patented double estimator scheme on wide bandwidth binary offset carrier signals – potentially an enabler for Galileo positioning reference signal exploitation. The SGR-Axio, subject to some minor refinements, has been selected for two forthcoming satellite missions in its basic mode of operation, already putting SSTL in a strong competitive position. The advanced Galileo and CSAC capabilities, when exploited, may establish the UK as the true world leader in space borne GNSS. |

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| Project Title | UK climate and environmental monitoring from space data integrity facility pilot project |
| Lead | Telespazio VEGA UK Ltd |
| Partner Organisations | Science and Technology Facilities Council – Rutherford Appleton Laboratories National Physical Laboratory |
| Background | The provision of a data integrity facility (DIF) within the UK Climate and Environmental Monitoring from Space (CEMS) facility is seen as a unique and innovative differentiator between this and other Earth observation (EO) data archive and processing centres. This project establishes a pilot data integrity facility within the CEMS environment, using data from the advanced along-track scanning radiometer (AATSR) as a case study. Based on recommendations from preceding studies, the system will demonstrate a data integrity (DI) assessment process for EO data, with associated metadata schema and web interface for results; a suite of tools for assessing the integrity of AATSR data; and a DI helpdesk function. |
| Outcomes | The outcomes of the project will be to demonstrate and gain experience of integrating software systems into CEMS; to test the definition of DI adopted up to this point in a realistic scenario; to demonstrate how the DIF can add value to CEMS; to identify issues with the extension of the concept to a full DIF, operating on all CEMS EO data holdings; and to explore the application of QA4EO principles in this setting. The outcomes will position the project partners for further work involving CEMS, and extend our expertise in establishing the integrity of EO data. |

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|---|---|
| Project Title | **Ultra-high efficiency X-Band monolithic microwave integrated circuits (MMICs) for portable satellite communications** |
| Lead | VIPER RF Ltd |
| Partner Organisations | Cobham Technology Services |
| Background | This research is based on developing world-leading high-power amplifiers (HPAs) for portable satellite communication equipment. A key requirement for portable equipment is to maximise battery life by optimising the microwave equipment to operate with high efficiencies, converting direct current (DC) to radio frequency power. The major component to be targeted for efficiency enhancement in these units is the HPA due to the large output power. This study is focused on applying novel harmonic tuning methods via measurement-based techniques to an X-band gallium arsenide (GaAs) MMIC HPA, targeted at improving present state-of-the-art performance with an ITAR-free solution. The MMIC will be designed, manufactured and characterised during the timescales of this project. The HPA will be designed to operate at 8GHz, with greater than 20W of output power and output stage efficiency of greater than 50%. This world-leading performance will offer the collaborators a leading edge in this growing application area. |
| Outcomes | Cobham Technology Services (CTS) currently provides portable satcom terminals to the homeland security, disaster recovery and military markets and will be able to develop its competitive advantage by further improving antenna efficiency and integrating beyond-state-of-the-art high efficiency amplifier technology. The next step in this project is to complete the characterisation at MMIC level and to look to incorporating the MMICs within a module footprint suitable for evaluation in CTS's portable terminals. The exploitable outputs of the project for VIPER RF are the custom-designed MMICs developed within this project for CTS and also for other opportunities within the X-Band market. This project also provides further opportunities for VIPER RF to increase its IP-licensing and MMIC product sales activity. |

| | |
|---|---|
| Project Title | **Ka-Band low-earth-orbit satellite transmitters based on new high-power, high-efficiency packaged monolithic microwave integrated circuits (MMIC) amplifier** |
| Lead | VIPER RF Ltd |
| Partner Organisations | Surrey Satellite Technology Ltd |
| Background | The evolving requirement for satellite downlinks to operate at higher data rates has led to the adoption and increased use of Ka-band frequencies. This project is aimed at developing an amplifier module for use as part of a state-of-the-art, ITAR-free Ka-Band transmitter for these high data rate downlinks. A set of gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) will be designed, fabricated and packaged before insertion into a newly developed and novel Ka-Band amplifier module for future low-earth-orbit (LEO) satellite communications. The intention is to develop a packaged high-power amplifier (HPA) and driver with world-leading output power and efficiency, which will offer a route to ultra linear operation for minimal distortion at high transmit powers. Novel packaging and MMIC combination technique will also be explored with the aim of maximising power and efficiency. The high power and efficiency targets will yield a world-leading transmitter product which will offer the collaborators a clear and well-defined market lead. |
| Outcomes | If the target specifications are realised then both collaborating partners will look at developing the bench prototypes further. Surrey Satellite Technology Ltd (SSTL) has a very active sub-system sales team which has received interest from USA (SpaceX) and France (CNES) about potential 25.5-27GHz transmitter products. SSTL's core business of remote sensing satellite manufacturing will also look to fly a 25.5-27GHz transmitter on future missions that require very high data rate downlink that cannot be contained inside the current X-Band Space to Earth downlink band of 8.025-8.4GHz, potentially targeting a maiden launch on a demonstrator mission around mid-2016. For VIPER, the outputs of the project are the custom-designed MMICs which are potentially state-of-art. They would be exploitable in the rapidly expanding Ka-Band space market, and also as a generic power amplifier for adjacent communication markets. |

