Space Activities in Glasgow; Advanced Microspacecraft from Scotland

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ABSTRACT

The City of Glasgow is renowned for its engineering and technological innovation; famous Glaswegian inventors and academics include James Watt (Steam Engine) and John Logie Baird (television), amongst many others. Contemporary Glasgow continues to pioneer and invent in a multitude of areas of science and technology and has become a centre of excellence in many fields of engineering; including spacecraft engineering.

This paper will discuss how Clyde Space Ltd and the space groups at both Glasgow and Strathclyde Universities are combining their knowledge and expertise to develop an advanced microspacecraft platform that will enable a step change in the utility value of miniature spacecraft. The paper will also explore how the relationship between the academic and industrial partners works in practice and the steps that have been taken to harness resulting innovation to create space industry jobs within a city that was, until recently, void of any commercial space activity.

INTRODUCTION

The City of Glasgow is famous for the contribution that it has made to the world of science over the last centuries. In particular, key advances in Steam Engine technology, the Kelvin temperature scale and the television, all invented by Glaswegians, have contributed hugely to the way that we live our lives today. Glasgow engineers, scientists and technologists continue to pioneer and invent in a multitude of areas of science and technology; recently, Glasgow has become a centre of excellence in spacecraft engineering.

Although modest in numbers, Glasgow is leading the advances in various areas of spacecraft engineering: research into spacecraft dynamics (in particular in the field of solar sail spacecraft); control of multiple spacecraft systems; advanced micro-spacecraft design; global trajectory optimisation; NEO missions, aerocapture and entry descent and landing; formation flying; autonomous systems; advanced small satellite battery systems and power management systems. These areas of expertise are realised within Glasgow based academic and industrial groups formed at the University of Strathclyde, the University of Glasgow and Clyde Space Ltd.

Glasgow has been active in space research and applications for several years and both Strathclyde University and Glasgow University have excellent research records and offer post graduate research and study. However, it has only been since 2005, when Clyde Space Ltd was established, that Glasgow has ventured into the commercial side of the space industry. Since inception, Clyde Space has worked closely with both Universities and this has in turn stimulated collaboration that has clearly been beneficial to all parties. More recently, this has culminated in the start of an exciting development project to produce Scotland's first satellite.

This paper will discuss how Clyde Space Ltd and the space groups at both Glasgow and Strathclyde Universities are combining their knowledge and expertise to develop an advanced micro-spacecraft platform that will enable a step change in the utility value of miniature spacecraft. The paper will also explore how the relationship between the academic and industrial partners works in practice and the steps that have been taken to harness resulting innovation to create space industry jobs within a city that was, until recently, void of any commercial space activity.

GLASGOW'S PARTNERS IN SPACE

The Space community in Glasgow has been able to develop a relationship that benefits both the academic and commercial objectives. Glasgow has had modest, but widely respected, space research activities for some years, but it has been only within the last 3 years that these seeds of space expertise have started to grow, resulting in a significant increase in space

related research and commercial endeavour in the area.

In 2005, Craig Clark, the former Head of Power Systems at Surrey Satellite Technology Ltd, met with Prof Colin McInnes and Dr Gianmarco Radice to discuss the prospect of starting a spacecraft hardware design and production activity in Glasgow. Later that year Craig started Clyde Space Ltd, a small satellite systems company based at a Science Park not far from both Strathclyde and Glasgow Universities. Three years have passed since the initial meeting, and all parties have made a point of keeping close communication.

As a result of the relationship that has been built between the academic and industrial space activities, there have been key benefits to both parties;

- The Universities now have an industry partner on their doorstep, making collaborative projects easier to coordinate.
- Clyde Space has a key source of skilled graduates locally, reducing the cost of recruiting.
- There are increased opportunities to perform joint research with commercial focus (funding is most often link with potential for economic growth)
- Ideas and innovations that Clyde Space are unable to resource can be examined by students as part of undergraduate and post graduate projects.
- Clyde Space offers an outlet for industrial placements, providing graduates the opportunity to gain industrial experience without the need to move country.
- Industry related advanced concepts can provide the opportunity for more commercially focussed student projects to develop hardware and software
- Both academic and commercial activities combine to the benefit of economic growth and more skilled jobs for the area (Scots educated in Scotland can stay in Scotland).

It is clear that the relationship is working extremely well and, with the recent award of the Knowledge Transfer Partnership between Clyde Space Ltd and the University of Strathclyde to develop an advanced micro-spacecraft platform, another significant step forward has been made in what is becoming a very successful partnership.

University of Strathclyde: Advanced Space Concepts Laboratory

The Space Dynamics Group comprises 2 academic staff, 3 research assistants, 5 PhD students and 2 long term visitors (http://www.mecheng.strath.ac.uk/space/home.html). The group aims to develop fundamentally new concepts in spacecraft dynamics and translate these concepts through to future mission applications. This broad aim is articulated through the development of new families of highly non-Keplerian orbits for solar sail spacecraft, the development of artificial potential field methods for the control of multiple spacecraft systems, work on microspacecraft autonomy and speculative work on advanced concepts. The program of work is undertaken in collaboration with a network of international academic and industrial partners and is funded by national research councils, industry and overseas agencies. Recent work on CubeSat development for Scotland's First Satellite is being funded by Clyde Space and STFC.

Solar Sailing

Families of highly non-Keplerian orbits devised by group members have been a principal driver in the recent development of solar sail technology. These new families of novel orbits provide a range of compelling near-term applications for solar sailing for space science and Earth observation missions. The Space Dynamics Group are working on the systematic analysis of highly non-Keplerian orbits for spacecraft with low thrust propulsion systems using the methods of modern dynamical systems theory. This analysis is discovering new families of orbits for solar sails and solar electric propulsion, again with exciting new practical applications[1]. Related work is translating these ideas into mission concepts through collaborative work with ESA and industry; such as the GeoSail TRS mission[2] (Fig. 1).

