Institution: University of Lincoln

Unit of Assessment: UoA 15 – General Engineering

Title of case study: The aerodynamic design of the Type 26 Combat Ship for maritime helicopter operations

1. Summary of the impact

Research conducted at the University of Lincoln into advanced modelling of ship aerodynamics, integrated with helicopter flight simulation, has led to a design analysis technique which has influenced both the design of a specific ship and the guidance given to naval ship designers. It has been used by BAE Surface Ships in the design of the forthcoming Type 26 combat ship. This will be the first naval ship to be designed using a technique that has led to a superstructure configuration which seeks to reduce the impact of the ship airwake on the helicopter, thereby improving flight handling and pilot workload, and maximising the operational envelope of the helicopter and improving pilot safety. The research has also directly influenced the international ship design community through the NATO working group on Ship Design Guidance for Aircraft Operations (AVT-217).

2. Underpinning research

Landing a helicopter to a ship in strong winds and high seas is extremely dangerous and difficult. Although the helicopter is the ship's most potent asset, its operability is limited by the impact of the superstructure aerodynamics on the aircraft's handling qualities and pilot workload. The analysis of ship superstructure aerodynamics and its direct impact on helicopter loads has hitherto not featured in ship design.

The research underpinning this case study was carried out at the University of Lincoln, though drawing on earlier research conducted by Professor Owen at the University of Liverpool before he joined Lincoln in March 2011. He has been a leading international figure in the simulation of helicopter launch and recovery from naval ships for over a decade, e.g. [1].

This work is a direct outcome from earlier research funded by EPSRC (EP/C009371/1, £450k). Owen developed an instrumented model-scale helicopter that could be placed around the flight deck of a model ship to measure and quantify the magnitudes of the mean and unsteady aerodynamic loads acting on the helicopter. This model helicopter was therefore an instrument which measured the effect of the ship's airwake on a helicopter and it was named the 'AirDyn' (Airwake Dynamometer) [2].

During 2011 to 2013 Owen has used the experimental AirDyn to evaluate the effect of ship modifications on a helicopter flying through the ship airwake [3]. He has also extended his earlier simulation research [4] and has developed a technique such that the aerodynamic loadings of the aircraft flying in the wake of the ship can be extracted from flight mechanics modelling software [5]. These new avenues of research, in flight simulation and ship design evaluation, have led to a new software design tool that replaces the physical helicopter model of the AirDyn by a flight mechanics computer model, and the actual air flow by a CFD-generated airwake. The unsteady loads imposed on a helicopter by a ship's airwake can therefore be obtained by computer simulation using a 'Virtual AirDyn'. Specifically:

Methods

- Using the geometry of a real ship, 45 seconds of unsteady airwake is computed for numerous wind angles using CFD with Detached Eddy Simulation on a high performance computer cluster.
- A helicopter flight mechanics model has been constructed in the modelling software Flightlab®. Using aerodynamic computational points on the rotors and body of the helicopter,

the time-varying airwake is imposed onto the aircraft on a structured orthogonal grid interpolated from the unstructured CFD grid.
- By trimming the helicopter for stable hover in the prevailing undisturbed airflow, and then positioning the aircraft in the ship's airwake and along the landing flight-path, the unsteady non-equilibrium loads can be recorded.

Findings
- Unsteady loads in the frequency range 0.2-2 Hz are the major contributor to pilot workload and aircraft operating limits. The integral between these limits of the power spectral density plots of the unsteady loads in six axes (3 forces, 3 moments) provide proxy measures of the pilot workload and aircraft operating limits.
- The geometric features on the ship (weapon systems, funnels, radomes, etc) which are the source of the previously quantified adverse loads, are identified through examination of the CFD, and considered for modification.

The Virtual AirDyn is therefore a software tool that analyses the design of a ship's superstructure from the perspective of the helicopter and pilot workload. It is the Virtual AirDyn that is the outcome from the research, and the impact is in its application to the design of the Type 26 Global Combat ship by taking into account for the first time ever the operability of the helicopter.

3. References to the research

1. Roper, DM, Owen, I, Padfield, GD and Hodge, SJ. *Integrated CFD and piloted simulation to quantify ship-helicopter operating limits*, The Aeronautical Journal, 2006, **110**, 419-218. (2007 Westland Prize)
2. Wang, Y, Curran, J, Padfield, GD and Owen, I. *AirDyn: An instrumented model-scale helicopter for measuring unsteady aerodynamic loading in airwakes*, Meas Sci Tech, 2011, **22** (4), 1-12. doi:10.1088/0957-0233/22/4/04590
3. Kaaria, CH, Wang, Y, Padfield, GD, Forrest, JS and Owen I. *Aerodynamic loading characteristics of a model-scale helicopter in a ship's airwake*, Journal of Aircraft, 2012, **49** (5), 1271-1278. doi: 10.2514/1.C031535
4. Hodge, SJ, Forrest JS, Padfield, GD and Owen, I. *Simulating the environment at the helicopter-ship dynamic interface: research, development and application*, The Aeronautical Journal, 2012, **116**, 1155-1183. (2012 RAeS Gold Prize)
5. Forrest, JS, Owen, I, Padfield, GD and Hodge, SJ. Fully Simulated Ship/Helicopter Operating Limit (SHOL) *Prediction using Piloted Flight Simulation and Time-Accurate CFD Airwakes*, AIAA Journal of Aircraft, 2012, **49** (4), 1020-1031. doi:10.2514/1.C031525