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| Project Title | **LIMPPET – lightweight miniature precision position encoding technology** |
| Lead | Zettlex UK Ltd |
| Partner Organisations | Astrium |
| Background | The project has specified, designed, built and tested an innovative form of position and speed encoder for space applications. The aim is to take an emerging terrestrial technology and develop it for space. Position and speed encoders are common elements in space equipment but the requirements for high reliability in harsh environments are extremely challenging for traditional technologies. Traditional solutions – such as potentiometers, resolvers and linear transformers – are either insufficiently reliable or too bulky and heavy for space applications.<br><br>The LIMPPET concept offers a high-precision, lightweight, miniaturised solution with the potential for ultra-reliable operation in space's extreme environments. LIMPPET uses an innovative non-contact, resonant, radio-frequency sensing technique whose main components are arrays of printed conductors on thin, flexible, laminar substrates. |
| Outcomes | A number of LIMPPET devices have been produced and are currently undergoing qualification. Functional testing has been successful and the predicted environmental reliability is good. The next steps are to progress from successful prototype and test results to industrial-scale manufacture. The LIMPPETT devices have been deliberately designed to use an absolute minimum of tooling and commonly available (MIL spec) parts as opposed to dedicated space parts. Consequently, the main barrier to exploitation is further testing and reliability analysis. |

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| Project Title | **Growth of NanoBlack for Space Sensing** |
| Lead | National Physical Laboratory Limited |
| Partner Organisations | Surrey Nanosystems Limited; ABSL Power Solutions Limited |
| Background | This project will utilise advances in nanotechnology to develop and characterise new concepts for space instrumentation applications. Many space instruments use black finishes for high emissivity performance across the infrared part of the electromagnetic spectrum. However, these finishes suffer from several issues, including ITAR, thus restricting UK trade in this area. This project will research, develop and test a novel high performance coating employing carbon nanotubes.<br>Objectives: Facilitate a characterised UK supply of carbon nanotubes as a black coating for space instrumentation by using black body calibration sources as a test case for use in a £100m market that also includes detectors and baffles.<br>Innovation: The novel low-temperature application of carbon nanotubes will allow aluminium to be coated; this is a vital step to open up the majority of space instrumentation applications. |
| Outcomes | This project will utilise advances in nanotechnology to develop and characterise new concepts for space instrumentation applications. Many space instruments use black finishes for high emissivity performance across the infrared part of the electromagnetic spectrum. However, these finishes suffer from several issues, including ITAR, thus restricting UK trade in this area. This project will research, develop and test a novel high performance coating employing carbon nanotubes.<br>Objectives: Facilitate a characterised UK supply of carbon nanotubes as a black coating for space instrumentation by using black body calibration sources as a test case for use in a £100m market that also includes detectors and baffles.<br>Innovation: The novel low-temperature application of carbon nanotubes will allow aluminium to be coated; this is a vital step to open up the majority of space instrumentation applications. |

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| Project Title | **Affordable Secured PURSUIT PRS Integrated Receivers (ASPIRE)** |
| Lead | QinetiQ Limited |
| Partner Organisations | NSL |
| Background | The ASPIRE project has been proposed as an accelerator to provide stimulus to the support and uptake of the Galileo Public Regulated Service (PRS) across a growing range of users and applications in the UK, EU (and potentially more widely) enabled by access to secured position, navigation and timing (PNT) services. The aim of this innovative project is to explore how strong secured PNT services, specifically including the Galileo PRS, can be delivered to a wide range of users cost-effectively and with minimal security requirements (at individual user and user organisation levels). A key objective is to drive the availability of very low-cost "PRS enabled" receivers ahead of the launch of Galileo services. This will be achieved by examining how security requirements can be integrated into GNSS receiver solutions and service architectures. The project builds on NSL's PURSUIT PNT receiver architecture and QinetiQ's PRS technology and security expertise. |
| Outcomes | The ASPIRE project has been proposed as an accelerator to provide stimulus to the support and uptake of the Galileo Public Regulated Service (PRS) across a range of users and applications in the UK, EU (and potentially more widely). This will be achieved by examining how security requirements and PRS can be integrated into GNSS receivers. The project is based on the use of a novel "local signal capture in the user device and off-board processing to obtain PNT using a remote secure server" receiver architecture (PURSUIT) which will be enhanced to meet security objectives as determined by QinetiQ. The specific benefits of the proposed approach will enable new cost-effective secured navigation applications (solving real Government and Commercial user business challenges), growing the PRS applications market and, positioning UK industry to exploit the business opportunity for these services by fielding 'PRS-ready' solutions even prior to Galileo PRS service launch. |