Swarming Systems

Swarms of interacting robotic agents hold the promise of delivering radically new ways of solving real engineering and societal problems. However, to field such systems for safety-critical applications will require the development of new methodologies to provide verifiable swarm behaviours. Our work aims to make steps towards this important goal by applying new insights into the collective behaviour of systems of interacting particles as the basis of a theory of swarm behaviour. We are conducting a systematic analysis of the underlying theoretical basis for swarm behaviour[3]. Using dynamical systems theory (through potential field methods) mathematical proof can replace algorithm validation as a verification tool. The work has applications in spacecraft formation-flying, swarms of pico/femto-spacecraft and terrestrial robotics[4] (Fig. 2).

Related work is focusing on exploiting concepts from dynamical systems theory to develop

provable behavioural autonomy for micro-spacecraft.

Advanced Concepts

A range of future large-scale engineering ventures are being investigated including near Earth asteroid deflection methodologies[5], Geoengineering[6] and novel concepts for Earth-to-orbit transportation (orbital towers). The work aims to provide a strong theoretical basis to such ideas to enable a reasoned and pragmatic view of their plausibility and future development.

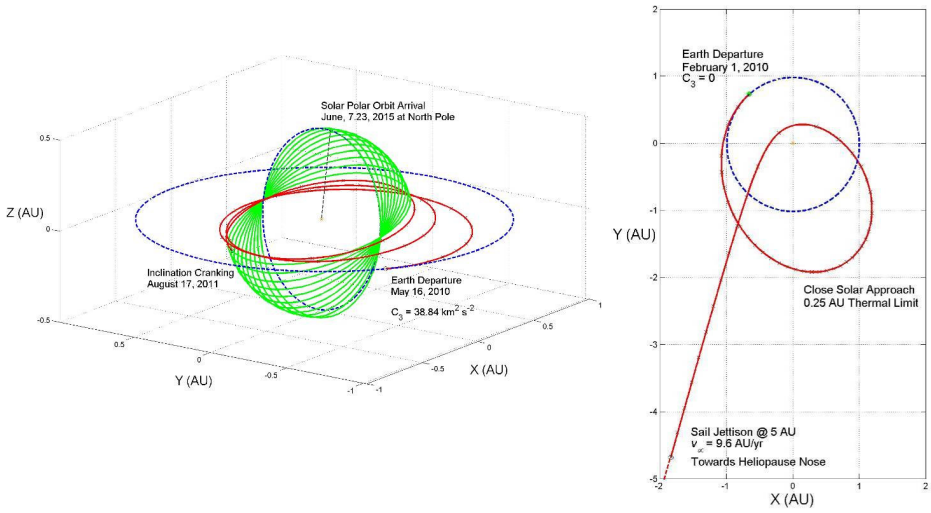

Figure 1. Minimum time solar sail trajectories for the Solar Polar Orbiter mission and the Interstellar Heliopause Mission

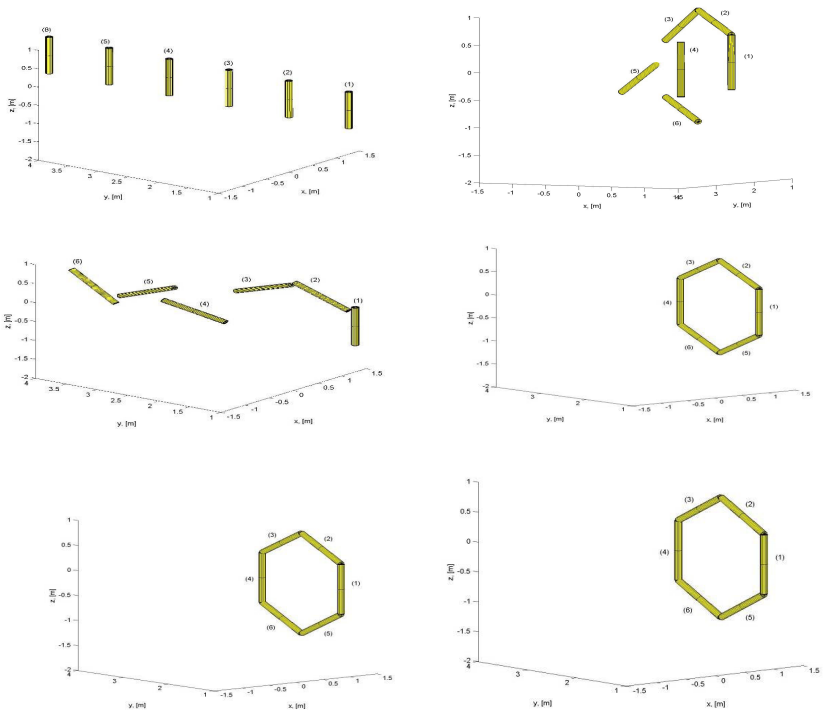

Figure 2. Automated on-orbit assembly using artificial potential field methods: formation of a hexagon with collision avoidance using superquadric potentials

Related Work at the University of Strathclyde

In addition to the work of the Space Dynamics Group (Dept. of Mechanical Engineering) other space engineering related activities at the University of Strathclyde include the MultiScale Flows Group (Dept. of Mechanical Engineering) who are developing new methodologies for modelling hypersonic flows for re-entry; the Strathclyde

Planning Group (Dept. of Computing and Information Sciences) who are developing on-board AI code for the ESA EXOMARS rover; the Risk and Reliability Group (Dept. of Management Science) who are developing new tools for space mission risk management; and the Astrochemistry Group (Dept. of Physics) who undertake parabolic flight experiments using ESA facilities.

