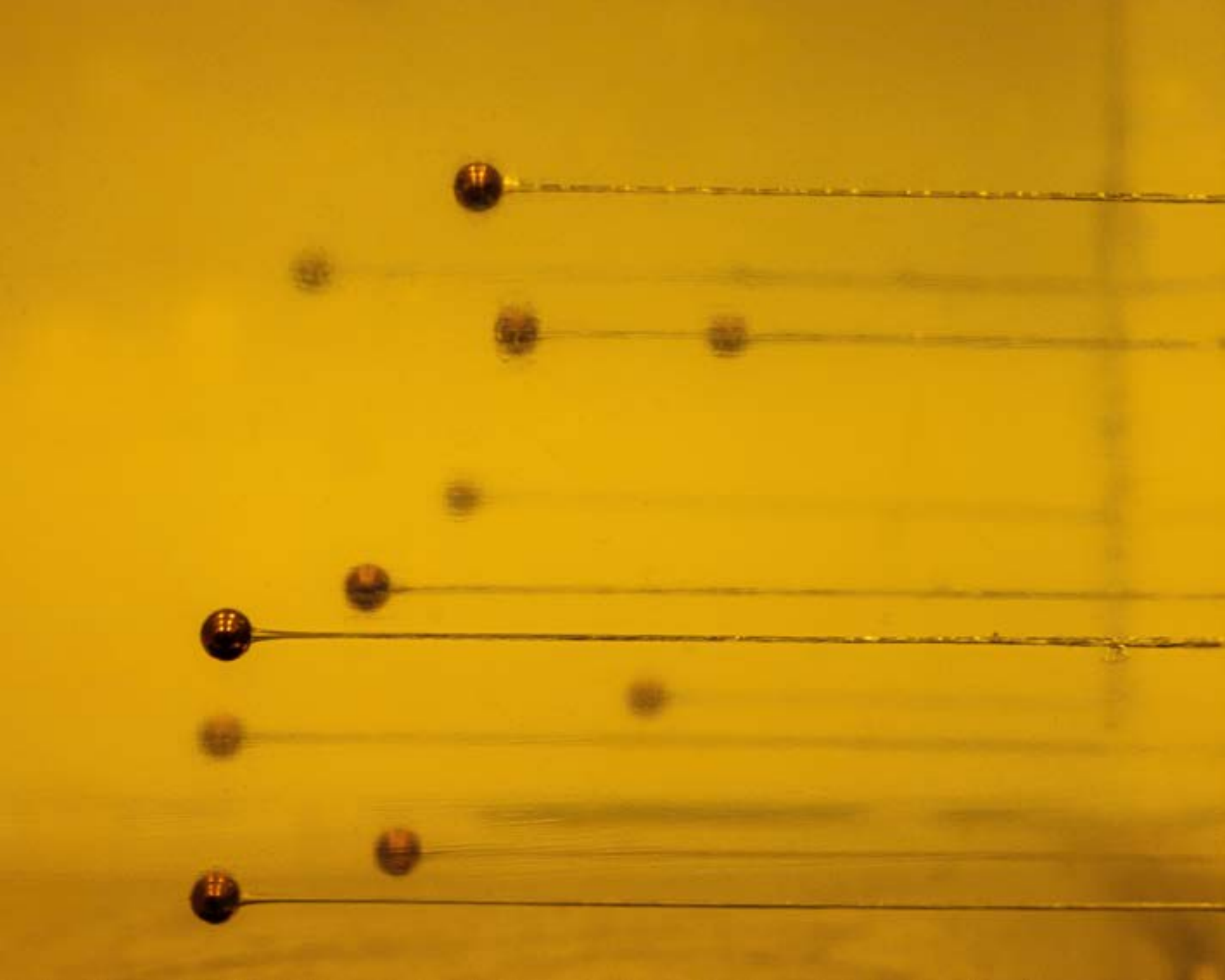




# Cranfield Defence and Security **Research Yearbook**



## Connecting research and resilience

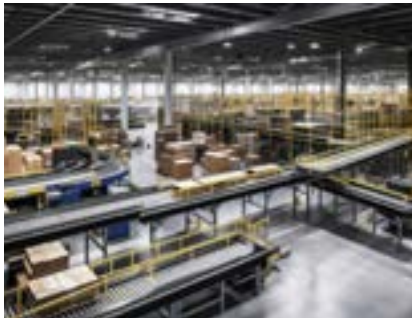
It is my pleasure to introduce you to the Cranfield Defence and Security 2022-2023 Research Yearbook, which provides a tantalising glimpse at some of the diverse, innovative and impactful research completed by our staff and students. As research students are at the heart of our creativity, the great majority of the research examples presented here derive from PhD theses completed over the last year.

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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## Optimal skin simulants for ballistic testing

For many defence and security applications, human body simulants are required to enable safe and ethical testing and evaluation. However, the complexity of human tissue and bone makes this extremely challenging.

In forensics, the reconstruction of shooting incidents requires accurate measurement of various phenomena such as penetration depth and energy transfer. Whilst ballistic gelatin is a common analogue for bulk tissue, an extensive literature review and practical experience in forensic ballistic testing revealed concerns regarding existing skin simulants. This is further compounded by the anisotropic characteristics of human skin, as well as the natural variation in skin properties influenced by factors such as age, gender and location

on the human body. For ballistic experiments, this contributes to a large variation in measured impact energies required to perforate human skin. The challenge of a skin simulant is therefore evident, and highlights the need for an adjustable / customisable skin simulant. Thus, this research focussed on finding a reliable and consistent skin simulant for forensic ballistic testing.

