Research thrusts and recent advancements in the modelling of helicopters during launch and Recovery Operations to Ships

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1. INTRODUCTION

The Defence Science and Technology (DST) Group within Australia's Department of Defence is devoted to applying science and technology to protect and defend Australia and its national interests. It delivers expert, impartial advice and innovative solutions for Defence and other elements of national security.

The Helicopter Systems Effectiveness (HSE) area within DST Group is dedicated to maximising helicopter safety and operational effectiveness in land and maritime operations. The core capabilities of the HSE group are:

- Development, provision, verification and maintenance of a range of rotary winged aircraft performance and flight behaviour models, for manned and unmanned platforms.
- Computational Fluid dynamic (CFD) modelling of ship airwake for various naval platforms and modelling helicopter aerodynamic characteristics.
- World-leading night vision lab to research aviation vision enhancement devices.

The development of flight models and CFD modelling are fundamental to the work performed within HSE group. Depending on the use of the flight model, different levels of model fidelity are produced. The flight models are used to support accident investigation, human-in-the-loop (HIL) simulation, slung load limit investigation and operations research activities carried out within DST Group. The airwake of the ship together with helicopter flight models has been extensively used to support First of Class Flight Trials (FoCFT) and investigate flight dynamic issues that are of major concern to Royal Australian Navy (RAN) when operating helicopters from ships.

To develop these models an extensive and detailed level of data is often required. Where data is lacking, HSE group generates data from a variety of sources and techniques that involves flight and technical documentation, DST Group low speed wind tunnel experiments, analytical modelling and estimation techniques, CFD modelling on DST Group advanced High Performance Computing (HPC) systems, flight and sea trials. With the increasing adoption of Unmanned Aerial Systems (UAS), HSE group is now incorporating UAS models into our core research activities.

This paper gives an overview of HSE group's capabilities and research undertaken for launch and recovery operations from naval platforms for rotary wing aircraft. The research outcomes can also be extended to support unmanned (rotary or fixed wing) applications. All research and development gains directly benefit the Defence's vertical lift capability through application of our improved modelling and simulation techniques.

2. LAUNCH AND RECOVERY RESEARCH

The provision of helicopter landing deck on naval ships significantly enhances the capabilities of maritime operations. However, operating a helicopter on the deck of a ship poses many challenges to its operators due to several factors and requires rigorous analysis. Prime amongst these is launch and recovery, which is the take-off and landing phases for aircraft operating from naval platforms. The complexity of helicopter-ship operation arises due to the coupling between ship airwake and helicopter downwash, including the effect of the atmospheric boundary layer (ABL), ship motion at various sea states and operations in degraded visual environments (DVE). To date, a FoCFT is still the best practice to determine ship-helicopter operating limits (SHOLs). To minimise the cost and practicality of covering every wind condition and sea state during a FoCFT, it is imperative to develop new experimental and numerical methodologies to simulate ship-helicopter operation accurately prior to the trial.

Figure 1: Helicopter launch and recovery on the Deck of LHD ship

With the advancements in computational and experimental techniques, several countries (including the US and UK) have attempted to develop SHOLs using a combination of computed airwake databases, often obtained using CFD codes; high-fidelity helicopter dynamic models; and high-fidelity simulators. It has been proposed by a number of researchers that high-fidelity piloted simulation might be one possible alternative [1], [2] and [3] - this method is known colloquially as a virtual SHOL. DST Group has attempted to use these same tools without a Human in the Loop (HIL) simulator to predict the potentially high risk conditions during launch and recovery operations from ships. In effect, the helicopter flight model is immersed in the ship airwake at various Wind Over Deck (WOD) angles and speeds to investigate what affect this has on the helicopter’s control and power margins. Simulation generated candidate SHOLs are now regularly used to optimise flight trials by providing information on critical operating conditions to target during the trial at sea. The candidate SHOLs are also used for the prediction of conditions not experienced during the sea trial. In DST Group, the modelling framework used to generate candidate SHOLs is called the CSHOL – Candidate SHOL.

