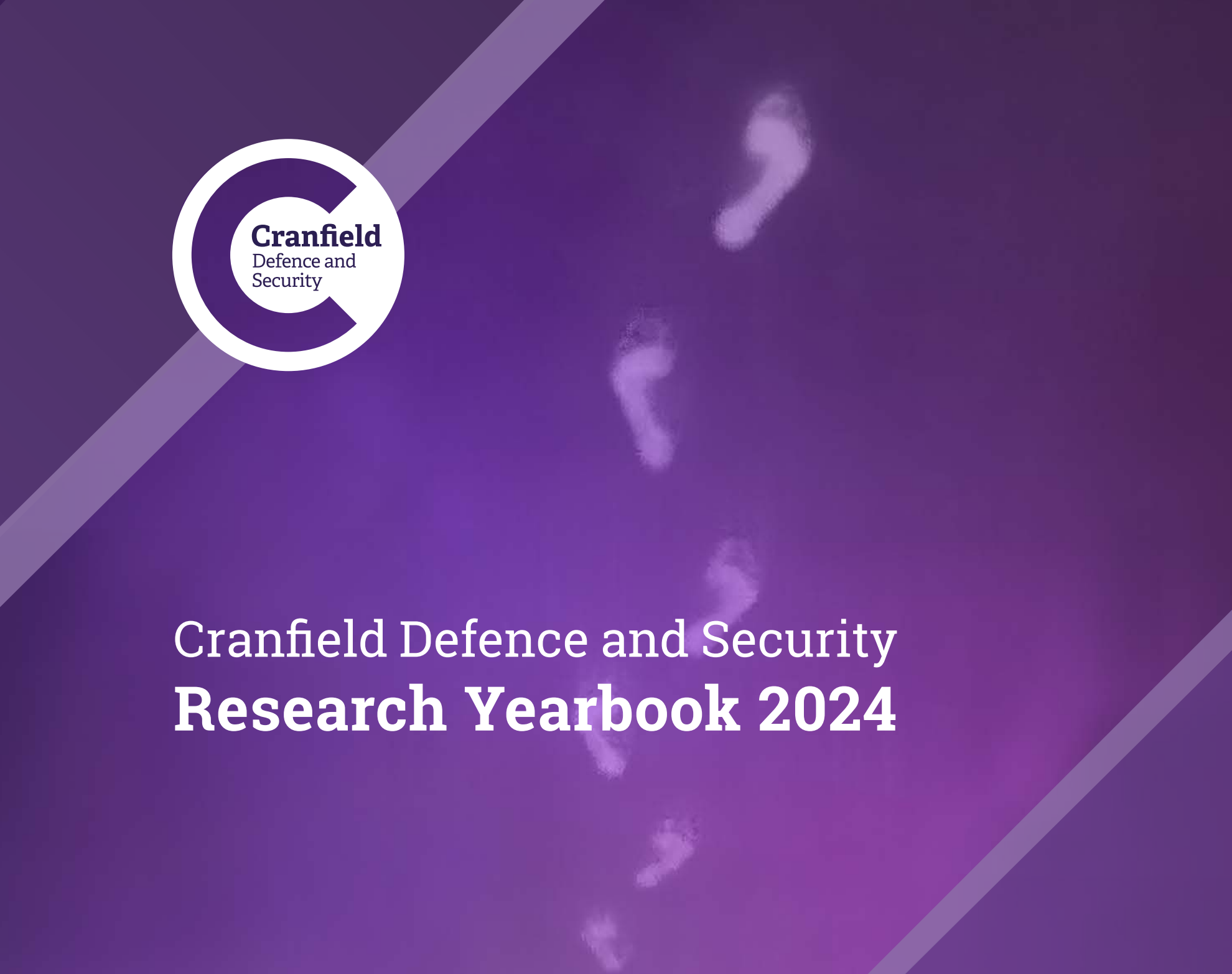

Cranfield Defence and Security

Research Yearbook 2024

Connecting research and resilience

It is my pleasure to introduce you to the Cranfield Defence and Security Research Yearbook 2024. It provides an exciting glance at some of the transformative and impactful research completed by our staff and students during 2023 - 2024.

We encourage a research culture whose central tenet promotes the articulation of intellectual contribution for useful application, and we are proud of our collaborative projects with industry and government. Research students are at the heart of our creativity and the research presented here derives mainly from PhD theses completed over the last year. We've also included examples of research projects by academic staff. Both aim at sustaining mutually beneficial strategic relationships with key industry partners.

Cranfield University is well-known throughout the world as a centre for scholarship with purpose, which is actively applied to industrial and societal challenges. In the 2021 Research Excellence Framework (REF) assessment, 88% of Cranfield University's research outputs were ranked 'world leading (4*)' or 'internationally excellent (3*)'. Although the research featured in this publication stems from Cranfield Defence and Security, research in this sector extends across all schools of Cranfield University.

I hope you enjoy reading this book and that it inspires you to work with us, as a student, a company, or a government department, in Defence and Security research.

Professor Andrew Shortland
CDS, Director of Research

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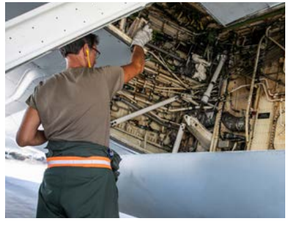







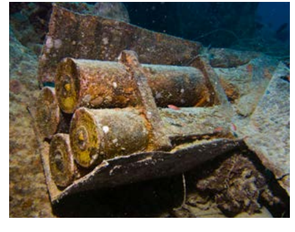

The identification, understanding and prediction of bullet behaviour through laminated vehicle glass as an intermediate barrier

The glass portions of a vehicle are commonly targeted by Law Enforcement Agencies when engaging suspects. Cars in the UK have laminated glass windscreens, and normally have tempered glass for side windows. Laminated glass has a layer of Poly Vinyl Butyral (PVB) polymer sandwiched between two sheets of glass and is the focus of this research to determine the deflection and efficacy of bullets when targeting windscreen glass.

