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Aerospace Engineering & Aviation

DR215 / MR215

Contents

DR215(PhD)/ MR215(Masters)
Aerospace Engineering & Aviation

Additive manufacturing for bio-inspired composite-Titanium joints

Aerospace Engineering and Aviation / Multifunctional Composite Materials Group

Project Description

Metal-composite joins are an unavoidable feature of modern aircraft structures, and present a range of design challenges including the need to minimise weight and maximum joint strength.

Additive manufacturing is finding increasing application in aerospace and other industries, particularly for Titanium, as the comparative benefits increase with the complexity, performance and material cost of the part. Biological materials use a range of topological features at various length scales to achieve strong attachment between dissimilar materials.

The project will build on previous work [1-4] and investigate the application of bio-inspired features manufactured with additive methods to improve the performance of adhesively bonded metal-composite joins. Metal-composite joint specimens that incorporate bio-inspired features will be manufactured in the RMIT Advanced Manufacturing Precinct, and tested experimentally.

The project will focus on quantifying the improvement in joint performance in comparison with traditional manufacturing techniques, and the mechanisms driving performance enhancement at the different length scales.

The project will also develop and apply high fidelity computational modelling to investigate and optimise the hybrid joint design to maximum joint performance. This will involve incorporating knowledge from previous experimental and numerical work as well as biological systems to develop joint concepts. These concepts will be investigated using computational analysis under varying loading and configurations, with a goal to identify optimal design concepts and features.

References:

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[3] A.T.T. Nguyen et al. Composites: Part A 98 (2017) 192-206.

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Integrated repair systems for composite aerospace structures

Aerospace Engineering and Aviation / Multifunctional Composite Materials Group

Project Description

Application of highly efficient bonded composite joints to flight critical aerospace structures is currently limited in use, and is generally applied to secondary structures where component failure is not detrimental to overall safety. Less efficient and more traditional fastened joints may be utilised as the behaviour is well understood and characterised thoroughly in literature. The limited use of bonded composite joints to primary components is partly due to the lack of damage tolerant assessment, particularly as a result from either adverse operational environments or defects in the bondline. It is currently problematic to evaluate the damage tolerant performance of bonded composite joints to an acceptable level due to the complexity of damage mechanisms and challenges in detection or monitoring of failure. The progression of damage is inherently difficult to appreciate because of different failure modes interacting and greatly influencing each other. These interactions can also be drastically affected by several features including changes in geometrical, material, boundary, and environmental conditions.

Understanding the various failure modes under typical aerospace operational circumstances, with regards to types of bondline faults, is essential to analysing damage tolerance of bonded composite scarf joints in primary structural application.

This research project aims to develop an integrated repair system by (i) investigating the main failure mechanisms including plasticity and damage progression of the adhesive layer; (ii) developing assessment techniques that can micrographically assess the inelastic deformation of a bondline; and (iii) development of a design tool that fully captures the progressive nature of damage in composite structures.

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Mission Effectiveness and Risk Modelling for Defence Operations

Aerospace Engineering / Sir Lawrence Wackett Centre

Project Description

As part of any defence acquisition process, the mission requirements and objectives have to be clearly defined and mapped to the possible solutions. The decision will need to consider risk, uncertainty and effectiveness of any mission considered. There are several different definitions for effectiveness. Generally, effectiveness is the indicator for the system completing given mission in given time. Based on specific mission, effectiveness includes three concrete coordinate concepts: quota effectiveness, system effectiveness and combat effectiveness. System effectiveness is more used to evaluate the weapon and equipment. There is no common concept for system effectiveness at present. According to GJB451-91 Reliability and Maintainability Term, the system effectiveness definition for weapon and equipment is “in certain conditions, the capacity of completing given quantitative characteristic and service requirement.” It is a comprehensive measure of system availability, dependability and inherent capacity. In general, the preferable definition for the system effectiveness is given by the U.S. WSEIAC. System effectiveness is the degree metrics for system completing series of given missions and the function of system availability, dependability and capability. Mission effectiveness of a defence system is the probability of system initiating and completing the mission with a certain probability that the mission objectives are achieved.

As there are generally several options or solutions in achieving a given mission, mission effectiveness can be compared to cost or investment, but also the risk associated with the selected solution. For example, an expensive solution can achieve the mission with 95% probability, while a less expensive solution could achieve the mission with 90% probability. The latter may still be acceptable, but these options should be visible through mission effectiveness simulation. The objective of this project is to develop a mission effectiveness and risk estimation methodology that can be used as part of a Zero Gate cost-benefit assessment process in defence procurement. The principal objectives of this PhD project are:1. Development of a Zero Gate Mission Effectiveness and Risk methodology for joint defence missions (air, land and sea). 2. Identify the variables, uncertainties and sensitivities in the model. 3. Demonstrate the methodology for a given case study.

References:

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[3] Peever, D.: First Principles Review: Creating One Defence, Department of Defence, 2015.

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Knowledge Retention and Transfer in a Complex Industry Environment

Aerospace Engineering / Sir Lawrence Wackett Centre

Project Description

Change will occur in the working demographic as baby boomers retire. Without strong a knowledge retention program, the enterprise will sub-optimize and be vulnerable to potential knowledge loss. Surprisingly, few organisations seem to have a formal knowledge retention strategy in place. According to a January 2009 Institute for Corporate Productivity report on knowledge retention, in which more than 420 organizations responded, about 77 percent indicated they don’t have knowledge retention initiatives, Some organizations—like NASA, through its Lessons Learned Process Procedure & Guidelines NPG 7120.6; John Deere, through its Retention of Critical Knowledge process; and some of the nuclear energy companies through a mandated need for knowledge retention and transfer—have recognized the importance of engaging in those activities and having a formal process established. However, for the bulk of organizations worldwide, there is little recognition for having a formal knowledge retention strategy and associated processes for their organisation.

The proposed PhD project will address the following research questions:
1. What is the impact of staff attrition due to retirement and job change on the defence and aerospace industry in the next 25 years?
2. What techniques are currently employed by prime defence and aerospace contractors to retain and transfer knowledge?
3. How are these complex organisations with significant supply chains affected by knowledge loss and what are the best measures to overcome this problem?

References:
[1] Marisa A. J. Stones: Knowledge Retention and Transfer in an IT Community of Practice:
Leader and Former Participant Perspective, PhD thesis, University of Phoenix, 2014.

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Cost-Benefit Assessment Methodology for Joint Defence Operations

Aerospace Engineering / Sir Lawrence Wackett Centre

Project Description

Variation in cost estimates for a new system program are high in the concept stage and then reduce over time as the estimate becomes more certain as the program progresses. The cost estimate baseline tends to increase as risks are realised. At the program start state the cost estimate reduces to a point estimate.

The current problem is that when looking back at end-of-life of the system, the total cost exceeds even the most pessimistic predictions during acquisition stage. If decision makers were aware at Zero Gate of the unforeseen future cost gap or 'blowout', it is quite possible the acquired system would have taken on a lower cost structure and scope, or in the worst-case been cancelled. The goal for Defence is to improve their current methods of cost benefit analysis (CBA) to reduce the magnitude and variability of the gap between the predicted cost of a concept system at Zero Gate and the actual end-of-life cost if that concept is acquired and put into service for defined life- time. In the Cost-Benefit Assessment of Future Aerospace Concepts for Defence project, RMIT is tasked with investigating innovative methods to allow Defence to prepare more accurate and precise cost estimates at the concept stage for future systems. For any improvement initiative, such as for this project, it is important to determine the current performance baseline to allow proposed improvements to be evaluated against the current state. The CBA process is comprised of a collection of tasks, events, gates, decisions and data collection in order to provide a system that meets a mission need to an acceptable cost. In order to improve a system it is necessary to have a solid understanding of this current system against which the beneficial effect of improvements may be measured. The principal objectives of this PhD project are: 1. Development of a Zero Gate Cost-Benefit Assessment methodology for joint defence missions (air, land and sea). 2. Determine the potential improvements and risks (uncertainties) achieved relative to the current methodology. 3. Demonstrate the methodology for a given case study.

