Developments in UK Ship/Air Interface Simulation

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ABSTRACT

The simulation of aircraft launch and recovery operations from naval vessels provides a unique set of challenges, requiring realistic modelling of the interactions between the air vehicle, the ship platform, and the environment. The aim of the UK Ship/Air Interface Framework (SAIF) programme is to use the industry standard High Level Architecture (HLA) to provide a realistic real-time simulation of the dynamic interface between the ship and the air vehicle. The initial phase of the project has developed a Ship/Helicopter Operating Limit (SHOL) prediction capability, utilising a networked version of the Merlin helicopter flight simulator at the Royal Naval Air Station (RNAS) Culdrose, UK. By developing an accurate and validated simulation capability, the results of simulation and flight test trials may be combined to maximise the aircraft's operating envelope. The SAIF architecture is highly flexible, and can be adapted to support the modelling of both fixed and rotary wing launch and recovery operations, including Maritime Unmanned Air Vehicle (MUAV) concepts.

This paper summarises the development, test and validation of the SAIF architecture, and highlights where the programme is aiming to make further fidelity improvements. Of particular importance is the highly complex real-time modelling of the airwake field around the ship, which can directly affect the level of pilot workload required to safely operate the air vehicle.

ABOUT THE AUTHORS

Ian Cox has thirteen years experience in modelling and simulation projects, developing distributed simulations and synthetic environments. After graduating with a degree in Aeronautical Engineering from Loughborough University, he spent almost six years working on the JOUST man-in-the-loop air combat simulator at the Defence Evaluation and Research Agency (now QinetiQ) Farnborough. This was followed by a period of work with Thales Training & Simulation, where he helped to develop a sortie generation rate model for the UK CVF future aircraft carrier programme. Ian then joined Systems Engineering & Assessment (SEA) Ltd, where he has been the technical manager of the Ship/Air Interface Framework project for the last four years.

Dr John Duncan is chairman of NATO Sub-group 61 on Virtual Ships. He was previously chairman of the NATO Specialist Team on Simulation Based Design and Virtual Prototyping and is the NATO NIREUS Project Director. John began his career with UK Ministry of Defence (MOD) in the Admiralty Research Laboratory at Teddington. There he worked within the mathematics and computing department becoming involved with a range of software intensive research projects. In 1978 he moved to Director General Ships in Bath and became head of the naval applications software team and later Head of Computer Science for the Sea Systems Controllerate. Since 1995 he has led the UK Simulation Based Acquisition Programme within the Future Naval Projects Group, subsequently transferred to the Defence Procurement Agency and Defence Equipment & Support (DE&S) organisation Sea Systems Directorate.

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INTRODUCTION

The task of accurately simulating the dynamic interface between a ship and air vehicle during the launch and recovery phase of operations has been tackled by various organizations throughout the last 10-15 years. The complex interactions between the two platforms and the maritime environment in which they operate provide many difficulties for the simulation developer. Not only do the traditional challenges of design, test and validation exist, but also expertise must be applied from the fields of aerodynamics, aircraft control, flight test, naval architecture and ship motion if an accurate set of models are to be developed and integrated. The added inclusion of a pilot-in-the-loop within a real-time simulation adds a measure of subjective analysis to an otherwise highly quantitative area of study.

In the mid-to-late 1990s, the simulation of helicopter operations from naval vessels was researched in the UK using the Bedford large motion flight simulator (Tate, 1995). More recently, work carried out by Liverpool University has looked at the fidelity requirements for helicopter/ship dynamic interface simulation (Hodge et al, 2006). In the US, the Joint Shipboard Integration Process (JSHIP) programme has developed the Dynamic Interface Modelling and Simulation System (DIMSS), with the aim of using modelling and simulation to define a process for expanding the flight envelopes for any ship/helicopter combination (Advani and Wilkinson, 2001; Roscoe and Wilkinson, 2002). The National Research Council of Canada is also active in the field of dynamic interface simulation (Zan, 2005).

The above projects highlight the challenges involved in developing a validated simulation capability, which can be used to predict the safe operating limits of air vehicles from naval vessels. The significant benefits that simulation may provide to future ship and aircraft programmes, including reduced costs, increased flexibility and shorter time periods for the development of operating limits, are attractive incentives. The aim of the Ship/Air Interface Framework (SAIF) project is to deliver these benefits via the use of a flexible simulation architecture.

SAIF PROJECT DEVELOPMENT

The SAIF project started as a development of the 13-nation NATO/PfP Interoperability and Re-Use Study (NIREUS), which developed a High Level Architecture (HLA) based simulation of the recovery of an Unmanned Air Vehicle (UAV) on to a moving ship platform (White and Reading, 2001; Woodrow et al, 2002). The NIREUS concept simulation pioneered a number of different approaches to the problem of simulating the ship/aircraft interface, including the successful de-coupling of the aircraft flight dynamics and ship air wake models into separate federates on an HLA network.

