THE EFFECT OF SHIP SIZE ON AIRWAKE AERODYNAMICS AND MARITIME HELICOPTER OPERATIONS

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Abstract

This paper describes an investigation that has used piloted flight simulation to assess pilot workload while manoeuvring a helicopter over the landing decks of three different size, but similar, ships. Three generic ships with lengths of 100m, 150m and 200m were created to be representative of the range of size of single-spot ships that operate with maritime helicopters. Ship airwakes were produced using unsteady CFD simulations for a range of free stream wind speeds from 20 knots to 50 knots for a headwind and Green 45° Wind Over Deck. To reduce the numbers of expensive and computationally intensive airwakes that have to be produced for simulated deck landings it has been demonstrated that for a given wind angle it is possible to Strouhal-scale the airwake velocities from one representative wind strength to other wind strengths, and from one ship size to another ship size with accuracies which are considered acceptable for their implementation within a flight simulator.

Simulated deck landing trials for each of the three ships were used to provide subjective pilot workload ratings. It was found that the pilot workload generally increases with the ship size and that, despite the landing area being larger and the superstructure proximity being less threatening, the more aggressive airwake from the larger ship still makes the aircraft more difficult to control over the larger ship.

1. INTRODUCTION

The operation of maritime helicopters to naval vessels at sea is often a difficult and dangerous task for the pilot[1,2]. Along with the restricted landing area and the rolling, pitching and heaving of the ship's deck the pilot also needs to contend with the turbulent wake produced by the air flow over the ship's superstructure. This turbulent airwake is a product of both the ship's forward speed and the prevailing wind conditions. In recent years the topside design parameters for modern frigates have been strongly influenced by the requirement to reduce radar cross section, leading to less cluttered 'slab-sided' ships where the superstructure can be considered to be comprised of a number of bluff bodies. As the air flow separates from the sharp edges of the superstructure it creates a highly complex airwake containing steep velocity gradients and unsteady turbulent structures which can adversely affect the aerodynamic loads on a helicopter operating within the flow. The nature and severity of the airwake will vary with both the speed and azimuth of the Wind Over Deck (WOD). As the relative angle of the wind moves from a headwind towards more oblique angles, the flow becomes increasingly complex with large vortical structures being shed from the windward horizontal upper edges of the hangar and deck, and a strong vertical shear layer forms obliquely across the deck, emanating from the windward vertical hangar edge.

As the pilot manoeuvres through the turbulent airwake during an approach to the flight deck, there will be large perturbations in the aerodynamic loading and response of the rotor due to the highly unsteady velocity fluctuations, particularly those in the closed-loop pilot response frequency range of 0.2 to 2 Hz[3]. Disturbances within this frequency range have been shown to have the greatest impact on the pilot's workload[4].

On encountering a disturbance to the aircraft, the pilot will react by implementing control inputs to correct changes in altitude, attitude and heading. Therefore the geometric design of the ship superstructure can have a significant impact on the pilot workload, particularly when operating in close proximity to the ship during launch and recovery to the flight deck.

The demanding nature of ship-helicopter operations means that each ship and helicopter combination is subject to its own specific Ship-Helicopter Operating Limits (SHOL), as shown in Figure 1. Each SHOL denotes the safe operating conditions based on a

WOD speed and azimuth, with the terminology Red and Green referring to winds approaching from the port and starboard side of the ship respectively.

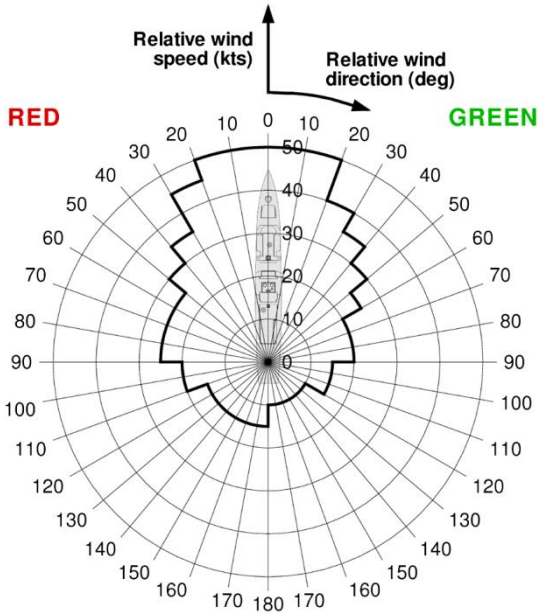


Figure 1 Typical SHOL diagram for a helicopter operating from a frigate

SHOLs are normally determined during the ship's First Of Class Flight Trials (FOCFT) and are inherently costly and dangerous to carry out, requiring aircraft to be flown to the limits of what is considered safe, and often beyond the capabilities of the average fleet pilot. Due to these shortcomings associated with the FOCFTs, considerable research has been conducted, at the University of Liverpool and elsewhere, into using flight simulation to support, or possibly replace, SHOL testing[5,6,7].

Over the past fifteen years the Flight Science and Technology Research Group at the University of Liverpool have developed rotorcraft flight simulation research facilities with the over-arching aim of improving the fidelity of flight simulation, with particular attention being paid to the helicopter-ship dynamic interface. Much of this work has involved the use of the HELIFLIGHT-R motion-base flight simulator, shown in Figure 2[8]. The simulator features a three-channel 220° x 70° field of view visual system, a six degree of freedom motion platform, a four axis control loading system and has an interchangeable crew station. As well as the usual simulation environment, i.e. visual and aural cues, full motion, and aircraft flight mechanics models, an unsteady CFD-generated airwake is also provided to disturb the aircraft when it is within the ship's airwake[7-10].