References:
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Low-Noise and Reliable Air Taxi Operations in Australia

Aerospace Engineering / Sir Lawrence Wackett Centre

Project Description

Uber plans to begin testing its VTOL mobility system in Dallas in 2020, with plans for a commercial launch of the service in 2023. VTOL aircraft need little infrastructure, and can land at "vertiports" on the top of a parking garage without disturbing those nearby. This provides door-to-door trips when combined with its car service. The trials will help prove the safety of the system and allow people to get used to the idea of electric flying taxis. Once that happens, people will be treated to fast, safe, and efficient air travel, avoiding the congestion and the perils of the highway. Many aerospace companies are designing and developing all electric propulsion VTOL aircraft that are low-noise and no emissions, eg. Airbus and Westland. Initial operations will be using piloted aircraft.

The question is if this type of business is viable in Australia, e.g. in greater Melbourne. This will depend on typical flying distances, number of passengers, suitable landing sites and, of course, cost. The proposed PhD project will address the following research questions:

1. How can an air taxi business work well in Australia, eg. greater Melbourne, in terms of passenger volume, suitable landing sites and cost?
2. What are the local rules and regulations that affect air taxi operations in Australia.
3. What type of aircraft design is most suitable for air taxi operations in Australia, eg. range, payload, noise and safety.

References:

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[4] Research Triangle Institute. North Carolina fourth-tier air transportation market analysis. NC DOT Division of Aviation, 2002.

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Thermographic Detection and Prognostic Assessment of Impact Damage in Fibre Composites

Aerospace and Aviation, Multifunctional Materials and Composite Group, Bundoora East Campus

Project Description

Impact damage poses a serious threat to the safety of aircraft containing primary structure made from fibre composite material. Even relatively low energy impacts can result in damage sufficient to significantly affect the mechanical properties of potentially critical structures. Such impacts are commonplace throughout an aircraft's service life and the resulting damage may be visually undetectable. Given the potential ramifications, the detection and monitoring of such damage is crucial.
The proposed work will focus primarily on post-impact internal delaminations and the resultant prognosis for the structure. These delaminations can further grow with fatigue as experienced with the cyclic loading of aircraft. With the increasing use of lightweight fibre composite construction by aircraft manufacturers, exemplified by aircraft such as the Boeing Dreamliner, the Airbus A350 XWB, the MRH90 and Triton, concerns relating to such threats are set to grow.

Predicting the post-impact load capacity and stiffness of fibre reinforced composite structures is complex and dependent on many factors. Currently there is very limited understanding of fatigue life and residual strength for damaged composite structures, however, traditional structural integrity management practice involves rigorous experimental testing to demonstrate that a structure is able to withstand design ultimate limit loads in the presence of damage below a threshold size. Such tests are qualitative in nature and where visually undetectable structural damage is present, the possibility of damage growth during subsequent service must be incorporated into this evaluation. While damage growth modelling and prediction capabilities have advanced considerably over recent years, exhaustive experimental testing is still required to establish that relevant structural integrity requirements are satisfied.

In-situ thermoelastic stress analysis (TSA) may provide an important new tool for assessing impact damage growth in composites. TSA involves visualizing stress through thermal imaging. TSA has previously been implemented for crack growth tracking in metallic coupons experiencing fatigue, and based on preliminary experimental work. TSA may potentially provide a capability for real-time monitoring of the damage progression growth and give further insights over traditional full-field displacement measurement methods. The aim of this project is to establish some of the basic principles of damage growth assessment in fibre composites using low-cost TSA techniques. This work is aligned with the Defence Science & Technology Group (DST) and Defence's interest in developing a deeper understanding of the impact damage vulnerability, and the durability of advanced composite structures and its subsequent implications for aircraft safety, operational availability and fleet management and support affordability.

References:

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Structural Shape and Topology Optimisation for Fracture Strength and Fatigue Life Improvement

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Project Description

Optimisation of structural components is being increasingly used to extend their operational life beyond their initial design fatigue life, to improve load carrying capacity, and to reduce the loss of structural integrity. Conventional optimisation approaches are mostly aimed at reducing the peak stress in a structure and does not take into account the inevitable presence of defects or cracks. These optimisation methods are thus only applicable to 'idealised flawless' structures, which hardly exist in practice. Currently available optimisation methods cannot therefore be readily used for damage tolerant (those having defects/cracks) structures [1-3].

The primary objectives of the research are to develop a range of effective and efficient structural optimisation tools for optimum design of damage tolerant structures, i.e. to maximise the fracture strength and fatigue life considering the existence of cracks and defects, thus integrating damage tolerance design philosophy with design optimisation.

The outcomes of this research, and possible future developments, will be a boon to industries where failure by fracture or fatigue plays a dominant role. The application of damage tolerance optimisation in the design and maintenance of structures can dramatically reduce the loss of structural integrity and the likelihood of fatigue failure. This will allow the operation of these structures more effectively and efficiently with a greater durability and an improved operational life.

The project provides opportunities to collaborate with aircraft industries and research institutes in the UK and Germany. Knowledge and background in Solid Mechanics and Finite Element Analysis will be beneficial to undertake this project.

References:

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Damage Tolerant Hybrid Composite Materials for Applications in Critical Aerospace Structures

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Project Description

Fiber reinforced composites are often considered and selected for weight-critical structural applications due to their high specific stiffness and strength. However, lack of sufficient knowledge in the failure and life time prediction methodologies implies that the composite structures are often over designed with a large factor of safety, and numerous tests are to be performed on prototypes for prediction of performance over the required life time.

Residual strength degradation and fatigue behaviour of composite laminates are of vital importance to the damage tolerance design of structures. Cyclic loading causes adverse effects and leads to accumulated damage and degradation of residual strength in composite laminates. Predicting the residual strength of composite structures for both monotonic and fatigue loading has several advantages in the design of critical load bearing structures and components.

The aims of the research are to develop efficient and accurate computational and experimental methodologies for characterising hybrid, multifunctional fibre metal laminate composites for aerospace components. This includes damage type, location, mechanisms under complex monotonic and fatigue (cyclic) loading and assessing their effects on the residual strength degradation and consequent fatigue life. Using this information, a parametric study will be conducted with different composite material parameters (thickness, lay-up, and types of fibre and matrix) in order to develop optimised FML composites with high durability and fatigue life.

The expected outcomes of this research will be well-validated computational analysis methods to predict failure mode, and quantify defect and damage produced in fibre metal laminate composites. The models can be used to predict residual strength and estimate fatigue life of composite structures under monotonic and cyclic loading conditions. The modelling and optimisation tools will then be used in developing high strength composites with high durability and longer service life for critical aerospace components.
The project provides opportunities to collaborate with aircraft industries and research institutes in the UK and Germany. Knowledge and background in Solid Mechanics and Finite Element Analysis will be beneficial to undertake this project.

References:

[1] Shokrieh, M.M. and L.B. Lessard, Progressive Fatigue Damage Modeling of Composite Materials, Part I: Modeling. Journal of Composite Materials, 2000. 34(13): p. 1056-1080.
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Understanding Cranial Injury: Virtual Forensic Laboratory

Aerospace and Aviation, Multifunctional Materials and Composite Group, Bundoora East Campus

Project Description

In the context of the investigation of serious crime and its resolution in court, some of the most difficult issues to resolve include distinguishing between accidental, intentional and suicidal causes of death, the specific role of individuals in the causing of injury or death, especially their intent and degree of force used, determining the nature of the injuring cause (e.g. type of weapon used) and assessing the viable biomechanical scenarios for injury causing events. Essential to solving some of these problems is a thorough understanding of the mechanism of wounding and blood spatter and the development of valid methods to be able to distinguish one mechanism from another. Relatively little is known about the specific physics and fluid dynamics of blood spatter, but this has not stopped 'experts', with little or no appreciation of the science involved, giving sometimes controversial opinion evidence in courts around the world.
In cranial gunshot wounding it is thought that the initial contact between the projectile and the skin tissue produces spattered material with some sort of splashing mechanism. This spattered material can transfer to the firearm or the shooter which is sometimes used as evidence of proximity and therefore guilt. It would be valuable to be able to make predictions about the extent and range of this spatter. The objectives of this project are to determine if the mechanism of splashing associated with projectile impact on human tissue can be numerically modelled and whether such models can be used to make realistic predictions about backspatter.