It was recognized that by replacing the PC-based UAV flight model in the NIREUS simulation with a federated manned helicopter flight simulator, a flexible architecture could be developed for the purposes of predicting Ship/Helicopter Operating Limits (SHOLs). The requirement to produce the SHOLs for the Royal Navy (RN) Merlin helicopter operating from the new Type 45 destroyer provided an ideal motivation to develop the simulation with the aim of predicting the SHOLs well ahead of the first-of-class flight trials, scheduled for 2009. With these aims in mind, the use of a high fidelity flight simulator is required. The Merlin Cockpit Dynamic Simulator (CDS) is used for aircrew training at the Royal Naval Air Station (RNAS) Culdrose, UK, (Figure 1).

Figure 1. High fidelity Merlin CDS

This state of the art facility provides a fully functional Merlin cockpit, surrounded by a wide Field-Of-View (FOV) dome projection system, mounted on a hydraulic motion base. The wide FOV is required so that the pilot can view the ship flightdeck throughout the standard RN landing manoeuvre. The cockpit itself is mounted on a separate vibration platform, and additional motion cues are provided to the crew via dynamic seat-pan cushions.

The initial aim of the SAIF project was to develop a federated version of the Merlin CDS, which could be integrated with federated models of the environment, ship motion, airwake and visual landing aids systems, building upon the lessons learned from the NIREUS UAV project.

System architecture

The SAIF federation architecture provides a flexible system, which can be adapted to simulate any ship and air vehicle combination. The system is comprised of the following six federate models, connected via the HLA Run-Time Infrastructure as shown in Figure 2. The federate models shown in green can be run on standard PCs, with one or more federates potentially operating on the same PC.

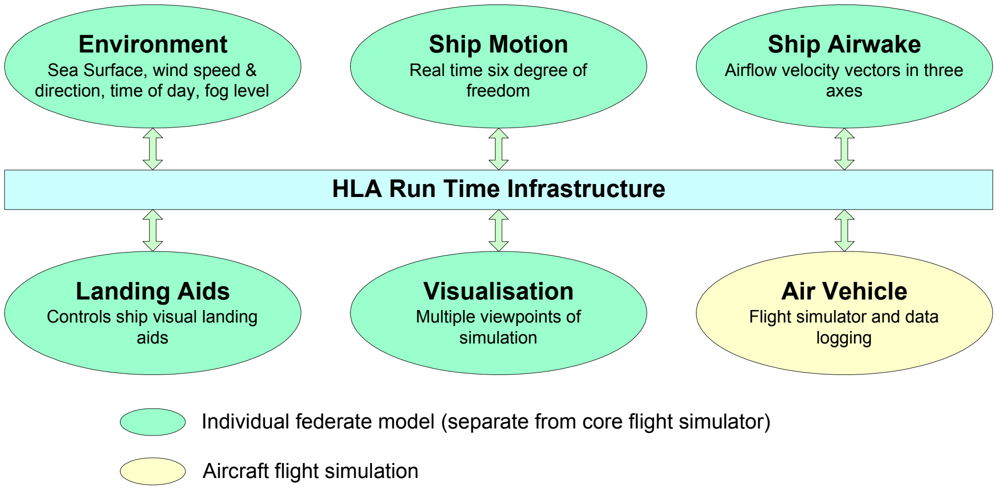

Figure 2. SAIF Federation Architecture

- **Environment Federate**: Publishes data on the wind speed and direction, sea state, wave spectra, time of day and visibility levels to the federation;
- **Ship Motion Federate**: Calculates in real-time the six degree-of-freedom motion of the ship, either by using a pre-recorded time history file or by calculating the response to the individual wave sinusoids published by the Environment Federate, using ship-specific Response Amplitude Operator data (Rocca and Crossland, 2001);
- **Ship Airwake Federate**: Calculates the three-dimensional airflow velocity vector at various sample points around the air vehicle. A grid of airwake flow perturbation and turbulence intensity values around the ship is calculated offline using Computational Fluid Dynamics (CFD) methods. The position of the air vehicle relative to the ship is then used to access the look-up tables, and calculate the airflow velocity vectors at the sample points. The airflow data is then fed back to the air vehicle flight dynamics calculations;
- **Landing Aids Federate**: Controls the functionality of the various ship-borne visual landing aids systems used to support aircraft operations;
- **Visualisation Federate**: Provides a dynamic visualisation of the simulation from multiple user-selected viewpoints;
- **Air Vehicle Federate**: Provides a simulation of the flight dynamics of the air vehicle.

