Institution: University College London

Unit of Assessment: 9 – Physics

Title of case study: Enabling space companies to deliver contracts and supporting growth of the space sector

1. Summary of the impact

UCL's research and development programme in space science and engineering enabled it to complete four major contracts with European and Canadian space companies between 2009 and 2011. These contracts were for the supply of equipment that will fly on European and Indian space missions, and for support of the ground testing of those space missions. The fact that these contracts were won by UCL in a competitive environment against low-cost industrial providers demonstrates that customers value the capability that UCL possesses. By acting as a specialist provider within the UK space sector supply chain, UCL enabled the prime contractors European Astrium Aerospace and Canadian Routes AstroEngineering Ltd. to deliver substantial commercial contracts with space agencies. Its provision of specialist input into these major contracts enabled UCL to also directly support the growth of the commercial space sector.

2. Underpinning research

The Department of Space and Climate Physics (also known as the Mullard Space Science Laboratory, or MSSL) at UCL has built up expertise in space science from its 40 years of space programmes. Major contributions to this research since 1993 include:

The development of instrumentation for use on spacecraft: A primary function of MSSL is to design and build space instruments and associated on-board software to meet the scientific objectives set by the investigators. The development of such instrumentation involves a platform of research both in the subject area of the science mission (such as astrophysics) and the instrumentation necessary to deliver new science. Research outcomes included successful system designs, and mechanical and electronic designs for space; fabrication, test and calibration of many instruments; and a full engineering understanding of science requirements [1-4]. Particular insights involved the trade-off of various noise sources that contributed to the ultimate performance of a microchannel-based detector (the XMM mission, launched in 1999 [1]), and the lifetime estimation of electron and ion detectors in systems operating in the Earth's magnetosphere (the Cluster mission, launched in 2000). This programme of research involved the following key UCL researchers and space missions/instruments: Prof. Culhane (SOHO, 1995), Prof. Johnstone (Polar, 1996), Prof. Coates (Cassini, 1997), Prof. Mason (XMM, 1999 [1]; Swift, 2006), Prof. Fazakerley (Cluster, 2000; Double Star, 2004), Prof. Smith (Integral, 2002), Prof. Harra (Hinode, 2006 [2]), Prof. Page (Herschel, 2009) and Prof. Cropper (NIRSpec for JWST, 2000; Gaia, due for launch late 2013 [3]). For brevity only the lead scientists are shown in the above list.

Development of high voltage power supplies for multiple science instruments: High voltage supplies are integral to a number of detectors used in space science, particularly image intensifiers (for example, those used on the satellites XMM, launched in 1999, and Swift, launched in 2004) and particle detector microchannel plates (for example, those used on the satellites Cluster, launched in 2000, and Double Star, launched in 2004). MSSL has developed the capability to design and build bespoke high voltage power supplies to meet the requirements of industrial customers; for example, it built the power supply for the XMM mission that was launched in 1999 [1]. Important advancements included making the supplies small, lightweight, and power efficient; and the development of supplies that can very rapidly sweep across wide voltage values, which is required for key applications such as particle detectors for missions to Saturn and the Sun, the energy/time cadence of which depends critically on the sweep rate. Key UCL researchers were Jim Bowles (Head of Electronics Group, 1990-1997) and Phil Guttridge (Head of Electronics Group, 1997-present).

Development of novel test facilities for multiple science missions: All items of equipment for space instruments have to be calibrated under vacuum, while being illuminated with light or stimulated with charged particles to demonstrate their function. The high accuracy of the required calibration needs a close understanding of the physics of the stimulating radiation and the design needed to achieve that; for example, high-accuracy optical flat fields and electron/proton beams.

Additionally, the temperature of the equipment has to be varied across a wide range to show that it has been built correctly and is able to maintain the correct performance in the harsh conditions in space. To achieve these aims, MSSL has developed many specialist test systems that were designed or adapted for individual mission requirements and has developed the capability to respond to the needs of industrial customers. An evolving programme of development has been in place since before 1993 and has included the commissioning of specialist facilities for Cluster (~1995) and CCD (charge coupled device) based missions (e.g. Integral ~1998). Calibration facilities require traceability to national standards and extremely accurate characterisation. In general, the physical processes associated with the facility have to be understood at least as well as the instrumentation that is being calibrated, and so such developments have required modelling and model verification. For instance, when the Cassini instrument required a stable ion beam in 1995, UCL researchers modelled magnetic field distortion within a thermal vacuum chamber [4], together with the development of magnetic shielding provisions and beam monitors.