This research investigates the performance of 9mmx19 and 5.56mmx45 calibre law enforcement ammunition, fired from police issue firearms (Glock 17 pistol and H&K G36C carbine respectively), using six bullet types against a vehicle laminated glass surrogate. Traditionally research in this field has used recycled vehicle windscreens, which can induce measurement errors due to the curvature present. To eliminate this error, flat laminated glass targets were commissioned, made to the composition and dimension specifications of typical UK saloon vehicle windscreens.

The work examines the levels of deformation, fragmentation, and deflection of bullet types in service. The six bullet types included were:

9x19mm

- Full metal jacketed 123 grain;
- 124 grain Federal HST mechanically bonded hollow point;
- 124 grain Speer Gold Dot chemically bonded hollow point.

5.56x45mm

- 62 grain BAE (Radway Green) L17A2 full metal jacket NATO ball round;

- 62 grain Federal Tactical Bonded chemically bonded barrier penetrator soft point;
- 69 grain RUAG Swiss-P hollow point.

Although intended to examine performance of law enforcement issue ammunition, the investigation of the L17A2 British Army issue round, and 9mm NATO FMJ also provides useful context for military application. Also tested were monolithic, mild steel cored and lead cored bullets in non-police calibres including .300 Blackout, 7.62mmx39 and 9mm Makarov used in the used SIG MCX carbine, Vz.58 rifle and Makarov PM pistol respectively.

The 'Critical Angle' of ricochet from laminated glass targets concerning both the 9mmx19 HST bullet and the 5.56mmx45 Tactical Bonded bullet was also tested to inform Law Enforcement Agencies as to the angles to prevent ricochet. Finally tested was the 'estimated kinetic energy' (EKE) transfer into synthetic ballistic gel soft tissue simulant after perforating the laminated glass intermediate barrier, to see how effective these bullets are at wounding after passing through a windscreen.

This research utilises extensive use of the open access measurement software, 'Image J'. It looks at the practical performance of the ammunition tested and identifies the detailed fracture mechanisms involved as a bullet passes through glass. This will help inform forensic examiners as to the direction and angle of the incoming bullet.

The outcome of this research will:

- Inform the tactical use of the UK Law Enforcement Agencies' ammunition against vehicle glass targets;
- Increase understanding of the physical processes of a bullet's perforation of glass;
- Give a practical solution to the investigation of shooting scenes by highlighting a tool for practitioners examining the perforation of glass at crime scenes.

Results indicate that bullets consistently deflect downwards when fired into windscreens at acute angles, the extent dependent on the bullet design, and have a 'sliding scale' range of ricochet angles. The work also demonstrates the effectiveness of current law enforcement issue 'barrier blind' ammunition designs, which helps affirm its selection.

Research by
Dr Peter McCutcheon, Dr Aimée Helliker
and Professor Gareth Appleby-Thomas

Improvised explosives: How to understand the threat and assess the risks

This research focused on understanding the risks posed by dual-use industrial chemicals which have potential applications as explosive charges in Improvised Explosive Devices (IEDs). Generally not considered as explosives due to the large quantities often required in order to undergo detonation, these materials are able to act as tertiary explosives which may be initiated by a sufficient booster charge. An example is ammonium nitrate, used largely as a fertiliser, but which is now regulated as an explosive or explosive precursor due to terrorist use and unplanned industrial detonations.

While these materials and other tertiary explosives are of greatest concern when detonated in large quantities, large-scale experiments require specific facilities and involve kilograms of product. These campaigns can be time-consuming, difficult to organise, expensive and, depending on the sensitiveness of the energetics under investigation, potentially hazardous. Due to these factors there is a need to predict large-scale detonation performance parameters of energetics from small-scale tests.

Urea Hydrogen Peroxide (UHP), widely used in the dental, cosmetic, and pharmaceutical industries, has been identified as a potential emerging threat, but minimal study of its explosive properties had previously been performed. UHP was selected as the material to be investigated, with the intention of determining its detonation properties to allow assessment of the risks from UHP-containing IEDs.

Small charges of UHP were investigated initially, and were

shown to detonate when shocked by a suitable booster charge under heavy confinement at a range of densities, demonstrating the viability of UHP as an explosive fill for IEDs. These small-scale experiments were optimised to validate a setup and charge geometry that closely approached large-scale behaviour, and should provide a suitable methodology for the study of other energetic materials of interest.

Detonation performance parameters were then determined using thermochemical calculations, numerical simulations, and instrumented experimental firings at both small- and large-scale. The data from these complementary approaches were then compared and contrasted, furthering understanding of the behaviour of UHP at a range of charge sizes.

The final stage of the research involved assessing the risk posed by UHP by analysing the collected academic data within a Counter-IED (C-IED) perspective within the scope of a limited release technical-operational threat assessment. This process considered both the availability of raw materials, using a specific predictive threat analysis, and the potential use as a main charge in IEDs, building upon previous academic work on UHP.

In addition to furthering the understanding of the risks posed by UHP as an explosive charge, this work has also provided valuable insights into the non-ideality of UHP, highlighting the limitations of the available characterisation methods and modelling tools. The project, which included 150 instrumented firings, was one of the first attempts to thoroughly characterise a tertiary explosive for risk assessment purposes, demonstrating an approach that may be applied to other poorly understood materials of this kind.

In terms of real-world impact, the results published in this body of work provide relevant knowledge to the scientific community, complementing the rather limited available academic literature with a comprehensive characterisation of UHP detonation performance. The outcome is also of great interest for industrial risk management and process safety. This work was equally important to understand the threat and assess the risk posed by tertiary explosives in a C-IED context and address relevant recommendations to worldwide intelligence services and law enforcement agencies.

Research by
Lt Col Dr Francis Halleux, Dr Jeff Pons and Dr Ian Wilson

Polynomial correction method for dynamic targets on a phased array seeker

Current RF (radio frequency) seekers use a mechanically stabilised and steered array which, despite being robust and proven for many years, present shortcomings that provide a motivation for improvement. One of these is the rate at which the array can scan for targets. Currently this is limited by the efficiency and quality of the gimbal as well as physical limitations on rotation speed. A further shortcoming with mechanically stabilised and steered arrays is that they feature a single point of failure for the whole system. If the mechanical component breaks, the radar loses any scanning capability and cannot function in any capacity.