There is currently a NATO led investigation underway looking at the differences between the various methods employed by different nations. DST Group, together with a number of other partners within NATO, are currently conducting research to find ways to improve upon the advice for FoCFTs and investigating how modelling and simulation could reduce the dependence on sea trials for the generation of a SHOL. However, it has yet to be demonstrated that this combination is able to adequately reflect the results obtained during a FOCFT. Some of these techniques are listed in Table 2. The green column in Table 2 refers to the DST virtual SHOL tool – CSHOL.

Table 2: Classification of integrated modelling and simulation methods used by different nations (reproduced from the NATO AVT-315 report)

	Flight simulation methods				Experimental methods	
	Real-time	**Desktop (Piloted)**	**Desktop (Non-Piloted)**	**Desktop (UAV)**	**Wind/water tunnel**	**Flight test + wind tunnel**
Aircraft	Flight dynamic model	Flight dynamic model	Flight dynamic model	Flight dynamic model	Physical model	Aircraft
Airwake	CFD model	CFD model	CFD model	CFD model	Physical model	CFD/Physical model
Controller	Human pilot	Software controlled pilot model	Prescribed trajectory or fixed in space	UAV Controller	Prescribed trajectory or fixed in space	Human pilot
Deck motion	Simulated	None[1]	None	Simulated	Physical model	Physical model
Measured quantities	• Pilot ratings • Control margins	• Control margins • Control activity • Landing accuracy	• Forces • Moments	• Control margins • Control activity • Landing accuracy	• Forces • Moments	• Land based control margins
Derived quantities		Pilot ratings	Pilot ratings		Pilot ratings	Ship based control margins
Example tools	VirtualSHOL (UK,US)	DST CSHOL				SHOL-X (Aeromath)

3. DST GROUP VIRTUAL SHOL TOOL - CSHOL

Prior to the introduction into service of a new aerial system (helicopter or UAS) or ship type, the RAN has a requirement to certify the specific helicopter-ship combination for operations. Part of this certification includes the determination of the SHOLs via a FoCFT. This testing is the responsibility of the Aircraft Maintenance and Flight Trials Unit (AMAFTU). The SHOLs indicate the safe operating limits in the conduct of naval aviation operations. One of the many risks associated with helicopter-ship operations is the interaction between the rotor system and the turbulent airwake in the vicinity of the ship. This is especially true during launch and recovery, when aerodynamic loading of the rotor system can be considerably altered by the passage through an eddy or a region of cross-flow. The changes in rotor loading can affect the aircraft control and the power margin for a safe landing. To reduce the risks associated with the turbulent ship airwake, prior to a FoCFT, AMAFTU, generally, requires an indication of the airwake characteristics in the vicinity of the helicopter deck. This information is used to help determine the WOD angles and wind speeds that may cause aircraft controllability problems during launch and recovery.

In the past, DST Group has provided the ship airwake information to AMAFTU derived from wind-tunnel tests [4]. These tests would usually take the form of smoke flow visualisation, which give indications of turbulent or disturbed air around the ship in question. In more

[1] DST Group currently does not have the capability to include the effect of ship motion in the CSHOL simulation; however, there is a plan to include this in the future.