3. References to the research

[1] The XMM-Newton optical/UV monitor telescope, K. O. Mason, A. Breeveld, R. Much, M. Carter, F. A. Cordova, M. S. Cropper, J. Fordham, H. Huckle, C. Ho, H. Kawakami, J. Kennea, T. Kennedy, J. Mittaz, D. Pandel, W. C. Priedhorsky, T. Sasseen, R. Shirey, P. Smith and J.-M. Vreux, *Astronomy and Astrophysics*, 365, L36-L44 (2001) doi:10.1051/0004-6361:20000044

[2] The EUV Imaging Spectrometer for Hinode, J. L. Culhane, L. K. Harra, A. M. James, K. Al-Janabi, L. J. Bradley, R. A. Chaudry, K. Rees, J. A. Tandy, P. Thomas, M. C. R. Whillock, B. Winter, G. A. Doschek, C. M. Korendyke, C. M. Brown, S. Myers, J. Mariska, J. Seely, J. Lang, B. J. Kent, B. M. Shaughnessy, P. R. Young, G. M. Simnett, C. M. Castelli, S. Mahmoud, H. Mapson-Menard, B. J. Probyn, R. J. Thomas, J. Davila, K. Dere, D. Windt, J. Shea, R. Hagood, R. Moye, H. Hara, T. Watanabe, K. Matsuzaki, T. Kosugi, V. Hansteen and Ø. Wikstol, *Solar Physics*, 243, 19-61 (2007) doi:10.1007/s01007-007-0293-1

[3] The GAIA spectroscopic instrument (RVS): a technical challenge, M. Cropper and D. Katz, *EAS Publications Series*, 45, 181-188 (2010) doi:10.1051/eas/1045031

[4] The calibration of the Cassini-Huygens CAPS Electron Spectrometer, G. R. Lewis, C. S. Arridge, D. R. Linder, L. K. Gilbert, D. O. Kataria, A. J. Coates, A. Persoon, G. A. Collinson, N. André, P. Schippers, J. Wahlund, M. Morooka, G. H. Jones, A. M. Rymer, D. T. Young, D. G. Mitchell, A. Lagg and S. A. Livi, *Planetary and Space Science*, 58, 427-436 (2010) doi:10.1016/j.pss.2009.11.008

References [1], [2] and [4] best indicate the quality of the underpinning research.

Research grants: The programmes listed above were supported by grants to a total value of £12.5 million from SERC and PPARC.

4. Details of the impact

The commercial space sector is highly internationalised; within Europe, it is dominated by multinational prime contractors (including EADS Astrium, which has a major UK presence in Astrium UK). The current annual contract value of satellite and support system builds in the UK is around £1 billion. Around half of the European upstream space sector serves the production (under contract) of world-class science satellites devoted to space science and earth observation. These contracts, worth hundreds of millions of pounds, provide revenue and employment but also, more importantly, underpin the growth of the civil space sector (telecommunications, GPS etc.) through transfer of technology and personnel. This symbiotic relationship has been widely recognised; for example, in the UK Space Innovation and Growth Strategy (IGS) [A] and the UK Space Agency Civil Space Strategy [B]. The IGS was published in 2010 and is the outcome of a major UK government initiative. It provides a framework for space sector government support and investment up to 2030, and recognises the strength of the UK space sector. Amongst other things, it defines an approach that will see the UK's share of the world space market increase to 10% by 2020, and it anticipates the creation of 100,000 jobs [A]. MSSL's role in the space sector has included the provision, in a competitive marketplace, of essential skills and technologies as part of major satellite procurements, thereby enabling growth.

UCL researcher Alan Smith is a member of the National Space Technology Steering Group (NSTSG), which was set up in 2010 after publication of the IGS. In 2011, the NSTSG created technology roadmaps (updated in 2012) [C] that have become the basis for national investment in space technology. Smith also contributed to the 2013 'Restack' of the IGS, particularly in the area of bilateral programmes and their value to the UK economy, and presented on this topic to the UK community at the UK Space Conference in Glasgow in July 2013. These contributions and presentations are underpinned by a profound understanding of the issues associated with the development of space hardware and the link between space science and its enabling technology, which has been built up whilst conducting the research described in section 2.

Research conducted within MSSL has also had an impact on the space companies European Astrium Aerospace and Canadian Routes AstroEngineering, which hold contracts with space agencies – including the European Space Agency (ESA) – for the supply and testing of equipment that will form part of satellites or space probes. Astrium and Routes in turn contracted out this work to MSSL, whose extensive prior research into the development and testing of space equipment enabled it to successfully meet the requirements of the space companies. MSSL's contribution therefore enabled Astrium and Routes to fulfil their contracts to the space agencies.

The research programmes and insights described in section 2 gave MSSL the background, expertise and track record to win the contracts with Astrium and Routes through competitive tender, evidencing the value of the underpinning research to these companies. The scientific background of MSSL staff also allows the response to the customer's requirements to be interpreted to the best advantage of the customer; issues can be identified in the specifications that would not necessarily be noted by another contractor without MSSL's scientific and space engineering heritage.