Currently, one of the most commonly used materials for skin simulation in ballistic testing is a type of leather, chrome crusted cow hide. However, being a natural material, it exhibits inherent physical variability in factors such as thickness and strength. Inevitably these introduce uncontrollable inconsistencies that could affect the reproducibility and repeatability of ballistic experiments, a fundamental flaw for forensics



(and also any defence and security research requiring a skin simulant).

Therefore, 10 chrome crusted cow hides were each shot 50 times with steel ball bearings fired from an air weapon at different velocities. It was found that the velocity required for 50% of the impacts to perforate the hides (termed v50%) varied by more than 100%, emphasising the need for a more reliable and consistent standard. Further tests on alternative existing natural / manmade materials were similarly unsatisfactory.

To overcome these limitations, the research looked at a novel use of gelatin, a material commonly used for bulk soft tissue simulant when mixed at 10 or 20 wt% with water. Moulds were made enabling the casting of 4 mm thick sheets with varying gelatin concentrations (30

to 45 wt% in 1% increments). The sheets were then applied to the face of the bulk gelatin blocks before determining the v50% (of the skin simulant) for each mixture. The result was a linear trend between increasing v50% velocities and increasing gelatin percentage, with values covering the entire range of v50% velocities reported in the scientific literature for human skin.

Importantly therefore, this flexible approach holds out the potential to give scientists the possibility of tailoring a skin simulant to the desired or required ballistic perforation conditions. For forensics, this would be extremely useful for the reconstruction of shooting incidents as requested by court.

In conclusion, whilst there is scope for further refinement, the use of

gelatin sheets as a reliable and adaptable skin simulant has been demonstrated for use in forensic ballistic testing. A further advantage is the potential to cast complex shapes, e.g. a torso, for more indepth applications of impact studies in defence and security.

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Research by  
Dr Ruud Hes, Professor Gareth Appleby-Thomas  
and Dr Jonathan Painter

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## The historical use, development and influence of improvised explosives devices

The UK faces a multitude of potential issues in identifying possible threats from future improvised explosive devices (IEDs).

In a speech at the US Department of Defense news briefing on February 12, 2002, Donald Rumsfeld stated:

‘Reports that say that something hasn’t happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns - the ones we don’t know we don’t know.’

In a perfect world there would be no terrorism, and there would be a mathematical model that could

predict who, what, where and when any terrorist attack might occur, should it ever emerge. Sadly and clearly, that is not the case.

So is it feasible to develop a methodology to predict future unknowns (IEDs) by looking back at the past, or is the realisation that with terrorism and IEDs combined, the prevailing and ever-present manner of uncertainty means that there will never be the opportunity to simply extrapolate the past, to determine the future?

An analysis of the extensive IED related published data, covering the global landscape of historical and current IED use, was undertaken. In doing so, it was possible to identify and extract a set of key environmental driving factors (DFs) that influence and shape the IED



landscape. Examples of these DFs are:

- Right wing extremism;
- Social media (dark net);
- Increasing availability of commercial-off-the-shelf (COTS) autonomy and high precision navigation systems i.e. swarmed drones with enhanced hybrid payloads and killer robots;
- The use of nano and micro technologies including 3D printing for synthesis of explosives, chemical and noxious substance attacks;
- Sharing of skills and knowledge;
- The emergence of new groups with perpetrator threats;

- The use of maritime IEDs domain including subseas communications and energy targets;
- Cyber enabled capabilities particularly attacks on data management systems.

The use of artificial intelligence (AI) and its emergence as a COTS technology is seen as major area of interest. This might potentially allow the construction and use of a driverless vehicle-borne IED type device (VBIED). If this plausible situation becomes reality, a future scenario exists where the IED is deployed with no human intervention.

Will IEDs change from a stand-alone explosive device into something that is perhaps part of a broader,

more complex, multi-dimensional, multi capability system which offers perpetrators a much wider capability spectrum?

So to the original question - is it feasible to develop a methodology to predict future unknowns (IEDs) by looking back at the past? The answer - it is believed that the IED will manifest itself in unpredictable ways, not seen in the past.

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Research by  
Dr Andy Pettit, Professor Jacqueline Akhavan,  
Dr Lorraine Dodd and Dr Christopher Stennett

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## Strategic trade control and compliance: A case study of the UK

In recent years, strategic trade controls have proved to be a hot topic for both governments, academia and UK defence and aerospace industry. The controls are governmental measures to preserve and protect national security, global competitiveness and commercial intellectual property rights (IPR). Controls help to foster trust between the technology exporter and the original technology supplier country. In a rapidly changing technological environment, the development of emerging technologies requires exporting firms to incorporate a control rule-based system to manage controlled technologies and combat proliferation of weapons of mass destruction.

It is recognised that non-compliance hurts companies in two ways:

infringement of national and supranational controls invite global stigma causing significant damage to a company's brand and image, not to mention stakeholder trust; equally, unauthorised transfer of especially US strategic technologies to third countries runs counter to International Traffic Arms Regulations (ITAR) and/or corporate IPR that will likely lead to the imposition of fines amounting to hundreds of millions of dollars. For example, in 2010, BAE Systems paid a hefty penalty of \$400 million dollars to the United States Department of Justice (US DOJ) for a breach of the ITAR governing US controlled technology. Recently in 2020, Airbus settled for civil payment violations with the UK Serious Fraud Office amounting to €984 million and paid the US DOJ \$526 million for US ITAR compliance failures.



UK defence and aerospace companies need to demonstrate a high level of compliance commitment, trust and confidence in sealing an export contract that involves the ownership and protection of controlled technologies.

The study aim was to examine the nature and extent of UK defence and aerospace compliance operational practices through the development of a novel 5C Corporate Cultural framework. This study applies a creative systematic and pragmatic approach through three points of analysis; secondary data, governmental and corporate reports, and primary data. The 5C Corporate Cultural framework includes Code of Conduct, Commitment, Competence and Change Management which act as key enablers to drive forward best practice in strategic trade

control and compliance policy across the wider defence and aerospace industry. The use of the framework will help UK defence and aerospace and international consortiums to identify, establish and conform to the compliance policies and export trade laws and controls.