In the first practical example of the application of the SAIF architecture, the air vehicle functionality is provided by the federated version of the Merlin CDS, connected via a ‘gateway’ PC to the HLA network. However, a simple PC-based simulation could provide the aircraft model, using the same HLA interface. In some areas such as the environmental data, ship motion and ship airwake, internal CDS functions have been switched off and replaced with data supplied by the federates.

By adopting a flexible federated architecture, the individual models could be developed and tested without accessing the heavily utilized Merlin CDS. This distributed development contrasts with the modification of a single large monolithic simulator, which is likely to take place at a single site. The flexibility of the HLA architecture also supports rapid changes between ship types, and allows individual federates to be enhanced and upgraded without changing the whole federation, provided that the same interface is used.

TEST AND VALIDATION

UK SHOL Definition

In the UK, SHOLs are described by a series of polar plots, showing the relative Wind Over Deck (WOD) velocity and direction for the boundary conditions between acceptable and unacceptable pilot workload and aircraft control levels. Figure 3 shows a typical SHOL plot.

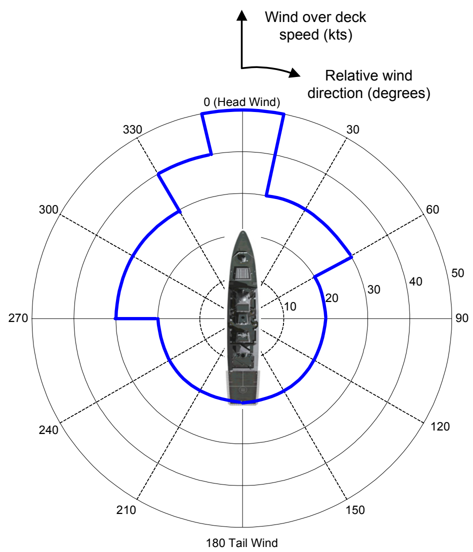

Figure 3 – SHOL plot showing the boundary conditions (blue line) for acceptable pilot workload and aircraft control

A SHOL diagram is produced for a range of different aircraft operating weights, for a certain set of conditions (*e.g.* day or night operations, using a certain approach path to the flightdeck). The SHOL boundary points are determined by assessing the pilot workload and aircraft control issues for an aircraft recovery and take-off at specific test points, defined by the WOD speed and direction.

The Deck Interface Pilot Effort Scale (DIPES) workload rating is used to assess the level of workload associated with the task. A DIPES rating of 1-5 is given by the pilot for the test point, together with a number of letter descriptors, which define the main causal factors behind the given rating (*e.g.* R = Roll control, Y = Yaw control, H = Height control). Figure 4 shows an abbreviated version of the DIPES decision tree.

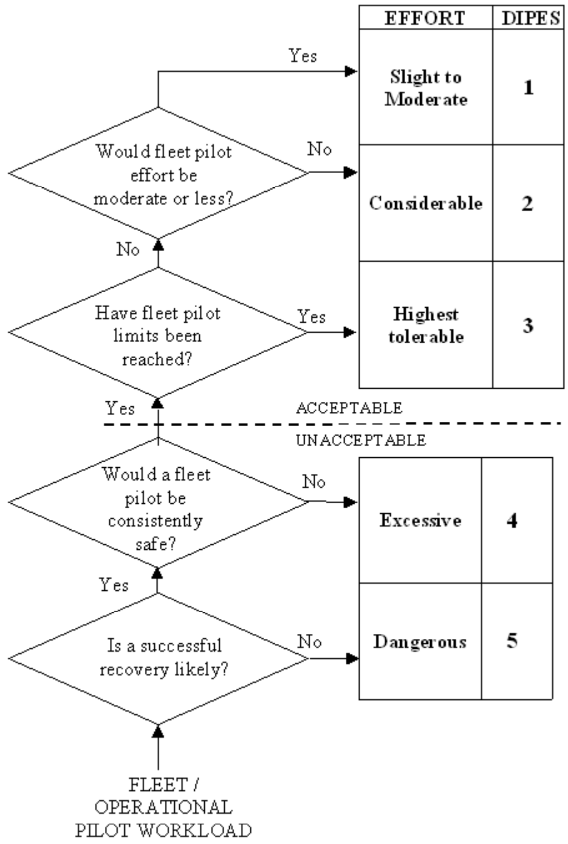

Figure 4 – DIPES decision tree

In addition to the DIPES workload rating, the mean and peak values of engine torque and pedal position are evaluated, using recorded data from the flight test trials. This data is analysed to assess if the aircraft exceeded performance limits relating to the power demanded from the engines and transmission system, or the amount of remaining pedal control authority. A rating between 1-5 is then given for the torque and pedal. The SHOL boundary is then determined by the boundary between ratings 3 and 4 for the highest score between the DIPES, torque and pedal ratings.