Figure 2 The HELIFLIGHT-R motion base simulator as used at the University of Liverpool

Using piloted flight simulation, Forrest et al[11] compared the simulated SHOLs of the UK's Type 23 naval frigate and the Wave Class oiler. It was found that although the oiler has a much larger deck area it had a more restricted SHOL than the Type 23 frigate due to the larger turbulent flow structures shed by the larger superstructure. The increased energy contained within the turbulent flow of the oiler in turn increased the level of pilot workload. Although the two ships were substantially different in shape, the conclusion was that larger ships created more problematic airwakes.

Building on this conclusion, the current study has investigated the effect of ship size on the airwake over the deck, and its impact on the helicopter and on pilot workload during a landing task; three geometrically similar ships of different sizes have been used. As indicated above, the airwake from the larger ship can be expected to provide greater disturbances to the aircraft, but the larger deck may be easier to land to. Current naval ships routinely operating helicopters can be as small as half the size of a conventional frigate, for example the Knud-Rasmussen class patrol vessel operated by the Royal Danish Navy with a length of 71m, Figure 3, and the similarly sized River Class patrol vessel in service with the UK Royal Navy. The small size introduces further challenges to pilots in that they are often asked to operate much closer to the superstructure of the ship during launch and recovery than they would be expected to on a larger ship.

Producing unsteady full-scale CFD simulations of the ship airwake is extremely computationally expensive and time consuming, taking several days to compute the unsteady data required for implementation within the flight simulator. The present study has therefore also explored the

feasibility of computing an airwake, for a given WOD, for one ship size, and scaling it to another ship size using Strouhal scaling.



Figure 3 Knud-Rasmussen Class Patrol vessel[12]

2. SHIP AIRWAKE SCALING

To investigate the effect that ship size has on the level of pilot workload during a deck landing, a generic ship model was created to be representative of a modern, single-spot naval frigate of 150m length and 20m beam. This ship model was then scaled up and down to create two further ship models that were 200m and 100m in length, Figure 4. The airwakes for each of these three ship sizes were used to provide comparative data to (i) demonstrate the feasibility of Strouhal-scaling the airwake, and (ii) to investigate the consequences of a change in size on helicopter operations and pilot workload.

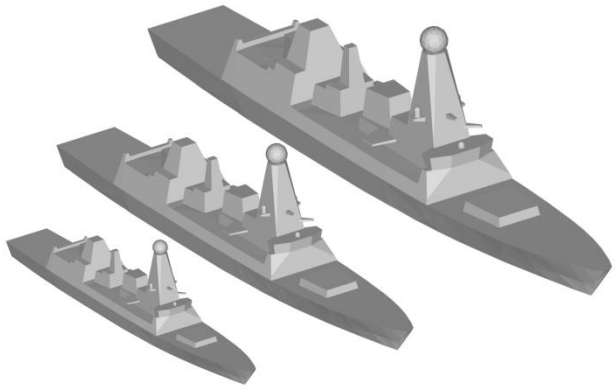


Figure 4 The generic naval frigate geometry and the range of ship sizes used for this study

The scaling of airwake data involves the use of the Strouhal number, shown below in Equation 1. The vortices shed from bluff bodies within a flow are created at distinct frequencies which can be described by the Strouhal Number (Reynolds number dependence is acknowledged, but is known to be less important at high values and for sharp-edged bodies). Strouhal number relates the characteristic length of a bluff body, l, the flow speed v, and the frequency f of the vortices shed from the body. This simple relationship shows that for an increase in free stream speed there will be a proportional increase in shedding frequency, and for an increase in length scale there will be a proportional decrease in frequency. While this may be obvious for vortex shedding at a single frequency, the principle can also be extended to more complex shedding from the multiple bluff bodies that make up a ship's superstructure.

$$St = \frac{fl}{v} \qquad (1)$$

The scaling of airwakes in terms of velocity magnitude has been previously carried out by Polsky[13] who showed that the linear scaling of the airwake magnitude was possible. Further observations by Zan[14] "noted that the airwake should be shifted in frequency content as well as the velocity magnitude due to the large scale turbulent structures within the ship airwake which are the result of flow separation. In order to use Strouhal scaling to modify the airwake data, for example to change the airwake in terms of velocity magnitude from a free stream of 40 knots to 20 knots, the velocity components and frequency spectra are simply halved. Using this approach, Hodge et al[8] showed that the Strouhal scaling of CFD airwake data from 40 to 30 knots, in both frequency and velocity magnitude, gave good results when compared to a computed 30 knot airwake.

3. CFD METHODOLOGY

Ansys Fluent CFD software with Detached Eddy Simulation turbulence modelling was used throughout this study.

3.1. Geometry and Meshing

The ship models were imported into the mesh generation software Ansys ICEM, so that it could be 'cleaned' to repair unsuitable surfaces and to remove small features to create geometries suitable for meshing. Features such as small antennae, railings and other small deck clutter would have little effect on the airwake but if not removed would increase the cell count and hence the run time of the CFD; generally objects less than 0.3m in diameter were removed.

The final 'cleaned' ship model was then placed within a cylindrical flow domain, shown in Figure 5; this style of domain allows the relative WOD angle to be varied through 360° by changing the magnitudes of the x and y free stream velocity components of the flow, without having to change the computational domain. The orientation of the domain is such that the x-direction is in line with the longitudinal axis of

the ship, while y is the lateral direction.