The overarching conclusion of this study is that UK defence and aerospace companies operate a set of compliance measures and export control practices. This overall finding supports the view that broad based UK defence-related companies have made progress in promoting and reinforcing the desired cultural corporate behaviours through the implementation of established ethics training, published code of conduct practices, enforcement of export procedures, risk assessment procedures,

enforcement of anti-corruption policies and communication procedures. However, it was difficult to establish how organisations measure performance following the introduction of major change programmes.

The findings of the study should represent a major statement on the status of present UK compliance for key stakeholders, including the government, corporate responsibility managing directors, chief executive board members, compliance officers, investigation committees and industry compliance practitioners.


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Research by  
Dr Michelle Patricia Charles, Professor Ron Matthews  
and Dr Irfan Ansari

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## A framework for optical features selection and management for camera-only autonomous navigation in the proximity of small celestial objects

Small celestial bodies such as comets and meteors (generally known as ‘shooting stars’) have stoked and captivated the human imagination for millennia. Throughout modern history, human fascination with these has become more and more concrete, to the point that landing on them was even made possible with the increasing help of autonomous algorithms.

The first discovery of a small celestial object was made by Giuseppe Piazzi on January 1, 1801, when he observed the dwarf planet Ceres. Since then, numerous remarkable milestones have been achieved in solar system exploration. For example, at the very beginning of the 21st century, NEAR Shoemaker became the first spacecraft to orbit and land on an asteroid, Eros.

Then in 2014, the Rosetta spacecraft achieved another historic feat by successfully orbiting the comet Churyumov–Gerasimenko. Its lander module, Philae, became the first human-made object to land on a comet. Despite these and other extraordinary milestones in space exploration, the surfaces of the comets and asteroids abundantly present in the solar system remain largely unexplored. Achieving regular access to these surfaces would have a major impact on capabilities such as planetary defence, in situ resource utilisation, and scientific research about the origins of celestial bodies and the possibility of extraterrestrial life.

However, missions close to small celestial objects remain challenging in at least two aspects:



- Technically, due to weak gravity fields, complex operational environments and latency from long communication times;
- And commercially, with the applications still being few and cost-ineffective.

The use of small, camera-only spacecraft has been identified as a potential solution to these. This approach reduces development and operational costs and makes it easier to obtain robust, scalable operations.

Enabling camera-based autonomy requires building appropriate computer vision pipelines. Generally, computer vision pipelines start with the detection of features - salient patterns within the scene. This research presented multiple methods and tools enabling the appropriate

selection and management of different features for autonomous navigation in proximity to asteroids. To achieve that, this research made a number of contributions including:

- The development of a software toolbox for prototyping and testing optical navigation technologies through a parametrisable synthetic 3D visual environment;
- An analysis of the response of feature detectors to internal factors (e.g. feature model) and external factors (e.g. illumination). This response, once known, can be used for designing the system or to obtain situational awareness;
- An assessment of the response of template matching methods

when the template (model) does not perfectly match the observed target (asteroid, with illumination);

- A design tool used for developing the on-board artificial intelligence (AI) of a mobile autonomous platform, aiming to optimise the interplay between cooperating factors through a continuous coevolution process.

Through the above contributions, it was shown that considering environmental cues and the perception model helps in achieving robust camera-only navigation processes. This capability could lead to small satellites autonomously exploring hundreds or thousands of small celestial objects or being employed on more powerful spacecraft for redundancy.

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Research by  
Dr Marco Zaccaria di Fraia, Dr Lounis Chermak,  
Dr Joan Pau Sanchez Cuartielles  
and Dr Leonard Felicetti

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## Post-mortem interval estimations in medico-legal death investigations

The ability to accurately estimate the time since death, or post-mortem interval (PMI), from the observable state of human decomposition is a long-standing goal for the field of medico-legal death investigations. The most critical application of the PMI is in homicide investigations where the PMI can be used for investigative leads to identify potential criminal suspects, corroborate witness statements, and assist in deceased identification. Research in forensic taphonomy, (the study of human decomposition processes from death to recovery), has attempted to devise models of PMI estimation over the past 40 years with little success.

Acquiring an accurate PMI estimation is significantly challenging due to the plethora of environmental variables that affect the decomposition

process. In medico-legal death investigations where only a 'snapshot' of decomposition is encountered upon discovery of the deceased, the onset and impact of these variables remains largely unknown. The problem is further exemplified by the high variability in the pattern and trajectory of decomposition traits between individuals.

The development of outdoor experimental taphonomy facilities has made it possible to conduct daily observations of the wide array of variables affecting decomposition. However, their deductive experiments are often criticised for their use of porcine analogues, and adoption of small sample sizes. Consequently, there is currently no single, or accurate, method of PMI estimation used routinely in medico-legal death investigations.



This PhD research, consisting of four published papers, aimed to develop a statistical model of PMI estimation for use in medico-legal death investigations. The research was informed by the operational experience of the candidate's crime scene investigator role for UK police.

A huge body of decomposition data (n=1,813) in the form of photographs and case reports was collected and analysed from international and UK law enforcement in an alternative approach to model the complexities of decomposition. The development of Bayesian Belief Networks (BBNs) presented the first ever cross-comparison of human decomposition across three different geographical regions that could importantly account for the inter-relationships of environmental variables. Sensitivity analysis was performed to identify

the most influential parameters of decomposition variance, with weaker variables (e.g. age, sex, clothing) being excluded during model refinement. This novel approach conferred predicted power of the PMI during validation testing and communicates the PMI with an associated degree of confidence.