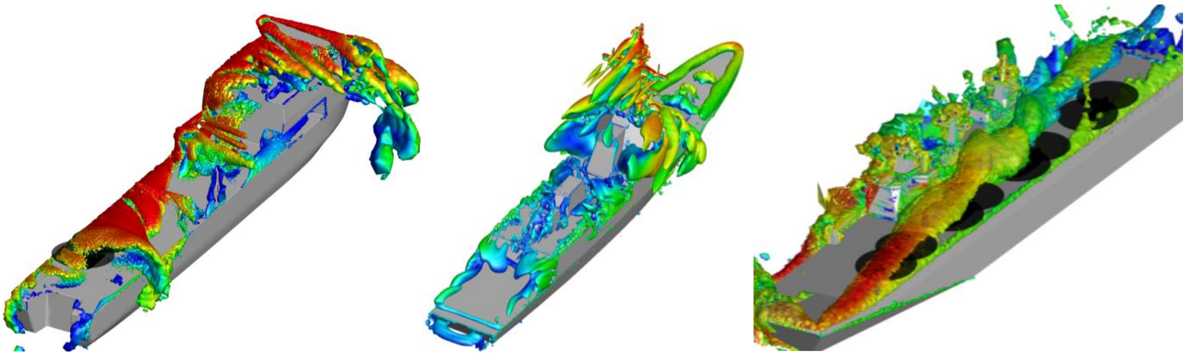

Figure 2: Example of few CFD ship airwake from DST Group database

recent years, DST Group has been using a combination of Computational Fluid Dynamics (CFD) as well as wind-tunnel tests [5], [6] and [7]. This led to the development of an extensive database of ship airwake for various naval vessels (see Figure 2). On these occasions, the CFD results have been able to provide more detailed information, such as wind speeds in the airwake (including the variation with time). The wind-tunnel tests are now being used more for the validation of the CFD results.

The acquisition of a database for ship airwake as well as significant experience in the development of flight models and control systems played a vital role towards the development of CSHOL. CSHOL now is DST Group's key modelling capability to produce candidate SHOLs for the RAN. The architecture of the CSHOL tool presented in Figure 3 indicates that a high fidelity flight model of a candidate helicopter (or UAS) is embedded into the time-dependant wake of a given ship. The tool then uses a virtual pilot to conduct an approach and landing to the given ship. From the simulation a number of parameters can be used to help determine the candidate SHOL. These parameters include: pilot controls (limits and variability), accuracy of flight path and landing position. Unlike a piloted simulation, the virtual pilot has the advantage of repeatability, which, in turn, allows this method to properly compare numerous parameters that may affect the SHOL. These parameters can include: variation in wind direction and speed, landing position, approach path, hover height and duration. The virtual pilot can also be 'tuned' to follow the desired path as aggressively as required.

