DEVELOPMENT OF A SHIP DYNAMIC INTERFACE SYNTHETIC ENVIRONMENT FOR A ROTARY-WING UNMANNED AIR VEHICLE

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ABSTRACT

This paper describes the work carried out towards the development of a Ship Dynamic Interface (DI) for rotorcraft (crewed & un-crewed) at the Engineering Simulation Facility in Yeovil, UK over the past 7 years. The paper presents the development and validation of the ship DI from a crewed AW159 helicopter perspective and further development on to Rotary Wing Un-crewed Air System (RWUAS) platforms, especially AWHERO helicopter and later on to the Proteus configuration. The ship DI synthetic environment models described in this paper formed fundamental building blocks for the Proteus maritime missions demonstrated to the Royal Navy customer in April 2025. The paper describes how comprehensive FLIGHTLAB flight mechanics models have been successfully ported to a more flexible Simulink environment – an environment where a wide variety of validated and tested helicopter system models were available. One of the key outcomes of this work was the development of the simulation control functionalities of the auto-coded FLIGHTALB model at run-time from a widely used industry standard Matlab/Simulink environment. The Simulink flight model hosting high fidelity FLIGHTLAB flight mechanics models is deployed in the AFCS/Avionics integration rig for testing the control laws used for the Proteus Technology demonstrator aimed for a first flight later in the summer of 2025.

Acronyms:

ADU	Air Data Unit
AHRS	Attitude Reference System
AFCS	Automatic Flight Control System
API	Application Programme Interface
CCU	Core Computing Unit
CFD	Computational Fluid Dynamics
CG	Centre of Gravity
DDS	Data Distribution Service
DI	Dynamic Interface
ESF	Engineering Simulation Facility
FFP	Fitness for Purpose
FOCFT	First of Class Flight Trials
FSIR	Full Systems Integration Rig
GUI	Graphical User Interface
HLA	High Level Architecture
ICD	Interface Control Document
LH	Leonardo Helicopters
MOD	Ministry of Defense
PFF	Port Forward Facing
QEC	Queen Elizabeth Carrier
RWUAS	Rotary Wing Un-crewed Air System
SAIF	Ship/Air Interface Framework
SE	Synthetic Environment
SHOL	Ship Helicopter Operating Limits
TDP	Technology Demonstrator Programme
UAS	Un-crewed Air Systems
UoL	University of Liverpool
VTOL	Vertical Takeoff Landing
WOD	Wind Over Deck

1. INTRODUCTION

The ship DI is a challenging operating environment for rotorcraft and is a similarly challenging scenario for engineers wishing to characterize, de-risk and develop solutions for via modelling and simulation. The advent of RWUAS and the natural development to integrate them into ship deck operations brings a new level of complexity in both modelling and simulation. This activity represents part of a drive towards the vision of full exploitation of synthetic environments to steer a step change in design to in-service cost and risk both in support of the route to certification of a RWUAS platform and whole system design and development. The paper will describe the work that was carried out in creating and integrating a Flight Model that is core to the synthetic environment representing a rotary wing unmanned system operating in the ship dynamic interface.

RWUAS Technology Demonstrator is a collaborative programme between Leonardo and the UK MOD to deliver an aircraft known as Proteus, designed to inform the future of maritime aviation, prove the viability of large VTOL UAS and advance technologies in autonomy.

2. BACKGROUND – CREWED AIR SYSTEMS

The LH UK based Engineering Simulation Facility (ESF) was established to enable system development and evaluation of the Human Machine Interface (HMI) through piloted simulation. The ESF has further developed into a highly capable, high value asset with good representations of the Wildcat and AW101 cockpits, high definition visuals and excellent system and flight mechanics models. The ESF is a fixed base system with an AW159 and AW101 aircraft cockpit that are geometrically representative of the aircraft and is equipped with an instrument panels, centre and overhead consoles. Standard flight controls are provided with a Control Loading System which provides representative stick feel and force feedback to the pilot.