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| Project Title | **Security Threats and Vulnerabilities of GNSS - Analysis Specification & Test Services** |
| Lead | General Lighthouse Authorities of the UK & Ireland |
| Partner Organisations | University of Nottingham |
| Background | Security vulnerabilities and threats to services based on Global Navigation Satellite Systems (GNSS) are increasing concerns as their use for positioning navigation and timing (PNT) becomes ever more widespread and dependencies grow. The proposed work analyses specific operational needs in order to deduce and document Threats and Vulnerabilities (T&V) applicable to particular users. These T&V specifications are directly applicable to support user activities of equipment and service procurement to ensure fitness and robustness for purpose. Expert T&V analysis and specification for end users will be created as a revenue-generating service. We further propose to analyse and consolidate methods for testing GNSS equipment / services to verify performance. |
| Outcomes | Security vulnerabilities and threats to services based on Global Navigation Satellite Systems (GNSS) are increasing concerns as their use for positioning, navigation and timing (PNT) becomes ever more widespread and dependencies grow. The proposed work introduces innovative services to analyse specific operational needs in order to deduce and document Threats and Vulnerabilities (T&V) applicable to particular users. These T&V specifications support user assurance that equipment and services procured will be fit and robust for purpose. Expert T&V analysis and specification for end users will be created as a novel revenue-generating service. We further propose to create new and innovative services to specify, carry out, and document testing for testing GNSS equipment / services to verify performance. Exploitable elements are then (i) T&V Specification, (ii) T&V Test Specification, and (iii) Testing Service using appropriate state-of-the-art Simulators and Tools. |

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| Project Title | **Feasibility of Novel Optimal Attitude Planning and Control algorithms for low cost spacecraft** |
| Lead | Clyde Space Limited |
| Partner Organisations | University of Strathclyde |
| Background | This feasibility study will assess the practical implementation of novel motion planning algorithms within flight representative hardware for a miniaturised ADCS, addressing the problem of performing minimum resource attitude manoeuvres within the limitations of available on board processing capability, and sympathetic to small to nanosatellite sensing and actuation. The on-board optimal motion planner will enable small low-cost spacecraft to perform to the high-precision pointing capability of larger, more expensive, spacecraft. The aim is to develop control algorithms that enhance the capability of small spacecraft re-pointing capabilities that are affordable to a wider range of consumer |
| Outcomes | This feasibility study will assess the practical implementation of novel motion planning algorithms within flight representative hardware for a minaturised ADCS, addressing the problem of performing minimum resource attitude manoeuvres within the limitations of available on-board processing capability, and sympathetic to small nanosatellite sensing and actuation. The on-board optimal motion planner will enable small low-cost spacecraft to perform to the high-precision pointing capability of larger, more expensive, spacecraft. Whilst the target for initial studies has included constraints applicable to smaller lower cost satellites, the solutions could be offered as an alternative to large spacecraft to a wider market |

| Project Title | **Definition of ARM CPU for Space** |
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| Lead | ARM Limited |
| Partner Organisations | |
| Background | Computers are used in a variety of space-borne equipment for numerous on-board applications and Central Processing Units (CPU) are at the core of these. However, the existing space solutions are not suitable for the next generation of Telecommunications Processor because they are too big, not scalable and not power-efficient. This fast track proposal aims to define what CPU functionality will be needed for the next generation of Telecoms Processors. |
| Outcomes | Computers are used in a variety of space-borne equipment for numerous on-board applications and Central Processing Units (CPU) are at the core of these. However, the existing space solutions are not suitable for the next generation of Telecommunications Processor because they are too big, not scalable and not power-efficient. This fast track proposal aims to define what CPU functionality will be needed for the next generation of Telecoms Processors and this same technology will also apply to a wide range of other applications in Earth Observation, Navigation and Science. The deliverables will be reports investigating CPU micro-architectures, power and cost figures, on-board applications, fault and radiation tolerance features and it will also map ARM CPU cores to space equipment types and it will make recommendations with respect to future radiation hardening. The project is expected to enable the foundation of a future flagship project in which an ARM CPU core is radiation hardened for space. |

| Project Title | **Package for NIR LFA CMT Sensors** |
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| Lead | E2V Technologies PLC |
| Partner Organisations | Selex ES Limited |
| Background | This project will develop innovative large format array packaging technology for near infra-red imaging sensors. This project will support sensor arrays for the next generation of large telescopes and it will be a crucial enabler of the sensor technology that will investigate events early in the evolution of the universe. |
| Outcomes | e2v and Selex Galileo will design and test a custom package for a near infra-red, large format array (NIR LFA) CMT sensor. The project will prove a novel package design and sensor assembly process to achieve adequate device flatness, successful MIL -883 thermal and mechanical tests and confirmation of operation.<br><br>The project partners will use innovative materials and processes to package a NIR LFA CMT sensor and provide a route to rapid exploitation for space programmes such as Euclid and Echo with a £30M/annum addressable market and further potential of > £5M/annum per project for E-ELT and other international projects.<br><br>The vision for this INNOVATE UK proposal is to accelerate the exploitation of UK manufactured NIR LFA sensors and ensure a UK leading position. |