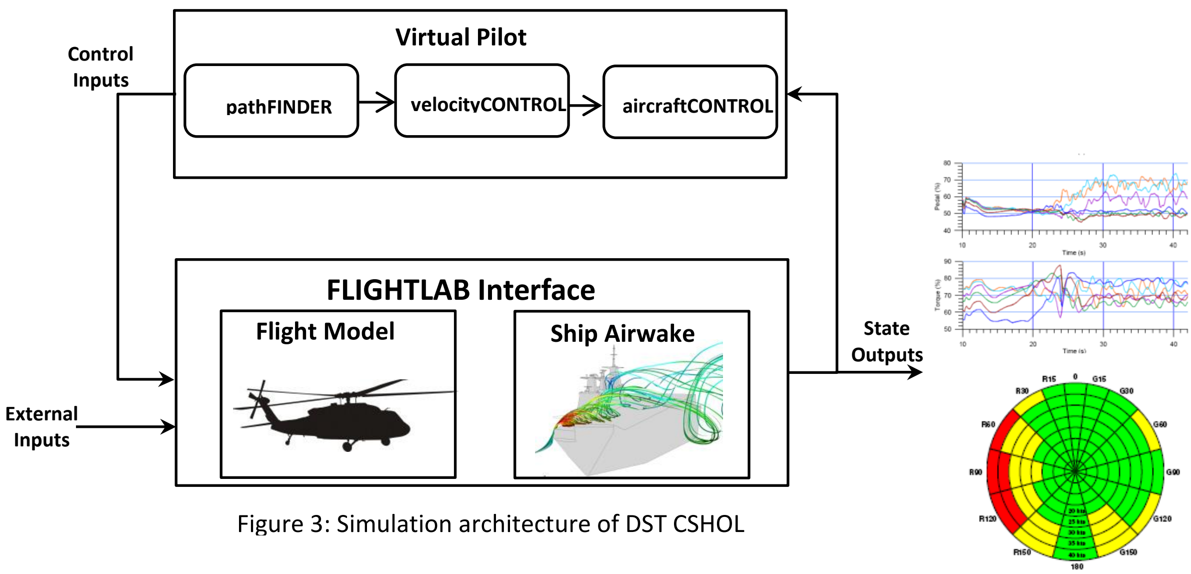

Figure 3: Simulation architecture of DST CSHOL

The superposition of the airwake and simplification of ship motion and sea state effects on airwake has served the DST and RAN reasonably well, guiding and optimising at sea flight trials to problematic areas of the SHOL. The current simplifications offer some scope to greatly reduce the sea based flight trials. Over the coming years, RAN will commission new vessels, many that will have manned helicopters operating from them, along with a range of UAS platforms. The need for reliable modelling and simulation based launch and recovery limit production is greater than ever.

3.1. CSHOL Applications and Challenges

ADF expects to operate every helicopter at sea including Army helicopters. This is unique to Australia. Operating Army helicopters that are not built for maritime environment poses several other challenges. CSHOL has been successfully used to provide advice to RAN by performing risk reduction studies for various Army and Navy helicopters operating on a variety of naval platforms. Some of the areas investigated include different approach and flight pathways to landing on a ship using an autopilot, on-spot engagement and disengagement simulation for issues such as blade sailing [8] and mast bending [9]. Blade sailing is a phenomenon where a helicopter blade experiences excessive flapping motion, which can lead to undesirable consequences and limit the operational capability of the helicopter. Mast bending moment is a result of a rotor system that has less lag in control response because of the large hub moment typically generated due to flexing of blades in the absence of hinges.

A key challenge has been the accurate representation of the ship-helicopter dynamic interface, in particular the fluid dynamics of the ship air wake and the interaction with the helicopter. To date, Defence along with other Naval Aviation operating countries, have modelled the ship air wake, obtained through trials, CFD or wind tunnels, with no coupled interaction of the helicopter's air wake. Typically, the combined air wake is a superposition of the two independent air wakes at any point of interest. Another key factor commonly left out of the ships airwake modelling is the ship motion and sea state. The ship's airwake is commonly anchored at the ships centre of gravity and ship roll and pitch set to zero. DST group has started research programs internally and with our university partners to begin to address the key deficiencies of the SHOL production problem. These are discussed in the following section.

3.2. Enhancement of Existing Capability via Collaborations

3.2.1 Coupled CFD ship and helicopter

One of the more difficult aspects of simulating the helicopter-ship interface is the accurate modelling of the interaction of the rotor aerodynamics into the environment. In the past, researchers have tackled this problem in one of two ways. The first is to simplify the model by de-coupling the interaction between the rotor down-wash and the ship airwake. This increases the speed of the simulation to the point where simulations can be conducted in real time; however, it is done at the expense of model fidelity. The second is to model the helicopter and ship wake interaction using high-fidelity CFD simulation typically requiring multiple days to run on a supercomputer.

The University of Sydney, in collaboration with DST Group, has developed a computationally efficient tool for the simulation of ship-helicopter dynamic interface. The numerical