The project has two parts: the development of physical models to test various wounding mechanism hypotheses, and the use of mathematical/numerical modelling techniques to simulate wounding and blood spatter. The key accomplishments will be physical models with simulant materials emulating properties of biological structures for use in lieu of animal subjects to simulate ballistic impact studies, and computational models with realistic anatomy and material behaviour of biological structures to simulate ballistic-human interaction. The main outcome will be a novel scientific and validated virtual tool for the forensic scientists to inverse predict the possible causes of an incident based on scene evidence, that will bring a new dimension to forensic science and crime scene investigation, whereby crime scene evidence could be analysed in-depth to provide new information and draw conclusions. This project will involve collaborations with the New Zealand Forensic Agency.

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Multifunctional Auxetic Materials for Critical Engineering Structures

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Project Description

Next-generation engineering technology has generated great demands for products and structures that need to withstand extreme operating conditions whilst meeting lightweight requirements. As an example in aerospace and automotive applications, the competing goals of “stronger and lighter structures” subjected to extreme loading and/or operating environments have led to a limiting situation, whereby conventional engineering materials are no longer able to meet the multiple desired properties and performance criteria. Novel architected materials provide an elegant and practical solution to address this. The advent of auxetic materials with negative Poisson’s ratio (NPR) [1-3] along with additive manufacturing (3D printing) offers new possibilities for development of advanced engineering structures with tuneable properties. The proposed project involves design, manufacture and optimization of multifunctional auxetic materials to obtain customised and multi-functional properties, for example, high stiffness to weight ratio, high energy absorption, impact resistance, vibration damping, and vibro-acoustics control.

The research aims to combine the two technologies of heuristic meta-modelling with topology optimisation and advanced additive manufacturing of hierarchical structures to explore novel multi-scale auxetic materials, whereby individual properties can be optimised independently by changing a single-scale topology within the hierarchy. Simultaneous occurrence of two or more properties in a structure, with their range being modifiable to a certain limit, allows for its extensive applications ranging from electronic sensors and actuators to composite structures with extreme mechanical and thermal load-bearing capabilities.

The objectives of this project are (i) to conduct computational modelling of hierarchical auxetic structures to explore the design space; (ii) to perform parametric studies and topology optimisation to determine the best structural configurations with target multi-functional properties; and (iii) to demonstrate the feasibility of fabricating such novel systems using 3D printing and evaluate their performance using mechanical and/or functional tests.

The project provides opportunities to collaborate with research institutes and industries in Australia, UK, and Germany. Knowledge and background in Solid Mechanics and some experience with finite element modeling will be beneficial.

References:

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DR215(PhD)/ MR215(Masters)
Aerospace Engineering & Aviation

CFD Simulations of Pre-Combustion Shock Trains at Mach 8 Flight Conditions

Aerospace Engineering and Aviation Discipline and CRC-P Hydrocarbon Fuel Technology for Hypersonic Air Breathing Vehicles, Bundoora

Project Description

This project involves the numerical simulation of shock tunnel data of a dual-mode scramjet with a focus on the pre-combustion shock train. Scramjets and ramjets offer an attractive means of powered hypersonic flight due to their high specific impulse compared with conventional rockets. However, despite over five decades of research effort from multiple countries, including flight experiments, a hypersonic air-breathing propulsion system does not form part of any space launch system currently in operation.
One of the major challenges to scramjet propulsion is the ability to operate over a wide range of Mach numbers. The dual-mode scramjet has the advantage that it can operate much like a ramjet at low Mach numbers, with subsonic flow entering the combustion chamber, and as a conventional scramjet at higher Mach numbers where the flow remains supersonic throughout the engine. A dual-mode scramjet is able to operate as a ramjet by allowing a shock train to form in the section between the inlet and combustor known as the isolator. This pre-combustion shock train, which is a series of intersecting shock and expansion waves, provides additional compression of the flow allowing subsonic flow to be supplied to the combustion chamber.

Recent shock-train experiments have been performed in the T4 Stalker Tube at The University of Queensland at a Mach 8 flight condition. The test model was a simple axisymmetric duct comprising a short diffuser, an isolator (L/D=4.1) and a constant-area combustor (L/D=15.7). Gaseous hydrogen was used as the fuel and was injected via six portholes equi- spaced around the perimeter of the duct. This work demonstrated that pre-combustion shock trains can be studied in shock tunnels at the upper end of the dual-mode regime. Only a quasi- one-dimensional analysis has been performed of the results of these experiments and is limited to broad engine performance parameters. This project proposes numerical simulations using high fidelity CFD on large supercomputers in order to model the flow structures. Pre-combustion shock trains are inherently difficult to model numerically due to the coupling of large regions of separated flow, cross-jet interaction and supersonic combustion. Detailed experimental data presently available to the supervisors will be used to support the simulations and provide a basis by which validation of the numerical results can be established.

References:
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Novel Energy Storage Technology using Multifunctional Textiles

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Project Description

The conventional energy storage devices (e.g. capacitors and lithium ion batteries) are too heavy and bulky for wearable electronics. As a result, developing flexible and lightweight energy storage devices which can be shaped into smart garments is necessary. Several excellent properties make graphene as an outstanding nano-material for energy storage applications, such as lithium-ion batteries, supercapacitors, solar cells, and fuel cells. Furthermore, graphene-based blends with MnO_2, NiO, CuO, Co_3O_4, and polyaniline have exhibited excellent electronic and electrochemical properties.

One primary aim of the project is using natural resources combined with nano-materials such as graphene to enhance their electrical properties. The processes of various coatings techniques will be investigated to obtain higher electrical conductivity and capacitance of grapheme coated fibres. The expected outcome of this research is the development of knittable energy storage devices based on the natural and synthetic yarns/fabrics. Such a rechargeable energy storage device will be cheap, easily processed and light-weight, and will have various potential applications such as in portable consumer electronics, computer memory backup systems, hybrid electric vehicles and next generation all-electric vehicles.

The project provides opportunities to collaborate with research institutes in the UK and Korea.
Knowledge and background in Solid Mechanics and Materials will be beneficial.

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Multifunctional Composite Laminates interleaved with Nanowires for enhanced Through-thickness Mechanical Properties

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Project Description

The ever-increasing demand for high performance aerospace materials with improved mechanical properties and reduced weight has intensified research into multifunctional fibre- reinforced polymer (FRP) composites [1]. Compared to traditional monolithic metallic alloys typically used in aerospace engineering, FRP composites have improved in-plane strength- and stiffness-to- weight ratios, excellent fatigue resistance, and superior resistance to corrosion.
However, despite the excellent in-plane mechanical properties, laminated composites have inferior through-thickness mechanical properties due weak interfacial bonding between the laminate ply layers [2].

Therefore, this research project aims to improve the inter-ply bonding between composite layers through the use of nano-anchored metallic nanowire interleaves. The metallic nanowires will be uniformly dispersed on the glass or carbon fabric and then treated through laser technology to achieve 3D interleave networks. The through-thickness reinforcement in the form of metallic nanowire interleaves is envisaged to result in laminated composites with improved interlaminar fracture toughness. Further, the integration of high thermal and electrical conductive nanowire inclusions will improve the overall thermal and electrical conductivity of the laminated composites resulting in truly multifunctional structural engineering materials. The multifunctional properties exhibited by the novel composite materials will result in significant weight savings for aerospace structures.

This research project will: (i) develop an efficient fabrication methodology to obtain nano- anchored metallic interleaves at the composite interlaminar interfaces; (ii) explore the effectiveness of nano-anchored metallic interleaves with different morphologies in enhancing the interlaminar properties; (iii) characterise failure mechanisms associated with interlaminar interfaces modified with nano-anchored metallic interleaves; and, (iv) develop a theoretical framework to evaluate the through-thickness and in-plane properties of interleaf-modified composite laminates.

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Reconstruction of three-dimensional aerodynamics flows by coupling simulations and experiments

Aerospace Engineering & Aviation Discipline

Project Description

Aerodynamic design remains a slow and costly activity owing to the complicated physics involved in the performance of aircraft. Aerodynamic flows are unsteady, nonlinear, and present a broadband range of scales. Consequently, the pressure and velocity information required for the design process is scarcely available.

Experimental wind tunnel testing of aerospace components requires a laborious process and it only provides limited flow data information even using advance instrumentations. The counterpart methodology, numerical simulations, are also hardly affordable with to date computational capabilities due to the large number of flow scales needed to be solved simultaneously. Other present approaches, like empirical methods or turbulence modelling are only valid for existing configurations and their application to new aircraft configurations can be questionable [1].