Both of these shortcomings can be addressed with the introduction of a phased array antenna on the seeker. Scanning rates on a phased array are many times faster than their mechanical counterparts, as the scanning speed depends on the digital processing rather than physical constraints. Additionally, the failure of individual elements in the phased array does not render the system useless but rather causes a potentially very small reduction in performance. This is the natural successor to current seeker systems and the next generation of radar seeker is well thought to be guided by an electronically scanned array (ESA).

ESA will provide a more advanced, flexible and high performance system through beamforming and signal processing techniques. However, to implement such a system a whole new range of technical challenges arise that include guidance and stabilisation errors.

This research conducted an investigation in to electronically steered radar seekers, implementing algorithms that improve the signal return for fast accelerating targets. By simulating a radar guided missile in MATLAB, the performance of these algorithms was proven and tested to show potential significant improvements to the signal return of a target with known dynamics. A future system of this kind, produced by Leonardo UK, was simulated to assess performance characteristics when detecting high velocity, high acceleration targets. A target like this returns a spread Doppler and has less integration coherence which reduces the signal-to-noise ratio (SNR). Applying a polynomial correction to the received signal based on the target dynamics resolves this issue. For a case where the target trajectory is known, it was shown that the SNR can be corrected to that of a constant velocity target. However, for the more complex cases where the target dynamics are not known more research is required to improve the SNR gain. In the future, the MATLAB simulations developed in this work will be used to compare against a real demonstrator to determine if the actual experimental performance is in line with the simulations.

Research by
Evan MacWhirter, Professor Alessio Balleri and Dr David James

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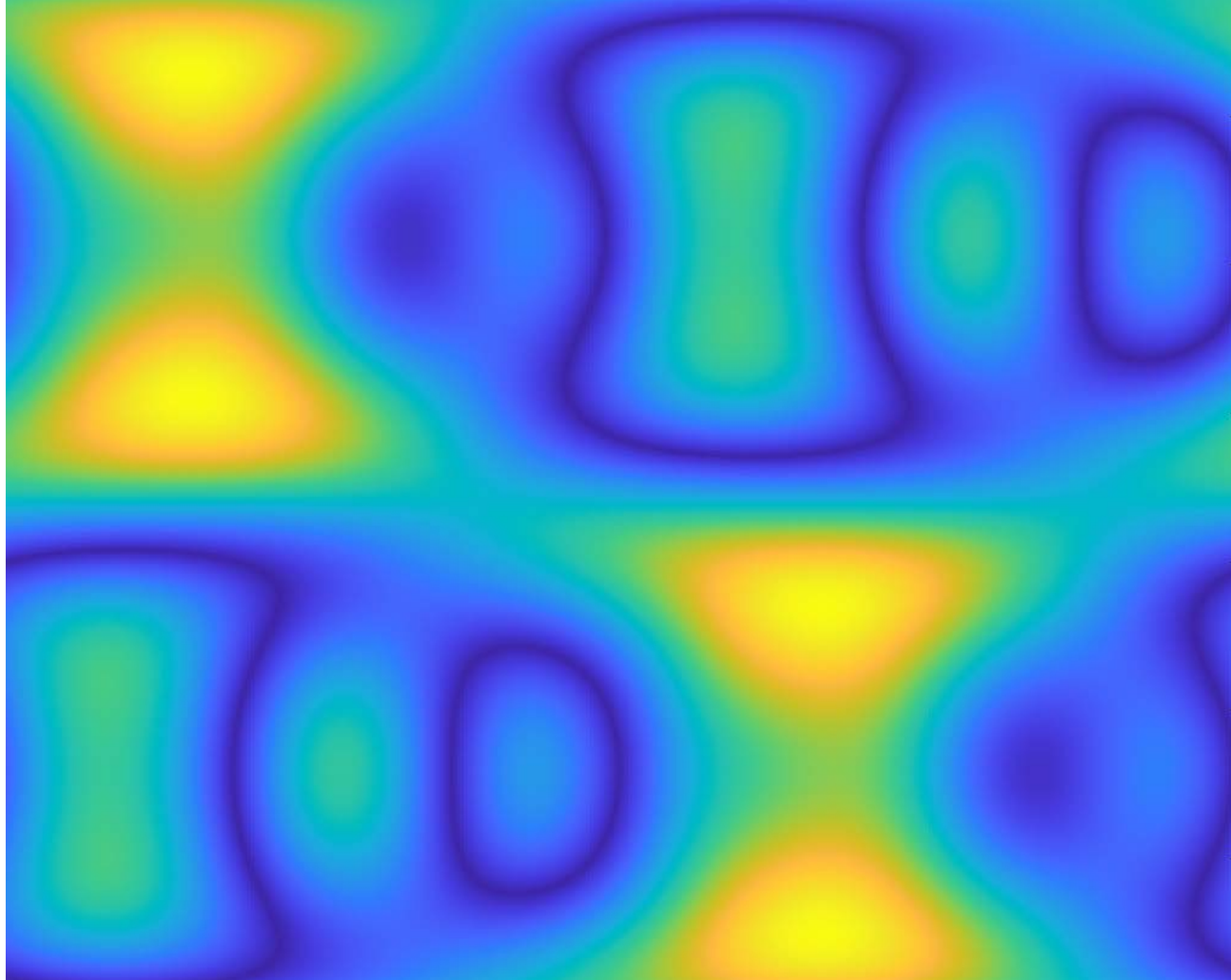


Is there a link between ‘no fault found’ and airworthiness?

A system develops a fault. Engineers subsequently investigate and conduct fault diagnostics, including testing. They are unable to reproduce the fault and report ‘no fault found’ (NFF). It all works as expected. The fault may have been intermittent, which makes it harder to diagnose and find, or it may only be present when installed in the system and not when tested in isolation.

The NFF phenomenon is experienced across many disciplines, including the automotive, telecommunications, aviation and rail industries. The impact of a NFF can range from an inconvenience to a major safety hazard. Much depends upon the context of when the fault first occurred and then reappeared.

This research aimed to establish if a link between NFF and airworthiness exists and to garner the aircrew’s perception of the link. Semi-structured interviews and a questionnaire were conducted to generate primary data. Pilot and aircraft accident investigator interviews were conducted to establish a foundation of knowledge, experience and perspectives on NFF and airworthiness to support the questionnaire.