Astrium: Impacts on Astrium involved three contracts within the REF impact period to supply or test equipment for two scheduled space missions: the NASA/ESA James Webb Space Telescope (JWST, the replacement for the Hubble Space Telescope), due to be launched in 2018; and Gaia (ESA's next generation astrometry mission to map the Galaxy), due to be launched in late 2013.

The JWST work involved the building of equipment for both on-board calibration (the Calibration Assembly, or CAA) and ground testing (Calibration Light Source and Optical Alignment equipment) of the telescope's NIRSpec instrument, which is being built by the German arm of Astrium. Two CAA units were built for Astrium by MSSL, where previous extensive research into space instrument development (including development of NIRSpec itself) allowed staff to understand fully the scientific requirements and develop the instruments successfully. The CAA is an example of an instrument for which MSSL was able to provide industry with specialist expertise in inflight, stable, optical calibration that was not otherwise available. UCL won the contract in part because of this expertise, which significantly reduced the risk to Astrium of late or inferior delivery of the instrument. Astrium took delivery of the equipment in February 2010, enabling them to then successfully deliver two flight-capable CAA units to ESA [D].

The Calibration Light Source and Optical Alignment equipment are two separate instruments (a calibrated infra-red light source and a computer-controlled optical alignment and measurement system) used for testing NIRSpec before launch. They were also built by MSSL, underpinned by previous research on the development of optical systems and test facilities (e.g. [1], [2]) for space missions as well as research on NIRSpec. Again, UCL research results (including novel calibration technologies) were vital for Astrium to be able to provide ESA with successful working equipment, as Astrium had developed complex equipment requirements that other industrial bidders were not able to meet. Astrium took delivery of the equipment in December 2009 [D]. These two UCL contracts on NIRSpec [text removed for publication] played a role in allowing Astrium to meet the terms of its contract with ESA [text removed for publication] [D].

The Gaia work involved the testing and integration of over 100 CCDs and their associated electronics for the Gaia mission, which is being built by the French arm of Astrium. This work was underpinned by previous MSSL research involving both the development of the Gaia instrument concept [4] and the integration and testing of CCD-based camera systems (e.g. for the XMM [1], Integral and Hinode [2] missions). The extensive research and experience of MSSL in this area resulted in properly tested CCD units being delivered to ESA by Astrium, and provided Astrium

with validated test results that were acceptable to ESA [F]. Astrium took delivery of the final tested units in May 2011, helping it to meet the terms of its contract with ESA [F], which had a value of €317 million [G]. [text removed for publication]

Routes AstroEngineering: Impact on the Canadian Routes space company involved one contract within the REF impact period with the Indian government to supply equipment for the Indian Astrosat mission, due to be launched in 2014. MSSL built the high voltage power supplies for Astrosat's UV telescope, equipment that will support the image intensifiers that detect UV radiation from astronomical objects under study; Routes took delivery of this equipment in September 2009 [H]. MSSL's previous research on the development of high voltage power supplies (e.g. [1], [5]) ensured that Routes was able to deliver appropriate equipment that met the requirements set by the Indian government. If MSSL had not conducted this underpinning research into the development of novel power supplies and therefore become one of the few organisations with design heritage from previous projects, Routes would likely have had to initiate a high-risk (due to reduced expertise) development at another organisation [H]. The value of the UCL contract was £417,000 [I].

5. Sources to corroborate the impact

[A] A UK Space Innovation and Growth Strategy 2010 to 2030, available online: http://bit.ly/196k7BF – corroborates that space contracts such as those undertaken by MSSL help underpin the growth of the civil space sector.

[B] UK Space Agency Civil Space Strategy 2012-2016, available online: http://bit.ly/Ht2oK3 – corroborates that space contracts such as those undertaken by MSSL help underpin the growth of the civil space sector.

[C] The 2011 National Space Technology Strategy roadmap and the 2012 update are available at: http://bit.ly/1eDR8JC – corroborates that the NSTSG, which includes a UCL researcher, has published space technology roadmaps.

[D] The benefit to Astrium Germany of MSSL's work on the JWST NIRSpec programme [text removed for publication] can be corroborated by Astrium Germany's Project Manager for NIRSpec. Contact details provided separately.

[text removed for publication]

[F] The benefit to Astrium France of MSSL's work on the Gaia programme can be corroborated by Astrium France's PEM-CCD Contract Manager. Contact details provided separately.

[G] The value of Astrium's contract with ESA for the Gaia satellite is corroborated by the following news story on ESA's website: http://bit.ly/1dm6nDT.

[H] The benefit to Routes of MSSL's work on the Astrosat mission can be corroborated by the UVIT Contract Manager at ComDev, which now holds the Astrosat contract. Contact details provided separately.

[I] The value of UCL's contract with Routes for the Astrosat mission is corroborated on page 16 of the UCL Business (UCLB) Annual Report 2008/2009: http://bit.ly/1aR7G9Z.