A recently developed method has overcome the limitation of resolving all the scales of the flow at the cost of requiring limited experimental data for calibration [2,3]. This method builds up a bridge between experimental and numerical approaches, and could deliver pressure and velocity distributions with present wind tunnel and computational capabilities. Although the method is promising, it has only been validated against simple flow configurations [2,3].

This objective of this project is to extend such methodology to three-dimensional aerodynamic flows. The project will involve direct numerical simulation (DNS), CFD modelling and experiments in RMIT's wind tunnel. Successful outcomes of the project will open up a new avenue for aerodynamic design and a breakthrough in wind tunnel capabilities.

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Acoustic streaming modelling using input-output analysis

Aerospace Engineering & Aviation Discipline, Micro/Nanomedical Research Centre

Project Description

The understanding of microfluidics is critical for many novel technologies, such as medical diagnostic lab-on-a-chip devices, in which acoustic forcing of flows enables the manipulation of cell and particles. Despite this field has flourished over the last two decades, many questions remain unexplored owing to the strong nonlinearity arising from large-amplitudes and disparity of frequencies in these flows [1].

On the other side of the fluids spectrum, large scale turbulent flows, the resolvent analysis of McKeon & Sharma [2] has shown spectacular results with regards to unveiling the role of nonlinear terms in turbulent flows and has open up a new avenue for the understanding and control of such flows [3]. This approach consists of reformulating the Navier-Stokes equations into an input-output framework in which the nonlinear terms are treated as a forcing that acts upon the linear dynamics to yield a velocity response. This strategy simultaneously accommodates all the flow scales without further assumptions, hence it could overcome many of the challenges dealing with the study of microfluidics.

This objective of this project is to extend the resolvent methodology to acoustically-driven microfluidic flows. The project will involve direct numerical simulation (DNS), mathematical modelling and post-processing of experimental microfluidics data. Successful outcomes of the project will serve to improve existing microfluidics-based technologies and design new applications.

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A data-driven strategy to control flow separation past inclined slender bodies

Aerospace Engineering & Aviation Discipline

Project Description

The control of hydrodynamic flow instabilities around inclined slender bodies is of major importance in submarine technologies. Unsteady flow separation and vortex shedding could induce vibrations and undesirable acoustic noise that ultimately can lead to deficiencies in stability and control, increased drag or inadequate stealth capabilities of submarines [1].

Despite there exists a broad range of methods to control flow instabilities [1,2], these methods are often tailored to specific flow phenomena and are based on costly trial and error parameter sweeps studies owing to a lack of understanding of the unsteady flow mechanisms. In the case of flows around submarines, typically modeled with a hemisphere-cylinder configuration at non-zero angle of attack, several experimental and computational investigations [3] highlights the presence of an unsteady vortex system emerging from a separation bubble at the nose. These “horn vortices” and their unsteady interaction with boundary layer transition phenomena play a major role on the submarine performance. However, despite the importance of these flow features, there has not been significant attempts to control this flow phenomena owing to their complexity and three-dimensionality.

The goal of the PhD is to unveil these mechanisms by employing a novel data-driven approach [4]. This method, based on experimental or numerical data, consists of establishing a correlation between unsteady flow phenomena and nonlinear forcing. Such relationship enables the identification of self-sustained flow mechanisms and their subsequent control by disabling the forcing that drives the different unsteady flow features. The extension of such methodology to the particular case of the flow around an inclined body can pave the way to the identification of promising flow control strategies to enhance capabilities of future submarine technologies.

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Design of surface textures to delay laminar-turbulent transition

Aerospace Engineering & Aviation Discipline

Project Description

The problem of transition to turbulence in boundary layers around surfaces is of great fundamental and practical interest in engineering. For instance, the skin friction drag caused by a laminar boundary layer is significantly smaller than the caused by a turbulent boundary layer. Hence, an increasing of the laminar extent of a surface can vastly improve the performance of ground, maritime and air vehicles [1].

The most common scenario for laminar-turbulent transition consists of the development of a linear instability known as Tollmien-Schlichting (TS) waves [2]. Despite several attempts to control these flow structures have been developed, including a highly promising approach [3], none of these has been translated into real applications yet. The reason for this apparent failure can be attributed to invalid assumptions on TS waves modelling, noisy environments or unpractical strategies such as body forcing.

This objective of this project is to elucidate novel strategies to control laminar-turbulent transition able to overcome the mentioned limitations. The project will involve direct numerical simulation (DNS) of boundary layers and a novel data-driven analysis of the flow data able to identify the physical mechanisms [4] leading to transition. The information obtained from this analysis will serve to generate surfaces textures that can delay transition in boundary layer flows.

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Performance Metrics for High Altitude Long Endurance Sensor Platforms for Rapid Wildfire Detection

Aerospace Engineering and Aviation, Bundoora

Project Description

With global warming, wildfires represent a growing global threat to the human society and ecosystems [e.g., 1]. Rapid, effective, warning-alerts of such wildfires is therefore required to permit better-informed suppression efforts and safe evacuations. To bring about such rapid detection, high-altitude-long-endurance (HALE) remotely-piloted, aerial platforms carrying suitable infrared sensors have been proposed, but have not yet been realized [2, 3]. Aside from issue of sensor capability improvement, a current challenge is the development of integrated sensor-platform systems that are subject to tight mass and power constraints. Airbus DS are currently marketing such a HALE (pseudo-atmospheric satellite) platform and have agreed to provide RMIT interface data to permit the integration of 5 kg sensor array system. A key research problem inhibiting in the optimum design of this array is determining exactly how optimum performance is assessed. In principle, cost minimization is necessary, provided the end-user requirements are met, but at this juncture end-user requirements are not well-defined. The fidelity of the infrared data that may be acquired is also not yet known, since atmospheric attenuation effects and signal-to-noise ratios are difficult to quantify [3]. Flight tests are planned to constrain these uncertainties, but extrapolation will be needed to predict what data fidelity can be achieved by a commercially viable system. The end-user ultimately needs to be informed on the growth rate and directional movement of any detected wildfire with sufficient accuracy, implying the need for image processing to translate raw data into useful warning indicators [4]. Performance assessment is also strongly related to the operational strategy adopted which will involve multiple platforms and cooperative data management, in particular with open source satellite data. The research intended has no ethical concerns, but interface data from Airbus DS will be subject to non-disclosure agreement.

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Advancing Lighter-Than-Air Aircraft Technology

Aerospace Engineering and Aviation, Bundoora

Project Description

Lighter-Than-Air (LTA) aircraft include balloons, airships and any aircraft that has appreciable aerostatic buoyancy [1-7]. There are a set of distinct, interlinked LTA aircraft technology-related research challenges that call for attention: quantifying the loading and dynamic responses to gusts [2,3]; prediction of buoyancy changes caused by changes in heat transfer (especially from solar heating); hull aeroelastic modeling [4]; effective propulsive-power system integration and drag minimization [2, 4]. The exact nature of these research challenges depend on the applications considered which include: cargo transporation [1]; aerial surveillance and station-keeping at high altitude for long endurance; exploration of planetary atmospheres, in particular of Titan [5] and Venus [6]; dendronautical exploration of rainforest canopy [7]. The common research methodology in all these cases is the application of multi-physics [e.g., 4], in order to construct comprehensive models that can be used to accurately predict behaviour. Scope exists not only for computational studies including CFD and FEA, but also for limited experiments and flight tests to verify key parameters, [e.g., 5 and 7]. A major, near-future, potential for realizing remotely-piloted LTA aircraft appears to be within reach (e.g., via the RMIT “Activator”), provided some of the aforementioned challenges are properly addressed.

