Institution: Nottingham Trent University (NTU)

Unit of Assessment: D32 - Art and Design: History, Practice and Theory

Title of case study: Using advanced textiles to enhance UK-based technology and manufacturing capability in the US dominated space satellite telecommunication industry

Period when the underpinning research was undertaken: 2004-2020

Details of staff conducting the underpinning research from the submitting unit:

Names:	Roles:	Periods employed by submitting HEI:
Tilak Dias	Professor	2000-present
William Hurley	Senior Lecturer	2000-present
Jose Carlos Oliveira	Experimental Officer	2013-present

Period when the claimed impact occurred: 2016-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The impact is an enhanced UK space technology capability which was achieved through the development of a pioneering, lower-cost, lightweight and deployable knitted metal mesh reflector for new generation antennae for Oxford Space Systems (OSS).

The Advanced Textile Research Group (ATRG) at NTU created a new technology to produce a viable alternative to costly US warp-knitted metal fabrics for use in UK/EU space telecommunication satellites. The micro-knitting technology utilised computerised flat-bed knitting with ultra-fine metal wires to create a seamless, 3D parabolic mesh reflector that was capable of being unfurled in space.

Tests showed that these new UK-manufactured reflectors met European Space Agency performance standards and therefore demonstrated the technology's potential to deliver significant commercial advantage that is aligned to UK government space and security aspirations to establish an internationally-leading national commercial space industry.

2. Underpinning research

Communications satellites still use expensive (£615,000/m^2) metal mesh reflectors made by warp knitting developed by NASA in the 1960s. These are not suitable for new generations of micro satellites that require lightweight, tightly-packaged, accurately-shaped, unfurlable reflectors that can operate at a higher frequency and higher data-throughput rates.

In 2006, Dias researched how stainless-steel wire was processed on Computerised Flat-Bed Knitting Machines (CFBKM) in order to craft cut-resistant gloves. The results were protected with a granted patent [**R1**]. This early research on knitting with stainless-steel provided a knowledge base which has underpinned the work of the Advanced Textiles Research Group on knitted mesh for antennae since 2010. The later work included knitting superfine tungsten wire on CFBKM and led to a collaboration with Oxford Space Systems (OSS).

Dias developed understanding of functional electromagnetic textile structures to operate as antennae and reflectors. Through [**G1**] (2010-2013), Dias produced antennae that were embroidered using twisted multi-strand fine copper wires and silver-plated multi-filament Zylon (p-phenylene-2,6-benzobisoxazole) yarn onto fabric for search and rescue purposes [**R2**].

Through [**G2]** and [**G3]** Dias and Hurley further explored the potential of using CFBKM in a project with the University of Sheffield funded by the Defence Science and Technology

Laboratory (DSTL) [**R3**, **R4**] and then with BAE Systems [**G4**, **G5**]. The IP related to knitting fabric antennae has been protected with a granted patent [**R5**]. A new approach that used CFBKMs to manufacture conducting textiles, which were able to operate at microwave frequencies, subsequently demonstrated that the technique could be used for the mass production of frequency selective surfaces (FSS).

The approach used 3D knitted spacer structures that were made from silver-plated nylon yarn in combination with a polyester spacer yarn. It confirmed that low-pass, and high-pass, knitted, flexible, frequency-selective surfaces could operate together [**R4**]. Further research through [**G5]** demonstrated the use of a knitted conducting fabric as an electrical ground plane in a single-layer radar absorber and in a microwave patch antenna. This was manufactured by knitting a silver-plated conducting yarn.

Dias and Hurley continued their fabric antennae research through developing an F-antenna grid for BAE by knitting the host and silver-plated Zylon yarns together into a single layer of fabric antennae for VHF and UHF range for portable communication equipment [**R5**].

In an Innovate UK project with OSS [**G3**], the work on knitting conductive yarns to create fabric antennae was combined with the earlier knowledge of using stainless-steel wire to produce cut-resistant gloves [**R1**]. This led to the crafting of knitted metal mesh reflector surfaces that utilised ultra-fine gold-plated tungsten wire. Dias and Hurley developed a novel, knitted metal mesh surface material that could perform at Super High Frequency band (K and Ka) in the demanding space environment and a novel wire delivery technique [**G6**]. The manufacturing process was low cost, highly efficient and produced a knitted metal mesh of parabolic shape [**R6**]. It used commercial CFBKM to produce an entire structure in one continuous process.

This knitted metal-mesh reflector surface enabled the method of tensioning the reflector structure to be significantly simplified. As a result, a less complex, lighter, cheaper reflector was developed through [**G6]** and [**G7]**.

3. References to the research

The quality of the underpinning research has been evidenced by rigorous externally peer reviewed grants and outputs.