The research concluded that NFF is linked to airworthiness by virtue of the aircraft’s technical design and how it is operated, such that dormant faults can become activated or undetectable based on the operating environment. These faults can present a distraction and significant hazard to both aircrew and third parties. Furthermore, approved procedures may be insufficient to detect NFF and thereby perpetuate the risk.

The questionnaire established predominately RAF aircrew views on the impact of NFF on airworthiness, the key aircraft systems affected, communication methods and the associated training completed. Secondary data from an aviation company's maintenance records were analysed for NFF frequencies. The research analysis included systems engineering, Bowtie, Functional Resonance Analysis Method (FRAM) and fuzzy logic inference.

The research established that RAF aircrew perceive NFF to negatively impact airworthiness; causing missions to be cancelled, curtailed or replanned. NFF events diminished the trust between RAF aircrew and engineers and this impacts the analysis and recording of NFF and airworthiness. Training the aircrew and engineers on how to conduct the post-sortie engineering debrief, in a dedicated location whilst using a dedicated proforma, will decrease the occurrences of NFF. The debrief should focus on NFF and airworthiness and reviewing the aircraft's NFF history.

An iterative relationship between Bowtie and FRAM established the key aspects that impact the link between NFF and airworthiness. Based on mission success, the fuzzy logic inference of the aircrew and RAF engineers' linguistic variables, (negligible to severe), that described the aircraft's airworthiness level as a consequence of repeated NFF were combined, creating three-dimensional surface plots to represent the aircraft's overall airworthiness level. When combined, these confirmed that airworthiness is not binary. The fuzzy logic surface plots showed that the NFF/airworthiness relationship varies over longer periods but is most pronounced in those periods that are shorter and with more NFF occurrences. This indicated that the current methods for analysing and assessing the impact of NFF on airworthiness require redefining, and this research suggests that NFF/airworthiness working groups with key stakeholders are a means to achieve this. As the questionnaire participants were mainly RAF aircrew the external validity for them has been established.

Research by
Dr Laura Lacey, Professor Alistair Saddington and Dr Simon Place

Tracking the untraceable: An assessment of global obliteration techniques on small arms

The movement and trafficking of illicit small arms and light weapons (SALW) is a transnational threat faced by law enforcement, policymakers, and forensic investigators. Due to the size of most SALW, they are easily transported, sanitised, and concealed, and therefore susceptible to diversion.

In conflict-afflicted zones such as West Africa, the Middle East, and some parts of Eastern Asia, firearms are often left as remnants of war, which are then filtered across regions through trafficking networks. In these areas, firearms of all types are easily available and are at the forefront of armed violence, crime, and insecurity, and are lucrative income-generating commodities. In more developed regions, such as North America and Europe, nearly half of the illicit firearms used in criminal activity are handguns because of their small size and the fact that the long range of rifles is not typically required. These firearms are often sourced legally in the first instance and are subsequently sold into black markets, where they end up in the hands of criminals and are used for intimidation or committing violent crimes.

The ability to trace firearms globally is paramount for illicit diversion investigations. Firearms tracing efforts are made by a multitude of organisations, including police bodies during criminal investigations and non-government organisations operating in SALW diversion networks. Serial numbers are documented through a firearm's lifecycle as a means of record keeping; they are relied upon to identify all the way through

manufacturing, consignments, and to end users. Tracing, therefore, relies on the serial number as the only unique identifier marked on the firearm. Violent extremist groups and organised criminal groups demonstrate sufficient forensic awareness to know that serial numbers and other identifying marks are used to track firearms throughout their lifecycles, across porous borders, and through criminal networks, exposing illicit actors to risk of prosecution. These identifying marks are intentionally removed, rendering the firearm anonymous. Depending on the type of investigation and the global region, an attempt may be made to forensically recover removed marks.

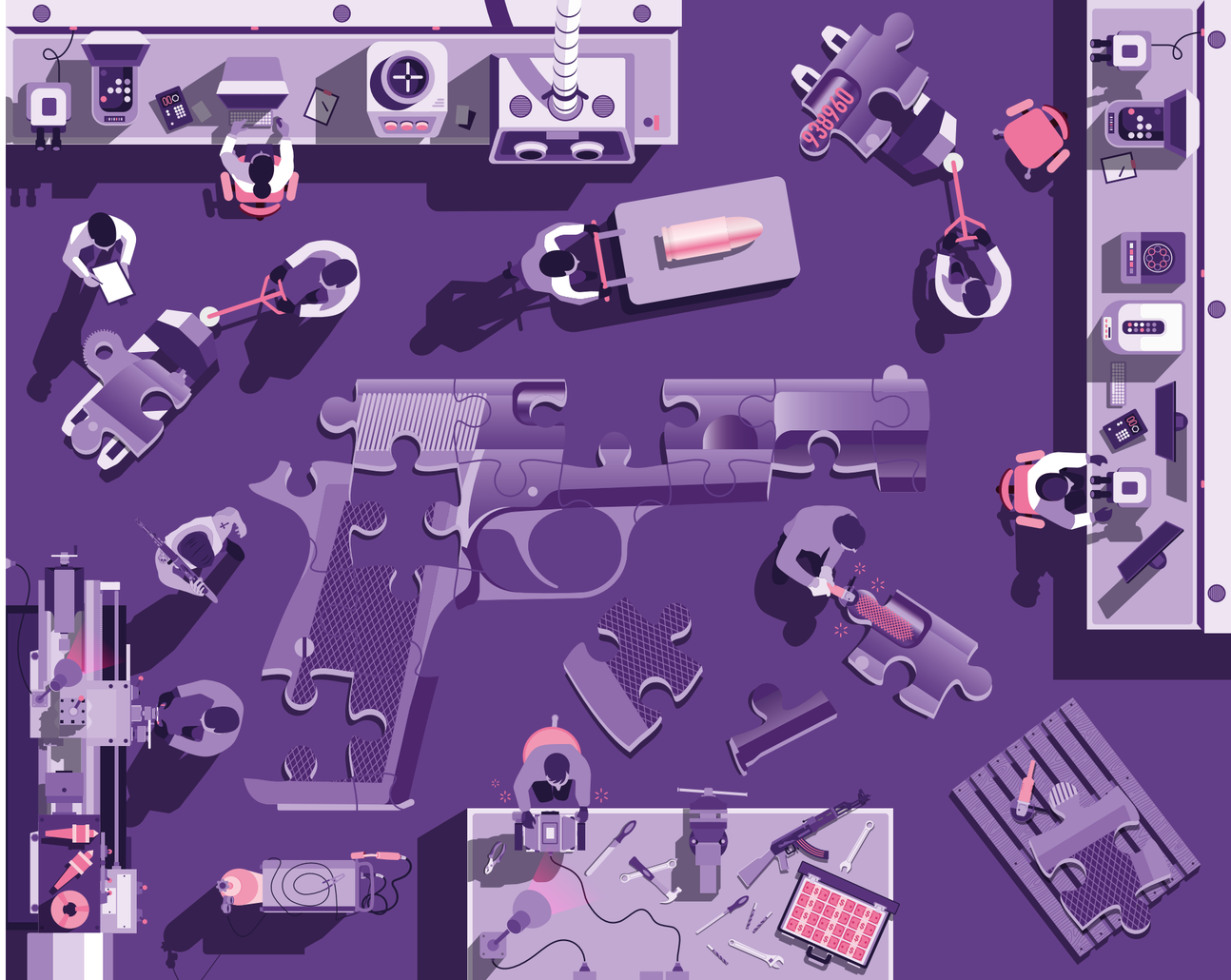
This work undertakes the first known investigation into the tracking of obliterations on a global level by developing a novel, intelligence-led investigative codification tool based on the toolmark analysis of individual obliterations. This unique tool has been designed to ensure that technical analysis is not restricted by location nor forensic capability. The development and methodology of this novel framework to critically analyse the toolmarks within obliterations has been presented. This approach has been proven in this work to be a useful method to track global obliteration trends when coupled with local intelligence, showing physical links between sanitised weapons documented in Africa, the Middle East, Canada, the United Kingdom, and Australia.