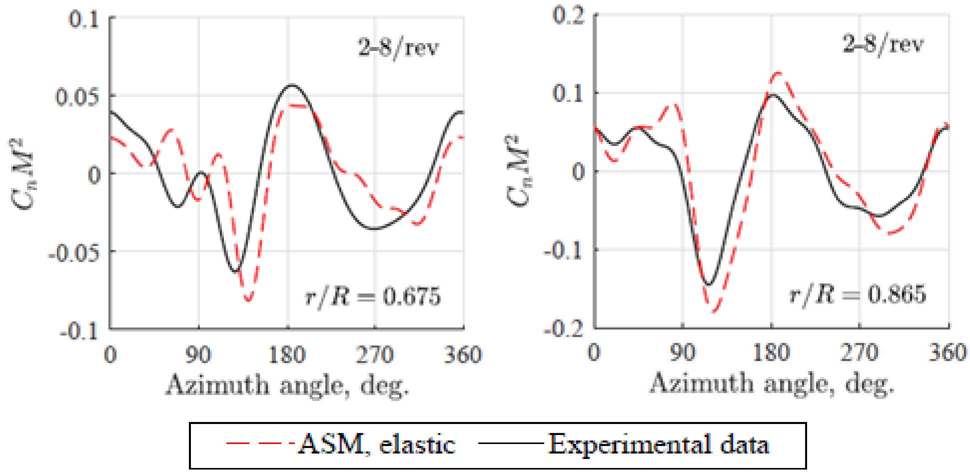

Figure 4: 2-8/rev vibratory components of normal force coefficient as a function of azimuth angle at two spanwise stations on the UH-60A rotor in forward flight at an advance ratio of 0.368. ASM simulation results compared to experimental data.

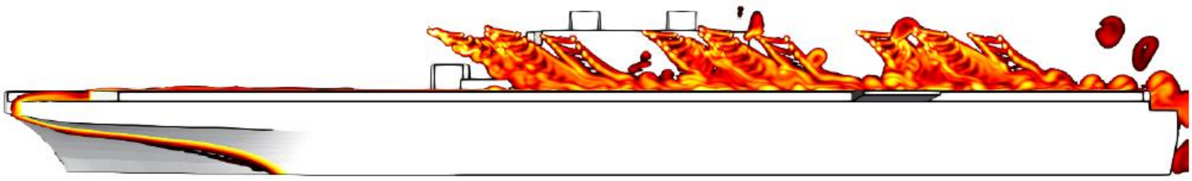

Figure 5: Vorticity magnitude on a plane through the port landing spots on the LHA ship with three tandem rotor helicopters

simulation uses a hybrid approach by utilising detached eddy simulation (DES) for ship airwake and actuator surface method (ASM) to model helicopter rotor. The savings from this hybrid method derive from the substitution of the rotor blade geometry for distributions of momentum source terms added to the Navier-Stokes equations in the vicinity of the blades. With such a hybrid method there is no need for the computational grid to resolve the geometry of the rotor, thus saving grid points and removing the need for overset grids, sliding planes, and grid deformation. Setup and configuration of ship-helicopter dynamic interface simulations are also significantly simpler when using a hybrid method, again due to the removal of the rotor blade resolving grid. Further details on the implementation of ship airwake and rotor model can be found in [10]. The Hybrid ASM has been validated against a number of scenarios ([3], [11]) and shows great promise going forward. Examples of some of the studies include comparisons with the X2, S-76, UH-60, and CH-47B. An excellent agreement was found between the ASM simulation and experimental data for the case of UH-60A rotor in forward flight (see Figure 4).

The hybrid ASM simulation tool has been developed with the objective of making studies of concurrent or adjacent rotorcraft operations over a range of operating conditions accessible, while still retaining the ability to assess unsteady rotor loads which may influence pilot workload. The simulation has shown a good potential of investigating concurrent operations of helicopters by capturing promising aerodynamic interactions for the case of three tandem rotor helicopters operating simultaneously on the flight landing deck of the Landing Helicopter Assault (LHA) ship. The partially developed vorticity field in Figure 5 shows the flow field at a particular WOD condition dominated by the rotor wakes. The tool can be further used to investigate other factors such as sea states, ship motion and atmospheric boundary layer. Additionally, this concept can also be extended to the helicopter formation flight issues which are heavily dependent on rotor-rotor coupled airwake interaction. While the preliminary simulation of dynamic interface served as the proof of concept, full potential of the tool is yet to be explored for the Defence specific naval platforms with various helicopter combinations.

3.2.2 Characterisation of Ship Motion and Sea State of Ship Airwake

Another major limitation of current ship-helicopter dynamic interface analysis comes with the assumption (typically due to reduce complexity) that the ship airwake is not affected by ship motion. However, the research on ship hull design and its influence on seakeeping characteristics anticipate that the ship motion and sea state impart energy into airwake which could affect seakeeping performance of a ship, especially for rough sea states. This could result in a time lag between ship motion and airwake response. Therefore, it is important to consider motion-induced effects on the airwake for dynamic interface modelling [12].