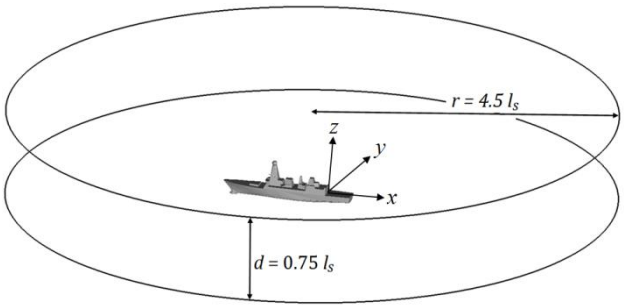


Figure 5 Computational flow domain for a ship of length l_s

An unstructured meshing approach was used for this study, which suits the Detached Eddy Simulation turbulence model (DES) well due to the near isotropic nature of the tetrahedra away from the walls[15]. The mesh was generated by first creating a surface mesh, from which a Delauney volume mesh was then grown. The surface mesh size on the ships was set to 0.05 times the hangar height and the growth of the volume mesh was controlled using an expansion ratio of 1.2 so that a smooth transition occurred away from the ship's surfaces.

Areas of particular interest within the volume mesh, such as immediately above the flight deck, were refined using regions of dense mesh within the volume to control the cell size and provide better resolution of the turbulent structures within the wake. Several layers of prism cells were grown from both the ground plane and the ship's surface into the volume mesh to resolve the boundary layers. These techniques allow better resolution of the vortical features shed from the ship and ensure the velocity distribution within the atmospheric boundary layer profile was modelled correctly. The surface mesh over the sea can be seen in Figure 6. The number of cells for each volume mesh was typically around 15 million.

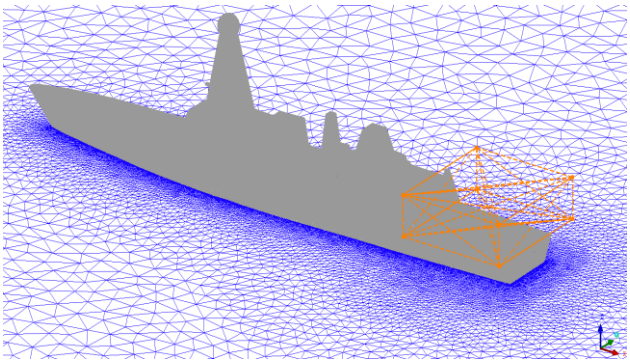


Figure 6 Surface mesh, note the region of dense mesh over the flight deck

3.2. Boundary Conditions

The surface of the ship was modelled as a series of walls with a zero-slip condition so allowing for boundary layer formation. The sea surface was also set as a wall but with zero shear stress, as this allows the specified atmospheric velocity profile to propagate unchanged through the domain. The top of the computational domain was set to a symmetry condition, which assumes there is zero flux across the boundary while specifying a zero shear condition.

The outer circumference of the domain was set as a 'pressure far field' which models the free stream conditions to infinity. This boundary condition requires that the free stream Mach number is defined along with the components of the flow direction.

An Atmospheric Boundary Layer (ABL) was applied within the CFD using the power law given in equation 2.

$$\boldsymbol{V = V_{ref}\left(\frac{z}{z_{ref}}\right)^{\alpha}} \qquad (2)$$

Where V_{ref} is the velocity at the reference height z_{ref}, and α is a constant dependent on the surface roughness. The following values, defined for a sea surface, were used within the simulations: V_{ref} = 50 knots, z_{ref} = 200m, α = 0.13[16]. The free stream wind conditions led to a nominal 40 kt wind speed at the ships' anemometer height.

Adding an ABL has been shown to be essential to creating the correct airwake, but it should also be noted that to obtain complete dynamic similarity between the flows over the three ship sizes, the inlet velocity profile should also be scaled. However, scaling the ABL is not realistic as it does not change with ship size. Therefore, to explore the effect of applying the same ABL to the three ship sizes, airwakes were also computed for a uniform inflow (i.e. no ABL) so achieving the correct conditions for dynamic similarity between the three cases.

3.3. Computational Methods

Second order-discretisation was used in time and space, and a blended upwind-central differencing scheme was used for the convective terms. Pressure-velocity coupling was resolved through use of the Pressure-Implicit with Splitting of Operators (PISO) scheme.

3.4. Turbulence Modelling

Since DES is a 'time accurate' CFD method, having been developed to resolve the flow separation from large bluff-bodies at high Reynolds numbers, it is

very well suited to computing the flow around the superstructure of a ship. DES CFD turbulence modelling has the advantage of resolving the medium to large scale turbulent structures explicitly, thereby allowing the unsteady airwake to be captured fully.

3.5. General CFD Approach

The approach used to produce the time-accurate unsteady CFD simulations initially involved the generation of a steady-state solution by performing 1000 iterations. The results from the steady-state flow field were then used as the initial conditions for calculating the unsteady flow field. The unsteady solver was activated in DES mode and the simulation was carried out at 100Hz. First, 1500 time steps were computed to allow the transition from steady state to unsteady to develop fully. These initial time steps were then discarded after which a further 3000 time steps were computed, while sampling data every fourth time step to produce data for later post-processing and use within the flight mechanics modelling software, FLIGHTLAB. The development of the CFD technique and its validation against experimental data has been reported by Forrest & Owen[15].