Validation Methodology

Having designed the SAIF federation and developed the software models, the project moved into a test and validation phase. Various methods have been used to validate the individual federate models, and the operation of the federation as a whole.

For the CFD-generated ship airwake data used within the airwake federate, comparisons have been made where possible against wind tunnel data and full-scale measurements obtained from anemometer readings during ship airflow pattern trials. Due to the highly dynamic nature of the ship airwake and the difficulty involved in accurately capturing validation data, this data comparison exercise may result in only a reasonable estimation of the validity of the CFD data. The 'acid test' occurs when the data is applied in the simulation, and the pilot feels the resultant effect of the airwake turbulence upon the performance of the aircraft.

The ship motion model can be validated against data from at-sea ship motion measurements, or from data from other validated models. This has not proved to be as straightforward as first envisaged, due to a lack of validation data, and the large amount of variability in the methods used to derive ship motion and sea surface characteristics. For example, several different standards exist in order to define the seaway as a spectrum of wave sinusoids, which can be uni-directional or defined as a spread spectrum about a dominant wave direction. To-date, the SAIF project has used a uni-directional 50 sinusoid Joint North Sea Wave Atmosphere Programme (JONSWAP) wave spectrum to define the seaway.

Validation and acceptance of the Merlin CDS flight dynamics model for training purposes was carried out as part of the MOD acceptance of the training facility. For the purposes of SAIF, it was therefore assumed that the CDS flight model provided an accurate simulation of the Merlin helicopter, although additional checks against available aircraft flight test data were carried out during 2004.

A hardware test rig was used in late 2003 to test the HLA connectivity between all of the federate software. The test rig provided an exact copy of the gateway PC and CDS software, but without the cockpit, motion base or visual system. This was a useful exercise to de-risk the many interfaces and data transformations taking place within the simulation. Following successful completion of test rig experiments, the SAIF software was integrated with the federated Merlin CDS at Culdrose during the first half of 2004.

Since the CDS facility is a heavily utilized RN training asset, it was necessary to prove that the SAIF configuration would not impact upon the RN training configuration. Integration tests were completed in July 2004, at which point the SAIF configured Merlin CDS was ready for a series of SHOL validation exercises.

SAIF SHOL Simulation Process

The SAIF project has endeavoured to use a realistic approach to developing SHOLs using simulation. The flight test engineers and test pilots from the Rotary Wing Test Squadron (RWTS), who carry out the real SHOL trials, have been involved with the simulation validation process. The RWTS personnel, together with the simulation team have developed a repeatable process for flying simulated SHOL test points. Standard RN approach profiles to the ship are flown in the simulator, with each test point starting with the simulator at a ¾ mile separation distance from the ship. Once the aircraft has landed on the deck, the pilot waits for a suitably benign ship motion period, and then performs a take-off and transition to forward flight. At this point the simulation is frozen and the DIPES workload rating taken, whilst the simulation log file is written and the next test case loaded.

Since a simulation can never fully replicate real world conditions, the test pilots attempt to account for simulator deficiencies when giving their DIPES rating scores. This means that the ratings provided in the simulator should be applicable to the same WOD conditions in the real world. Where possible, more than one test pilot is involved in a simulated SHOL trial, in order to gain the most amount of subjective feedback on the quality of the simulation.

SAIF SHOL Validation Results

Validation is a major concern to all simulation projects, as highlighted by the US JSHIP DIMMS project (Roscoe and Wilkinson, 2002; Zan, 2005). The UK has used the DIPES rating scale for its real world SHOL trials for the last seven years, and together with documented test reports and recorded flight test data provided by QinetiQ and the RWTS, provides the SAIF project with the means to carry out an effective comparison between simulation and flight test results.

Two ship/helicopter combinations were selected as the validation cases for the SAIF-configured Merlin CDS; Merlin operations from the RN Type 23 frigate, and from the Wave Class Auxiliary Oiler (AO) fleet replenishment ship. Flight test data from the original SHOL trials exists for both combinations. The first validation assessment of the SAIF simulation for the Merlin/Type 23 combination took place in August 2004. The results indicated that the ship airwake turbulence levels in the simulation were too low, which resulted in comparatively low DIPES ratings for the same test conditions when compared with real life.