The industry output of this research was examined in the form of a groundbreaking proposal for a National PMI database. Providing a collaborative database of reference cases for comparison is envisaged to support PMI estimations in major crime and policing. Furthermore, subjecting the database to statistical evaluation transcends to the development of predictive PMI models that attempt to quantify PMI uncertainty. In forensic taphonomy research, the PMI database offers

unique opportunities to further decipher the complex relationships of important environmental variables (e.g. temperature, humidity) and has proved to be a valuable resource in answering taphonomy-related research questions. This alternative research approach provides a novel solution to investigate the PMI and assists in bridging the ever-increasing gap between forensic taphonomy research and practice.

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Research by  
Dr Stephanie Giles, Dr Nicholas Márquez-Grant  
and Dr David Errickson

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## Evaluation of off-road uninhabited ground vehicle mobility using discrete element method and scalability investigation

Military operations require vehicles to sustain support on the battlefield and deliver the necessary effect. Operational challenges include a vehicle's ability to remain mobile over a range of terrains and local conditions, including rapid inclinations, soft/hard terrain and wet/dry local conditions.

This research helps to understand the scalability aspects of soil testing and the tyre-soil interaction system which is a key enabler for the leader-follower vehicle approach and effective path planning resulting in the best vehicle route. The novel research approach presented, that of a full-scale crewed vehicle (follower) teaming with uncrewed ground vehicle (UGV) (leader), enables more flexibility and potential for effective dynamic adaptation of the follower vehicle based on the terrain

conditions established by the UGV. In an expeditionary mission, this offers better mission planning opportunities by reducing the cognitive effort.

Full-scale military vehicles teaming up with UGVs could improve the success rate of tactical operations on off-road terrains over a range of environmental conditions. UGVs can perform initial mobility testing on soft soils to evaluate the performance (e.g. go/no-go conditions, maximum load bearing capacity and energy cost optimisation on feasible paths) for full-scale military vehicles. Therefore, the concept of scale model testing is proposed whereby the UGVs can provide feedforward terrain-vehicle information to the larger (full-scale) vehicles, thus resulting in an operational advantage to the path planning algorithms.

To enable the improvement of the path planning algorithms, it is paramount that there is a better fundamental understanding of the scalability considerations of the tyre-soil interaction. The scale model testing can be divided into two parts, i.e. the scalability of soil and the scalability of the tyre-soil interaction.

The scalability of soil is defined as a relationship between the mechanical properties of an in-situ terrain (heterogeneous) soil system and a laboratory (homogeneous) soil system while accounting for the differences in sand, silt and clay particle shapes and size distributions. Physical properties such as moisture content, bulk density, compaction, and interparticle forces are kept the same for laboratory and in-situ terrain conditions. The coarse and fine-grained soils were modelled using

the discrete element method with the Edinburgh-Elastic-Plastic-Adhesion (EEPA) contact model. It was found that the scalability depends on the testing conditions and soil's nature. The heterogeneity of soil affects the cohesive and adhesive forces present in the soil. The pressure-sinkage and shear stress vs shear displacement relationships are found to be scalable.

Over the last few decades, the resource-intensive experimental testing of lightweight military vehicles on different terrains has led to the development of mobility prediction methodologies including the NATO Reference Mobility Model (NRMM). However, with the recent development of small, lightweight ground vehicles, there is a lack of a mobility performance empirical database and simulation methods for this class of vehicles. This research establishes

that the mobility performance data of full-scale lightweight military vehicle and UGV are within a one-standard deviation band in the simulation domain. Therefore, it can be suggested that the mobility prediction methodologies such as NRMM for lightweight military vehicles can be used to predict the mobility performance of small, lightweight ground vehicles, such as UGVs, on similar terrains.

Key ideas emerged from this research, which, if adopted, could help to computer simulate heterogeneous soil including effects of moisture and organic materials for vehicle tyre-soil interactions. This would result in improvements in modelling multi-wheeled vehicle dynamics, and consequently in improvements for optimising vehicle routing problems in off-road terrains.

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Research by  
Dr Ayush Nuwal, Professor John Economou  
and Ajay Kumar

Image on page 26  
UK MOD @ Crown copyright

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## Effects of particulate contamination and jet fuel chemistry on the nucleation of water and ice in aircraft fuel systems

This research was about the interaction between water and jet fuel. Jet fuels supplied for both civilian and military aviation are blended to meet certain national and international standards, to allow for interoperability on a global basis. The specifications largely relate to physical properties, and they do not define a specific chemical composition.

Jet fuels can be blended from a large range of hydrocarbons, each of which may exert a small but measurable influence on how a fuel performs in service. One of these properties is the way that the fuel will absorb traces of water from the atmosphere. Most people assume that oil and water do not mix and water, being the denser phase, will drop out of suspension. This is largely true, but very small water droplets and dissolved water will remain and can bypass the

filter systems used during aircraft fuelling, thereby introducing traces of water into aircraft fuel tanks. The risk to aviation is that if the water crystallizes to form ice when an aircraft is flying at high altitude, the ice may be ingested into the fuel supply system thereby compromising fuel supply to engines.

An additional problem is that the aviation industry faces increasingly tough environmental and energy challenges regarding its fuel use. Research is therefore under way to develop new, sustainable aviation fuels ('alternative' jet fuels), which will be similar to conventional jet fuels but may have subtle differences in properties, including those of water solubility, water settling and propensity towards ice formation.



This work reviewed the conditions that might lead to the nucleation of water and ice in aircraft fuel systems. These conditions were then applied to characterising dispersed water droplets in conventional Jet A-1 (a fuel commonly used in civil aviation), five alternative jet fuels, and blends of the fuel types in laboratory tests.