4. Details of the impact

Influencing government policy and practice: The potential impact of this research was identified in its early years by the Ministry of Defence and, on the basis of his research expertise, Owen was invited [Finlay] to be a UK representative on the Aerospace Systems Group of The Technical Cooperation Programme (TTCP), a body with representatives of the defence agencies of the UK, US, Canada, Australia and New Zealand. The Group coordinates and disseminates international research into maritime helicopter operations and Owen has been the sole UK academic on this group (TTCP-AER-TP2). In 2011 Owen was also invited by the UK MoD [Duncan] to represent the UK on a NATO working group (AVT-217) which is coordinating international efforts in ship design guidance for aircraft operations.

Owen was also asked by MoD to use his research expertise to create the airwakes of the Type 23 frigate and the Wave Class auxiliary oiler; these were implemented in the Merlin simulator at RNAS Culdrose to improve the realism of the simulation environment.

Professional practice in design: In 2012 Owen was engaged by BAE Systems Surface Ships to provide design advice for the new Type 26 Combat Ship [Foreman]. This advice drew on the techniques developed from research conducted while Owen has been at Lincoln.

The Type 26 will operate with Merlin and/or Lynx helicopters and to maximise the wind conditions (strength and direction) under which the aircraft can operate it is essential that the ship superstructure does not unnecessarily shed excessively large and unsteady flow features into the flight path of the helicopter, particularly above the main rotor. The design presented to Owen in January 2012 showed that the ship had a 'stealthy' superstructure, relatively uncluttered with sloping surfaces. However, on top of the hangar and ahead of the landing deck there were a number of large structural and operational features which were of concern because of their aerodynamic profile and their emitted thermal signature. This preliminary design was evaluated and modified using the Virtual AirDyn technique outlined in Section 2.

Using Computer Aided Drawings of the ship provided by BAE, the Virtual AirDyn technique was applied such that, for different wind directions, the helicopter model was held at seven positions along the path of the lateral traverse that a helicopter follows when repositioning from off the port side of the deck to the landing spot. The simulated helicopter was placed at each position for 30 seconds in which time the unsteady forces (lift, drag, side) and moments (pitch, roll, yaw) were recorded. From the integral of the power spectral density plots, the root-mean-square unsteady loads in each of the 6 axes were quantified, and the effects of the different features on the ship superstructure were isolated and quantified. The final superstructure design had to consider not just aerodynamics but other factors such as structural architecture, operational efficiency and radar cross section, requiring close cooperation with the BAE design team to evolve a favourable design.

From applying this research methodology, the design of the Type 26 has been changed so that the placements of the weapon systems and the position and profile of the exhaust stacks have been modified. Analysis of this detail has never before been carried out on a naval vessel at the design stage. Engineering drawings of the ship are restricted and permission to include a detailed image in this submission was not forthcoming. However, the image below is a close representation of the final ship design following Owen's design guidance. Of note are the various large-scale features on the superstructure ahead of the landing deck. It is the design and placement of these features that were the subject of the AirDyn analysis.

This experience has also been fed into TTCP and the NATO project [Wilkinson], so extending the reach of the impact. Further impact will be achieved because Owen has been commissioned by BAE [Hodge] to apply this research to the new Queen Elizabeth class aircraft carriers, and by the MoD [Finlay] to unmanned air vehicle launch and recovery from ships.

5. Sources to corroborate the impact

Bryan Finlay, Defence Science & Technology Laboratory of the UK MoD to corroborate statement relating to TTCP and application of research to ship-launched Unmanned Aerial Vehicles

Dr John Duncan, Maritime Combat Systems, UK MoD to corroborate invitation to represent UK on NATO project AVT-217

Kevin Foreman, BAE Systems Surface Ships, Type 26 Global Combat Ship to corroborate input to Type 26 design.

Colin Wilkinson, US Navy Naval Air Systems Command (Navair), coordinator for NATO AVT-217 to corroborate contribution to AVT-217 and NATO ship design guidance.

Dr Steve Hodge, Senior Simulation Engineer, BAE Flight Systems to corroborate input to Queen Elizabeth Class aircraft carrier project