Several areas were identified where the simulation required improvement, in order to raise the quality of the simulation up to the standard required for SHOL assessment. The key areas of improvement were:

- Higher fidelity CFD modelling of the ship airwake;
- Improved sampling of airwake data at the aircraft centre of gravity and tail rotor hub points;
- Better selection of the federated ocean wave parameters that drive the ship motion response;
- More detailed visual models, particularly in the area of the flight deck and hangar face, giving better depth perception and visual cues to the pilot.

The simulator response to increasing levels of airwake turbulence was also tested, in order to better understand the turbulence threshold for an unacceptable level of pilot workload in the simulator.

Following on from the integration of the above modifications, the Merlin/Type 23 validation test points were re-flown in the simulator using a RWTS test pilot in March 2005 and an experienced RN Squadron pilot in June 2005. Analysis of the results for 25 test points showed that there was a good match between the simulated and real data. Given these encouraging results, it was decided to progress with an evaluation of the SHOL for the Merlin operating from the new RN Type 45 destroyer (due to enter service in 2009). This was a *world-first* in using simulation for the development of an indicative set of operating limits for a new ship/helicopter combination (Turner et al, 2006).

Validation tests for the SAIF simulation of the Merlin operating from the AO ship were completed in November 2006. A total of 216 simulated test points were flown, with 136 of them replicating real flight test data points. Table 1 indicates how well the DIPES, torque and pedal ratings obtained from simulation matched the flight test data.

Table 1. Comparison Between Simulation and Flight Test Ratings

	% of Simulator Ratings That Match Flight Test Data			
	DIPES	**Torque**	**Pedal**	**All**
Merlin/T23 (Pilot 1)	80%	76%	64%	44%
Merlin/T23 (Pilot 2)	44%	84%	72%	24%
Merlin/AO	70%	82%	84%	51%

Turner has defined a set of metrics in order to evaluate how well the simulation results match the flight test data (Turner et al, 2006). For a simulated result to be deemed to be a 'good' match to the flight test data, the simulated DIPES rating must be within one point of the flight test rating, with at least one of the causal factors matched to the flight test data. For the torque and pedal ratings, the simulated rating must also be within one point of the flight test rating. Previous studies have indicated that a difference of one DIPES point between different pilots for the same test condition is not uncommon, due to the subjective nature of the rating scale (Roscoe and Wilkinson, 2002).

One then has to answer the question: how well must the simulation results match the real flight trials data for the results to be considered valid? Table 1 shows that for the Merlin/Type 23 tests, Pilot 1 achieved good matches for all three ratings, but when looking for a combination of three good matches at the same time, the simulation matched the flight test data in less than half the cases flown. This suggests that trying to achieve a good match for all three ratings is an unrealistic aim for the simulation.

Pilot 2 for the Merlin/Type 23 tests achieved good matches for the torque and pedal ratings, but poorer results for the DIPES comparisons. However, since the SHOL boundary is drawn to the worst of the rating scores, this may not result in a different SHOL being produced from the simulation results. The results for the Merlin/AO tests appear to be reasonably good across the board, but again with only a good comparison for all three ratings occurring half of the time.

The variability in the above data highlights the difficulty in determining "how good is good enough". It is suggested that a pragmatic approach is used for the validation of the simulation, using a combination of:

- Numerical validation (where possible) for the simulation source data, such as the CFD-derived ship airwake and ship motion data;
- Expert qualitative assessment of the simulation as a whole;
- Further numerical analysis comparing the simulation results against flight test data.

It is recognized that the simulation may be more accurate for certain areas of the SHOL envelope. In this event, a combination of SHOL prediction using simulation and flight trials for new ship/aircraft combinations may be employed, whereby expensive flight tests are only carried out in areas where the simulation accuracy is believed to be degraded.

Throughout all of the SAIF validation tests, it has been apparent that a key driver behind the pilot workload and aircraft control issues is the level of airwake turbulence. The Merlin/AO simulation tests in 2006 indicated that further fidelity improvements are required within the ship airwake model in order to provide a more realistic simulation.

SHIP AIRWAKE MODELLING

The accurate modelling of the ship airwake and its subsequent effect upon the air vehicle within a real-time simulation has provided one of the greatest challenges to the SAIF project. In the UK, an empirical mathematical model for ship airwakes was developed in the mid-1990s, based upon combining known airflow patterns for the elements that make up the ship's geometry (Woodfield and Tomlinson, 1995). The model was tested with some degree of success within the Bedford large motion simulator.

Such approaches have since been superseded by the development of increasingly powerful CFD methods. Three-dimensional ship geometry data from a Computer Aided Design (CAD) package can be input into a CFD model, which can then produce assessments of the airflow velocity and turbulence intensity for a specified area of interest. The Merlin CDS pioneered the use of CFD-generated ship airwake data combined with a blade element rotor model within a training flight simulator (Bogstad et al, 2002). The use of a blade element model allows the varying airflow velocity vectors over the area of the rotor disk to be sampled and used within the flight dynamics calculations.