Figure 1: ESF AW159 Cockpit

As part of the Rotary Wing Unmanned Air System CCD2 programme (RWUAS), a Fitness for Purpose validated Synthetic Environment (SE) comprising air wake models and ship motion models was created within the ESF (Ref. 1), this was based upon the established ESF physical and software architecture and the use of system models derived from AW159. Several new software components were developed or modified to support the RWUAS simulation programme for the maritime environment. CFD generated unsteady air wake data for several Wind Over Deck (WOD) directions and speeds and a set of ship motions were implemented. Fitness for Purpose (FFP) validation of the SE based on piloted assessment and comparison against flight test data were performed. Qualitative assessment in the form of the DIPES ratings scale and a quantitative assessment via comparison of SE Trial data against SHOL flight test data were performed (Refs. 1 and 2). For the implementation and the FFP validation studies an AW159 Wildcat Flight Model (developed within the ESF) was used.

2.1. Flight Models for the Crewed Air Systems

Validated Flight models of LH UK specialist military helicopters (Wildcat and AW101) were readily available within the ESF simulation facility. These Flight Models have been developed from a physics core, with further development and refinement throughout the service life of the helicopter and configured with aircraft-specific design data. The Flight Models continue to be developed and will enhanced through on going and future aircraft programmes.

One of the aspirations of the RWUAS CCD2 programme was to have the ability for the ESF to support modular "plug and play" aspects where the different disciplinary elements (flight mechanics models, Flight Control System FCS models and engine models) can be easily replaced offering a flexible capability. In order to satisfy this requirement, in addition to the ESF 'in-house' flight mechanics models, the ESF SE has now the ability to host FLIGHTLAB based flight dynamics models

2.2. Early Air Wake Implementation

CFD (in ANSYS Fluent software) generated unsteady air wake data for the Type 23 Frigate (supplied by University of Liverpool) for several wind speeds and directions were implemented at the ESF simulation facility. UoL performed a comprehensive validation, comparing CFD results of the air wake with high quality wind tunnel data provided by the National Research Council of Canada. Comparisons of mean quantities and velocity spectra showed good agreement, indicating that UoL methodology is able to resolve the large scale turbulent structures which can adversely impact helicopter–ship operations. Type 23 air wake data was also compared to full-scale experimental results obtained at sea (Refs. 3 and 4). The 30-second data sets provided include a straight ahead and Green 45 wind case, with a ~35kt (defined as 40kt at the free stream) wind speed. The airwake data was integrated into the Flight Model as 4-dimentional (function of space and time) look-up tables.

This approach was very restrictive to the type of ship and the number of simulated WOD azimuth conditions due to the memory limitation of holding an entire ship airwake tables for a wide range of WOD azimuths. In the next phase of the ship DI development, ship airwake data was made available externally to the Flight Model by the use of a system called SAIF. The UK Ship/Air Interface Framework (SAIF) project has developed a networked simulation architecture for the purposes of studying the dynamic interface between an air vehicle and the ship from which it operates (Ref. 5 and 6). An important component in the SAIF project is the provision of a time-accurate air wake flow field and ship motion into the simulation framework. Implementation of the SAIF system substantially improved the capability of the ESF for predicting the SHOLs for aircraft operating from a wide variety of current and future ship platforms. The SAIF system is described later in this paper

2.3. Ship Motion

The Type 23 ship motion data was provided by UoL. The data provided was generated using a ship motion prediction software tool which has been validated against real ship data (Ref. 7).

Random seaways were generated representing sea states 3, 4, 5, and 7 using the Bretschneider Spectrum, which is widely used, to model point wave spectra in the open ocean. Ship speed was set at 12 knots and significant wave heights and peak wave periods were specified for each sea state of interest as detailed in Ref 8. 120 second time histories sampled at 5 Hz for the following set of conditions were provided as shown in Table 1 below.

Table 1: Available T23 ship motion tables

WOD Direction	Available sea states
Straight ahead	3,4,5 &7
G45	3,4 &5

2.4. Qualitative Verification of the SE

In order to support validation of the SE relative to the development intent of the RWUAS phase 2 programme, piloted trials were performed to obtain qualitative and quantitative feedback on the take-off and landing of the integrated air to ship handling models and the SE. The aim of the Simulator trial was to support the verification and validation of the SE for use with the RWUAS programme. This was achieved by the use of two available airwake datasets (35kt-G45 and 35kt-Straight Ahead) and a ship motion data set corresponding to these airwakes for different sea states (SS3 and SS5). The validation basis was comparative assessment with flight test data as described.