Glasgow University, Department of Aerospace Engineering

Research in space systems engineering at the University of Glasgow is centred in the Department of Aerospace Engineering with collaborations with the Department of Mechanical Engineering and the Department of Electronics and Electrical Engineering. A wide range of research activities are pursued in tight collaboration with industry, government and space agencies. Grant, contract and consultancy work is performed for many customers including, the European Space Agency (ESA), the Engineering and Physical Sciences Research Council (EPSRC), EADS Astrium, Thales-Alenia, QinetiQ, GMV and VEGA. This work involves mission studies, interplanetary trajectory optimisation, autonomy technologies for planetary rovers and spacecraft and guidance and control activities centred on attitude and formation flying.

The Space Advanced Research Team (SpaceART) at the University of Glasgow was set up in 2006 to take care of all these research activities. SpaceART is a team of young scientists and engineers coordinating a group of PhD students dealing with a wide spectrum of research topics. Although most of the activities are on the development of advanced research and cutting-edge technology, SpaceART is actively involved in the design of real space missions currently under development by the European Space Agency.

NEO MISSIONS

In the last 50 years astronomers have discovered a vast number of small asteroids orbiting the Sun. A tiny fraction of these objects follow trajectories, which bring them near to the Earth. These Near Earth Objects (NEO), which travel at very high speeds relative to Earth, range in size from pebbles to kilometre-sized objects. Such objects have collided with our planet since its formation and have contributed to shaping life on Earth. NEOs represent a huge risk to human kind, but no near-term means to mitigate the consequences of such impacts currently exists. This threat raises major issues: among them the inadequacy of our current knowledge of the orbits of such bodies, confirmation of hazard after initial observation, disaster management and communication with the public. Another crucial issue, which needs to be addressed, is how to reach a potentially dangerous NEO as quickly and effectively as possible, and how to minimise or indeed remove the threat it poses.

Deflection Comparison

The possibilities for mitigating or removing the risks of NEOs impacting the Earth depends on improving our ability to detect such objects well in advance as well as accurately measuring their orbital parameters and physical properties. A number of mechanisms have been proposed for deflecting or breaking up potentially hazardous NEOs; most require the use of a spacecraft with some means of transferring energy and momentum to the object. Although at a very primitive stage, these methods can be classified as impulsive or low thrust. Impulsive methods aim to instantaneously alter the linear momentum of an asteroid through an impact, which may be explosive. The main drawback of this approach is that an impact or explosion on or below the surface could risk breaking it into a number of smaller pieces, which would still impact the Earth and potentially do more damage. Any proposal to use nuclear explosives to deflect an asteroid or comet could also prove politically difficult in a world that is trying to reduce or abandon nuclear weapons. A less drastic approach would be to alter the trajectory of the asteroid. This could be achieved by changing the surface properties of the asteroid and exploiting the

Yarkovski effect; by ablating the asteroid through lasers or reflected sunlight or by orbiting the asteroid with a large spacecraft thus exploiting mutual gravitational attraction. Other low thrust approaches require a spacecraft to land on the asteroid and then deploy a solar sail; by thrusting at regular intervals; or by excavating asteroid material and ejecting it at high velocities.

Surface Ablation via Solar Collector

This method was first suggested in the 1990s and conceptualised directing solar energy using mirrors onto a small area on the surface of the asteroid. The concentrated heat sublimates the surface matter creating narrow but expanding jets of gas and dust that produce a low continuous thrust. This low thrust would finally alter the orbit of the NEO by producing a change in velocity, similar to the effect of the 'tail' on a comet. A thermal and gravitational model for the NEO was developed in order to analyse the thrust, and by extension the achievable continuous Δv given the solar power collected and the total thrust time[7]. Two mirror configurations, a single flat mirror and a more complex 3 units (parabolic reflector, collimating lens and flat mirror) system have been evaluated, outputting the power density and illuminated area on the asteroid surface. The design of low-fuel, periodic orbits about an asteroid was examined for both single and multiple spacecraft. The cost in terms of propellant and mass for the control of the spacecraft,

as well as the transfer cost from each, were examined. Extensive work has been done on the design and control of a spacecraft formation in the vicinity of an asteroid[8]. A first approach exploits the orbital environment by finding the artificial equilibrium points in the Sun-asteroid-spacecraft three body problem. The second approach uses an extension of the proximity-quotient law, originally developed for low-thrust transfers[9].

European Student Moon Orbiter

The European Student Moon Orbiter (ESMO) is the third mission within ESA's Education Satellite Programme and builds upon the experience gained with SSETI Express (launched into LEO in 2005) and ESEO (the European Student Earth Orbiter planned for launch into GTO in late 2010). Some 300 students from 29 Universities in 12 countries are participating in the project, which has successfully completed a Phase A Feasibility Study and is proceeding into preliminary design activities in Phase B. The ESMO spacecraft is scheduled to be launched into Geostationary Transfer Orbit (GTO) as a secondary payload in the 2011/2012 timeframe. The mission objectives are to place the spacecraft into a lunar orbit, acquire images of the Moon from a stable lunar orbit and deploy a small satellite to conduct global, precision lunar gravity field mapping. SpaceART was the primary team for the mission analysis study during Phase A. Two transfer strategies were investigated; a Weak Stability Earth-Moon transfer through use of chemical propulsion system, and a low thrust Earth-Moon transfer via solar electric propulsion[9-12]. Two different target orbits had to be considered; a 250 x 3600 km altitude polar orbit for the outreach objectives of the mission and a more demanding 100 x 135 km altitude polar orbit for the scientific objectives as shown in Figures 3-4.