Current SAIF 'Time-Averaged' Model

The airwake model currently used within the SAIF project uses 'time-averaged' CFD data. Within the CFD modelling process, a mesh is generated around the 3D CAD model of the ship, and a CFD solution is derived using Reynolds-Averaged Navier Stokes (RANS) methods. These methods have been used for many years within CFD modelling to provide steady-state flow solutions. The CFD model also uses a turbulence model to predict the turbulent conditions in the flow and the mean fluctuations. The data output from the CFD model contains time-averaged values for the flow velocity perturbations (*i.e.* the change in the freestream velocity due to the presence of the ship), and a Root-Mean-Square (RMS) value for the turbulence intensity. This data is then re-formatted into a look-up table for a fixed grid area around the ship.

During the SAIF simulation, the airwake federate model calculates the airflow velocity vectors at a number of specified sample points as requested by the air vehicle federate. The model takes account of the relative position of the air vehicle to the ship, and the relative direction and velocity of the WOD in order to select the correct data from the look-up tables. A federate wrapper handles all communication between the SAIF federation and the airwake model. Figure 5 shows the main model elements.

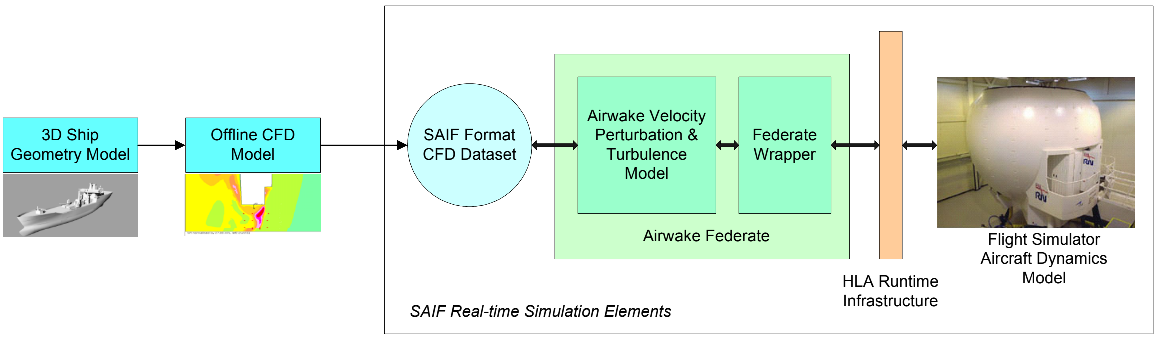

Figure 5. SAIF Airwake Model Elements

As part of the simulation improvement work carried out during 2005, a number of improvements were made to the CFD modelling process. The most important modifications were the inclusion of a low-level atmospheric boundary layer including a wind-shear layer and turbulence effects typically found close to the surface of the ocean, and the application of a Reynolds Stress Model instead of the previous k-epsilon model to calculate the individual turbulence intensity values in each axis. This increased the overall level of airwake turbulence predicted by the CFD model.

During the Merlin/Type 23 validation tests in 2005 it also became apparent that a further increase in airwake turbulence levels was required to get a good match between the simulation and flight test results. A scaling factor was applied to the turbulence intensity values, which resulted in an acceptable level of pilot workload due to turbulence. The reasons why the turbulence scale factor was required remain unclear, and could be due to contributions from the following factors:

- The time-averaged airwake being unable to capture the time-varying features such as vortices that drive pilot workload, and so the scale factor is required to compensate for this deficiency;
- The flight simulator damping out the effects of airwake turbulence due to the physical limitations of the motion system, which cannot generate all of the motion cues that the pilot would feel in a real aircraft. The scale factor therefore attempts to compensate for this effect.

It was hoped that a single turbulence scale factor could be applied for all ship and aircraft types using the time-averaged CFD data. However, the results from the Merlin/AO simulation trials indicate that the turbulence values for headwinds are overestimated, using the same scale factor applied during the Merlin/Type 23 study. In order to increase the fidelity of the airwake model and hopefully remove the need for the turbulence scale factor, the SAIF project is now considering alternative airwake modelling techniques.

Enhanced 'Time-Accurate' Models

The US has led the development of time-accurate CFD methods for predicting ship airwake flow fields as part of the JSHIP programme. The US Naval Air Warfare Center Aircraft Division (NAWCAD) at Patuxent River in particular has studied the benefits offered by using time-accurate methods when compared with time-averaged CFD (Polsky and Bruner, 2000; Polsky 2002). The time-accurate CFD appears to capture the turbulence much more accurately, at the expense of higher computational time, and much higher complexity when trying to apply the data to a real-time simulation.