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Flying Insect Performance Metrics and Wing Aeroelasticity

Aerospace Engineering and Aviation, Bundoora

Project Description

The engineering study of winged insect (Pterygota) flight has been fruitful, not only since it offers 'biomimetic' analogies for the design of Micro Air Vehicles (MAVs), but also since it leads to improved understanding of insect evolution [1-3]. Biologists [e.g., 3] refer to the ecological importance of "agility" and "maneuverability" in insect flight, especially in predator-prey interactions, but both remain poorly defined. Metrics of fighter aircraft agility [e.g., 4] are potentially useful in this regard and could lead to an improved quantification. Another outstanding problem is the magnitude of flight loads and safety factors in determining the investment in insect flight apparatus. Many insects such as dragonflies (Anisoptera) are capable of lifting 2-3 times their own weight in hover [1], and this excess load capability undoubtedly promotes agility in conspecific flight combat. Dragonfly have corrugated wing structures that are essentially made of hollow spar tubes of chitin joined by resilin and a thin wing membrane in a manner that promotes stiffness in bending, yet high torsional flexibility to permit efficient flapping. Little is known about the wing inertia power input required during flapping, and how much of this inertial power is recovered each cycle. Some insect wings also contain active sensors that help improve flapping flow interactions [2]. By adopting a multi-physics approach, it is possible the model the aeroelastic response of wings to gain functional insight into features such as the pterostigma of dragonfly wings. Maximum aerodynamic loading can be determined from analysis of rapid maneuvers. By stereo-videoing the flight of insects, it is also possible to quantify manoeuver rates and accelerations. There are no ethical concerns with videoing insects in their natural environment. In summary, insects provide a rich seam of accessible data and the opportunity for multidisciplinary research that is likely to lead to high quality publications.

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Design Optimisation and Uncertainty Quantification of Space Transportation and Deployment for Microsatellite Missions

Aerospace Engineering and Aviation, City

Project Description

Miniaturised satellites have been drawing increasing attention as cost-effective, viable options for space missions to achieve various objectives including scientific research, technology demonstration, and commercial applications since the CubeSats concept emerged in 1999 [1]. The utilisation of microsatellites for space missions and platforms has been promoted with the active development of low-cost space launchers and the availability of commercial-off-the-shelf (COTS) hardware components and advanced design tools [2]. The advancement in propulsion technologies, in particular electric propulsion, has further extended the opportunities for microsatellites from low-Earth orbit (LEO) to geosynchronous orbit (GEO) and interplanetary missions for both scientific and commercial objectives, owing to considerable advantages offered in the reduction of fuel consumption hence specific launch cost for the payload [3].

The design of spacecraft systems and missions is inherently characterised by complex couplings, interactions and interdependencies between components and subsystems at various levels. The space environment has manifold effects on the operation of space-based applications, adding further complexity and uncertainty to system and mission design. Sophisticated methodologies are essentially required in order to enable efficient and robust design and effective analysis by taking all important elements and relations into account in a comprehensive manner.

This research project aims to develop advanced design and simulation capabilities for space systems including transportation and deployment, particularly aiming at microsatellite missions. It will conduct multi-objective design optimisation (MDO) studies for the launch systems considering the full trajectory comprising the launch, parking, and deployment phases. MDO will also be applied for the system design to simultaneously achieve multiple objectives with respect to various aspects such as the fuel consumption, time, communication and radiation. Surrogated-assisted evolutionary algorithms will be coupled with trajectory optimisation codes based on pseudo-spectral methods, precise orbit propagation/determination tools considering high-order environmental effects, and high-fidelity electromagnetics solvers for the MDO of transport, deployment, and electric propulsion, respectively. Uncertainty and sensitivity quantification will be performed by means of statistical and mathematical methods incorporating surrogate models to quantify the influence of the design parameters, operating conditions, and environmental factors on the performance and behaviour of the system.

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DR215(PhD)/ MR215(Masters)
Aerospace Engineering & Aviation

Physics and Optimisation of Hypersonic Airbreathing Propulsion for Reusable Space Transportation Systems

Aerospace Engineering and Aviation, City

Project Description

Hypersonic airbreathing propulsion offers the potential for reliable and economical transport for access to space and high-speed atmospheric flight. Supersonic combustion ramjet (scramjet) propulsion is a promising technology that can enable efficient and flexible transport systems by removing the need to carry oxidizers and other limitations of conventional rocket engines [1], but it can operate only in the hypersonic regime, thus requiring auxiliary propulsion for acceleration.

RBCC (rocket-based combined cycle) has been contrived to overcome such limitations and enable economical and flexible access to space by combining rockets with airbreathing engines, *i.e.*, ramjets and scramjets [2]. However, the substantial nonlinearities associated with aerodynamic and aerothermal phenomena and propulsion characteristics of multi-mode engines inherently represent a formidable challenge for RBCC design. The air intake is the principal component responsible for the compression of incoming high-speed flow and subsequently overall performance, but efficient compression and intake starting would essentially require thorough understanding and reliable control of complex flow phenomena including shock wave reflection and shock wave / boundary layer interactions [3]. For the combustor section accurate changeover between the ramjet and scramjet modes (*i.e.*, transition between subsonic and supersonic combustion modes) is of crucial importance. Fuel injection plays a key role in thrust production through the mixing and combustion process as well as for the control of the RBCC modes for sustainable and reliable RBCC operation [4].

This project aims to investigate the RBCC characteristics primarily in numerical approaches. Computational fluid dynamics (CFD) simulations will be performed in order to scrutinise the steady and transient flowfields, with primary focus on the intake and combustor sections. Multi-objective design optimisation studies will be conducted by coupling state-of-the-art surrogate-assisted evolutionary algorithms with high-fidelity CFD solvers. In-depth analysis is to be performed for the representative flowfields so as to identify the key design factors, working characteristics, and underlying physics for intake compression and starting, fuel mixing and combustion, and mode transition. It will also investigate the presence and mechanism of the potential hysteresis that may exist in the Mach reflection mode particularly in axisymmetric intakes as well as that in the reverse transition process from the ramjet to scramjet mode.

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Reduced-Order Modelling and Optimisation of Nonlinear Aeroelastic Systems

Aerospace Engineering and Aviation, City

Project Description

Nonlinearities inherently exist in various engineering applications including aerospace and civil systems, critically affecting their behaviour and performance. In dynamic aeroelasticity, in particular, the mutual interactions between aerodynamic, elastic, and inertia forces can induce dangerous instabilities of the elastic body when exposed to the fluid flow, exerting significant impact on the design, performance, safety, operation, and lifecycle management [1].

Amongst aerospace applications, transonic aircraft in manoeuvre are characterised by substantial couplings of various nonlinearities, requiring special consideration for design and operation. Aerodynamic nonlinearities arise from fluid-dynamic phenomena caused by viscous and compressible effects such as unsteady aerodynamic phenomena (*e.g.*, shock-wave/boundary-layer interactions, shock-induced flow separation, boundary layer transition and separation), which, when coupled, can give rise to dynamic nonlinearities including a sustained, low-frequency periodic shock motion, *i.e.*, transonic buffet [2].

Nonlinear aeroelastic interactions often lead to limit cycle oscillations (LCOs). Most preceding studies on LCOs have focussed on the understanding of aerodynamic mechanisms for transonic buffet, with the dynamic response of the structure neglected or modelled by using limited degree of freedom representations [3]. Indeed, there have been very few studies conducted for nonlinear wings or full aircraft models due to the prohibitive cost and modelling difficulties associated with full-scale, fully coupled aeroelastic simulations, leaving a significant gap in the complete understanding of the feedback mechanism in nonlinear aeroelasticity, where the effects of nonlinearities on vortex shedding, transonic buffet and LCOs are yet to be understood.

This project aims to address challenges posed by nonlinear aeroelasticity by developing trusted reduced-order models and efficient digital modelling framework based on high-fidelity fluid-structure interaction (FSI) analysis. It expects to advance the understanding of system characteristics by coupling trusted reduced-order models, optimisation algorithms and data assimilation in a unified framework. Expected outcomes include an advanced methodology that enables accurate prediction of dynamic systems, discovery of key physical mechanism and their robust optimisation. This should provide significant benefits such as enhanced efficiency and reliability in the development and operation of multidisciplinary systems.

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Physics and Optimisation of Flow Control with Plasma Actuators

Aerospace Engineering and Aviation, City

Project Description

Plasma actuators are a novel flow control technology based on ionisation of air over electrodes due to high voltage imposed between dielectric barriers. A body force is induced consequently, acting as a driving mechanism for active aerodynamic control [1]. This control method offers numerous advantages over conventional flow control techniques, featuring adaptive operation and fast response as well as simple and light structure involving no mechanically moving part. Universally applicable to any aerodynamic devices, this control method has received considerable attention in the global community and led to abundant research efforts for a wide variety of engineering applications. It can be applied for the surface flow control on the wings of UAV/MAV aircraft, rotor blades of helicopters, and wind turbine blades, effectively improving the aerodynamic performance, manoeuvrability and robustness in harsh flight conditions involving unexpected turbulence and windshear [2]. DBD (dielectric-barrier-discharge) plasma actuators have also been found to be effective in controlling tip clearance flow of turbine blades and suppressing flow separation over backward-facing steps, enhancing the efficiency of turbomachinery (*e.g.*, gas turbines, jet engines) and automotive applications, respectively [3].