Interplanetary Trajectory Optimisation

In recent times there has been a flourishing interest in methods and tools for preliminary mission analysis and design. In particular the key point is the generation of a large number of mission alternatives that can serve as first guesses for more detailed and sophisticated analysis. It has been statistically demonstrated that the success of this preliminary phase decreases drastically the development cost, the time from concept to launch and increases the chances of a successful design. In order to be successful, the preliminary analysis phase has to analyse in a reasonably short time a large number of different mission options. This applies to one of the first steps of mission analysis, which consists of the design of an optimal trajectory. In mathematical terms the problem can be seen as a global optimisation or as a global search for a solution. This search goes along with the definition of a mathematical model for the problem under investigation. In general, the preliminary phase requires the definition of a model and the application of a search strategy. Since the difficulty of the search is directly related to the complexity of the model a simplified model is usually desirable. On the other hand an oversimplification, though leading to a very efficient search, produces unreliable results. Depending on the strength of the relation between search method and trajectory model we can classify the approaches for trajectory design in two categories: problem dependent, problem independent. This classification of global approaches is dual to the traditional classification of local approaches, which distinguish between direct and indirect methods. Traditional problem dependent

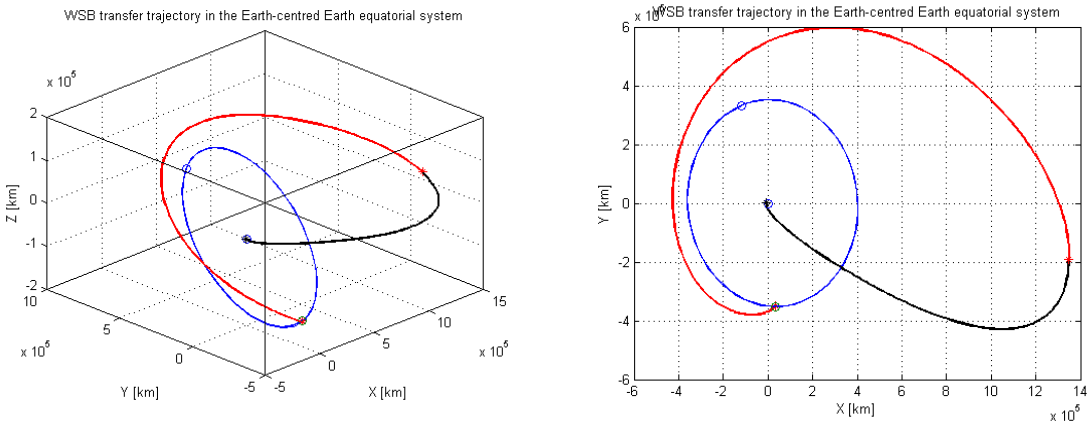

Figure 3: WSB transfer for outreach mission.

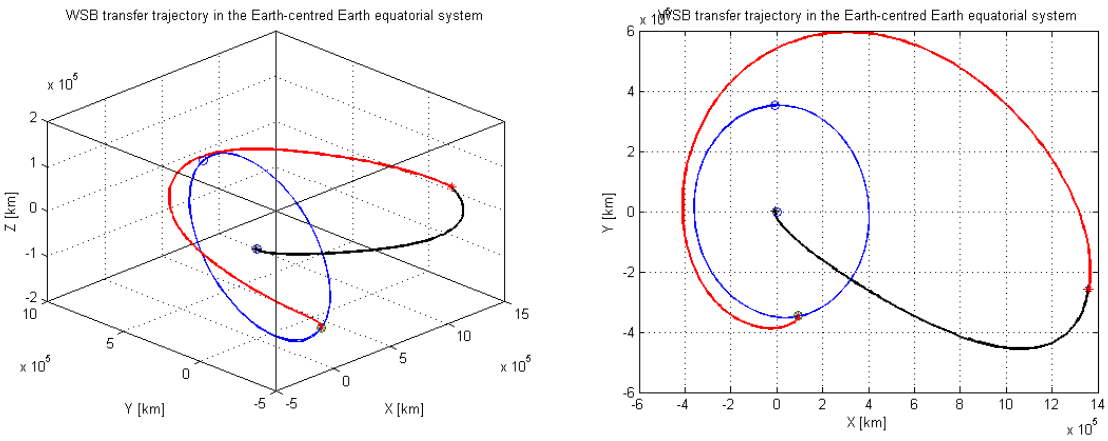

Figure 4: WSB transfer for science mission.

approaches are enumerative methods or branch and prune methods that make use of problem dependent information to prune undesirable portions of the solution space. Problem independent methods are, for example, those that are based on the use of evolutionary algorithms to find a solution to black-box problems. The approach developed here, implemented in a code called EPIC, blends the characteristics of evolutionary algorithms with the systematic search, typical of branching techniques[13-16]. The idea is to use a limited set of possible solutions and evolve them over a limited number of generations – the stochastic step – in certain regions of the search space identified by the branching procedure – the deterministic step. Some trajectories identified with this approach are shown in Figures 5-8 for missions to Jupiter and to asteroids,

Robust Mission Design

In the early phase of the design of a space mission, it is generally desirable to investigate as many feasible alternative solutions as possible. At this particular stage, an insufficient consideration for uncertainty would lead to a wrong decision on the feasibility of the mission. Traditionally a system margin approach is used in order to take into account the inherent uncertainties within the subsystem budgets. The reliability of the mission is then independently computed in parallel. An iteration process between the solution design and the reliability assessment should finally converge to an acceptable solution. By combining modern statistical methods to model uncertainties and global search techniques for multidisciplinary design, the current work proposes a way to introduce uncertainties in the mission design problem formulation. Using evidence theory both aleatory and epistemic uncertainties, coming from a poor or incomplete knowledge of the design parameters, can be effectively modeled[17-18]. The values of uncertain or vague parameters are so expressed by means of intervals with associated probability. Ultimately all the information is collated to yield two cumulative values, belief and plausibility, that express the confidence range in the optimal design point.