3.6. Airwake Processing for Flight Simulation

Each CFD simulation produces thirty seconds of unsteady CFD data, generated on a high density, unstructured mesh. Due to memory constraints when running real-time piloted simulations the computed airwake data requires post-processing before it can be used within FLIGHTLAB. Reduction of the airwake data size is undertaken by first sampling the 100Hz data at every fourth time step and then by interpolating the unstructured CFD data onto a structured mesh using a grid spacing of 1 metre, covering a region of interest around the flight deck of the ship. Once interpolated, the individual airwake files are re-formatted into a pair of data files containing the airwake data and grid information so that the co-ordinate axes of the CFD data match those of FLIGHTLAB. The 30 second airwake data was looped smoothly for the duration of the flight test.

The FLIGHTLAB Generic Rotorcraft model used for this research was configured to be representative of the Sikorsky SH-60B Seahawk, a maritime development of the widely used UH60 Black Hawk. The model is constructed from a set of modular components such as the rotor, fuselage and turbo-shaft engine. The unsteady, interpolated airwake data is integrated into the helicopter flight mechanics model by applying the time varying velocity components to the aircraft via a number of Airload Computation Points (ACP) which are located at various points along each rotor blade, fuselage, tail rotor and empennage, Figure 7.

FLIGHTLAB includes a dynamic inflow model and also accounts for the downwash from the rotor. However, the interaction between the airwake and the rotor model is not fully coupled, i.e. it is 'one-way', such that the helicopter is affected by the airwake, but the rotor downwash does not interact with the airwake.

A comprehensive description of the simulated SHOL testing process can be found in Reference 9.

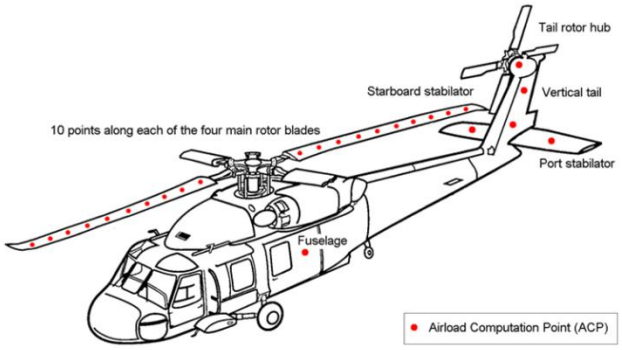


Figure 7 Location of the ACP's used on the SH60-B helicopter model in FLIGHTLAB

4. RESULTS

4.1. Airwake Scaling on Velocity Magnitude

For the medium sized ship, headwind WOD cases were computed at free stream speeds (V_{ref}) of 50 and 20 knots to allow velocity scaling to be carried out and compared.

Figure 8 shows the results of scaling unsteady velocity data from 50 knots to be representative of 20 knot data, alongside the computed 20 knot data, using power spectral density (PSD) plots. The point in the flow field at which the velocities were extracted from the CFD is at hangar height above the landing spot. While the data do not exactly overlie in the central region of the PSD, the scaling can be seen to be reasonably good, capturing the shift in both frequency and power. The scaled velocities are considered suitable for representing the airwake in the FLIGHTLAB flight simulation software, thus confirming the observation of Hodge et al[8] that it is not necessary to compute airwakes for all free stream velocities; for a given wind direction they can instead be computed for one velocity and scaled in magnitude and frequency for other free stream velocities.

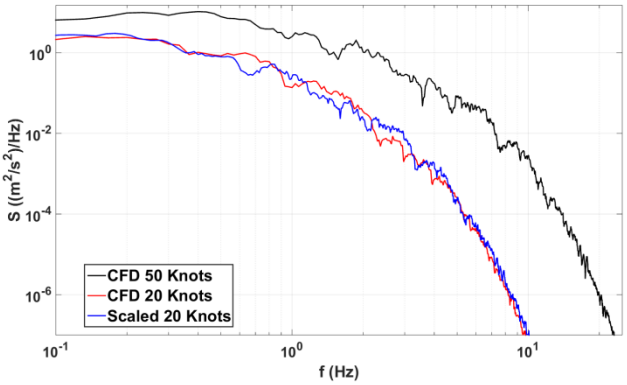


Figure 8 Power spectral densities of the total velocity for the computed 50 and 20 knot data and the scaled 20 knot case

4.2. Airwake Scaling on Characteristic Length

Having confirmed the velocity spectra scaling based on a characteristic velocity, the next step was to demonstrate the scaling of velocity spectra based on characteristic length, or ship size. As before, the velocity PSD was extracted from the CFD at a point above the landing spot at hangar height, in a headwind. The airwakes were computed for the large and small ship, and then the velocity PSD for the large ship was scaled to represent the small ship, and the computed and scaled PSDs were then compared to judge the effectiveness of the scaling.

Figure 9 shows the velocity data and scaling comparison for the case when the ABL was applied; the free stream velocity was 50 kts, which is equivalent to 40 kts at the anemometer height. Despite the lack of dynamic similarity due to the ABL not being scaled, the scaling of the velocities from the large ship to the size of the small one does produce a reasonably representative velocity PSD.