To enable field-based forensic recovery of removed markings, this research also explores an emerging magneto-optical technology.

A methodology for utilising this kit has been established within this research, with the recovery of obliterated markings surpassing the current methods that utilise a chemical etchant by up to 22%. This emerging technology has proven to be a beneficial forensic capability and preserves the integrity of evidence, while highlighting that some marks may never be recovered even using the most effective, current techniques.

The developed methods and techniques, conclusions, and recommendations of this research have been presented to, and adopted by, international research organisations demonstrating the impact of this work.

Research by
Dr Bailey Henwood, Dr Rachael Hazael and Dr Kate Hewins



Thermal footprint based localisation for indoor environments

Accurate knowledge of where a person is located is crucial for many technologies, including virtual reality, wearable navigation devices, and systems that enable humans and machines to work together. These technologies are used in healthcare, the military, and various industries. Traditional methods like GPS often fail indoors or in areas with poor signal, so new computer vision techniques have been developed. These techniques use images of the surroundings to figure out a person's location. However, they struggle in places with poor lighting or few distinct features, like hospitals, offices, or ships.

The main challenge is to create methods that don't depend on the existing features of an environment to determine a person's location. Some research has tried using markers placed in the environment beforehand, but this limits where the technology can be used. For example, NASA's Mars rover used its tracks in the sand to find its position, but this required specific conditions and equipment.

This research introduces a new method that uses the heat left behind by a person's footsteps to figure out their location. This method doesn't need any changes to the environment and can work in places that don't have visible features. By using a thermal camera to capture the heat differences between a person and the ground, this method can track where someone has walked.

Thermal footprints are a unique feature because they don't depend on the existing environment and are

less affected by lighting conditions. As a person walks, these footprints are constantly created and can be detected by a thermal camera. This makes thermal footprints a useful tool for locating people in featureless environments like empty rooms or corridors, which are common in hospitals, offices, and ships.

This research presents three main achievements:

- A new technique to separate thermal footprints from the rest of the thermal image which improves the accuracy of identifying footprints by 27% compared to older methods;

- A method to match these footprints between different images, ensuring the system can accurately follow a person's path. This method improves the correct matching of footprints by over 40% compared to the best current techniques;

- A new method to determine the scale, or size, of the area being analysed using just one thermal camera. By knowing the size of a person's foot, the system can estimate distances and positions more accurately. This new method shows a 24% improvement in overall accuracy compared to existing methods.

In simple terms, this research presents a new way to track where people are by using the heat they leave behind as they walk. Notably this method also works well in places without visible features, making it useful for many real-world applications in challenging environments. The improvements in accuracy and reliability make this a promising approach for locating people in places like the aforementioned hospitals, offices, and ships.

Research by
Dr Eddie Jackson, Professor Mark Richardson and Dr Lounis Chermak

Effect of wind turbulence on wind ballistic trajectory of a medium calibre weapon system

To improve the accuracy of medium calibre weapon systems, a Fire Control System is often employed to assimilate the data inputs and provide a correction to the gun. A typical engagement timeline takes the format of lazing the target (0 s), processing and computing the required offset for the given inputs (2 s) before firing (3 s), and the projectile hitting the target (5 s). These inputs can include the range, barrel wear and local environmental conditions such as temperature and wind speed and direction. Current Fire Control Systems take a single constant crosswind value which is then used to calculate the ballistic drift offset required to correctly engage a target at range. However wind is not consistent, variations in crosswind speed and direction known as gustiness cause drift and errors in flight which can potentially result in the projectile missing the target. To account for the potential variations in crosswind speed and direction, this research looked at the potential to apply a correction factor to account for this variability, increasing the probability of hitting the target.

Data was extracted from real wind values provided by a meteorological database. It was taken from three different months, over 10 day periods at different times of the day. These samples were selected to accommodate the standard weather expected across temperate European weather seasons. The data was analysed to determine the variation in wind speed and direction at height. The data collected at one-second intervals at a height of two, five and ten metres above land was interrogated to produce

wind gradient curves suitable to be incorporated into ballistic models.