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| Project Title | **Mars Rover Autonomy using Endocrine based Algorithms (ENDOVER)** |
| Lead | Astrium Limited |
| Partner Organisations | Aberystwyth University; EADS UK Limited |
| Background | Endocrine based algorithms which mimic biological processes have been shown to have applications in the area of autonomous power management on robotic vehicles. This project intends to adapt the work carried out in the UK for use by robot rovers on the surface of Mars. The highly dynamic power generation and load profiles in this environment mean that the currently used simple operational schedules have significant margins built in, such that the rover will stop all activities if one criterion is not met. The proposed technique will enable a more intelligent autonomous assessment of the power available, and will allow the rover to carry out low risk, low power activities that can significantly improve the science return. These activities could include imaging and other surface or atmospheric sensing. It is anticipated that there will be other space based opportunities for this technique where autonomy will add to the science or commercial return from a mission or product. |
| Outcomes | Power management for Martian Rovers, such as planned for ExoMars, is currently performed by the ground operations team and the rover's daily activities are planned using a prediction of the available power. If the rover detects that insufficient power is available, then the planned activity is cancelled, and even if excess power becomes available, the rover will not attempt to perform any additional activities. An autonomous power management technique based on available power would allow the rover to carry out additional operations, such as locomotion or imaging, which would significantly increase the valuable science output of the mission. This project will adapt the biological processes mimicking the actions of endocrines and hormones that maintain the stability of a biological system under varying external states. The project innovation is to develop algorithms for generating the hormone concentrations that manage the rover power system under highly variable power conditions. |

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| Project Title | **Advanced avionics for low cost satellites** |
| Lead | Surrey Satellite Technology Limited |
| Partner Organisations | University of Surrey |
| Background | Working with the University of Surrey's Space Centre (SSC), Surrey Satellite Technology Limited (SSTL) aim to define and breadboard a new generation of commercial off the shelf (COTS) avionics architecture for low cost satellites. This proposal is to investigate state-of-the-art developments in COTS data buses and determine if they have the relevant capabilities to be used in a robust, failure tolerant satellite architecture whilst also reducing costs through rapid software development tools. With innovation in fault tolerant buses and rapid software design, SSTL and SSC are also proposing to investigate methods to perform distributed processing across the avionics architecture with an aim to remove the need for large central processing units for multiple heterogeneous computing nodes and therefore reduce the time and cost of production of the satellite avionics. |
| Outcomes | Working with the University of Surrey's Space Centre (SSC), SSTL's proposal is to define and breadboard a new generation of commercial off the shelf (COTS) avionics architecture for low cost satellites. This proposal is to investigate state-of-the-art developments in COTS data buses, such as Ethernet operating at over 100 Gb/s, and determine if they have the relevant capabilities to be used in a robust, failure tolerant satellite architecture whilst also reducing costs through rapid software development tools. With innovation in fault tolerant buses and rapid software design, SSTL and SSC are also proposing to investigate methods to perform distributed processing across the avionics architecture with an aim to remove the need for large central processing units for multiple heterogeneous computing nodes and therefore reduce the time and cost of production of the satellite avionics. |

# Appendix D – Pathfinder Programmes

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| Project Title | **Evaluation of Reduced Hazard Clean Combustion Propellants** |
| Lead | Reaction Engines Ltd |
| Partner Organisations | Airborne Engineering Ltd |
| Background | Carbon monoxide is demonstrated as a viable propellant with a non-contaminating exhaust free of water and hydrocarbons, thus enabling a Mars landing mission which would avoid contamination of the surface. |
| Outcomes | Initial analysis identified methane and carbon monoxide as the most promising propellants, as 'clean' alternatives to hydrazine. Test results show that a stable reliable combustion with good pressure and thrust stability can be achieved for both propellants. For carbon monoxide overall combustion is very efficient, with 90 – 94% of the theoretical vacuum exhaust velocity being realised. For a high aspect ratio nozzle vacuum exhaust specific impulses of 275 – 290 seconds, can be achieved and the thrust can be throttled in the range from 1500 – 3700 N over the total mass flow range investigated. For methane, efficient combustion was not achieved and further work is required to characterise the limits of performance. |