Figure 2 shows the results of the qualitative DIPES assessment performed on the ESF simulator by an experienced LHUK test pilot, with specific and extensive experience in real-world AW159 SHOL trials. The DIPES rating results are used to indicate that the pilots were experiencing an environment that represents those experienced in real SHOL trials by using a subjective comparison method. By randomizing the approaches and environmental conditions flown by the pilot they are unable to 'learn' how to deal with the conditions; as expected by the unpredictable conditions of real SHOL trials. This method ensures the pilot's ratings can be used to produce a qualitative assessment of the SE and ensure greater level validation is made. It is shown in Figure 6 that DIPES ratings were generally 1 level higher for the simulator compared to the real SHOL trials data recordings especially for G45 sea state 5. However, the degree of correlation achieved between simulation and flight test was judged to be good and consistent with the expected difficulty of the scenarios providing the weighting to assert that the SE environment is of sufficient quality to represent an initial Integrated Air to Ship Handling Model. The differences in DIPES ratings are to be expected as the preliminary environment has limitations with the current configuration, furthermore, the subjective opinion of a single piloted trial is likely to influence differences in results. Simulation provided an additional degree of difficulty over real aircraft particularly primarily due to the following deficiencies of the ESF simulator

- Lack of perceived motion cues due to the fixed base cockpit
- Texture of sea and depth perception - this led to difficulty with sink rate