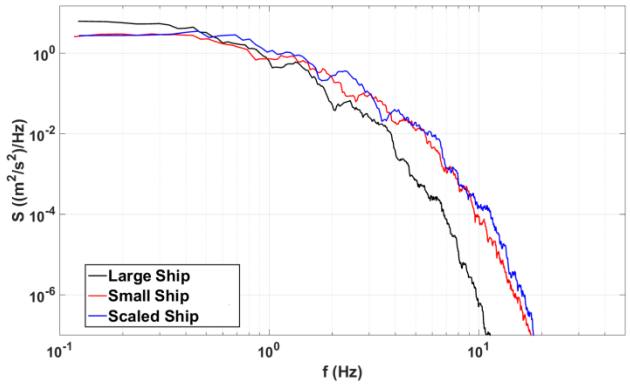


Figure 9 Power spectral densities of the total velocity for a headwind WOD using an ABL, showing computed data for the small ship compared with the data scaled from the large ship

In Figure 10, the same comparison is made but this time with a uniform inlet velocity profile (UBL) of 40 kts, so that it matches the previous inlet velocity at anemometer height. It can be seen that there are differences in the comparisons for the uniform and atmospheric profiles, but the magnitudes of the differences between the computed and scaled PSDs are similar. At this stage in the research it is not certain that airwakes can be simply scaled between similar ships of different sizes to be used in flight simulation, but it looks promising.

Although not reported in this paper, similar PSD comparisons have been made at different locations within the airwake, and for different wind angles; equally good comparisons between scaled and computed data were found for both velocity-based and size-based scaling.

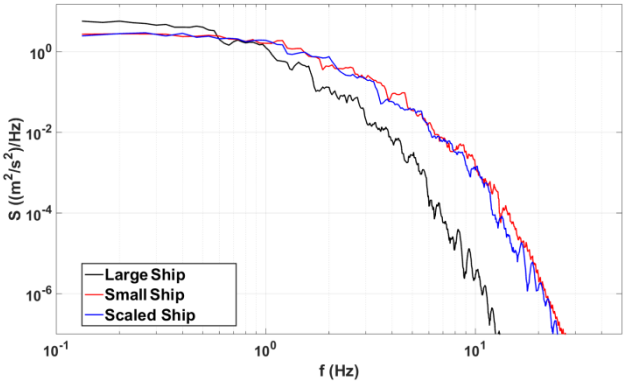


Figure 10 Power spectral densities of the total velocity for a headwind WOD using a UBL, showing computed data for the small ship compared with the data scaled from the large ship

Overall this data suggests that Strouhal scaling is a feasible method to scale airwakes to account for changes in both ship size and velocity magnitude. The use of an ABL profile during the CFD simulation does not appear to preclude the use of airwake scaling.

4.3. Piloted Flight Simulation

Having demonstrated the airwake scaling process, the investigation then went on to consider the effect of ship size on pilot workload, with a point of interest being whether the more benign airwake of the small ship would be negated by the smaller deck and reduced space for manoeuvre. To illustrate the space restriction in the horizontal plane the rotor disc diameter is superimposed on some CFD data in Figure 11. As can be seen, the shear layer that is formed across the deck is larger and more turbulent for the larger ship, which can be expected to affect the unsteady loading on the helicopter.

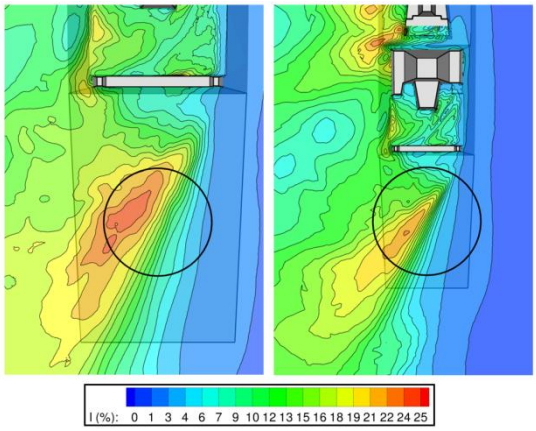


Figure 11 Comparisons of turbulence intensity contours at 100 % hangar height showing the relative size of the SH60-B rotor disc over the large and small flight decks

As part of the scaling investigation described in the previous sections, the airwakes had been computed separately for each size of ship, and they were then scaled up and down from the computed velocity of 40kts at the anemometer height to produce airwakes for a range of wind speeds. The wind directions were restricted to a headwind and a Green 45°.

While the focus of the study being reported in this paper was the effect of ship size on the airwake and on pilot workload, it is also recognised that ships of different size will have different motion, for a given sea state. Therefore, to avoid too many variables being changed, the ship motion (heave, roll, pitch) used in the flight simulation, and applied to the ships' centres of gravity, was the same for each ship. Future work will involve scaling the ship motion (frequency and amplitude) to provide the pilot with another challenge that will vary with ship size.

The unsteady airwakes for each of the three ship sizes were therefore formatted and integrated into the FLIGHTLAB software, as described in the previous sections and more comprehensively in Reference 9. An experienced test pilot was tasked with conducting approaches to each of the ships using the HELIFLIGHT-R motion base flight simulator. The piloted flight testing consisted of a series of approaches to each of the three ships for the headwind and Green 45° WOD conditions while subjected to a range of wind speeds. The pilot was asked to give an assessment of the difficulty of the task using the Bedford Workload Rating Scale as shown in Figure 12.