Key Outputs

R1: Dias, T. et al, European patent EP2155942B1 (granted on 10.08.2011, Bulletin 2011/32), US patent US8,322,167B2 (granted on 04.12.2012); Proprietor: BM Polyco Ltd.
R2: Acti, T., Chauraya, A., Zhang, S., Zhang, S., Whittow, W.G., Seager, R., Vardaxoglou, J.C. and Dias, T., (2015). Embroidered Wire Dipole Antennas Using Novel Copper Yarns IEEE Antennas and Wireless Propagation Letters, 14, pp. 638-641. ISSN 1536-1225. DOI:10.1109/LAWP.2014.2371338.
R3: Tennant, A., Hurley, W. and Dias, T., 2013. Knitted, textile, high impedance surface with integrated conducting vias. Electronics Letters, 49 (1), pp. 8-10. ISSN 0013-5194. DOI:10.1049/el.2012.3896.
R4: Tennant, A., Hurley, W. and Dias, T., (2012). Experimental knitted, textile frequency selective surfaces. Electronics Letters, 48 (22), p. 1386. ISSN 0013-5194 DOI:10.1049/el.2012.3005.
R5: Kitchener, D., Wyllie, C.B., Lewis, R.A., Juraite, I., Dias., T., and Hurley, W. Fabric Antenna. UK Patent GB2539306 (Date of Publication 25.10.2017/Date of Filing 11.03.2016) Assignee: BAE Systems PLC, UK.
R6: UK patent, Title: Satellite Reflectors, Application Date: 18th February 2020; Application Number: GB 2002196.0.

Grants

G1: EPSRC/IeMRC: High performance flexible, fabric electronics for Mega-Hertz frequency Communication (2010-2013); GBP246,000.

G2: DSTL; Knitted metamaterials for communication systems (2012, 06 months); GBP30,000,
G3: DSTL: Manufacture of conducting textile electromagnetic structures using flat-bed knitting and laser ablation techniques (2013, 06 months); GBP31,998.
G4: BAE Systems; (2014-2015), Manufacture of an item of clothing incorporating an antenna and feed design supplied by ATC - Phase 1. GBP57,023.
G5: BAE Systems; (2015-2016), Manufacture of an item of clothing incorporating an antenna and feed design supplied by ATC - Phase 2. GBP13,182.
G6: Innovate UK. (2017-2019), Development of a Novel Space Antenna Surface Material and Manufacturing Processes; GBP157,704.
G7: Oxford Space Systems/European Space Agency. (2019-2021). DeCSA-M: Deployable Cassegrain Antenna for Microsatellites. GBP100,000.

4. Details of the impact

The significance of UK capability and competitiveness in the space sector is demonstrated by recent investment and growth. Since 2000, the sector has trebled in size. The space sector now supports 14% of UK GDP. The sector is recognised as a vital element of UK economic growth. This growth ambition is to create a sector worth £40bn by 2030, (Satellite Applications Catapult, UKRI/Innovate UK, 2020).

A research collaboration between NTU's Advanced Textiles Research Group (ATRG) and Oxford Space Systems (OSS) has resulted in the development of a proven-in-principle light-weight, unfurlable, knitted antenna that is manufactured from electro-conductive super-fine metal wires. As a consequence, OSS has leveraged £1M European Space Agency (ESA) investment to develop 3 to 5m diameter 'Wrapped-Rib' Antenna (WRA) for telecommunications and defence sectors [**S4**] at a new large-scale production facility at Harwell Space Cluster, Oxfordshire. Post Brexit, the UK remains a member of the ESA with UK businesses able to bid for contracts through ESA [**S5**].

The development of a wrapped-rib antenna will make the UK the first European country with the capability to advance space telecommunications through flight-proven parabolic deployable antenna [**S4**] and to comply with International Traffic in Arms Regulations (ITAR) [**S1**].

Strengthening OSS Capability

The Innovate UK and DeCSA-M (ESA) research projects (TRL 5) have enabled OSS and ATRG to develop the weft-knitted metal mesh for deployable antennae to allow it to be employed on larger reflectors [**S1**]. Evidence collected demonstrates the potential for superior performance over rival technology, but at lower cost.

The research developed a single-piece multi-gore mesh that proved the potential of a scalable, novel manufacturing process. OSS CEO confirmed, *'NTU's expertise in high-performance textiles enabled our consortium to overcome many technical challenges and prepared the path for future robust characterisation, qualification and industrialisation of the technology'* [**S2**].

The antenna's bespoke design meets the requirement for small, lightweight, resilient and reliable engineering, capable of operating at high radio frequencies with low risk of failure in space [**S1**]. The fine wire mesh seamlessly integrates with the deployable structure. With low mass, the antenna folds compactly when stowed for transport. It adopts the correct geometry and uniform mesh tension when deployed, which is critical for efficient high-frequency radio transmission in space [**S1**].