Past studies on flow control via plasma actuators, however, have predominantly been conducted in experimental approaches by means of flowfield visualisation and measurements, focussing on the investigation of the control effects on the flowfields, while fewer studies have been performed numerically so far due to the complexity of modelling and computational cost. This project aims to develop thorough understanding of the underlying physical mechanism for flow control with plasma actuators, and establish a computational model to represent the behaviour and characteristics of the flow. A multi-objective design optimisation (MDO) framework is to be developed by coupling surrogate-assisted evolutionary algorithms with a high-fidelity computational fluid dynamics (CFD) solver implementing the plasma flow model. MDO studies will be conducted for a range of engineering applications with various geometries and plasma configurations. Multiple objectives such as minimum flow separation, non-uniformity, total pressure loss, and power consumption, will be considered to be optimised simultaneously, with various parameters for the geometry and configuration for the plasma actuators employed as the design parameters (decision variables). Experimental studies including flow visualisation and force measurement will be conducted in the low-speed wind tunnel in order to validate the optimised configurations and gain further insights into the flowfield and control for the improvement of the plasma flow model.

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Intelligent Transport Systems: Air and Surface Transport Evolutions

Intelligent Transport Systems Research Group, Bundoora East Campus

Project Description

The Intelligent Transport Systems (ITS) Research Group of RMIT University has a leading role in the iMOVE CRC (Intelligent Mobility & Vehicle Evolutions Cooperative Research Centre) in addressing the opportunities and challenges of Future Air and Surface Transport (FAST) systems integration, focussing on the major role to be played by Air Traffic Management (ATM), aviation electronic systems and airport automation. To achieve this goal, the RMIT FAST Research Cluster operates within the iMOVE CRC in collaboration with world-class industry and academic partners. The ambitious goals set for enhanced safety, efficiency and environmental sustainability of passenger and freight transport in Australia and globally, demands for an evolution of the air and surface transport/mobility network that can only be achieved by introducing innovative Information & Communication Technology (ICT) based cyber-physical and intelligent system solutions. These include a variety of emerging Communication, Navigation & Surveillance (CNS) system, advanced Decision Support Tools (DSS), and Navigation, Guidance & Control technologies. Substantial efforts are required to successfully integrate these technologies into vehicles and infrastructure, particularly in terms of ensuring that the required levels of safety are achieved at all times and that disruptions are reduced to a minimum.

This project addresses key contemporary research challenges associated with the design and operational integration of advanced technologies with the objective of improving safety, efficiency and environmental sustainability of single and multi-modal transport systems, adopting an integrated engineering approach to systems development, operations and lifecycle management. Fundamental research aspects include the safe integration of trusted autonomous air and surface vehicles in urban areas, dynamic management of network resources, congested traffic flow management and optimisation, multi-objective trajectory optimisation, network synchronisation, safety and security certification framework evolutions, indoor and relative navigation (also for pedestrians/individual passengers), GNSS augmentation and cyber-physical security.

The fundamental engineering disciplines nurturing the multi-disciplinary ITS research context include vehicle dynamics, uncertainty modelling, transportation human factors, traffic modelling and simulation, multi-platform interoperability and machine learning.

Students undertaking this project are required to possess a solid expertise in mathematical modelling and simulation, computer programming skills including MATLAB and possibly a compiled language.

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Human Factors Engineering for Avionics and Air Traffic Management Systems

Intelligent Transport Systems Research Group – Aviation and Aerospace Systems Team
Aircraft Systems & Autonomous Systems Laboratory, Bundoora East Campus

Project Description

Avionics and Air Traffic Management (ATM) systems are rapidly evolving to incorporate a wide number of emerging Communication, Navigation and Surveillance (CNS) technologies with the overall purpose of increasing efficiency and sustainability of aircraft operations while accommodating unprecedented traffic growth trends [1, 2]. The fundamental proposition revolves around a more predictable and flexible management of airspace and airport resources through higher levels of information sharing and more accurate navigation. While the pace of technological advances in this domain is faster than ever in history, aircraft operations vitally rely on human flight crews and air traffic controllers for ensured safety. These operators undertake some of the most complex duties that humans can perform and their high mental workload can at time exceed their cognitive capabilities, potentially leading to fatal accidents. To relieve human operators and increase the levels of safety, avionics and ATM system evolutions involve substantial increases in automation support both in the flight deck and on the ground, as well as significant changes in the roles and responsibilities of pilots and air traffic controllers. In particular, their primary role will shift progressively towards supervisory duties, intervening only when necessary. These new roles require significant evolutions in Human-Machine Interfaces and Interactions (HMI^2), which were already a key area of avionics and ATM system research and are thus becoming a crucial enabler for more efficient and synchronized air traffic operations.

This project will therefore explore the underlying mechanisms associated with the roles of human flight crews and air traffic controllers with the aim of defining the design and operation of new avionics and ATM systems HMI^2. Various scientific methodologies will be exploited for this purpose, including human-in-the-loop experiments exploiting the flight simulation and ATM simulation facilities in the aircraft systems & autonomous systems laboratory in Bundoora East. Industry-grade development tools (including Presagis VAPS XT) will be used in the project. As this project involves human research activities, an ethics approval will be required. The project requires solid modelling and simulation skills, MATLAB/Simulink skills and, possibly, foundations of compiled language programming.

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CNS/ATM and Avionics for Unmanned Aircraft Systems

Intelligent and Cyber-Physical Transport Systems Research Group, Bundoora East Campus

Project Description

Unmanned Aircraft Systems (UAS) are being extensively employed in a variety of applications as these vehicles provide cost-effective and safe alternatives to manned aircraft in a wide range of operational scenarios. The introduction of a new Air Traffic Management (ATM) regulatory framework for Trajectory Based Operations (TBO) and Performance Based Operations (PBO) have also shifted the focus from the traditional on-board avionics to the integrated Communication, Navigation and Surveillance/ATM and Avionics (CNS+A) domain. This project will focus on identifying and addressing the unique aspects and challenges of UAS development, test and evaluation and certification aspects both from an avionics and from an ATM/UAS Traffic Management (UTM) perspective.

This project addresses: UAS operations in the ATM/UTM system; command, control, communication, spectrum and security issues as well as airworthiness and continued airworthiness challenges. In this project, accurate and fail-safe algorithms for Guidance, Navigation and Control (GNC) of the platform will be developed to accomplish mission-essential and safety-critical tasks. Furthermore, the interactions between the GNC and Track, Decision-making and Avoidance (TDA) loops will be evaluated to support a variety of UAS applications.

Innovative real-time four dimensional trajectory optimisation algorithms will be evaluated for Line-Of-Sight (LOS) and Beyond LOS (BLOS) communications of single-UAS, multi-UAS and combined manned aircraft-UAS operations. Furthermore, CNS integrity monitoring and augmentation algorithms will be introduced allowing an extended spectrum of autonomous and safety-critical operations. A continuously monitoring of CNS integrity levels will be required to provide suitable caution (predictive) and warning (reactive) flags to the unmanned aircraft remote pilot.

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Aerospace Trusted Autonomous Systems for Safety-of-Life Operations

Intelligent Transport Systems Research Group – Aviation and Aerospace Systems
Team Aircraft Systems & Autonomous Systems Laboratory, Bundoora East Campus

Project Description

Trusted Autonomy in Systems (TAS) is one of the game-changing technologies that has been identified by the Australian Government for providing a distinctive edge in today's and future aerospace capabilities. Novel autonomous systems are required that can be trusted in adversarial, congested, contested and complex environments where the consequences of an error/failure can have a big impact on the successful completion of an aerospace mission. The current focus areas of RMIT University in the area of aerospace TAS include avionics and air traffic management systems (hardware and software) safety, security and integrity requirements, addressing in particular the challenges of properly designing, testing and certifying autonomous systems for Safety-of-Life (SoL) operations.