The task was based on the standard approach to a ship as used by the Royal Navy, shown in Figure 13. This technique involves an approach to a hover, approximately one beam width off the port side of the ship, followed by a lateral translation to a hover over the deck spot before descending to land on the flight deck. During the manoeuvre, the pilot was asked to hold a hover position over the port edge of the flight deck at approximately hangar height for

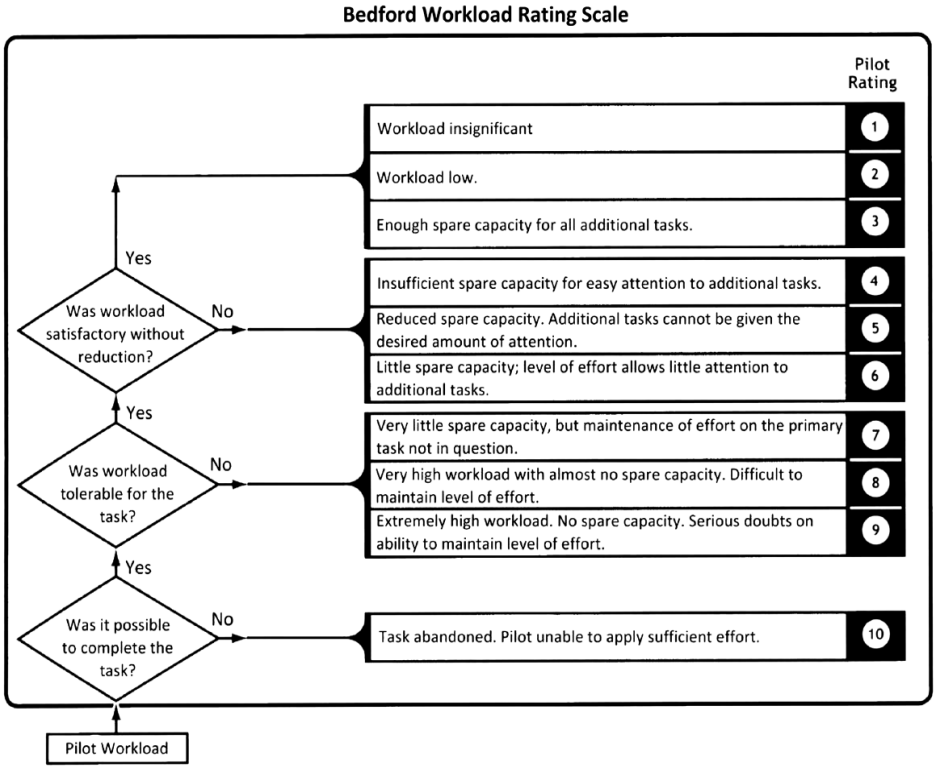


Figure 12 The Bedford Workload Rating scale

thirty seconds and provide a rating of the workload experienced, followed by a thirty second hover over the flight deck, again with an evaluation of the workload.

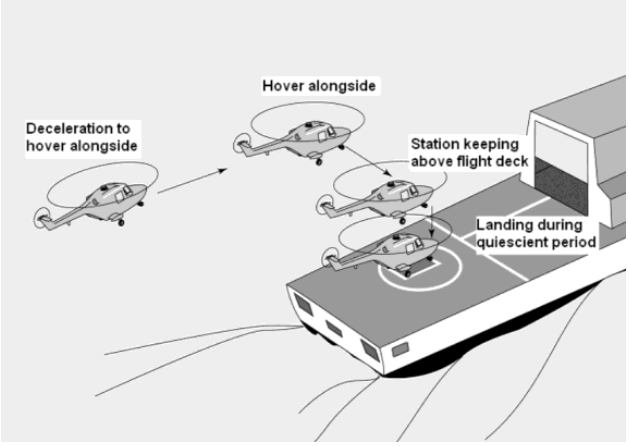


Figure 13 The Royal Navy UK standard approach to a deck landing

Figure 14 shows the Bedford workload ratings given by the pilot for the headwind WOD when asked to maintain a hover position over the flight deck landing spot for each of the three ships. The wind speeds relate to those that would be measured at the height of the anemometer. As is usually the case, the workload in a headwind case is less than that in a green wind so for that reason the maximum wind speed in the headwind was 60 kts, while it was 40 kts in the Green 45° wind.

Pilot assessment of their workload is a subjective process and, although guided by the methodology of the rating scale, each workload rating will have an uncertainty attached to it. Also, the rating scale is not linear, i.e. a rating of 4 does not reflect twice as much work as a rating of 2. To add further complexity, the reasons for the workload will also vary between test points; for example the effort being expended could be in the cyclic controls, or in a combination of collective and pedal controls.

Bearing in mind the previous comments, the workload ratings in Figure 14 show that the effort required by the pilot to hold position over the landing spot, while in a headwind, was low for wind speeds up to 30 kts, and the ship size did not seem to matter. However, as the wind speed increases the workload also increases, as the airwake becomes more aggressive, and also the increase in workload is greater for the larger ship. The pilot comments also revealed that the reason for the workload ratings changed between ships from being due to difficulty in holding position due to the severity of the fluctuating airwake loads over the large ship, to difficulty in holding position while so close to the superstructure of the small ship.

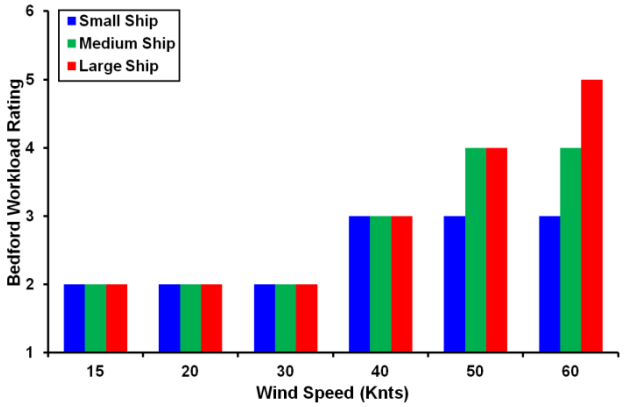


Figure 14 Bedford Workload Ratings for the hover postion over the flight deck for the headwind case

Figure 15 shows the trace history of the cyclic control inceptor for the hover task over the flight deck of both the large and small ships for a 40 knot wind speed. The control activity for the large ship shows larger control inputs were required to maintain position than was seen for the small scale ship.