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| Project Title | **Pultruded Spacecraft Components** |
| Lead | Magna Parva Ltd |
| Partner Organisations | Excel Composites Ltd, Astrium Ltd |
| Background | The project demonstrated that it is possible to replace existing spacecraft components with less massive CFRP assemblies, manufactured using pultrusion techniques, in a cost effective manner if standardisation is adopted. |
| Outcomes | Spacecraft strut test pieces were designed and manufactured, consisting of a pultruded and pull-wound CFRP tube with adhesively bonded steel end pieces. This can directly address some of the requirements of the Next Generation Telecomms Platform. To achieve the benefits that may be accrued from this technology requires a shift in manufacture culture towards using standardised components. |

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| Project Title | **Development of a High Temperature Anti-oxidation Coating for next generation Rocket Thrusters** |
| Lead | Archer Technicoat Ltd (ATL) |
| Partner Organisations | Moog ISP Ltd, University of Manchester |
| Background | The project made significant steps in coating iridium onto C103 niobium alloy to provide a high temperature thruster. Experiments showed that a duplex layer of tungsten and iridium on niobium can ensure good adhesion without delamination. |
| Outcomes | Initial coating trials with a tungsten layer were successful, but coating of iridium directly onto C103 Niobium (Nb) based alloy was not possible. Investigations proved that the lack of adhesion was due to the 10% hafnium content in the alloy and hence later experiments were performed using pure niobium substrates. The experiments and analysis showed that a duplex layer of tungsten and iridium could be deposited on niobium without delamination. Due to the scientific potential of the material combination and its commercial interest, work will continue on the coatings under the ESA HTAE project until April 2013. |

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| Project Title | **Additive Layer Manufacturing (ALM) for Complex Waveguide Assemblies** |
| Lead | Astrium Ltd |
| Partner Organisations | None |
| Background | Additive layer manufacturing was shown to be a viable method to produce waveguides and was considered best suited to short and complex waveguide structures; however some issues need to be resolved to improve surface finish. |
| Outcomes | The ALM waveguide study work has shown that this technique can be used to manufacture viable waveguides for use on a satellite payload. The initial results suggest that the strength is comparable with existing aluminium waveguides. The ALM technique has some surface finish issues as well as accuracy for larger parts which means that ALM is not suited to long waveguide runs. This technique is most suited to short and complex waveguide structures which can be very expensive to manufacture by existing techniques. However, the choice of item and its detail design must be undertaken with an ALM technique in mind if full benefit is to be achieved. |

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| Project Title | **Science and Exploration Mission Opportunities and Requirements for Nuclear Power Systems (NPS)** |
| Lead | Astrium Ltd |
| Partner Organisations | SEA Ltd, University of Leicester |
| Background | Through an end-to-end assessment of future space nuclear power systems, a technology development roadmap was produced for heaters and power generators that would mature these systems for use in European missions in 5-10 years. |
| Outcomes | The end-end requirements for multi-mission nuclear power sources have been analysed to harmonize with future developments for European space exploration and science missions, investigating Radioisotope Heater Units (RHU), Radioisotope Thermal Generators (RTG) and Stirling Radioisotope Generators (SRG). The main conclusions of the study were that for an RHU 2-3 Watt output power is recommended and the heat source for RTG/SRG should generate ~200 Watt-thermal, giving ~10W electrical power from a RTG and ~ 50W electrical power for a SRG. A modular design should be developed with multiple outer containment units to suit different mission requirements. To develop a range of NPS units, to suit different mission requirements, the main cost is associated with the heat source. |

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| Project Title | **Titanium Matrix Composite Arm** |
| Lead | TISICS Ltd |
| Partner Organisations | Morson Projects Ltd |
| Background | Silicon carbide fibre reinforced titanium composites structures were shown to be viable alternatives to standard CFRP units and offer superior performance for selected niche space components such as robotic arms with complex metal joints. |
| Outcomes | Fabrication of 3 representative silicon carbide fibre reinforced titanium composites structures, consisting of two full arms with end pieces (760mm, 640mm long) and a 400mm tube section, was completed successfully. One arm was tested under deflection showing agreement to the FEA model to within 5%. FEA modelling was also used to compare the performance of TMC with comparative CFRP robot arms. FEA analysis predicted superior bend, torsion and compression stiffness for TMC compared to CFRP per unit mass in all configurations. |

| Project Title | **Experimental Proof of Concept for an Electrochemical Plasma Thruster** |
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| Lead | EADS Innovation Works |
| Partner Organisations | University of Surrey |
| Background | A concept demonstrator was developed for a self-sustaining plasma thruster that would alleviate the need for heavy external electrical power supplies; the results show the concept has strong potential of commercial pull-through. |
| Outcomes | A proof-of-concept model of the Electrochemical Plasma Thruster has been designed, built, and tested within an aggressive 6 month timeframe. This work has made considerable progress and gained valuable experience in the operation of the device, although not all of the experiments planned for this prototype could be completed within the timeframe available. This project has resulted in significant return for both the University of Surrey and EADS Innovation Works in terms of laboratory hardware and expertise, scientific data that will lead to academic outputs for the University, and the production of valuable IPR that can be exploited commercially. |