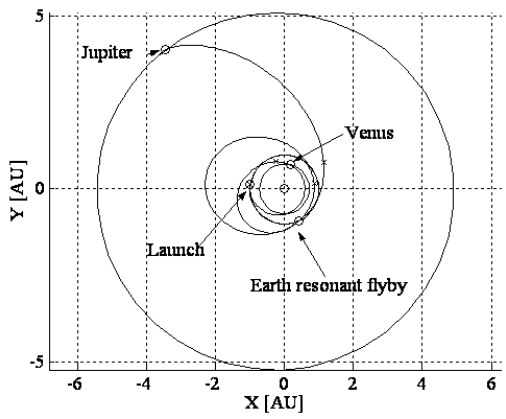

Figure 5: Solution for a EVEEJ sequence for 2009 launch.

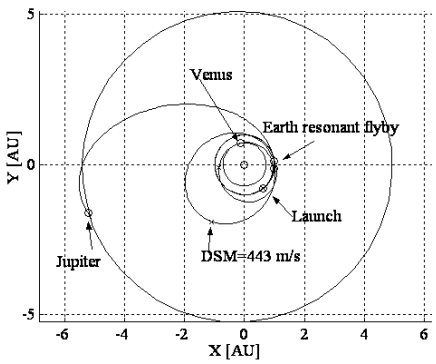

Figure 6: Solution for a EVEEJ sequence for 2010 launch.

Spacecraft Attitude Control

To address and solve the problem of attitude stabilization and tracking we have made extensive use of a control methodology based upon the concept of artificial potential functions. This originates from Lyapunov's Second Theorem but instead of achieving only some desired state for the system it extends the methodology for avoiding any undesired states for the system[19-22]. In this way the Lyapunov function for the system consists of two parts: an attractive component

and a repulsive component. One of the drawbacks of this approach is that the required control input may be above the capabilities of the actuators. There is therefore the need to limit the effort imparted by the actuators and avoid any control input saturation.

Formation Flying

The coordination and control of a constellation of spacecraft, flying a few meters from one another, dictates several interesting design requirements, including efficient architectures and algorithms for formation acquisition, reorientation and resizing. The spacecraft must

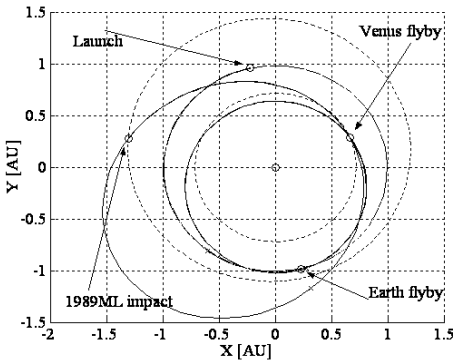

Figure 7: Projection into the ecliptic plane of an impact trajectory with asteroid 1989ML

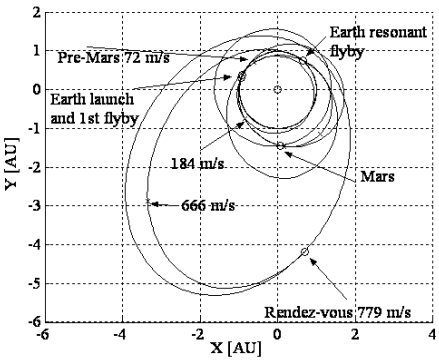

Figure 8: Projection into the ecliptic plane of an optimal trajectory for the Rosetta mission

perform these transitions without interfering or colliding into each other. Furthermore, position keeping is fundamental for formation efficiency. Spacecraft thrusters send gas streams of various species onto spacecraft surfaces. The plume of gas particles emitted by thrusters may cause contamination, degradation or damage to surfaces and can either directly or indirectly cause localized heating and contamination. Plumes and the resultant impingement phenomena are currently not well understood. Simple engineering models are used conservatively to estimate plume effects. The problem of plume impingement is a major concern for a cluster of spacecraft with close relative motion. The problem is compounded by the fact that when approaching each other, the spacecraft will have to fire the thrusters towards the incoming satellite to manoeuvre away from it[23-25]. By implementing an appropriate strategy it is possible to ensure that plume impingement is avoided, as shown in Figure 9-10

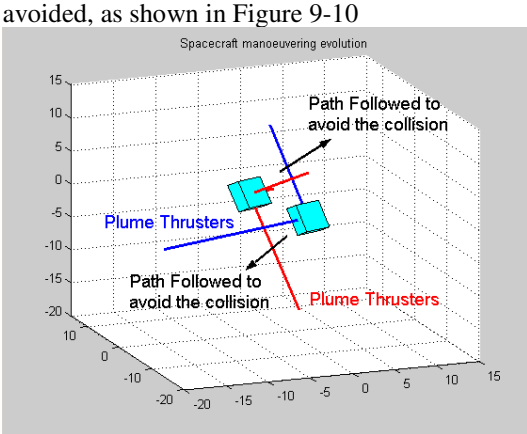

Figure 9: Plume impingement during deceleration

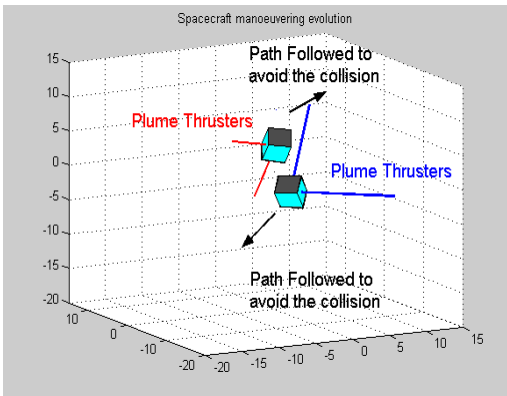

Figure 10: Plume impingement during avoidance phase.