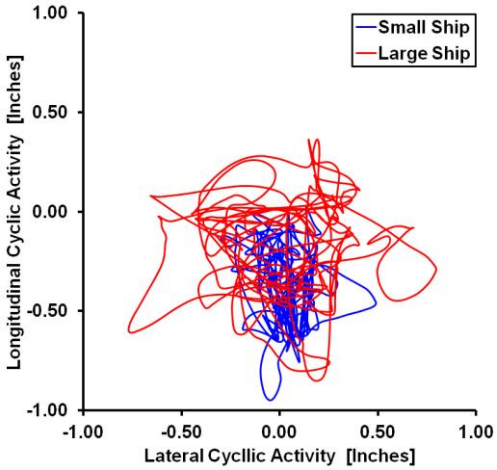


Figure 15 Cyclic control activity for a 40 knot Headwind WOD case

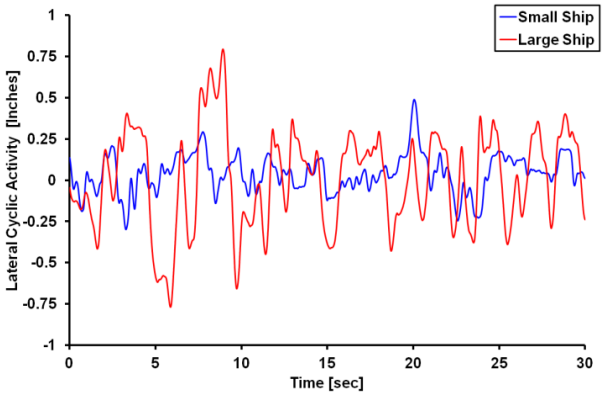


Figure 16 Time histories of lateral cyclic activity for a 40 knot Headwind WOD case

The time histories of the lateral cyclic activity for both the large and small ships for a 40 knot headwind, shown in Figure 16, also demonstrate the larger displacements applied by the pilot to the cyclic when holding position over the landing spot for the larger ship, and also the lower frequency.

Considering the Green 45° WOD condition, the workload ratings for the station-keeping task above the port edge of each ship are given in Figure 17. In this case the hover is over the deck edge, as opposed to over the spot as in Figure 14, because in the oblique wind this position provided more energetic airwake disturbances. Despite the scatter in the data, the trend is the same, i.e. workload increases with wind speed and is greater for the larger ship. The pilot comments about the reasons for the workload ratings, i.e. aerodynamic perturbations versus superstructure proximity were consistent with those for the headwind tests.

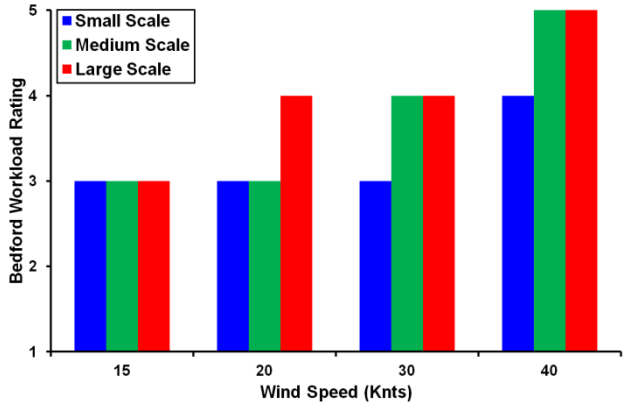


Figure 17 Bedford Workload Ratings for the hover position over the port edge for the Green 45° case

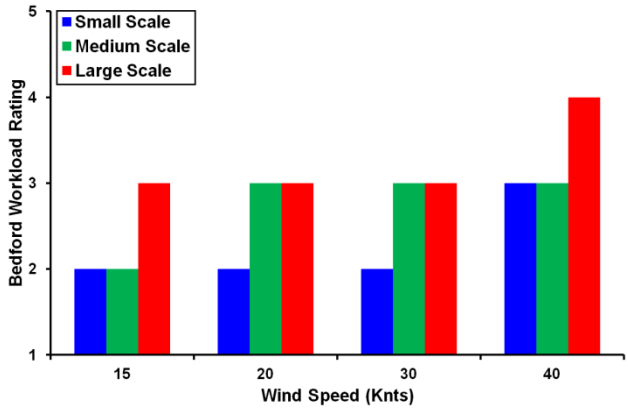


Figure 18 Bedford Workload Ratings for the hover position over the flight deck for the Green 45° case

The ratings given by the pilot for the thirty second hover above the landing spot of each ship, for a Green 45° WOD are shown in Figure 18. The overall ratings were lower than those given when station keeping over the port edge of the ships. Comments made by the pilot during the tasks indicated that the aerodynamic perturbations and subsequent upset on the aircraft were reduced as the helicopter translated across the deck.

The path followed by the helicopter's rotor hub while the pilot translates the aircraft from off the port side to over the landing spot, including holding the positions over the port deck edge and the landing spot for 30 seconds each, are shown in Figure 19. The WOD is a 40kt Green 45°. At the beginning of the flight test the control of the aircraft is handed over to the pilot while the aircraft is hovering off the port side of the ship. Therefore at the start of each trace an initial vertical displacement is seen where the pilot takes control and adjusts to the task in hand. Despite the size of the ship, and the different airwake characteristics, the trajectory followed by the pilot is relative consistent for the two ship sizes (and noting that the helicopter size is the same for each ship). The 30 second station-keeping task over the port edge shows greater vertical displacement for the smaller ship, although the pilot did not report greater workload for the smaller ship at that position and wind strength.