Rather than relying on traditional RANS methods, which determine average flow characteristics over a period of time, time accurate CFD models typically use Large Eddy Simulation (LES) methods, which can resolve instantaneous flow features and turbulent flow structures. This gives more accurate results for separated flows (*i.e.* the airwake behind a ship), but can result in very high computational loads when studying flows close to the surface of an object. To counter this drawback, Detached Eddy Simulation (DES) CFD models have been developed, which use RANS methods to resolve the flow close to an object, and LES methods to resolve the detached flows.

Time-accurate CFD ship airwake data has been applied to real-time flight simulation applications by a number of different projects. The JSHIP programme has used the DIMSS facility to test a time-varying airwake for a Landing Helicopter Assault (LHA) class ship (Bunnell, 2001). Liverpool University have also tested a time-accurate CFD solution for a simple frigate shape within their HELIFLIGHT manned flight simulator (Hodge et al, 2006). Pennsylvania State University have developed time-accurate models of the LHA and Landing Platform Dock (LPD) class ships (Sezer-Uzol et al, 2005), and applied the LHA data within a Dynamic Interface simulation using an artificial pilot control model (Lee et al, 2003).

The above examples have used a sample of airwake data for a specified time period (in the region of 20-40 seconds) that can be recorded in a 4-D look-up data table (with the x, y and z co-ordinates of the grid of airwake data around the ship, and time as the four dimensions). The data is only applicable for a certain WOD direction, but may be scaleable for a different WOD velocity, as in the case of the time-averaged CFD data. The SAIF project is planning to develop a time-accurate CFD based airwake model into the real-time HLA federation for SHOL simulation purposes. It is planned to test a new airwake model for Merlin operations from both Type 23 and AO ships in the simulator in early 2008, with the aim of providing improved validation results for both ship types.

Coupled Airwake Models

The step from a time-averaged to a time-accurate CFD airwake model represents a large increase in modelling fidelity for the SAIF project. The approach used throughout the project has been to make incremental improvements to the system, whilst considering the cost effectiveness of improving the system fidelity. The use of a flexible HLA architecture has supported this approach, allowing individual models to be upgraded without requiring access to the flight simulation facility.

Developments in CFD technology now mean that is possible to include the effects of ship motion coupled with the airwake model for a time-accurate solution. For example, vortices may be shed from the corners of the ship's superstructure as the ship rolls in the seaway. A further advancement being studied in the US is the inclusion of the helicopter rotor downwash within the CFD solution, which will greatly affect the flow field under certain conditions, (e.g. when the helicopter is hovering over the flightdeck, with the downwash reflecting back off the deck and hangar face). Although it is believed that a coupled rotor and airwake model has yet to be tested within a real-time flight simulation environment, it shows the potential to provide a further step change in modelling fidelity (McKillip Jnr et al, 2002).

The SAIF project aim is to determine if time-accurate CFD can provide a 'good enough' solution for real-time SHOL simulation work, without going to the extra expense of attempting to incorporate coupled ship motion or rotor models within the CFD airwake solution for use within a flight simulator.

FUTURE DEVELOPMENTS

Increased Simulated SHOL Database

If the validation tests of a new time-accurate CFD model prove to be successful in 2008, then opportunities exist to expand upon the database of simulated SHOLs, to include:

- Further Merlin SHOLs from existing ship types, increasing the number of simulation validation test points;
- SHOL predictions for Merlin operating from future ships, potentially reducing the amount of costly flight trials time required for at-sea testing, and allowing flight trials to be focused on specific areas of the operating envelope;
- SHOL validation and prediction studies using the SAIF models connected to simulators for other helicopter types, such as the Lynx or Chinook.

Training Fidelity Improvements

The fidelity improvements offered by the SAIF models, in particular in the field of the ship airwake model, may allow existing and future training flight simulators to be upgraded using a common HLA interface. Many of the outputs from the SAIF project are government-owned assets, and efforts are being made to promote model re-use of a common set of models throughout the training community.

Concept Ship Airwake Evaluations

In addition to piloted simulations of aircraft operations, the SAIF project is now evaluating how CFD-derived ship airwake data can be used during the ship concept design phase, in order to improve the ship's ability to support aircraft operations. A study for the Military Afloat Reach and Sustainability (MARS) project, which will supply the next generation of UK fleet support vessels, is aimed at developing a process whereby the ship airwake and its likely effect upon an aircraft can be rapidly evaluated without need for man-in-the-loop studies. This will provide the MARS project with the ability to change the ship design in order to improve the airwake, and position the helicopter operating spots in the optimum location.