DST Group in collaboration with the University of Melbourne is working on developing a unique experimental capability to investigate the effect of ship motion and sea state on ship airwake. An extreme air sea interaction (EASI) facility (see Figure 6 for schematic and actual facility) located at the Department of Mechanical and Manufacturing Engineering, previously used as a hybrid tow tank and/or wind tunnel is now being utilised to investigate the influence of ship motion, ABL and waterline on ship airwake and its effects on helicopter landings. The facility has dimensions of 60 x 2 x 2 m (length x width x height) and the water is filled to a depth of 1m. The freestream velocity is controlled and monitored remotely and the pressure gradient of the facility can be controlled using an adjustable ceiling. Underwater optical access is available through a viewing window measuring 1.5 x 1.0 m (width x length) located at 20 m away from the upstream end of the tank for the purposes of optical technique based experiment apparatus such as Particle Image velocimetry (PIV) or Laser Doppler Velocimetry (LDV) systems. Current activity involves investigation of air-sea interaction, ABL and ship motion on generic platforms such as simple frigate ship (SFS2) and NATO generic destroyer (GD) ship. This work is in initial stages and results of this research outcome will be part of a NATO report.

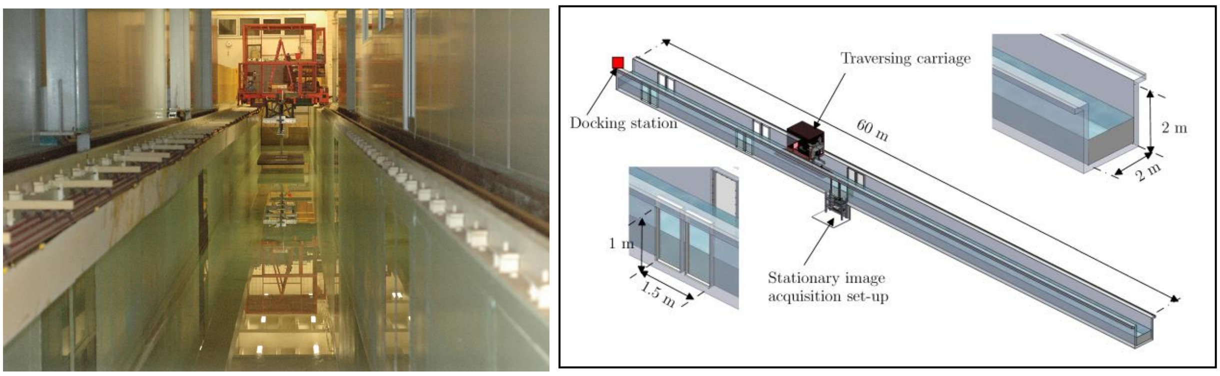

Figure 6: Extreme Air Sea Interaction (EASI) facility at the University of Melbourne