| Project Title | **Development of radiation-hardened CMOS image sensors for space use** |
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| Lead | The Open University |
| Partner Organisations | e2v Ltd |
| Background | This project successfully investigated displacement damage and ionising radiation damage effects in a range of e2v CMOS image sensor designs. |
| Outcomes | The project found that the proportion of pixels suffering random telegraph signals (RTS) increased with the photosensitive volume within the pixel. This confirmed that there is a trade-off between decreasing the percentage of RTS pixels for a given dose against increasing the sensitivity of the pixel, particularly to longer visible wavelengths or higher X-ray energies. I-V characteristics of individual MOSFETS were found to be relatively unchanged after gamma irradiation up to a total ionising dose of 500 krad(Si). This is equivalent to the expected dose for a Jupiter mission such as JUICE and indicates that a typical imaging device should be able to tolerate high ionising radiation dose with minimal impact on the basic functionality of the pixel readout circuitry. |

| Project Title | **Development of Extra High Frequency Ferrite Switch** |
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| Lead | COM DEV Europe Ltd |
| Partner Organisations | None |
| Background | The project successfully manufactured, assembled and tested a breadboard demonstrating that it is feasible to use higher order mode resonance techniques to implement a W-band ferrite switch. |
| Outcomes | During testing, classical Tchebyscheff response curves of return losses and isolation against frequency were observed indicating that the switch was operating as intended and that the implementation of the higher order mode resonance method had been successful. However the RF performance was poor by the standards of normal switches and the primary method of tuning the switch was seen to be largely ineffective. Additional development activity will be required to produce a marketable product. |

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| Project Title | **Enhanced sensitivity of SWIR and NIR detectors using HgCdTe e-APDs for space sensing applications** |
| Lead | Selex ES Ltd |
| Partner Organisations | None |
| Background | Electron-Avalanche Photo Diodes (e-APD) that offer in terrestrial applications improved signal to noise performance in low photon flux conditions were shown to be able to withstand periods of high temperature and high photon flux mitigating some of the perceived environmental risks over using them in space sensors. |
| Outcomes | The work has shown that the performance of electron-Avalanche Photo Diode (e-APD) SWIR focal plane arrays (FPA) are stable after extended life testing. The devices tested showed good stability and repeatability of avalanche gain even after subjecting them to extended periods at high temperatures and measurement in high flux conditions. With respect to the environmental testing undertaken, the project has successfully reduced the risk associated with using HgCdTe e-APD FPAs for space applications and other key programmes. However, there was a desire from the space community for radiation testing to be carried out but this was outside the scope of the programme. |

## Appendix E – Demonstration Programmes

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| Project Title | **TDS1 – Mission planning system** |
| Activity Cost | £334.5K |
| Duration | 10 months |
| Lead | The ISIC project team to procure the Mission Planning System (MPS) for TechDemoSat-1 on behalf of the UK SPACE AGENCY. |
| Background | As part of the development of the UK's TechDemoSat mission, it was decided that the mission operations would be performed using the EO Hub facility (now known as the mission operations centre) within ISIC. While the mission operations centre has the ability to control missions that use either the international standard CCSDS protocols or the SSTL specific ones used on TechDemoSat, the mission planning tools that were already part of the mission operations centre were not adequate for a mission like TechDemoSat. In consultation with the UK Space Agency, it was agreed that ISIC would manage the procurement of a suitable mission planning system, with funding to be provided by the Agency. |
| Outcomes | The procurement of the Mission Planning System for TechDemoSat was a success. The system was delivered on time and was demonstrated to work successfully in the ISIC working environment. There was considerable time pressure during the development, which originated in the later than planned start of the project due to protracted discussions about which organisations should be part of the team and the letting of the contract from the UK Space Agency. However, the team delivered on schedule and to budget. |

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| Project Title | **TDS-1 payload** |
| Activity Cost | **£50K** |
| Lead | RAL |
| Background | This experiment will be mostly comprised of existing hardware repackaged to fit the dimensions of Location A in the SSTL additional payload email, i.e. 250 x 200 x 270mm. The gradiometer is being developed under ESA contract for the LISA mission with a local magnetometer company Bartington Instruments Ltd. It is comprised of 10 miniature very low noise precision magnetometers housed in a Macor block, configured to measure very small differential magnetic fields. The other part of the experiment is a new radiation shield which we will test by flying 2 more HMRM miniature radiation monitors, 1 of which is encased in a new patented material produced by Cella Energy. The HMRM is already flying on TDS-1 as part of the CMS experiment and the entire CAN bus interfaces are currently being checked out with the SSTL team. There is an existing spare CMS CANbus/ HMRM driver board which will be used for the new experiment. |
| Outcomes | TBD |