Clyde Space Ltd.

Clyde Space is one of the most innovative and fasting growing space companies in the industry. A small satellite specialist and based in Glasgow, Scotland, Clyde Space provides high performance, affordable systems for small satellites and micro-spacecraft. Clyde Space has a unique blend of small satellite mission design experience and detailed design expertise; this is a key component to the continuing success of the company.

Clyde Space Ltd was formed in 2005 by ex-Head of Power Systems at Small Satellite World leaders, Surrey Satellite Technology Limited. Since starting trading in 2006, Clyde Space has designed, manufactured and tested spacecraft power system electronics, lithium polymer batteries and solar panels to small satellite programmes all over the world, including SOHLA-2 (Japan), SumbandilaSat (South Africa), InnoSat (Malaysia), Paradigm (USA), OPTOS (Spain) and many others.

The systems produced by Clyde Space consist of: Power Management Electronics for spacecraft with orbit average power requirements of 1W up to over

5kW. These systems include both Peak Power Trackers and Regulated Bus topologies; Space Qualified Lithium Polymer Batteries and Solar Arrays for Small Satellites.

The philosophy at Clyde Space is to provide cost effective, high performance, fit-for-purpose spacecraft subsystems for small satellite budgets. This approach is further demonstrated by development programmes to provide more off-the-shelf, standardized spacecraft hardware and by the introduction of an online spacecraft shop

Case Study: SOHLA-2

The SOHLA-2 mission represents a highly novel approach to small satellite engineering. The spacecraft is a 50 kg microsatellite and is the first demonstrator of Panel ExTension SATellite (PETSAT) which was first proposed by the Nakasuka Laboratory of University of Tokyo. PETSAT is unique in that it consists of a combination of standardised subsystem 'Panels' that are hinged together and deploy/unfold once the spacecraft is in orbit.

The idea behind the PETSAT concept is to provide the ability to quickly configure the spacecraft in order to meet the needs of a specific mission. This would enable mission designers to launch their own PETSAT for a significantly lower cost and shorter development time by providing the ability to select and assemble off-the-shelf panel subsystems as required.

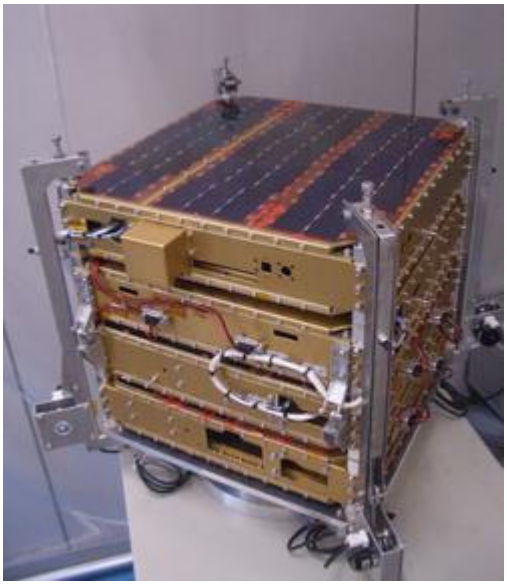

Figure 11 SOHLA-2 Flight Model

There were several challenges in the design of the spacecraft. These included effective and scalable communications between the Panels, distributed On-Board Data Handling and, importantly, a scalable approach to the power system design.

Given the modular nature of the PETSAT concept, the design of the power system had to be equally modular. Clyde Space provided the complete design, production and test of the power system battery and solar panels. The system provided the ability to have a completely modular satellite power system. Inherent in the design is the ability to grow the battery capacity by parallel connection of battery 'strings'. The power system within each Panel Module was sized such that the increments by which the solar array area and battery increase the overall spacecraft capability was slightly more than the power required by a typically Panel. In addition, the Power system can operate when connected to many Panel Modules, or in isolation with no additional operational constraints or requirements.

The image above is of the solar panels that were

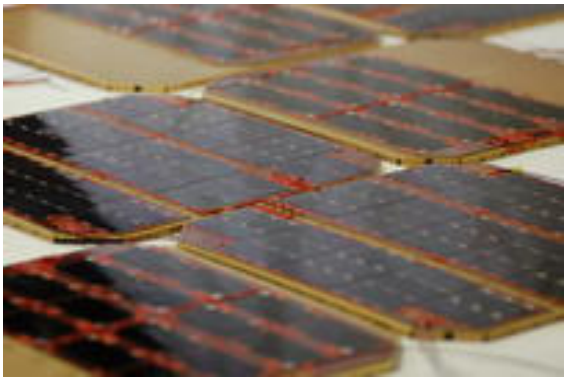

Figure 12 SOHLA-2 Solar Panels from Clyde Space

Figure 13 Flight Model Power System and Batteries

designed and built by Clyde Space for the SOHLA-2 project. For budget and schedule reasons, the solar arrays consist of both Triple junction GaAs solar cells and also space grade Silicon solar cells. Each of the solar arrays provides 16W of power when fully illuminated.

Four of the final Six FM power modules are shown in the figure above. The housing shown in the image is integrated into the panel Module and provides mechanical stiffness, thermal stabilisation, radiation shielding and EMC screening from the rest of the Panel Module. All of the power system electronics are located on the PCB underneath the lithium polymer battery board. The lithium polymer battery is designed as a daughter board to the power system electronics and connects directly onto the power system electronics PCB; Battery telemetry is also routed through the power system I2C node.