The results from the initial tests were used to inform the design, build and operation of a small-scale fuel/icing test rig (with a volume of 40 litres of fuel) to understand the types and amounts of ice that could be produced from different blends of

conventional and sustainable aviation fuel. From these tests, it was possible to rank the icing performance of the test fuels, and predict the likely behaviour, in terms of icing, of blending a particular alternative fuel with a conventional jet fuel, a situation that might occur during aircraft refuelling.

**Image on page 33**

Ice on the inlet face of a conical in-line fuel strainer, from one of the small-scale fuel icing tests; this illustrates the potential for strainer blockage and fuel supply constriction. Mesh size #20 (hole size approx. 0.85 x 0.85 mm).

Research by  
Dr Judith Ugbeh-Johnson, Mark Carpenter  
and Dr Nathalie Mai







## Conceptualising, defining and modelling supply chain management: An objective- oriented approach

Although it has been more than three decades since the term Supply Chain Management (SCM) was first introduced, there are still divergent views and different interpretations amongst scholars and practitioners about its meaning. The literature lacks consensus on a precise definition of SCM as different perspectives were identified. A conceptual or theoretical model has not yet been acknowledged, and the existing frameworks lack the call for a holistic model that encompasses the essence of the concept.

With this disagreement on what SCM is, there are repeated calls to achieve consensus on a unified definition, a unified understanding, a unified theoretical model, and a unified framework of SCM. The argument in the literature is that achieving consensus among scholars and

practitioners will improve research and practice and the SCM discipline.

The literature revealed that the prevalent and the most recommended approach of conceptualising SCM is the process orientation. However, there is no evidence in the literature that an objective-oriented approach was investigated in resolving those theoretical issues, and neither has a grounded theory research method been applied to that end.

Through an objective-orientated approach and applying the grounded theory method, it is found that the majority of the theory behind SCM is about managing business activities and achieving business goals through communication, cooperation, collaboration, and integration within and across firms in a supply chain or network. This research proposes a



new outlook and names it 'Business Relations Management Theory.' This states that individuals, organisations, societies, and nations achieve better performance and outcomes through communication, cooperation, collaboration, and integration.

A literature-based thematic analysis showed that SCM is being used as a synonym for Supply Management, Business Relations Management (BRM), or a combination of both. Also, an assessment survey that included more than 200 managers and employees from different countries showed unclear or limited understanding of the identified theory and perspective of BRM.

Accordingly, this research presents BRM and asserts that the term Supply Chain Management (SCM) is a misleading concept and should

be replaced with Business Relations Management (BRM). SCM, as a term, limits the benefits of communication, cooperation, collaboration, and integration to a chain or network of firms and enterprises within the production sector and excludes the final customers. In contrast, the concept of Business Relations Management (BRM) generalises the benefits to all sectors and all stakeholders, including the final customers, consumers, and services recipients. In addition to practitioners, universities or business schools are advised to replace SCM with 'Supply Management' or another name that combines supply and demand management fields.

A feedback survey included a group of managers and employees from different sectors in Bahrain showed a high level of satisfaction and

acceptance of the outcomes of this research, the researcher's argument, and recommendations. These outcomes led to the conclusion that the objective orientation was an effective approach to conceptualise SCM, and there is a probability of higher acceptance of the outcomes of this research and, consequently, achieving the looked-for consensus among academics and practitioners.

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Research by  
Col Eng Dr Hussain Alkebaisi, Dr Robby Allen  
and Dr Ken McNaught

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## Development of a co-operative multistatic radar network based on the Aveillant holographic radar

Staring radars use a transmitting static wide-beam antenna and a directive digital array to form multiple simultaneous beams on receive. Because the beams are static, the radar can employ long integration times that facilitate the detection of slow and low-reflectivity targets, such as drones, which present a challenge to traditional air surveillance radar.

Typical low-altitude trajectories employed by drones often result in low-grazing angle multipath effects, which are difficult to mitigate with a monostatic radar alone, that is a radar where the transmitter and the receiver are co-located. Using multiple spatially separated receivers cooperating with the staring transmitters in a multistatic network allows multi-perspective target acquisitions that can help mitigate

interference from the environment and improve the detection and localisation of drones.

This research presents the development of a cooperative radar network that consists of a staring transmitter and multiple bistatic passive receivers. The staring transmitter ensures a constant signal at the receiver nodes within the radar's coverage and, therefore, the receivers can be simplified as they do not need to employ pulse-chasing techniques. Target position and velocity estimation algorithms have been developed and the theoretical lower bound on the error of estimation algorithms is used to determine the estimation performance of the radar network. It is further used to optimise the network's geometry by minimising the target parameters estimation errors.



As part of this research, a passive bistatic dual-channel receiver has been developed and employed in a bistatic configuration with a staring transmitter of opportunity to test the theoretical algorithms and to measure a drone in flight. The receivers are designed along passive radar principles and consist of two receive channels:

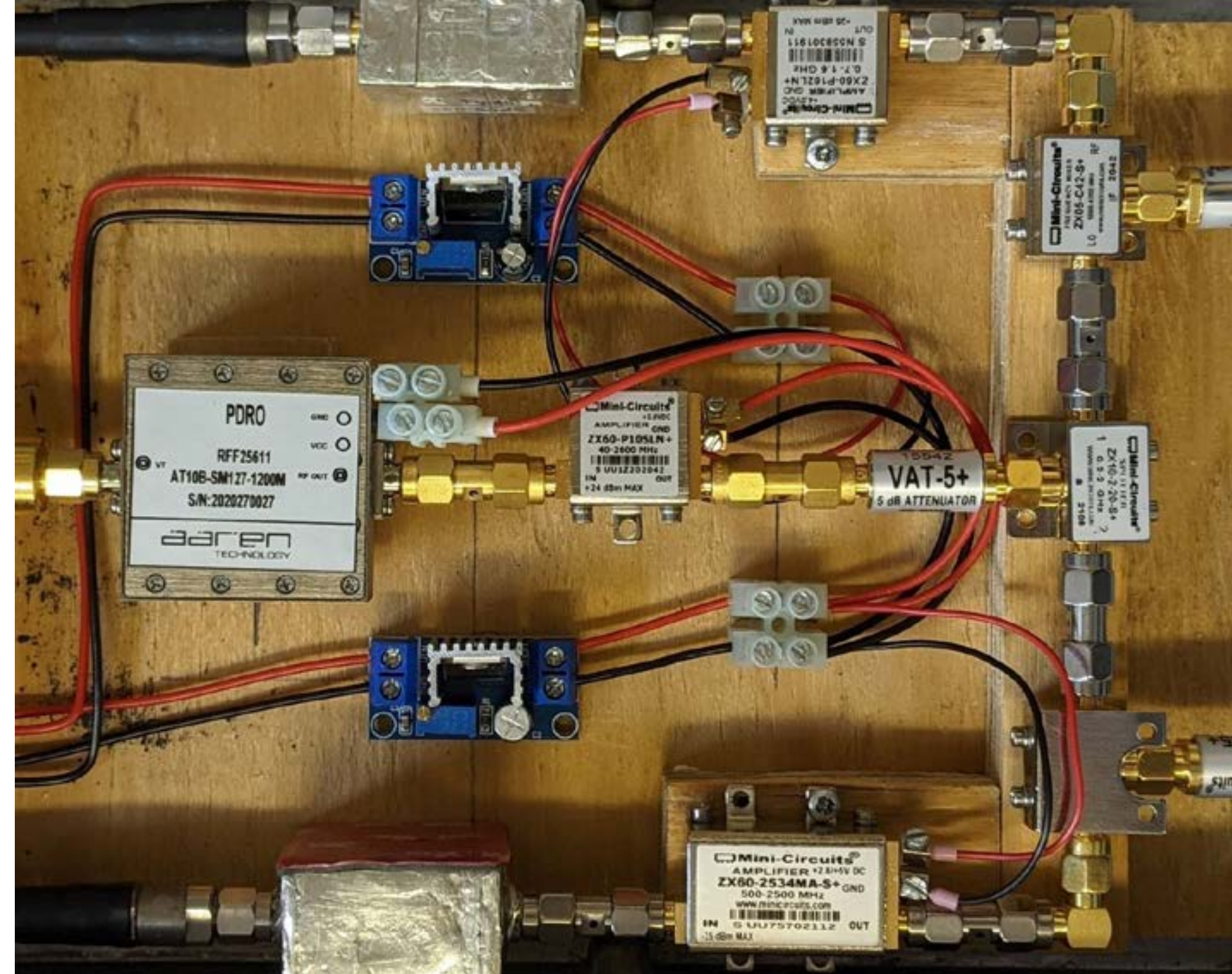
- A surveillance channel aligned with the transmitter;
- A reference channel aligned with the target.

The receiver employs horn antennas with a wide beamwidth and has also been used to perform laboratory measurements of a rotating fan, the micro-Doppler signature of a remote-control helicopter, a moving car and a drone in flight.

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Research by  
Dr Benjamin Griffin, Dr Alessio Balleri  
and Professor Chris Baker

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## The boundaries of work-related Flow: An empirical investigation of the relationship between subjective experience, capabilities and challenge

Have you experienced those moments of being completely absorbed in an activity, with your energies focused and concentrated when time flies by? If so, you have experienced a state of optimal experience known as Flow.

This state of optimal experience is predicated on balancing a person's challenges (demands, responsibilities) and capabilities (knowledge, skills, experience). When a person is intrinsically motivated and challenges and capabilities are in balance, Flow can ensue.

Research has shown that people who experience Flow are more resilient under conditions of adversity and report higher levels of happiness, health, well-being and flourishing. Conversely, when

challenges and capabilities are not balanced, two related but distinctly different states of experience occur.

Firstly, worry and anxiety ensue if challenge dominates and overwhelms a person's capabilities. Secondly, boredom and apathy occur if a person's capabilities are high and their challenge is low. Under the conditions of challenge overwhelming capability, people make poor decisions, or when a person is inadequately challenged relative to their capability, people's capabilities are wasted. These unsustainable, chronically stressful situations have been shown to adversely affect people's health and well-being and increase personal and societal costs.

This research sought to identify the upper and lower thresholds of



optimal experience when the balance between a person's challenge and capability moves to imbalance. However, this doctoral research project had to overcome several distinct problems:

- People experience challenges holistically and subjectively;
- A person's subjective experience is difficult to access;
- When people are in a state of Flow, they lose their sense of self, meaning their memory of the experience is limited.

A literature review identified deficiencies in the models, methods and practices used to address the overarching research problem and the three points directly above.

As a result, the project is divided into two phases. The first phase developed a new synthesised model of experience using an innovative suite of methods. The insights gained from the model were used to inform the second phase of the research project. The second phase utilises a novel design strategy grounded in a realist philosophy of science.

This approach facilitated the development of an innovative experimental protocol and construct elicitation method, where rock climbing was used as the means to investigate a person's subjective experience of varying degrees of challenge.

This research contributes to the body of knowledge in two distinct yet complementary ways. Firstly, the research identified a relational

link between challenge, capability and subjective experience. Secondly, as experienced by the individual, challenge is incremental, cumulative and experienced holistically.

Moreover, this project realises the overarching research objective by developing a codebook and a new synthesised model of experience. When the model and codebook are combined, they can be used in a nonintrusive way to identify when a person's challenges and capabilities are aligned or misaligned through the various instances and absences of experiential states. This contribution represents a proof of concept.