OSS have confirmed that baseline capability has been achieved and that the technology was ready for the development of larger antennae and greater manufacturing capability [**S3**]. OSS and NTU are formalising arrangements and an agreement (including filing IP arising from **G7** and **G8**), covering NTU's support [**S3**].

OSS CEO stated, *'Because of their low mass, stowability, resilience, compliance, thermo-elastic*

stability and high-RF reflectivity knitted metal mesh structures are ideal candidates to serve as deployable reflector antennas. Working with NTU has offered us the opportunity to commence the development of knitted metal mesh foldable reflector structures as well as the first steps toward integration into an antenna backing structure. Through enabling OSS to establish a proof of principle technology for novel deployable antennas - achieving technology readiness level between 4 and 5 - our collaboration has proved invaluable toward the commercialisation of advanced deployable reflector antennas' [**S2**].

OSS R&D Investment

OSS won a £1M ESA [**S4**] contract in 2019 to build on Innovate UK funding [**G6**]. The wrapped-rib antennae research includes designing, developing and manufacturing 3 to 5m diameter metal-mesh gores for 3 to 5m diameter deployable reflectors and establishing UK-based volume production that is commercially viable. Developing a wrapped-rib antenna makes the UK the first European country with flight-proven parabolic deployable antenna capability [**S4**].

Impact on OSS strategy/competitiveness

The prototype delivers a novel technology aligned to OSS's commercial objective of developing innovative solutions for creating light-weight, low-cost antenna systems for smaller satellites [**S1**]. NTU's development directly influenced the OSS business strategy, in particular the decision to invest in advanced manufacturing capability for the production of the next generation of microsatellite antennae. Initial investment of £100,000 has been made through the Innovate UK project. The potential for a satellite wholly manufactured in the UK positions OSS well in terms of the UK government Space and Security Policy to establish an internationally-leading commercial space industry in the UK. As such it offers OSS a significant commercial and competitive advantage [**S1**].

Historically, UK and European space companies have relied on US-manufactured metal-meshes for reflector antennas. This has made them vulnerable to US export restrictions. OSS characterised the strategic advantage of the new technology for OSS and UK PLC as follows: *'The fact that OSS can develop a facility so that it can be produced entirely in the UK is a significant commercial advantage. It negates the need to address potential United States export restrictions'* [**S2**].

The CEO at OSS also confirmed NTU's contribution has created significant competitive advantages in this growing sector: *'[The] prototype antenna is part of our objective to find innovative solutions to develop deployable antenna systems for a variety of space applications…[which] are targeting low cost and compact satellite buses where stowage volume and mass budgets are at a premium. This stowage efficient deployable antenna offers an attractive commercial product due to the performance, low mass and low volume attributes compared to conventional antenna architectures.'* [**S2**]. Furthermore, they will maintain UK military advantage over adversaries [**S4**] '*There are security and military elements which contribute to the increasing demand for domestic defence space assets. The technology…allows us to tap into the potential of these markets'* [**S2**].

5. Sources to corroborate the impact

Testimony:

S1: Programme Manager Oxford Space Systems (OSS), Harwell Space Cluster, Oxford. Interview, February 2020. This interview corroborates: (i) NTU's contribution to the design of the new technology; (ii) the industry need for small, lighter weight, resilient and reliable engineering, capable of operating at high radio frequencies with low risk of failure in space; (iii) the significant commercial advantage that the design affords OSS; and (iv) the further funding and investment that has been leveraged as a consequence. The interview also confirms the wider policy context and the potential of this novel, UK-based technology to provide a viable alternative for UK and

EU space telecommunication satellites to the existing, costly US warp-knitted metal fabrics which are currently imported from the United States and are therefore vulnerable to US-ITAR (International Trade in Arms) regulations.

S2: CEO, Oxford Space Systems (OSS), Harwell Space Cluster, Oxford. March 2020. Testimonial letter that corroborates the contribution of NTU's Advanced Textiles Research Group (ATRG) in creating capability through technical and competitive advantage to a pioneering UK-based company. The letter also highlights the potential of the novel technology to compete with US domination of the space sector in attractive markets including telecommunications, military and security.

Documentary Evidence:

S3: Collaboration agreement for current work completed within Innovate UK and ESA grant-funded projects (OSS/NTU).

Web-links and other documented sources of Evidence:

S4: OSS/ESA press releases "£1m injection into pioneering new space technology" Published 28 January 2019 https://www.gov.uk/government/news/1m-injection-into-pioneering-new-space-technology accessed 21 September 2020.

S5: UK involvement in the EU Space programme, https://www.gov.uk/guidance/uk-involvement-in-the-eu-space-programme accessed 12 January 2021.