The nature of the power system electronics design means that it is possible to have solar panels with different characteristics connecting onto the same bus, because each solar panel is regulated independently.

CubeSats and Microspacecraft

At the time of starting Clyde Space, there was a real problem with CubeSat failures related to the electrical power system; it was clear that CubeSats should be the first in-house developed power system for Clyde Space.

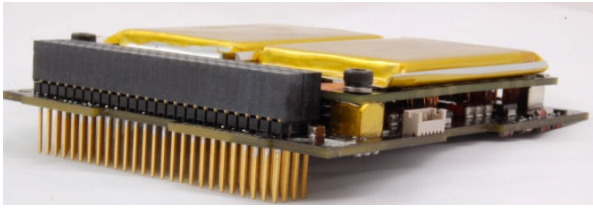

Figure 14 1U CubeSat Power System with battery.

Figure 14 shows the latest revision of the Clyde Space EPS. There are currently over twenty 1U EPS boards with customers and a further 50 in production. Some key features of the CubeSat EPS include Peak Power Tracking of the solar arrays with integrated battery charge management, regulated 5V and 3.3V, over current protected voltage buses and I2C for telemetry and telecommand. The system is designed for increased reliability, through careful design and selection of commercial components (to mitigate problems relating to radiation tolerance, etc.).

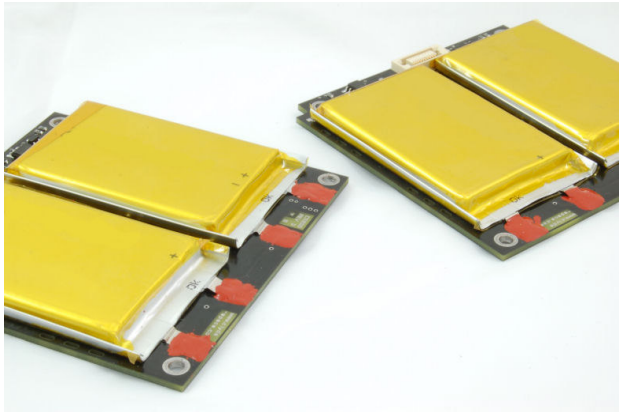

Figure 15 Battery Daughter Boards; 1.25Ah at 8.2V

At the same as developing the EPS, we also developed a battery that could be integrated with the EPS. Figure 14 show the 1U EPS with a 10Whr battery daughter board. Another daughter board (Figure 15) can be stacked on top to provide an additional 10Whrs.

In addition, Clyde Space also supplies the solar arrays for CubeSats, making it a one-stop-shop for CubeSat power components. (Figure 16 shows a 3U solar panel using EMCORE solar cells). We have also made 1U solar panels and solar panels with integrated magnetorquer coils.

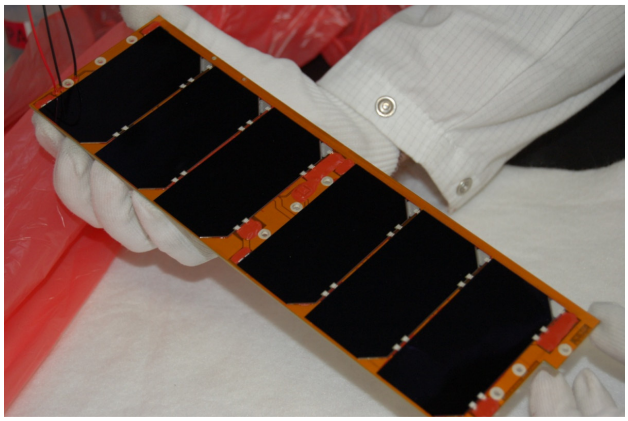

Figure 16 Solar panel for a 3U CubeSat.

Recent introductions to the range include a 3U EPS; this system has higher power ratings on the Peak Power Trackers to cope with the larger solar panels on a 2U and 3U CubeSat. (See Figure 17)

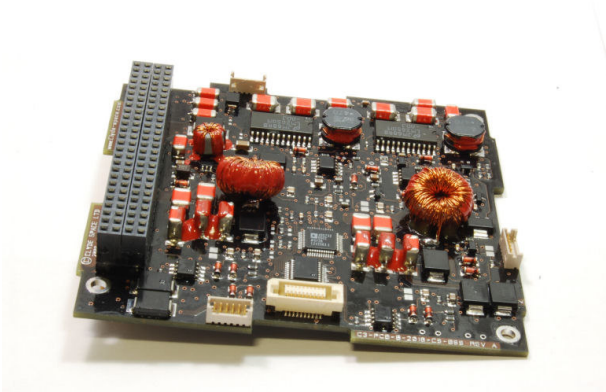

Figure 17 3U/2U CubeSat Power System.

Due to the larger components on the 3U EPS, it wasn't possible to fit a battery daughter board on this system. Therefore, a separate battery that was compatible with the CubeSat Kit needed to be developed. This battery is capable of being sized up to 30Whrs per unit, which is more than sufficient for most 3U CubeSat missions. The 3U Battery is shown in Figure 18.

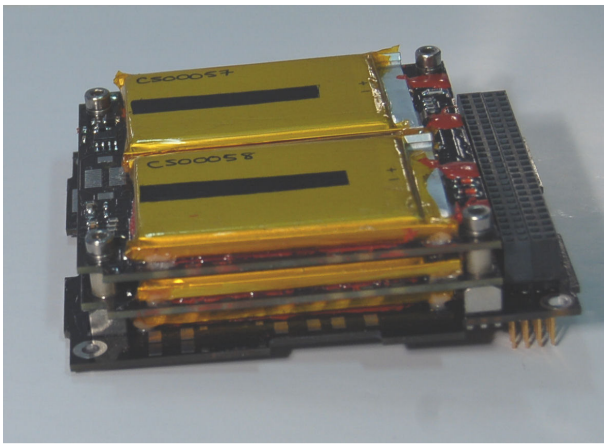

Figure 18 3U/2U 30Whr Battery.