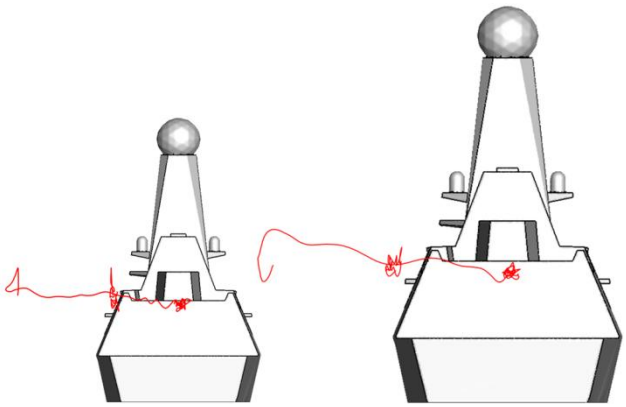


Figure 19 Trajectory of the path taken by the helicopter during the approach and station keeping to both the large and small scale ships for a 40 knot wind, Green 45 WOD case

The contours of turbluence intensity, shown previously in Figure 11, highlight that for this WOD the proportion of the helicopter's rotor disc operating in turbulent flow is greater for the larger ship, which is reflected in the greater excursion in the cyclic activity recorded in Figure 20.

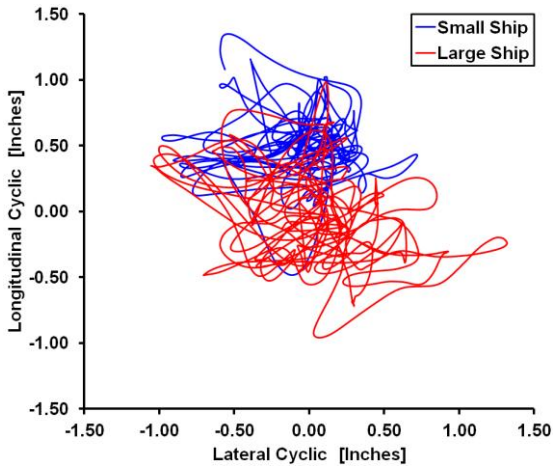


Figure 20 Cyclic control activity for a 40 knot, Green 45° WOD case

However, another intesting observation from Figure 20 is that for the smaller ship the cyclic activity has moved forward. An explanation for this can be found in Figure 21 which shows contours of mean vertical wind velocity at the rotor during the hover task. For the smaller ship, the rotor is placed into a region of flow where there is an updraft of 2.5 - 3 $m.s^{-1}$ passing through the starboard edge of the rotor, as the flow passes over the starboard edge of the ship and flight deck. This updraft results in a change in the aerodyanmic loading of the rotor and, due to the 90° phase delay, the rotor disc will pitch backwards requiring the pilot to maintain a constant correction with forward cyclic to maintain position over the deck. This behaviour was also observed by Forrest et al[6] when conducting simulated deck landings to a Type 23 frigate and shows that a pilot's control strategy must account for both the mean and unsteady velocity components of the flow.

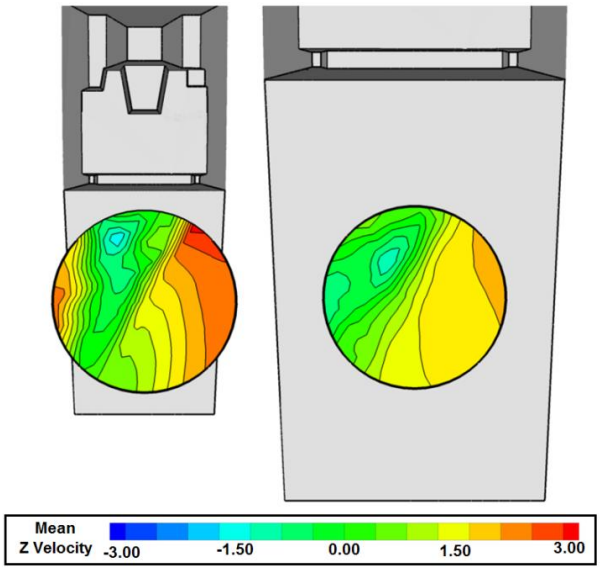


Figure 21 Contours of mean, vertical wind velocities shown at the rotor disc during the hover task.

5. CONCLUSIONS

Three ships with similar geometries but with lengths of 100m, 150m and 200m have been used to investigate the effect of ship size on airwake characteristics and on pilot workload during a simulated landing manoeuvre.

Creating unsteady airwakes for different ships, and at different wind speeds and directions is very time consuming and computationally expensive. It has been shown that for a given wind angle it is possible to Strouhal-scale the airwake velocities from one representative wind strength to other wind strengths with an accuracy that is acceptable for their implementation within a flight simulator. It has also been shown that it is possible to Strouhal-scale the airwake from one ship size to another ship size, again with an accuracy that could be acceptable for flight simulation. Both of these techniques will be very useful for creating flight simulation capability for helicopter launch and recovery to ships.

Piloted flight simulation in which a maritime helicopter was flown to the deck of each of the three ships has shown that the pilot workload generally increases with the ship size and that, despite the landing area being larger and the superstructure proximity being less threatening, the more aggressive airwake from the larger ship still makes the aircraft more difficult to control over the larger ship.

6. ACKNOWLEDGEMENTS

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