Institution: Glyndŵr University

Unit of Assessment: UoA12 - Engineering

Title of case study: Economic Impact of the Design and Manufacture of Airborne Optical Systems for High Altitude Pseudo Satellites and Similar Platforms

Period when the underpinning research was undertaken: September 2015 to August 2017

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

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Paul Rees	Professor of Optics: Technology and Metrology	May 2010 - present
Mr Martin Coleman	Principle Engineer	August 2017 – Present
Mr Martyn Jones	Senior Lecturer – Aeronautical Engineering	November 2011 – Present
Dr John Mitchell	Senior Metrologist	February 2012 - Present

Period when the claimed impact occurred: May 2016 to December 2020

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

1. Summary of the impact (indicative maximum 100 words)

The impact of this research is both technological and commercial.

By using advanced design and finite element methods, and applying ultra-precision optical manufacturing and optical metrology capability together with composite and lightweight materials research, this work has delivered the first ultra-lightweight imaging and communications solution for the next generation of uncrewed high-altitude platform systems (HAPS). This research has led to:

(4.1.) A sovereign capability that is being used to develop imaging for the Zephyr and other HAPS platforms.
(4.2.) A collaboration with QinetiQ Ltd to develop LIDAR for the Zephyr HAPS platform.
(4.3.) Development of a hyperspectral spectrometer for Airbus Defence and Space
(4.4.) Collaborations with Airbus Endeavr to support innovation in Wales and establish a supply chain within the Welsh photonics community.
(4.5) Development of an airborne optical communications system for Archangel Lightworks Ltd.

2. Underpinning research (indicative maximum 500 words)

Research was conducted with £456,610 funding won from UK Defence Science and Technology Laboratory (DSTL) as part of its “Research and Development into Persistent Surveillance” competition (3.2) and was published in 2020 (3.1). The objective was to design a high-resolution imaging camera for deployment on HAPS aircraft.

Prototype HAPS aircraft (flown only since 2010) are powered exclusively by solar cells, have an operating altitude of ~20 km, and are designed to have mission durations of significantly greater than one month. The Airbus Zephyr aircraft, from which the instrument design requirements were derived, has a wingspan of 25 m and weighs less than 75 kg.

Because this technology is new, the platform development is significantly ahead of the development of suitable payloads. This research is the first published record of the design and

manufacturing development of HAPS optical instrumentation. The design team consisted of the authors identified in the cited paper (3.1). During the research, all authors were employees of Glyndŵr University or contracted to the project.

The research was done in two design and build phases: November 2015 to March 2016 (Phase 1) and May 2016 to August 2017 (Phase 2). In Phase 1, a prototype was designed and manufactured using commercial off-the-shelf and 3D-printed components to demonstrate the feasibility of meeting the SWaP (Space Weight and Power) requirements. In Phase 2, the optical design was developed to meet SWaP and optical performance requirements, detailed analysis was undertaken to assure thermal performance, and two bespoke prototypes were manufactured and tested.

The underpinning research centred on two areas:

Development of a design methodology for optical instrumentation for HAPS aircraft
The challenge was to design an optical instrument able to operate at its specified performance within a temperature range from +30 Celsius (pre-flight calibration) to -40 Celsius (operating altitude). This required careful selection of both optical and structural materials to meet the environmental requirements in terms of structural behaviour and survival. To achieve the required athermal optical performance, the thermal expansion of all structural components were critically matched with that of the optical components. The design made heavy use of finite elements analysis and experimental performance assessment. The result was the use of a single glass type for all optical components and a diverse set of structural materials, including several metal alloys, carbon fibre composites and plastics. Environmental testing indicated the optical system to be capable of diffraction limited performance throughout its specified temperature range.

Development of manufacturing methods for ultra-light optical instrumentation
To manufacture ultra-light optical instrumentation for HAPS requires lightweight optical and structural components whilst ensuring the structural integrity over the expected environmental and shock loading.