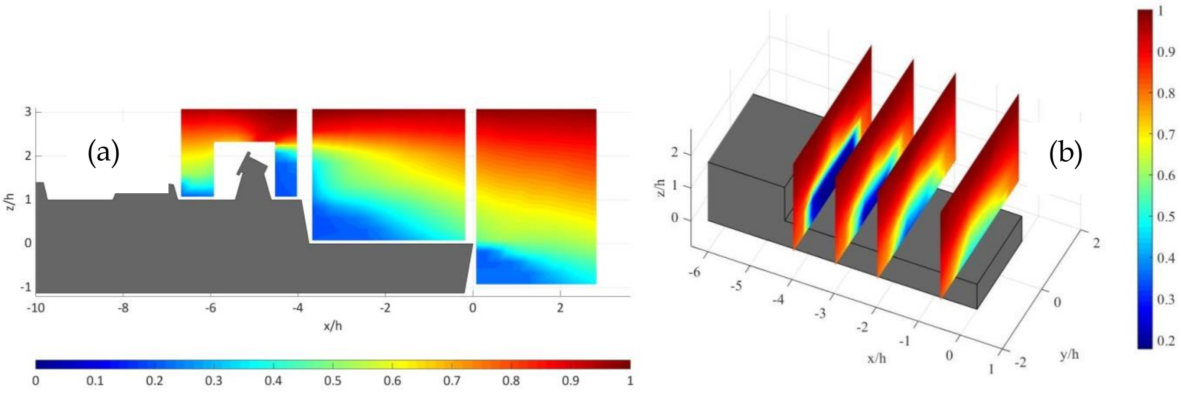

Figure 7: Normalised velocity contours over (a) NATO-GD and (b) SFS2

Some preliminary measurements using cobra probe and PIV were completed recently to validate ABL and turbulence intensities in a wind tunnel. Figure 7 presents the averaged velocity contours normalised over free stream velocity on the flight landing deck of SFS2 and NATO-GD. Next phase of the work will measure airwake on the landing deck due to prescribed motions, ABL and waterline. The results of this activity can be used to validate CFD simulations and can also be extended to Defence specific naval platforms.

4. SUMMARY

DST Group has been involved in launch and recovery research for 25 + years. The research has included investigation of alternative landing systems [13], maritime helicopter handling qualities standards [14], generation of candidate SHOLs with and without human in the loop simulation, mast bending, blade sailing, on deck modelling, Night Vision Goggles operations and crash investigation. Of the research activities listed above, the major activity has been production of candidate SHOLs. Over many years of collaboration with military research partners through The Technical Cooperation Program (TTCP) and NATO working groups, the augmentation of flight trials with modelling and simulation has greatly assisted the generation of SHOLs [15]. Our research has clearly shown that the airflow generated around a ship, from the hull and superstructure, can generate significant eddies and volumes of cross flow in the region of the flight deck. These flow regions can reduce the performance margin of a loaded helicopter or a UAS system. These factors, coupled with others such as pilot visual cues can lead to significant operational constraints that limit the ability to utilise the helicopter as part of the weapon system. Not being able to have a ship borne aerial system in the air significantly reduces the offensive and defensive capabilities of the naval system. Our research and advanced models ensure DST Group capability to support ADF safe and efficient ship-helicopter operations for current and future naval platforms.

5. FUTURE THRUSTS

With adoption of UAS platforms, we are increasing research to ensure full exploitation of the capabilities from naval platforms. The UAS platforms allow an increased ability to upgrade systems to meet changing threat environments at a far shorter development and acquisition cycle than traditional manned systems.

Application of the techniques applied in this paper to UAS platforms introduces a range of nuances, particularly when considering small scale UAS vehicles. As a vehicle becomes smaller relative to the dominant turbulent airwake structures, the demands on controllability and control power become increasingly significant. This influences the requirements for the ship airwake CFD solution and the fidelity constraints of the flight dynamic model.

Additionally, as human piloting demands reduce from high bandwidth attitude and trajectory control to basic navigation control or autonomous operations, the demands on the vehicle flight control system increase in consequence – the most relevant factor being disturbance rejection. Disturbance Rejection refers to the ability of the vehicle to reject external disturbances, either through dynamics inherent in the vehicle design or through active control from the vehicle flight control system. In order to simulate the vehicle performance in the CSHOL scenario, it is essential to develop a good understanding of its disturbance rejection characteristics and how these interact with the turbulence environment (this is akin to tuning the virtual pilot model in the manned helicopter scenario). This will be conducted through a combination of linear analysis of flight test results and non-linear studies involving the coupled CFD and flight dynamic model solution. As an extension of this work, DST Group is embarking on a resilient flight work program, focussing on establishing methods for robust control of autonomous unmanned vehicles in challenging aerodynamic environments including maritime operations. This study aims to facilitate comparisons between classical control techniques, non-linear adaptive control, and modern 'AI' inspired control strategies, to inform the development of future UAS platforms with superior performance in dynamic environments such as helicopter ship operations.

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