Future work should develop the method's applicability in organisational environments to support and enhance people's lived experience of work.

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Research by  
Dr Tim Forsyth, Jeremy Hilton  
and Dr Lorraine Dodd

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## Statistical analysis of in-flight drone and bird signatures for improved detection performance

Drones and drone-monitoring radars have been studied increasingly over the last 10 years. Over time more drone types and a more diverse set of radars have been developed, with many studies describing the radar signatures of various drones. Some of these characterisations are used to inform radar improvements and algorithmic detection and target characterisation logic (including machine learning and artificial intelligence).

Radars typically integrate many consecutive short pulses in order to improve signal to noise ratio and enable high target detection performance. Over the course of this coherent processing interval (CPI), many components of the drone signature change and the signature's amplitude and frequency Doppler modulations

may hinder coherent integration performance, even in the absence of range-Doppler cell migrations. A statistical characterisation of these fluctuations aids radar designers in selecting optimal CPI lengths.

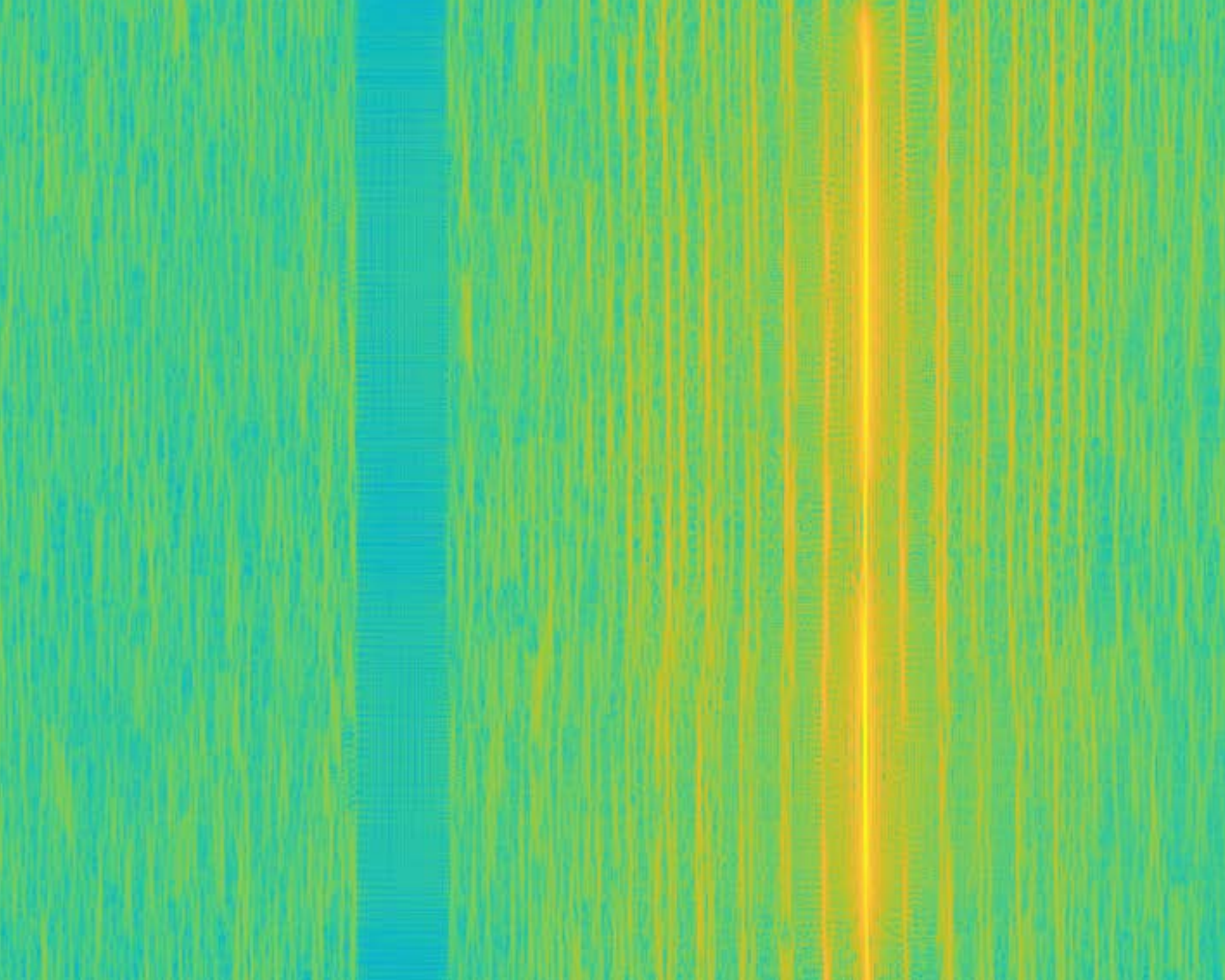
This research presents a statistical analysis of the experimental data of nine flying drones and three birds. Collected with a frequency modulated continuous wave Ku-band radar, it examines the statistical features of the amplitude fluctuations of the drone body and blades and of the composite bird signatures with an analysis of the signatures' decorrelation times. The method of moments is used to estimate the probability density function parameters of different drone spectral components, with the aim of informing the development of improved theory for predicting



drone signatures and ultimately increasing detection performance and drone classification performance against birds.

Results showed that, on average, the Weibull distribution provided the best mean square error fit to the data for most drone spectral components and drone types, with the Rayleigh distribution being the next best match. These results were further corroborated by a study of detection performance for a fluctuating target. Whilst decorrelation times of the various signatures varied significantly, even for the same drone, results show that an approximate inverse relationship between drone spectral component bandwidth and decorrelation time held, with individual spectral lines decorrelating after tens to hundreds of milliseconds.