To analyse the impact of the changing windspeeds during a projectile's flight, a Point Mass Ballistics model was developed based on a 40mm Cased Telescoped Ammunition (CTA) Target Practice - Tracer projectile. This model was assessed in relation to the NATO coincidence window to predict whether the projectile would hit a reference tank target, 2000m away. The NATO coincidence requirement states that a system should be able to maintain a coincidence error window of 0.3 mrads. The standard single constant crosswind correction factor was compared with the real wind data, along with considering the impact in delay between computing and firing on the hit probability.

This work found that the crosswind collected by a vehicle and inputted into the Fire Control System at two seconds will have a 45.21% chance of correctly producing a NATO coincidence accuracy result. The projectile hit probability can be increased by 10.95% to 56.16% by using a crosswind value in the millisecond prior to firing in the engagement timeline. The later point in the engagement removes the errors generated by using an out-of-data crosswind value to calculate the ballistic solution.

The real wind data was successfully extracted and modelled to accommodate the wind gradient effects caused by changes in velocity and height. These crosswind factors were incorporated into the ballistic model and demonstrated that multiple crosswind sensors can be included into the calculation process to increase the hit probability. This enhancement in performance of the ballistic solution is required when considering modern vehicles are fitted with advanced protection systems, which increase their protection levels. Reducing the drift effects of the medium calibre projectile would increase the hit probability and accuracy of the system.

Research by
Daniel Knight, David Simner
and Dr Aimée Helliker

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Organisation informatics in defence: Determinants of information technology acceptance in the deployed military environment

The deployed military environment is characterised as high tempo, high stress, risking the lives of those involved and with a low tolerance of failure. Military conflicts, and the associated defence technology sector, can be important environments for the cultivation of novel technologies from the jet engine or surgical techniques to the World Wide Web. The importance of technical strategic advantage set against an environment where failure costs lives highlights the importance of effective management of technology change in the Armed Forces.

Military campaigns from Northern Ireland, Iraq and Afghanistan present important case studies for how technology change and innovation can lead to success on the battlefield. Reviews have demonstrated the importance of having a strong culture of innovation, establishing procedures to best exploit the technology and creating a cycle of training relevant to the technologies used.

This research sought to identify the most influential technological (functional) and environmental (non-functional) factors and their relationships affecting the effective adoption of technology in the deployed military environment. Two case studies were used to gain evidence of trends and factor relationships affecting individual motivation to use new technology. These considered the use of specific applications within a NATO staff headquarters and the implementation of a new IT system into the UK's aircraft carriers, HMS Queen Elizabeth and HMS Prince of Wales. The Technology Acceptance Model (TAM) was employed to assess the relevance of a series of variables

aligned to two constructs, referred to as Perceived Usefulness and Perceived Ease of Use, and their relationship to technology use. Factors included aspects such as Performance, Usability, Functionality, Organisational Support, Task-Technology Fit, System Training and Subjective Norm. These can be visually portrayed within the Social System or Technical System.

Data was collected from questionnaires with military staff combined with interviews. These were analysed using a technique known as Structural Equation Modelling (SEM) to assess the relevance of relationships between the factors (determinants) and the underlying TAM constructs. SEM provides a highly effective technique for theory building and testing in social science. It demonstrated the relative alignment between the determinants and the higher order latent (unmeasured) variables, Perceived Usefulness and Perceived Ease of Use, and Behavioural Intent to use the technology.

The modelled data showed clear correlation between specific variables and the TAM constructs including behavioural intention to use the Information and Communitcation Technology (ICT) systems by the military staff. There were significant deductions about the relative importance and correlation of technological variables (e.g. usability and system training) and the non-functional, environmental conditions (e.g. technical support, job relevance) to the individual user. In the deployed military context, the cohesion of the team is important on a naval ship or within an Army or Royal Air Force unit. This was evident in the influence of team perspectives on individual choice highlighting the critical importance within the military of gaining group level acceptance to change. Several policy proposals were presented from the research. This included the need to engage a military organisation not just at an individual, but also at team level in the event of major ICT technology change. It was highlighted that some organisations lacked the digital skills and processes to fully exploit modern technology. This demonstrated the need for relevant and extensive training on the technologies before military deployment. The importance of a culture of innovation and a willingness to take risk in utilising novel technology was noted as significant. The focus of large organisations on delivering a step change in technology is understandable. The research showed that cultural conditions can have a stronger influence on perceptions of the utility and intention to exploit the opportunities it presents.

Research by
Dr Laurence Fowkes, Dr Annie Maddison Warren and Dr Ken McNaught

Advancing autonomous navigation: A framework for riverine scene understanding

Imagine a future where autonomous boats patrol our rivers monitoring for pollution, assisting in search and rescue operations, or even delivering goods. For this to become reality autonomous vessels first need to be provided with the ability to perceive and interpret essential elements from their surroundings to make adequate decisions in differing situations. This is particularly challenging because river landscapes are subject to various and ongoing changes in their environment due to factors such as light, vegetation and water flow.

This research addressed the problem by focusing specifically on how to enable autonomous boats to reliably detect and map the navigable areas of a river using only a single camera. This might seem straightforward enough as water is usually quite distinct from land. However, in the real world, things are much more complex.

Current autonomous navigation methods often rely on pre-existing maps created from satellite images or land surveys. This approach is limiting as it restricts autonomous operations to areas that have been meticulously pre-mapped. Having to map every inch of a river network before a boat could autonomously navigate it is not practicable, and a more flexible and adaptable solution is needed. The challenge lies in the ever-changing nature of rivers and the complexities of the outdoor environment - lighting conditions can shift dramatically, reflections can obscure the true surface of the water and vegetation can overhang the riverbanks. Such factors all create a confusing picture for a computer to interpret and traditional image

processing techniques often struggle to cope with this variability.

This research proposes a new framework that combines different aspects of visual information, spatial, spectral and temporal, to create a more robust and reliable way to identify water. Thus, instead of relying on a single method, we combine several techniques such as feature descriptors (mathematical representations of visual patterns) and segmentation methods (dividing the image into meaningful regions). This enables us to capture a richer picture of the scene, even under challenging conditions. We also leverage the fact that water often moves differently from its surroundings. By analysing how pixels change over time, we can distinguish the flowing water from stationary objects such as trees or rocks.