To achieve optimum optical/weight performance, a mirror-based design was chosen with an aperture of 150 mm diameter. The primary mirror is highly lightweighted (65% material removal) to minimise mass. The opto-mechanical mounting was designed in conjunction with the lightweighting pattern to ensure optical performance is not degraded. The opto-mechanical design is able to maintain its structural and optical performance. Glyndŵr Innovations Limited (GIL) is one of only four organisations in the UK able to perform this kind of optical fabrication.

The structural design of the instrument required the use of a diverse set of materials (above) to match the thermal behaviour of the optics. Interfaces between these materials included bolted and bonded interfaces. All interfaces required design and analysis to ensure the structural performance met the optical performance goals over the full range of specified environmental conditions. Bonded interfaces required extensive environmental testing to ensure structural failure did not occur at low temperatures.

3. References to the research (indicative maximum of six references)

The following published paper is open access and published in a refereed journal; it describes the development of a lightweight, high-resolution surveillance camera for deployment on HAPS aircraft, including the design of light-weighted optical components and the successful manufacture and testing of two prototype systems.

1. Paul C.T. Rees, Ian P. Baker, David A. Thomson, Dean Catterall, Martin Coleman, Martyn Jones, John B. Mitchell, "**Development of a Lightweight Camera for High Altitude Platform Systems**," Optical Engineering, 59(10), 105104 (2020). https://doi.org/10.1117/1.OE.59.10.105104

2. This work was funded by the UK Defence Science and Technology Laboratory (DSTL) as part of its "Research and Development into Persistent Surveillance – Challenge 1" programme under two contracts: contract DSTLX1000098365 (value £69,520) for Phase 1 of the programme and contract DSTLX1000103597 (value £387,090) for Phase 2. The funding was granted to Glyndŵr Innovations Ltd, a wholly owned subsidiary company of Glyndŵr University. The contract was managed through the Centre for Defence Enterprise (CDE).

4. Details of the impact (indicative maximum 750 words)

Development of a Sovereign Capability for the Supply of Optical Instrumentation for HAPS and Persistent Surveillance Applications

The objective of the DSTL/CDE competition on "Persistent surveillance from the air" was to develop sensor and communications packages that can be deployed on HAPS, and to produce solutions that are compatible with other airborne platforms and systems to improve export potential (other airborne platforms include larger high-altitude long endurance, HALE; medium-altitude long-endurance, MALE, vehicles). This has not been done before.

Technological and Economic Outcomes

1. In successfully delivering the Phase 1 and Phase 2 (November 2015 to August 2017) prototype products for this competition, Glyndŵr University has established a UK sovereign capability in the design and manufacture of optical instrumentation for high-altitude airborne persistent surveillance. This novel design and manufacture has led to sustained industry collaborations across Wales and internationally via commercial interest and investment in the new technology, stimulating economic growth for Wales and further collaborations for the University (***sources 1, 3a, 4b***).

   This new capability in the UK led Ordnance Survey (OS) to engage with GIL in 2016 to develop prototype remote sensing instrumentation for deployment on the Astigan HAPS platform. As a result, GIL delivered two Phase 1 prototype systems to OS for environmental and flight testing (***source 2***.).

2. This sovereign capability has enabled a collaboration with QintetiQ Limited to develop a LIDAR system for the Zephyr HAPS platform (from October 2018). The LIDAR system is for military and commercial use. The contract award is from UK DSC (Defence Solution Centre) to QinetiQ and has a value of £2.25 M, including investment from other partners. QinetiQ is investing a further sum to bring the total value of the programme to £5 M. GIL is contracted to design and build the geometrical optics of this LIDAR system (***sources 3a, 3b, 3c***).

   There is substantial market pull for this technology. QinetiQ is active in pre-sale marketing for this product but is unable to provide a specific market value at this stage. What is clear is that "free space optical communications continues emerging as a key capability within the military and commercially, and is a multi-million pound market area within the UK and beyond. However it is unclear how much of a role HAPS will play in future architecture yet, partly because key stakeholders are waiting to see how the critical technology performs/matures" (***source 3c***).