Research by  
John Markow, Dr Alessio Balleri  
and Professor Mark Richardson





## Vortex drift and advection: The effects of turbulence intensity and ground surface roughness on wing-tip vortices

Vortex formations are observable on various transport vehicles such as automobile, racecars, and aircraft (both civil and military). A vortex (which is a circular motion of the flow) is generated by the separation of a slow-moving flow (known as a boundary layer) nearby a surface and its subsequent 'roll up' into a vortex.

Wing-tip vortices are formed in both civil and military aircraft as the high pressure region (on the bottom surface of a wing) attempts to 'roll over' to the low pressure region (on the top surface of a wing). Very limited research has focused on a wing-tip vortex in ground proximity, especially when subject to external influences such as freestream turbulence intensity (FST, which is the ratio of the fluctuating velocity to the mean velocity) and ground surface roughness (GSR, which is

the roughness of the ground surface) - despite both having noticeable effects on the drift and advection of a wing-tip vortex.

This research study focused on enhancing the understanding of a wing-tip vortex in ground proximity whilst including the influences of FST (2% and 6%) and GSR (smooth, 0.2mm, and 0.6mm). A key objective of this research study was to explore the ill-researched phenomenon of vortex drift and rebound, as both have importance in industry e.g. for the trailing vortices of a civil or military aircraft. Computational fluid dynamics (CFD) software was used and validated against relevant experimental literature to show that low-order models are applicable to such studies. The validated CFD methodology was then applied to the NACA0012 aerofoil with a



ground clearance (which is the distance between a wing and the ground) of 0.1 chord (which is the distance between the leading and trailing edges) at various FST and GSR values.

Vortex drift and rebound were found to be a result of the vortex-ground interactions, resulting in differences between the upwash and downwash of a wing-tip vortex, and differences in its inboard and outboard velocities. The differences between these respective velocities were found to dictate the motion of the primary vortex. The formation of a secondary vortex was also found to affect the trajectory. If the secondary vortex detached from the ground, it influenced the velocity field of the wing-tip vortex by opposing the inboard velocity whilst contributing to upwash, resulting in reduced

lateral motion and increased upward motion of the wing-tip vortex. Overall, FST primarily affects the 'life-span' of the secondary vortex and therefore how far it can rotate about the wing-tip vortex, whilst GSR affects the ease at which the secondary vortex can detach from the ground.

These research findings are expected to have academic (by creating the new knowledge), economic (by making transport vehicles fuel-efficient by reducing losses), and societal (by reducing pollutant emissions as noticeably less fuel is burnt) impact.

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Research by  
Drew Tora-Willson, Dr Karthik Depuru-Mohan  
and Professor Kevin Knowles

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## Transforming the Kafala in Saudi Arabia: Turning weaknesses into opportunities

This research sought to find solutions to eradicate exploitation by reforming the modern Kafala in Saudi Arabia, and was conducted as a case study in the context of the Gulf Cooperation Council (GCC) as a whole. The Kafala is a system of migration that involves sponsorship by an employer (sponsor) of a migrant employee (sponsee). Historically, it has offered control on the part of the sponsor over the sponsee, which has led to human rights abuses.

The research focuses on female domestic workers, a group particularly vulnerable to exploitation and human rights abuses, especially sexual exploitation, as is well documented in the literature. Female domestic workers have so far been offered little protection within the present Saudi reforms of labour laws

and policy, although there is now a strong commitment to eradicating human trafficking.

The value of this doctoral research lies in four areas:

- Promoting the interests of Saudi and the GCC;
- Upholding human rights and associated principles;
- Contributing to an international understanding of Islam and the GCC;
- Providing a culturally specific solution to reforming the Kafala.

The research adopts the technique of semi-structured interviews with Government officials, practitioners working with migrants, and



female migrant workers who have experienced exploitation (survivors). It adopts a phenomenological perspective that centralises people's experiences as a source of knowledge. Practitioner and government interviews were conducted in order to understand the political and practical drivers for change, and how the law and policy works in practice.

A conceptual model was designed, reflecting the theoretical and practical importance of gender inequality, slavery and Islam and representing the explanatory variables impacting on the dynamics of the Kafala. Perceptions of women's roles and their inequality within society make women particularly vulnerable to exploitation, especially when employed within households with little visibility to the

outside world. Another significant barrier to the efficient working of the Kafala is the history of slavery in the region, creating the perception that foreign domestic workers are in a sense free labour, and treated as 'other'. However, not all members of Saudi society take this view, believing it contrary to the values of Islam. In fact, the research findings show that Islam totally opposes the exploitation that is occurring, and this confirmation may be used as driver for societal change. The need for Government direction to develop and implement reforms is acknowledged, as change cannot be achieved without strong political leadership and commitment.

Drawing from both Saudi and other GCC countries, the study explored how the Kafala operates in practice across different contexts, and

identifies common weaknesses. A central theme is the gap between law and policy and lived realities, and thus the essentiality of ensuring the Kafala framework resonates with practice. Three key areas are recommended for reform:

- Culture (in particular, the fact that the status of women and foreigners means that their exploitation is culturally acceptable);
- Migration (including the global context of migration and Saudi's own aims in relation to the system);
- And, access to justice (such as the problem of ensuring that legal reforms are implemented, such that people are able to exercise their rights).

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Research by  
Dr Madawi Abdulrahman Al-Saud,  
Professor Ron Matthews and Dr Irfan Ansari

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For further information please contact

**Professor Andrew Shortland**

Director of Research  
Cranfield Defence and Security  
Cranfield University  
Cranfield, MK43 0AL

[a.shortland@cranfield.ac.uk](mailto:a.shortland@cranfield.ac.uk)

[www.cranfield.ac.uk](http://www.cranfield.ac.uk)