Finally, we developed a 'water probability weighting' system that essentially encourages the algorithm to link together regions that are likely to be water, helping to create a cohesive map of the navigable space. Results show that this framework is significantly more effective at identifying navigable water than traditional methods, even in complex and dynamic environments. It has been successfully tested on real-world river imagery, demonstrating its potential for real-world applications. While there are still challenges to overcome, particularly in extreme lighting conditions, this research represents a significant step forward in enabling truly autonomous river navigation. The technology could be extrapolated to a wide range of defence and security applications, from maritime surveillance and patrol to disaster response and environmental monitoring.

By interpreting their watery world and giving autonomous boats the ability to 'see', the door is being opened to a future where these intelligent vessels can play a vital role in keeping our waterways safe, secure, and sustainable.

Research by
Dr Michal Szulik, Dr Lounis Chermak
and Professor Mark Richardson

Development of multistatic radar networks

The aim of this research is to develop and demonstrate radar network solutions that employ small, low-cost, dual-channel receivers, which could be deployed on Unmanned Aerial Systems (UAS). The receivers exploit a dual-channel design to provide network synchronisation without the need to share a reference signal between the network nodes. A solution of this type can be employed for a static network as well as for receivers on moving platforms.

The key objective of the solution is to offer a new capability: the ability to detect and track targets at extended range using low-cost hardware which is also suitable for contested areas where a high level of attrition can be expected. The solution could be oriented towards supporting additional sensing contexts, such as sensing of low-reflectivity targets in cluttered environments.

Current in-service radar systems are high-cost, large, monolithic platforms with a large electro-magnetic signature, and typically deployed in low numbers, making the capability vulnerable to attrition. Low-observable targets are typically optimised to evade such monostatic radars.

Radar network systems offer improved detection performance against low-observable targets because the environment can be sensed from multiple directions. Also mobile, low size, weight, power and cost receivers have potential to offer covert sensing while also mitigating the effects of attrition.

Our research is carried out in collaboration with Plextek Ltd and supports this context by addressing theoretical development of signal models and optimal performance predictions,

whilst also developing suitable hardware to provide low technology level readiness demonstrations.

The work conducted to date includes the development of the signal model relative to a network of moving receivers, together with the calculations of the theoretical performance bound for the estimation of the target position and velocity by such networks. The lower estimation bound was verified with bespoke simulations that operate on the type of data output from dual-channel receivers. It was then used to find the optimal receiver trajectories in representative tasks and scenarios. The optimal solutions were found with simulations and performance comparisons were carried out for techniques that fuse the pre-processed network data at each receiver and those that instead fuse data after some detection pre-processing. Estimation performance with respect to position, navigation and timing (PNT) errors were also assessed.

Two dual-channel receivers were prototyped to allow the experimental demonstrations. These were developed based on software defined radio technology. Each carried a bespoke surveillance antenna which was prototyped to offer a higher antenna gain at a lower cost than other off-the-shelf solutions. Experiments were run to demonstrate the proposed network could detect moving targets and to show the effects of clutter when the receivers are operated from moving platforms. Demonstrations of detection against a flying drone were also carried out, for both a static and moving network, to show low-RCS (radar cross-section) drones can be successfully detected by such a network.

The dual-channel feature of the receivers allows the exploitation of radar signals as well as other communication signals already available in the environment. For example, possible sources of opportunity include Digital Audio Broadcast (DAB), FM radio, Digital Video Broadcast (DVB), cellular phone base stations and various satellite stations. Digital Video Broadcasting - Terrestrial (DVB-T) is a very attractive option and the exploitation of DVB-T signals has been investigated in this research. This is because DVB-T signals are powerful and well-defined with sufficient bandwidth to provide good range resolution. DVB-T also uses noise-like signals which are suitable for radar applications.

Article by
Professor Alessio Balleri

Efficacy of activated carbons and biochar for underwater remediation of TNT contamination

The Environmental and Safety Group (ESG) at Cranfield Defence and Security focuses on the environmental impact of defence-related chemicals in water, soil, and air. Their research primarily examines the impact of explosives, specifically the toxicity and health issues that may affect environmental receptors. The group's scope has expanded to include the environmental impact of underwater munitions during clearance operations. They are investigating how these explosive materials can leak into the environment and the varying impacts of high-order and low-order detonations, as well as the presence of buried unexploded munitions.

High-order and low-order detonations are often used to dispose of or remove these munitions, which is crucial to mitigate potential ecological risks and safety hazards. However, neither method is entirely without environmental consequences. Therefore, it is important to develop suitable research and methods for removing these munitions from the seabed, especially given the large presence of unexploded ordnance (UXO) in the North Sea. This issue raises concerns regarding the implementation of renewable energy projects, such as wind farms. It is estimated that there are around 1.6 million metric tons of unexploded ordnance on the seabed off the German coastline and over 200,000 metric tons off the Norwegian coastline.

To mitigate possible contamination at sea from these UXOs, the ESG has investigated the use of non-graphitic Activated Carbons (AC) to remove chemical explosives from water

(Fawcett-Hirst et al., 2017). Although this research was successful, the use of bituminous coal-based AC materials raises concerns regarding the environmental impact posed by the final disposal of these materials. Therefore, there is a need to explore more sustainable alternatives, such as waste materials, e.g. rice and wheat-based carbons, to develop environmentally friendly solutions.

Recent ESG research involved comparing three commercial ACs, Cabot Norit 8 × 30 mesh (N830), Cabot Norit 12 × 40 mesh (N1240), and Calgon Centaur (Generic Activated Carbon), and two Biochars (rice husk and wheat husk). Previous studies have shown that commercial AC is efficient at absorbing 1,3,5-Trinitroperhydro-1,3,5-triazine (RDX) and trinitrotoluene (TNT) (Fleming & Christenson, 1996) and Insensitive High Explosives (IHE) formulations (Fawcett-Hirst et al., 2020). Furthermore, the substitution of carbon with nitrogen atoms within the matrix of the material has shown improved electrocatalytic efficiency (Fawcett-Hirst et al., 2020). From a sustainable perspective, two biochars, rice husk and wheat straw, have also demonstrated their efficacy for removing TNT and RDX (Lingamdinne et al., 2015) and Toluene (Mao et al., 2015). These studies highlight the potential use of sustainable materials in explosive removal from contaminated water.