Maritime UAV Studies

Since the SAIF architecture is independent of any particular aircraft type, it has the capability to assess the performance of Maritime Unmanned Air Vehicle (MUAV) designs in the key launch and recovery phase of operations. Such a simulation would allow issues such as the ship-to-MUAV data-link requirements, vehicle operator workload, and trade-offs between fixed-wing, helicopter and tilt-rotor designs to be investigated early in the project lifecycle. Another important benefit is the opportunity to develop the metrics and processes for evaluating MUAV operating limits using simulation. Since the vehicle is not likely to be under the full control of a 'pilot', the equivalent of a SHOL must still be developed without the subjective input of a pilot. Figure 6 shows how the SAIF architecture could be re-used for MUAV studies, replacing the manned air vehicle with MUAV dynamics, launch and recovery system and MUAV controller federates.

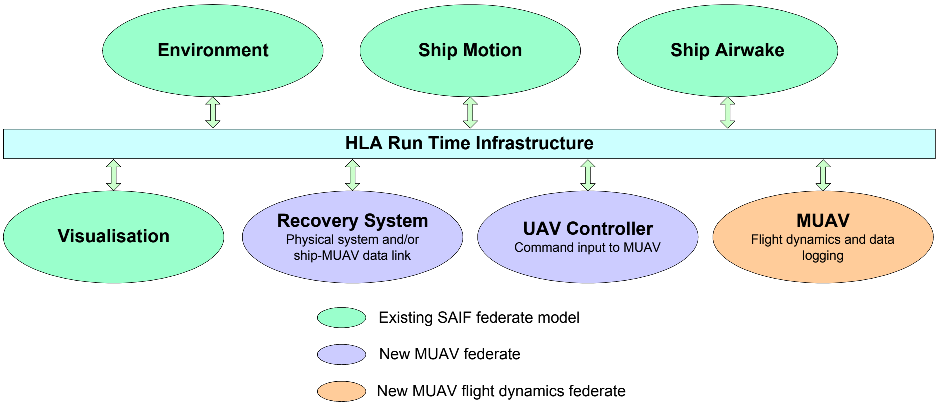

Figure 6. Potential SAIF MUAV Architecture Showing Model Re-use and New Federates

Fixed Wing Aircraft Studies

The first of two CVF future aircraft carriers for the RN is planned to enter service in 2012, and will operate a variety of fixed and rotary wing aircraft, all of which will require a set of operating limits to be determined. The SAIF system has the potential to provide an indicative SHOL for all aircraft types operating from the CVF using simulation, and with acceptable validation results, may greatly reduce the cost of CVF first-of-class flight trials. By integrating SAIF CVF models with high fidelity training flight simulators for each aircraft type to be operated from the ship, a set of simulated operating limits could be generated before the CVF enters service.

Both CVF ships plan to operate the Short Take-Off and Vertical Landing (STOVL) variant of the Joint Strike Fighter (JSF) as the primary strike aircraft. There is a possibility that the SAIF CVF ship models (airwake, ship motion, landing aids) could be connected to a JSF flight simulator based at the US NAWCAD facility at Patuxent River, Maryland. This configuration would build upon the experience gained from the Joint UK/US Distributed Simulation (JUDS) exercises held in 2001 and 2002, which tested the feasibility of a Wide Area Network simulation, whereby aircraft flown from a US NAWCAD simulator operated from aircraft carrier models running in the UK.

Collaborative Studies

Possible collaboration with other NATO nations in the field of ship/air interface simulation is under discussion. The Italian Navy also operates a version of the Merlin helicopter (referred to as the EH-101 in Italy), and a collaborative project with the Italian Navy and CETENA SpA is being considered, to simulate EH-101 operations from existing and future Italian Navy vessels.

CONCLUSIONS

By adopting a scaleable and re-usable federated architecture for the simulation of aircraft operations from naval vessels, the SAIF project has developed a cost effective and flexible capability for the prediction of safe operating limits. Some of the key conclusions of the project to-date are:

- Numerical validation is important, but the subjective assessment of the accuracy of the simulation by experienced operators is vital. This may mean tuning away from a good numerical comparison, in order to obtain a good subjective assessment. A pragmatic approach is being taken in deciding how good the simulation needs to be, for it to be considered as an acceptable alternative tool for use alongside real flight trials.
- The use of a federated approach has allowed individual models to be upgraded as and when fidelity improvements are possible. The improvements are only made when they are considered to be both practical and cost effective.
- The use of simulation early in the design lifecycle may help to optimise the ship/aircraft interface. Initial studies of the ship airwake can lead on to SHOL prediction studies, well ahead of the first of class flight trials. This process is applicable to wide range of future ship and aircraft combinations.

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