## Appendix F – Collaboration with other public providers

| Project Title | **DSTL** |
|---|---|
| Funding Allocation | £50k |
| Duration | 6 months |
| Partner Organisations | DSTL / STFC (ATC) |
| Background | A short programme of work to investigate scene based co-phasing techniques appropriate for small satellite systems. The UKATC have been developing concept designs for imagers for small satellites, including CubeSats. Some of these concepts rely on deployable mirror segments to provide larger apertures than would otherwise be available in the launch volume of the satellite. This increases the flux level for the sensor and allows higher ground resolution. However, to achieve the increase in resolution the mirror segments must be aligned in operation (co-phasing), and must maintain alignment during flight. |
| Outcomes | Co-phasing is possible, and the complexity is not impractical for a nano-satellite system. Automatic co-phasing is possible, but the criteria for requiring re-alignment need to be carefully determined. This study indicates that a nano-satellite imager, using deployable optics to provide an increased spatial resolution, is achievable. |

| Project Title | **STEAM-R** |
|---|---|
| Funding Allocation | £250K |
| Duration | 2 years |
| Partner Organisations | CEOI / STFC (RAL) |
| Background | STEAM-R will fly alongside a companion infrared limb-sounder to observe on finer scales than previously possible from space processes that control the composition of the upper troposphere and lower stratosphere, a region of particular importance for climate, and links to surface emissions and pollution. This is a UK contribute to a radiometer, which is being led by Omnisys Ltd on behalf of the Swedish National Space Board. This builds on the UK's strong heritage in millimetre-wave sounding and offers an outstanding opportunity for the UK to have a central role in a near-term satellite mission of high scientific importance. |
| Outcomes | A contribution to the STEAM-R radiometer will strategically position UK industry to build space hardware for Europe's Earth Observation Programme beyond 2020. A further advantage of underpinning and developing the UK technical strength in the Terahertz frequency region, which offers a broad range of new scientific and commercial opportunities. |

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| Project Title | **Project BA** |
| Funding Allocation | £85k |
| Duration | 6 months |
| Partner Organisations | STFC (RAL) / CGI / MSSL |
| Background | Project BA is a UK led international robotic lunar drilling mission. A spacecraft would land and create a borehole up to 100 metres deep at the lunar south pole, optionally returning a sample back to Earth. Scientists gain from investigating depth-related lunar rock 4½ billion years old, while the exploration community gains knowledge about the practicality of a permanent manned base. Engineers gain by developing a remote controlled drilling technique originating from the US. The project takes over from, and extends, NASA and ESA plans for a south pole lander. |
| Outcomes | The BA lander mission appears to be feasible with only modest deviations from the original pre-feasibility design concept. The baseline launcher, mass margin and desired payload elements are complementary and collectively allow a credible sequence of mission phases. A number of risks relating to descent guidance navigation & control, drill and robot arm robustness & redundancy, and landing structure have been identified and appropriate risk mitigation strategies have been identified. It appears reasonable that the primary mission can be carried out within a lunar day depending on the precise landing site. A detailed Phase A/B study by one or more contractors will aim to confirm the conclusions made here and refine the key budgets including cost & schedule. |

| Project Title | **Autonomous Intelligent Systems Programme** |
|---|---|
| Funding Allocation | £250k UK SPACE AGENCY, £9.6M from the other partners |
| Duration | 3years |
| Partner Organisations | EPSRC, Network Rail, Schlumberger, Scisys, Sellafield, National Nuclear Laboratory, BAE Systems, UK Space Agency, DSTL. |
| Background | This is a programme to support underpinning technology that can be applied to a number of sectors. Topics included in this programme are.<br><br>• software architectures<br><br>• sensor exploitation<br><br>• situational awareness<br><br>• decision making and planning<br><br>• information management<br><br>• Verification of autonomous systems<br><br>• Model building and learning<br><br>The programme supported 9 projects in total. |
| Outcomes | The primary outputs will be fundamental research products that have application across many domains. This will include concepts and technologies to provide the partners with the leading edge capability for developing market leading intelligent systems products. In addition there will be an opportunity to develop people with new skills and knowledge delivered through training and education. |