Results from this project indicate at small laboratory scale that the potential use of sustainable materials to clean up explosive residues left underwater could be a viable solution. However, more uncontrolled studies are needed to understand the potential increase in explosive degradation products, as they can lead to wider environmental concerns.

Article by
Professor Tracey Temple

F-35B: Saving major costs on the design and UK entry to service

Development of the short take-off and vertical landing (STOVL) variant of the Lockheed Martin F-35 Lightning II involved substantial aerodynamics challenges because of the required increase in energetic jets compared with legacy aircraft such as the Harrier. The complexity of the aircraft, and the multi-national nature of its development, also made airworthiness assurance a major challenge.

When the aircraft hovers into a headwind, or translates over the ground, a horseshoe-shaped ground vortex is formed. Our research on this phenomenon generated data used in the design process of the F-35B. Cranfield's research findings allowed the fixed-ground results to be corrected, without the need for an expensive moving-ground simulation, as part of the jet-effects wind tunnel test programme. Successfully demonstrated in 2018, the research also led to the adoption of the shipborne rolling vertical landing for operations with the F-35B by UK forces. Such a manoeuvre markedly increases the 'bring back' capability, reducing the likelihood of aircraft having to jettison unused payload, saving many millions of pounds over the lifetime of the aircraft and multiplying the force effectiveness.

Our research on jet/intake interactions identified that the flow into the main engine intakes was little affected by the jets below the airframe and provided the evidence needed to allow for separate jet and intake testing on the F-35B. This gave designers increased confidence in the validity of their approach, mitigating the risk of an overly restrictive operating envelope for the aircraft. An improved, more accurate, design

process allowed for a shortened flight test programme for this highly complex STOVL aircraft. Even a straightforward flight test programme costs hundreds of millions of pounds, which can be multiplied many-fold by poor design decisions.

Our research insights on wall jet (the outward flow created as the propulsive jets impinge on the ground) development have been used by BAE Systems to predict safe operating conditions for ground personnel in the vicinity of STOVL aircraft. The findings provided the necessary evidence to allow exclusion zones for ground personnel to be reduced, meaning a less restrictive operating envelope for the aircraft. This approach has been adopted for operational trials and has been particularly important in shipboard operations that began in 2018.

Cranfield's research delivered the systems engineering assurance framework needed to allow the UK MOD to go ahead with testing and operations from July 2012, following its acquisition of the F-35B aircraft. This was critical in overcoming the inconsistencies between US and UK socio-technical policies and technical standards. Our holistic approach to systems engineering ('Systems Engineering Structured Assurance' or SESA) was used by the UK's F-35B buying and certifying team to determine system threats and appropriate controls.

The SESA arrangement allowed for a continuation of flight testing under restricted employment, the development of operator and maintainer techniques, and responses to the incremental addition of capability until November 2017 when the UK F-35B was formally granted a Release to Service by the UK military regulator.

Knowledge and learning from the application of research has been shared via a series of Continuing Professional Development courses for engineers and project managers from industry and government agencies in both the UK and the US. Overall, more than 300 delegates have attended courses on STOVL jet aircraft design. This raised the competence levels of the design teams and helped them to ensure the validity of their designs. The courses also gave those involved in the F-35B programme the same understanding of the issues and the solutions being developed.

Article by
Professor Alistair Saddington

How NASA inspired robotics and autonomous systems for defence

Military missions involve a range of technologies that are designed to support the mission and enhance operational capability in a highly contested battlespace. Nowadays Uncrewed Aircraft Vehicles (UAV) and Unmanned Ground Vehicles (UGV), also known as Uncrewed eXpeditery Vehicles (UxV), can offer a competitive technological advantage in a fast-changing and dynamic battlespace.

A Ministry of Defence publication has acknowledged the British Army's approach to integrating Robotic and Autonomous Systems (RAS) within Human Machine Teams (HMT). Their vision for the future Army of 2035 details the importance of introducing RAS at both operational level and mission support level where it is intended to be delivered as part of an integrated military capability. RAS incorporates both the physical part of the overall system, for example, the robotic platform (vehicle), either air or land, as well as the other elements of the wider system such as the human-machine interfaces and the computer algorithms including Artificial Intelligence (AI), data and architectures.

The UK Army's approach to HMT is to provide an evolutionary use of autonomy utilising a three-stage progression:

- Level 1 - RAS Enhanced Teams enable an increase in performance of a human task within an existing force structure;
- Level 2 - RAS Integrated Teams where human and machine functions are integrated;

- Level 3 - RAS Supervised Teams whereby the machine trust is high and the humans supervise the process.

Our research approach to achieving increased autonomy is predominantly modular thus enabling compatibility with the Army's 3-stage RAS model as described. An example of this is the domain cross-cutting methodology of UxV mission planning. The UxV supervisor assigns the mission starting and end points, as well as points of interest and points that may be prohibitive, e.g. no-fly zones. Our computer AI algorithms will then generate the UxV travelling mission route.

Traditionally, this was achieved on an electronic map using conventional 'distance' calculations. In 2005, Cranfield research developed a method whereby an energy-based calculation was added to the algorithms thus enabling fuel/battery energy savings while also completing the mission safely. This work was funded by a major Defence supplier and has resulted in further work to improve autopilot algorithms to enable better tracking of the resulting UxV travelling mission paths. Furthermore, currently funded work has resulted in an improvement of our understanding of where our UxVs are located on a map (localisation problem), which in turn has enabled the capability to operate in GPS-denied/contested environments.

Our research has also shown that in real-life situations the sensors used to measure vehicle velocity, their intended purpose, also captures noise which can pose a threat to the UxV. Building on this, recent work with the use of Fuzzy AI systems and Kalman filters has enabled us to improve the sensing data and provide a better understanding of a platform's situation, e.g. location, thus enabling a significant improvement in battlespace situation awareness.

Inspiration for this work stems from Stanley F. Schmidt, an American aerospace engineer. Whilst working at NASA he realised the localisation problem of sending a spacecraft, Apollo, from earth to the moon. He called on Rudolph Kalman, an electrical engineer, for help to solve this. Scmidt's initiative to take a collaborative and collegial approach enabled NASA to be successful and inspire others, like us, to continue this ethos in our research and contribute to Defence and Technology.

Article by
Professor John Economou

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