This research project will investigate new system capabilities to enhance the decision-making in challenging mission scenarios, allowing for new adaptive, interactive and collaborative forms of data-fusion and decision-making in real-time. In particular, a number of techniques will be developed, evaluated and integrated as part of intelligent Decision Support System (DSS) prototypes. Areas of particular interest include: control and coordination of multiple manned and unmanned platforms; target detection, tracking and autonomous decision-making; and automated Separation Assurance and Collision Avoidance (SA&CA) capabilities required to integrate autonomous platforms in all classes of airspace. This research can also be extended to human-machine integration, human-autonomy teaming, heterogeneous multi-agent systems and network-enabled operations.

The aim of the project is to develop advanced multi-sensor data fusion algorithms for TAS involving highly non-linear dynamics and sensor measurement models. Additionally, this research project aims at developing a unified approach to state estimation and decision-making supporting SoL operations. The key performance parameters in SoL applications will have to be evaluated and new forms of model-predictive integrity augmentation will have to be introduced. The robustness of the DSS solutions to monitor threats and to detect, mitigate/exclude a faulty element of the TAS will be evaluated. Students undertaking this project will require a solid expertise in mathematical modelling and simulation, computer programming skills including MATLAB and possibly a compiled language.

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DR215(PhD)/ MR215(Masters)
Aerospace Engineering & Aviation

Elastic Metamaterials for Impact Energy Absorption

Multifunctional Composites Group/Aerospace Engineering and Aviation Discipline
Bundoora East

Project Description

The distinctive qualities of the elegant and complex architectures of natural structures have been developed through millions of years of evolutionary processes and therefore have inspired humankind in the development of novel engineering solutions. Nevertheless, design of macrohomogeneous composite materials that exhibit novel elastic properties have been attracting ever increasing interest in various areas of scientific research and practical engineering, including vibroisolation, acoustic lenses, acoustic cloaking and blast wave mitigation. Contrary to the intrinsic properties of constitutive materials, the effective properties of such a composite (i.e. effective-density and effective-elasticity) may become negative, thus providing new opportunities for creating composite materials with a desirable response to external loads. For example, solids with negative effective-density and negative effective-elasticity could selectively show liquid-like behaviour.

Particular arrangement of mass-spring resonators results in negative effective-density and/or negative effective-elasticity in elastic metamaterials. These negative properties, not found in naturally formed materials, uncover an unprecedented class of materials with novel applications. The outcomes of this innovation will greatly advance the knowledge of new generation engineering structures with applications that are not feasible using traditional engineering microstructures. Furthermore, understanding the fundamental properties of E/A Metamaterials is crucial in the design and development of advanced materials and structural systems. The objectives of this project to fulfil the current gaps in the knowledge are:

• To understand the fundamentals of damping in E/A Metamaterials with negative effective-density and negative effective-stiffness using advanced computational modelling software.

• To experimentally investigate damping in E/A Metamaterials by utilising state-of-the-art measurement techniques.

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DR215(PhD)/ MR215(Masters)
Aerospace Engineering & Aviation

Lightweight 3D Hybrid Composite Materials

Multifunctional Composites Group/Aerospace Engineering and Aviation Discipline
Bundoora East

Project Description

Fibre reinforced polymer matrix composites (FRP composites) consist of polymer resin matrix reinforced with fibres. FRP composites are lightweight with high specific strength/stiffness which makes them suitable for weight critical applications. The most common type of FRP composites is woven fabric with cross-ply stacking sequence and fibre volume fraction of 80%. Fibres provide high strength and stiffness, improve energy absorption of the resin and distribute the kinetic energy of impact laterally. The structural performance of FRP composites depends on the properties of the polymer matrix and reinforcements, stacking sequence, and structure of the fabrics. Current FRP composites made from 2D woven fabrics/prepreg sheets suffer from inferior through thickness properties which is an important factor in the final performance of the structure. A number of technologies exist for reinforcing the FRP composites in the through thickness direction including stitching, z-pinning, and 3D weaving. Whilst all three methods have shown promise in improving the through thickness properties, 3D preforms have the extra advantage of weaving the reinforcement into the final product shape therefore reducing the complexity and cost of manufacturing while improving the quality and performance.

The research on the manufacturing, modelling and experimental characterisation of 3D preform FRP composites is in its embryonic stage. Recent studies show that impact performance of FRP composites reinforced in the through thickness direction (e.g. 3D woven and stitched) is superior to 2D woven FRP composites. There are controversial reports in the literature regarding the fatigue performance of 3D woven FRP composites. Whilst some studies show longer fatigue life compared to conventional 2D structures, others show degraded fatigue life and residual properties. However, the through thickness reinforcement may reduce some structural properties of the composite if not designed properly. The objective of this project is to develop the capability within Australia to design and manufacture fibre reinforced composite materials from 3D preforms to reduce weight and improve the structural performance of components. The project will investigate the mechanical performance of 3D preform composites to determine the optimum material design (e.g. orthogonal and angle-interlock weave) for a range of representative loadings.

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Nano-Crystalline Cellulose Reinforced Composites

Multifunctional Composites Group/Aerospace Engineering and Aviation Discipline
Bundoora East

Project Description

The aim of this project is to develop and characterise novel wood-nanocomposites, through the incorporation of nano-crystalline cellulose (NCC) into fibre reinforced polymer (FRP) composites. Presently aerospace, maritime and Defence industries are not major customers of wood industry (except for marginal aesthetic applications) due to the inferior mechanical properties of wood products (including natural fibre composites containing micro-cellulose fibres) compared with engineered fibres (e.g. glass fibres and carbon fibres) and metal alloys. The main requirements of materials for utilisation in the industries are low weight (for improved performance and fuel efficiency), high strength, high modulus of elasticity, and high impact and fatigue performance. NCC composites could be used, for example, in internal structures of air vehicles for increased structural stability and strength and in fire retardant components.

Cellulose is renewable, biodegradable and the most abundant bio-polymer in the world with its main source being wood. NCCs can be produced from wood cellulose through mechanical and chemical processes such as acid hydrolyses. The fundamental research on physical properties of NCCs has been almost complete due to recent advances in nanotechnology enabling NCC synthesis. The current research focus is on the development of novel products for commercial applications by the wood industries in USA and Canada. NCC is a revolutionary material with exceptional mechanical, thermal and optical properties.

These exceptional mechanical properties have prompted the development of NCC nano-composites in recent years. However, the properties and applications of these nano-composites have not been investigated for use in high-end applications such as aerospace, maritime and Defence industries that have certain stringent requirements. Therefore, this project aims to characterise NCC nano-composites to develop commercial products with superior mechanical properties and multifunctional capabilities compared to conventional alloys and FRP composites.

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Flapping Wing Micro Aerial Robots – (I) Wing Compliance

Aerospace Engineering & Aviation Discipline

Project Description

Micro aerial robotics has been a nascent research interest due to its vast application potential. There have been a number of potential designs that have been tested including fixed wing, quadrotors, rotatory etc. as a suitable platforms. However these platforms are unsuitable at smaller scales due to a number of factors including aerodynamics inefficiency and limited maneuverability and inability to perch [1&2]. Flapping flight offers significant advantages in this realm due to the capacity to generate significant aerodynamics forces even at small scales as demonstrated by the myriad of biological systems that utilize this mode for powered flight [1]. A critical challenge in the development of flapping wing micro robots is designing wings capable of generating the necessary aerodynamic forces. Biological systems such as insects and birds possess wings that are highly compliant which has been attributed to increased efficiency [2]. Our understanding of the fundamental mechanics of wing compliance at small scale and the associated aerodynamic force generations remains unclear.

The aim of this project is to understand how wing compliance and flexibility influences aerodynamic force production necessary for flight. The aerodynamic forces generated by flexible flapping wings will likely depend on many factors such as kinematics, wing shape and its material (thickness); fluid-solid interaction (FSI) around the wing surface. Flexibility has been recognized as a key factor for flapping wing aerodynamics. Indeed, the present research will focus more on the study of complex fluid-structure interactions, flapping wing deformation, twisting and stiffness, which significantly leads to the flapping performance. Due to complexity, many people examine the wing deformation in terms of span-wise and chord-wise corrugated camber. Still, the unsteady 3D fluid flow phenomena are not yet fully explored. A direct consequence of this study will result in the fabrication of bio-inspired compliant wings that can are aerodynamically efficient while being damage tolerant.