Online Shop for CubeSat Flight Hardware

Given the nature of CubeSat systems it is clear that CubeSats represent very different approach to spacecraft, not just from a technical perspective, but also from a commercial perspective. Clyde Space had been experiencing a pressure from industry to introduce the ability to buy components using credit card. Therefore, we investigated the options available to us in terms of credit card sales and decided on an ecommerce element integrated with our website. It was also apparent that the ability to have our products sold online on our website, combined with the technology available for online sales, could open up a whole new approach to the specification and selection of spacecraft systems.

Immediately, with online sales, it is possible to list related products on a webpage when a main product of interest is selected. This is not only important as a sales tool, but it is also important for the customer as they will have more information at their finger tips to help them select the systems, accessories and test equipment that they require to make their mission run as smoothly as possible.

Another useful resource for us and our customers is the Frequently Asked Questions (FAQ) page. This enables us to list the commonly asked questions about the system (and anticipate a few others) and have them listed on the website for immediate access for the customer. The FAQs can even direct the customer to other sites that have software or interfacing components that can be used to address whatever issue has been encountered. Again, this is a very powerful tool to have and is ideal for the CubeSat community.

Following on from the FAQ pages, another very useful tool that we have included in our website is a user forum.

Future Developments at Clyde Space

Clyde Space is continuing to grow its microspacecraft and CubeSat product line through the development of new in-house systems such as off-the-shelf ADCS, Electric Propulsion and advanced structures. We are also licensing existing subsystems from other organisations. The ultimate goal of Clyde Space in this respect is to have a full mission suite of subsystems available to buy on-line off-the-shelf. There are two main objectives in this goal:

1. To encourage CubeSat projects to use the Clyde Space website to buy the subsystems they require and also as a resource for their mission planning and design.

2. To make it possible for a complete Spacecraft to be created and then purchased online using a credit card.

Objective number '2' is key as it will involve the use of web-integrated mission design tools that will down select the appropriate subsystems for the mission. An analogy for this capability is like buying a Dell computer online, where it is possible to customise the system to individual requirements.

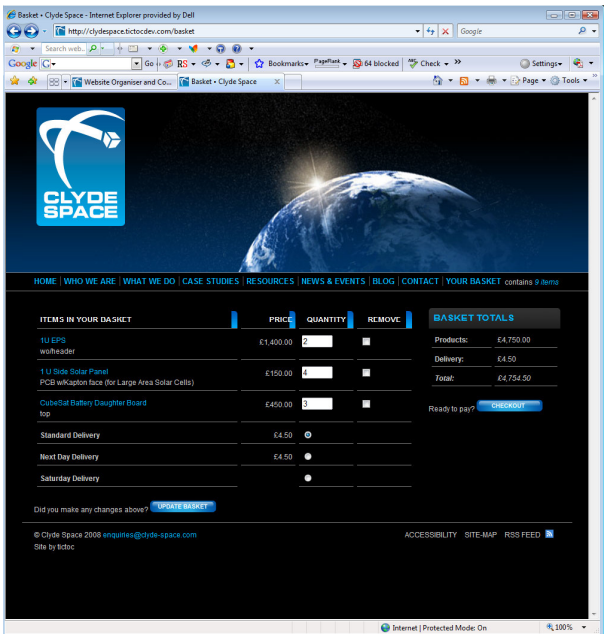

Figure 19 Online shopping basket with CubeSat subsystems being purchased.

OUR ACADEMIC/INDUSTRY PARTNERSHIP ACTIVITIES

Clyde Space Ltd and the University of Srathclyde have recently embarked on a joint development project, funded by a Knowledge Transfer Partnership (KTP) programme in the UK. The objective of the KTP is to develop an advanced micro-spacecraft platform based on the CubeSat standard. The combination of the systems and advanced space dynamics capability of the University of Strathclyde, and the small satellite hardware and mission experience of the Clyde Space team make the KTP a very exciting and technologically promising project.

The Clyde Space/Strathclyde University team have proposed a mission in order to demonstrate the capability of the platform under development. The mission is part of a programme (and is called SCOTSAT) to build and launch Scotland's first satellite and, in the process, deliver an extensive outreach element that will encourage children to embark on careers in Science and Technology and also to inspire the people of Scotland to achieve great things.

In addition, other Scottish universities, including the University of Glasgow, will be included in an activity to nucleate research specifically for advancement of systems and applications of the advanced microspacecraft platform. This will include mission design, bus system development and payload development.

The current schedule shows the launch of the first of two spacecraft being launched in 2010, with a further, more ambitious platform to be launch 8-9 months later.

This exciting programme is hoped to be the first step towards establishing Scotland as a leading nation in the microspacecraft systems.

CONCLUSION

Glasgow has great ambitions to create a city that is a significant contributor to the future of human endeavour in space. In order to achieve this goal it must be achieved by a combination of industry and academic activity. It has been demonstrated in this paper that there is significant synergy between the objectives of the academic and industry space community in Glasgow and this will critical to the success of the growth of Space activities within Glasgow in the future.

It is clear that the relationship between Glasgow's fledgling space industry and the established academic element of space expertise in Glasgow is working extremely well and, with the recent award of the Knowledge Transfer Partnership between Clyde Space Ltd and the University of Strathclyde, another significant step forward has been made in what is becoming a very successful partnership.

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