3. Airbus Defence and Space, UK, commented that they have responded to this capability "…by engaging GIL in a research programme to design, manufacture and system test a hyperspectral spectrometer intended for airborne and space borne deployment. The objective of the programme is to establish this capability within the UK and to develop a roadmap to deployment of this technology on airborne and space borne platforms. This research is being funded through Airbus Endeavr, a joint funding venture between Welsh Assembly Government and Airbus. The value of this investment to the Airbus-led collaboration is approximately £750K" (***sources 4a, 4b***).

They further state that "Missions utilising airborne and space borne hyperspectral payloads are of specific interest to Airbus. Market research conducted by Airbus and funded by this programme estimates the value of the global market for airborne and space borne missions with hyperspectral payloads to have an anticipated value of £1Bn by 2027. In addition, the global market for the products of these hyperspectral missions is anticipated to increase from $220M in 2020 to $307M by 2026" (***source 4b***).

4. The work has led to communications with Airbus Endeavr from October 2018, a joint initiative between Airbus and Welsh Government to support innovation in Wales. It is committed to the research and development of technologies in the areas of Digital Economy, Low Carbon Economy and Advanced Engineering and Manufacturing. Airbus Endeavr looks upon the development of this capability within Wales as an opportunity to establish an important supply chain within the Welsh photonics community. The potential value of this supply chain to Wales is estimated to be £12M by 2025 and has the potential to attract additional R&D funding to the region from ESA (European Space Agency) and other international agencies (***source 5***).

5. From February 2018 Archangel Lightworks Limited has sought assistance from GIL with the design and manufacture of the fore optics to an airborne optical communications system operating within a similar environment to HAPS. The optical aperture is twice that of the underpinning research, but the design of the optical system is a direct design descendant of the DSTL/CDE Phase 2 instrument design. This forms part of an ESA-funded demonstrator system for high bandwidth ground-to-space communication. The programme led by Archangel Lightworks has a projected global market value of approximately £1.5 Bn for Earth Observation data download. Other potential markets for this technology are quantum security (approximately $32.5 Bn by 2028), airborne broadband and hybrid telecommunications constellations (>$130 Bn by 2028), and military use (***source 6***).

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. News story on UK government DSTL webpage: https://www.gov.uk/government/news/ultra-lightweight-optical-system-for-aerial-ground-imaging
[corroboration of contribution to establishing a UK sovereign capability in the design and manufacture of optical instrumentation for high-altitude airborne persistent surveillance]

2. Testimonial from Head of Research & Innovation, Ordnance Survey.
[corroboration of OS engaging with GIL to develop prototype remote sensing instrumentation for deployment on the Astigan HAPS platform]

3. The following sources corroborate the award of funding via QinetiQ to design and build a Software Defined Multifunction LIDAR system for HAPS deployment:
a. "QinetiQ has won a contract to develop its unique Software Defined Multifunction LIDAR technology to a flight ready payload": https://ukdefencejournal.org.uk/qinetiq-wins-contract-to-develop-lidar-for-zephyr/
b. "QinetiQ team wins contract to develop Software Defined Multifunction LIDAR SDML after success in UK DSC innovation competition":
https://www.qinetiq.com/en/news/qinetiq-team-wins-contract-to-develop-software-defined-multifunction-lidar-sdml-after-success-in-uk-dsc-innovation-competition
c. Testimonial from Optical Sensors Team Lead, QinetiQ Limited

4. The following sources corroborate the award of funding via Airbus Endeavr to design and build a prototype hyperspectral payload for airborne applications:
a. "Imaging System Set to Revolutionise Industry": https://airbusendeavr.wales/high-tech-imaging-system-set-to-revolutionise.html
b. Testimonial from Head of UK National Eyes Only Bids and Studies, Airbus Defence and Space

5. Testimonial from Chief Operating Officer, Airbus Endeavr [corroboration of Airbus identifying the development of instrumentation for hyperspectral imaging as an important strategic technology] 6. Testimonial from Chief Technology Officer, Archangel Lightsource Limited [corroboration of Archangel Lightworks Limited seeking assistance from GIL with the design and manufacture of the fore optics to an airborne optical communications system]