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Flapping Wing Micro Aerial Robots – (II) Wing Actuation and Flight-Control

Project Description

The role of robotic systems including miniature unmanned autonomous vehicles is expected to grow significantly in the near future. With rapid advancement in sensor and robotic technologies (Fig. 1a), unmanned aerial vehicles are envisaged to be assigned various tasks including disaster monitoring, product delivery and, surveillance and reconnaissance. Current challenges in the implementation of miniature aerial vehicles in the outdoor environment lay in their inability to solve problems such as maintaining stable flight while navigating through complex environments. Aerial locomotion is particularly difficult close to the Earth's surface where the winds can very rapidly change in speed and direction rendering the conditions unfavorable for flight. High levels of turbulence in the wind can be adverse for flight and poses severe flight- control challenges. Flapping flight offers particularly advantages over other platforms especially at small size scales [1,2,3]. However due to the vastly different and dynamic nature of aerodynamic force production, wing actuation and flight control is extremely challenging.

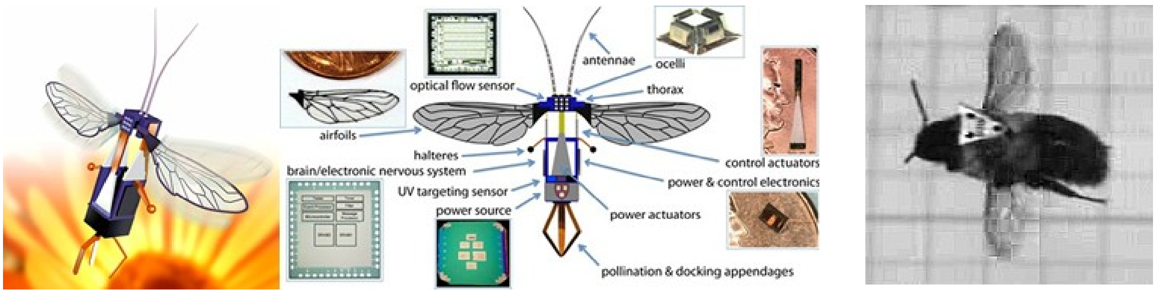

Fig.1: (a) Miniature flying robot developed by Harvard University. (b) Bumblebee instrumented with markers to study its flight control and dynamics in unsteady winds [4].

This project will aim to develop bio-inspired and mimetic wing actuation and control system for micro aerial robots [1,2,3]. In particular, the potential of electromagnetic actuation of wings to drive the wings in flapping motion will be assessed instead of resorting to traditional methods of converting rotational motion to reciprocating motion. The latter can be mechanical very inefficient while rendering limited control. The project will also seek to develop a "shoulder joint" for the robot that facilitated actuation of the different aspect of wing kinematics, including wing elevation-depression, pronation-supination, etc. The combination of an innovative wing driving mechanism coupled with high degree of freedom for actuation will bestow high flight control authority for micro-flying robots to tackle the control challenges posed inflight.

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Bioinspired Perching and Crawling Drones

Aerospace Engineering & Aviation Discipline

Project Description

Unmanned Aerial Systems (UAS) are the fastest growing sector of aviation with wide-ranging applications. Apart from flight there exists an urgent necessity for multi-role aerial robots. In spite of the rapid advancement in drone technology, there exist significant limitations including their inability to perform multiple roles. The development of aerial robots capable of diverse locomotion capabilities such as perching and crawling would further enhance their scope of implementation. From surveillance, reconnaissance and acting as communication relays during disaster recovery, the innovation potential and value of multi-role drones is evident. The UAS team in RMIT is uniquely positioned to tackle this challenge by combining advanced materials with drone technology to create bioinspired drones with extensive locomotion capability. This collaborative project will involve the integration of gecko-inspired dry adhesive technology to drones and develop an aerial robot prototype capable of autonomous non-horizontal surface landing, crawling and eventual detachment [1,2]. This can be particularly challenging since surfaces in the outdoor environment vary significantly in orientation, texture, contrast, etc. Therefore a perching drone require the capacity to initially identify landing surface subsequently perform a combination of flight maneuvers to enable safe attachment and detachment.

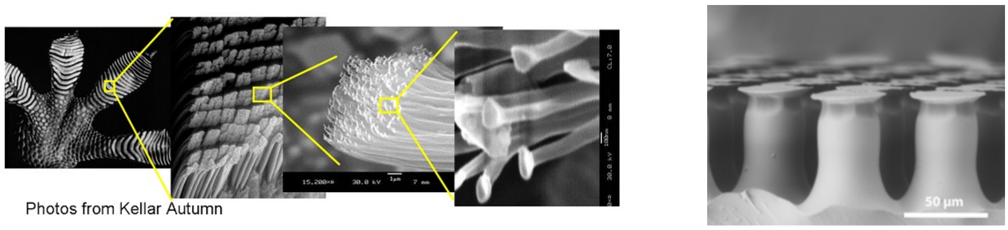

Fig 1. Microstructue of gecko setae showing attachment structures. Gecko inspired synthetic dry adhesive [2]

The aim of this project is to design and test flight control systems and maneuvers for quadcopter based drones to facilitate attachment, crawling and detachment from non-horizontal surfaces. Additionally the feasibility of drones quipped with bioinspired dry adhesives for crawling and scaling walls of different textures will also be explored. This will add to existing literature on mic that would result in journal and conference publications. The project will result in a prototype drone capable of perching, landing and safely detaching from vertical surfaces of different textures.

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Critical Packing Parameter Calculation Using Computational Approaches

Manufacturing, Materials and Mechatronics/Materials Modeling and Simulations group
City Campus

Project Description

This project aims to build a library of critical packing parameters for self-assembling amphiphilic materials using computational approaches. These materials have been a topic of intense interest due to their highly ordered nanostructures and potential use in drug delivery, medical imaging and membrane protein crystallization. [1] The driving forces for the self-assembly of amphiphilic molecules are the subtle interplay of the hydrophobic (solvophobic) effect, geometric packing (local) constraints and global constraints such as temperature, pH or pressure. The dimensionless shape parameter, known as the critical packing parameter (CPP), can provide a useful measure of the intrinsic shape of the amphiphilic molecule (local geometry) as well as the global geometry of the aggregation topology. CPP can be calculated using the following equation:

$$CPP = v/a_o l_c$$

where v is the volume occupied by an amphiphilic molecule, a_o is the effective headgroup area, determined by the balance of inter-chain attractive and headgroup repulsive interactions, and l_c is the effective length of the amphiphilic chain.
However, there is currently no comprehensive studies on how to accurately estimate CPP for many amphiphilic molecules using the same protocols to allow direct comparison of the packing behavior of different amphiphiles.

This project will involve performing molecular dynamics simulations using NAMD [2] for amphiphilic aggregates consisting of one single amphiphile as well as multiple types of amphiphiles to study the shape of these molecules in the aggregation and allow a systematical calculation of CPP. In addition, machine learning techniques [3] will also be employed to construct a mathematical model enabling the prediction of CPP values for other amphiphilic materials, eliminating the need for running lengthy molecular dynamics simulations.

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Artificial Intelligence for Developing Organic Solar Cells Materials

Manufacturing, Materials and Mechatronics/Materials Modeling and Simulations group
City Campus

Project Description

This project aims to build a new artificial intelligence tool for designing and developing novel materials for organic solar cells. These materials have drawn significant interest in recent years because they have desirable properties, including low cost of materials, high-throughput roll-to-roll production, mechanical flexibility and light weight. [1,2,3] However compared to other types of solar cells, such as perovskite, the current energy conversion efficiency of organic solar cells is still lower. A detailed understanding of the relationship between the molecular properties of the key components of the device as well as the processing conditions and their electronic properties is crucial. This project will employ machine learning techniques to identify significant factors affecting the electronic properties of solar cell materials and the efficiency of the devices. The techniques are also applied to elucidate the fundamental, underlying principles that govern the device characteristics such as the short circuit current (J_{sc}), open circuit voltage (V_{oc}) and the fill factor (FF). Such correlations are crucial to the design and synthesis of next generation materials to further improve the device efficiency.

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