# Appendix G – Space Collaborative Innovation Team Initiative (Space CITI)

Budget allocation: £500k Total of grants awarded £614,819

| Project Title | **UK Launcher Study** |
|---|---|
| Funding Allocation | Project Value £300K, Grant awarded £195,000, PRIVATE VENTURE: £105K |
| Duration | 6 months |
| Partner Organisations | SSTL, CST, London Economics and Reaction Engines |
| Background | A study into the different options for developing the capability of launching spacecraft from the UK in order to fulfil the demand from the UK for access to space in a manner that provides the UK with control over launch dates, an essential criteria in order to deliver a complete service to customers. The study covered different types of launch vehicles and examined the economic case for a launch site in the UK. |
| Outcomes | The UK is now better informed about the key components that would be part of any UK launch capability. The study made a compelling case that a UK launch capability would benefit the UK, both in terms of the services that it would offer industry and being a viable financial proposition in its own right. The next step is to actively consider whether and how, to develop a UK launch capability in the light of this and previous related studies |

| Project Title | **SeaSpace** |
|---|---|
| Funding Allocation | Project Value £238K, Grant awarded £135K, PRIVATE VENTURE £58K |
| Duration | 6 months |
| Partner Organisations | H R Wallingford, Mainstream Renewable Energy, Europa Technologies and Astrium |
| Background | To help to create new service feeds of Earth observation data to the private sector who are investing in the development and operation of offshore engineering projects, in particular, marine renewables. SeaSpace unlocks the information content from large data sets and makes them available as readily usable data streams. The project has demonstrated the ability to use the virtualisation environment of the Climate and Environmental Monitoring from Space (CEMS) infrastructure to set up data processing and information delivery systems targeted at a specific community that deliver real value. |
| Outcomes | The outcome of this project is that the ISIS consortium is now better placed to deliver a sustained supply of Earth observation data services to the offshore industry. The next step is to establish a marine data service hub as part of CEMS which would provide a credible demand-driven uptake of EO data, fuelling requirements for the next generation of missions and pushing the UK forward as an international player in this arena. |

| Project Title | **FlatSat** |
|---|---|
| Funding Allocation | Project Value £38,225, Grant awarded £30,580, PRIVATE VENTURE £7645 |
| Duration | 3 Months |
| Partner Organisations | SSBV, High-Q systems, STFC (RAL) |
| Background | A study into the need within the UK for a standard avionics testbed that can be used to de-risk the development of small satellites and their payloads. The study showed that while large space companies have their own facilities, smaller companies have difficulty in testing hardware that they have developed for a space mission in a realistic environment. This reduces their ability to convert the technology that they have developed into flight-ready hardware. The Flatsat, when used in combination with the Harwell ground control system, can also be used as a spacecraft simulator. This allows development and test of new on-board software without risking the in-orbit system. This develops new command and control strategies that can be tested on-ground before being used operationally. |
| Outcomes | The outcome of the study is that the Satellite Applications Catapult Centre have recognised the benefit of providing a FlatSat facility and are planning to provide one on the Harwell Campus in partnership with RAL Space and other companies that can deliver the required components of such a system. |

| Project Title | **I-PDHS** |
|---|---|
| Funding Allocation | Project Value:£391,136 , Grant awarded £254,239:, PRIVATE VENTURE: £136,897, |
| Duration | 6 Months |
| Partner Organisations | Astrium, RAL, SciSys and Imperial College London |
| Background | The Integrated Payload Data Handling System (I-PDHS) project is developing the hardware and software tools needed in order to reduce the power and mass requirements in multi-instrument missions by having one processor with the ability to control and process the data from multiple payloads. Each instrument has its own specific requirements, so rather than use a single processor with multiple processes as is commonly the case with ground-based computers, I-PDHS provides the ability to reconfigure the on-board system on the fly and so provides an optimal configuration for each instrument. |
| Outcomes | The outcome of the project is that the UK is better placed to offer competitive payloads to a wide range of international missions due to the reduction in mass and power that the I-PDHS methodology provides. The project demonstrates that central provision of the processor and its core system services frees the instrument teams to concentrate their resources on sensors and the science. |

# Appendix H – Horizon Scanning Studies

Budget Allocation £500k
Grant Awarded £50,434
Duration: 9 months

This activity was carried out by the University of Strathclyde – Advanced Space Concepts Laboratory who are internationally recognised as a leading centre of excellence in future concepts in space technology and are renowned for their wide range of national and international collaborations.

A National Space Technology Horizon Scanning team was established and a workshop was held in April 2013 with the aim of performing a driver analysis with a focus on societal, technological, economic, environmental and political (STEEP) themes and impacts. Once these drivers were identified, they were prioritised and can now be tracked and responded to, or directly influenced. However, this requires an on-going funding commitment to enable the tracking and response activities to continue.

UK SPACE AGENCY
Web www.gov.uk/ukspaceagency
Polaris House, North Star Avenue, Swindon, Wiltshire, SN2 1SZ
Tel +44(0)207 215 5000  Email info@ukspaceagency.bis.gsi.gov.uk
An executive agency of the Department for Business, Innovation and Skills