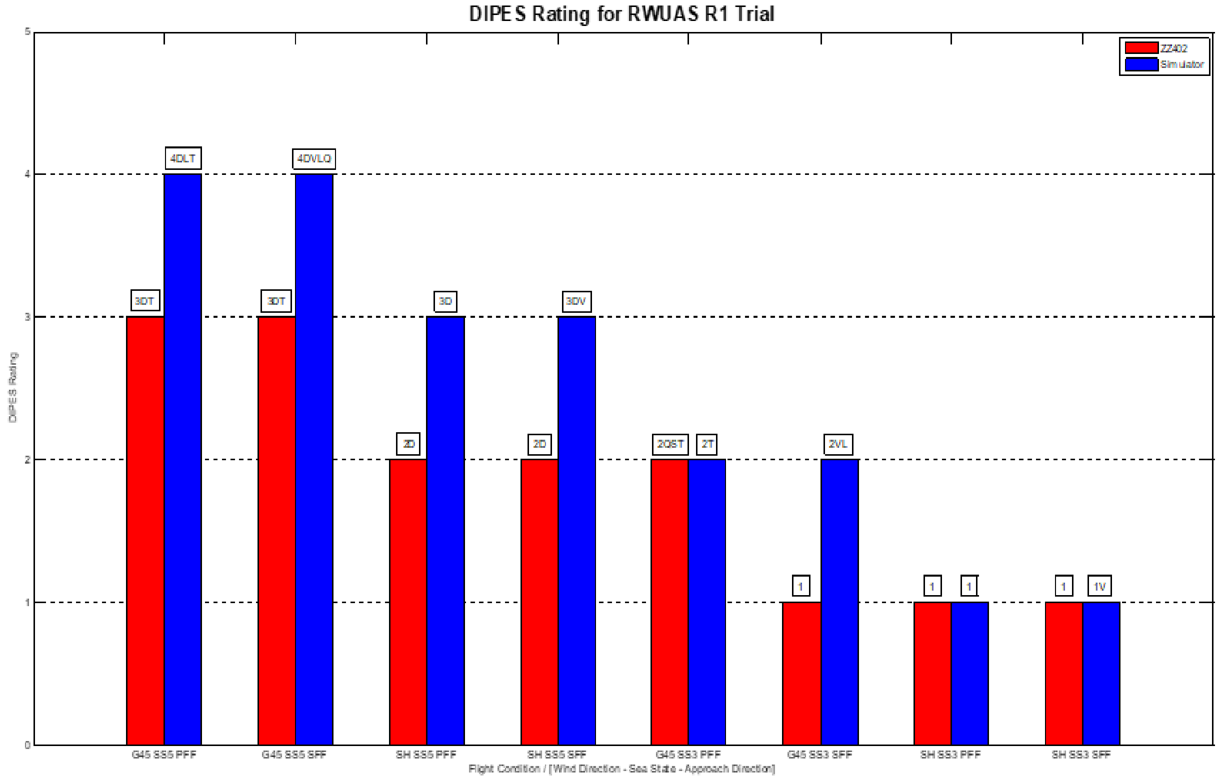

Figure 2: Comparison of DIPES rating – Simulator and AW159 SHOL data

2.5. Quantitative Comparison of Simulator Model against AW159 SHOL data

A comparison of the key aircraft parameters (attitudes, engine torque and stick positions) obtained from the simulator trial against matching WOD/sea conditions from a set of available AW159 SHOL data is performed and presented here. The comparisons were performed by dividing the flight into distinct flight phases of side-hover and hover over deck (deck-hover). Two plots were produced for each of the flight phases; pilot control scatters and flight condition scatters. Pilot Control scatters analyse the stick positions to indicated how the pilot is controlling the aircraft during the flight phases; this provides a comparison against real SHOL data to identify if the pilot is performing differently i.e. greater workload and or more exaggerated controls. The aircraft parameters investigated were the attitudes and engine torques to decide if the aircraft is performing in the same manner to that observed in the real SHOL trials. Comparison of simulator and the AW159 SHOL data for a G45 port side approach for a side-hover are given below. The table below shows the wind/sea conditions. Note that the SHOL data is (from flight 78) corresponds to G55 and 30kt WOD speed.

Table 2: Wind & Sea conditions

Aircraft	Flight No	Wind	Sea State	PFF /SFF	DIPES
Simulator	-	G45/35	SS5	PFF	4DLT
ZZ402	78	G55/30	SS5	PFF	3DT

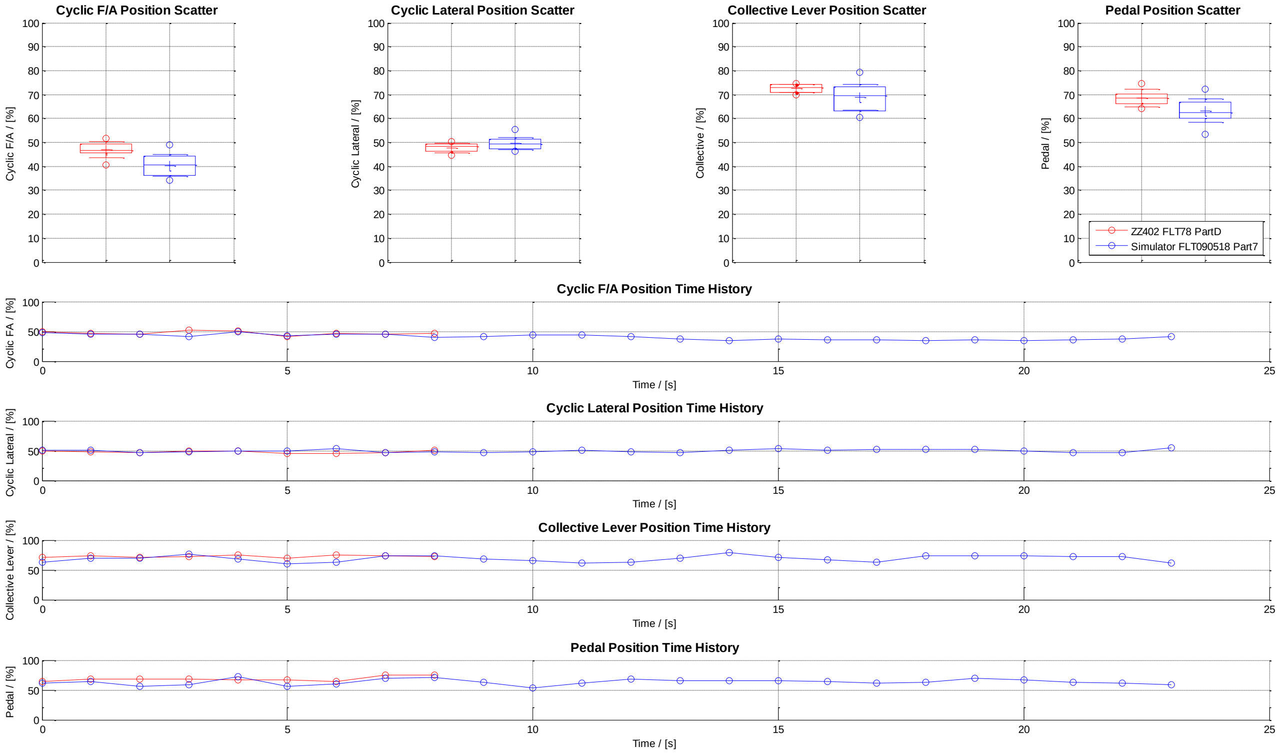

Figure 3: Pilot control positions for side-hover

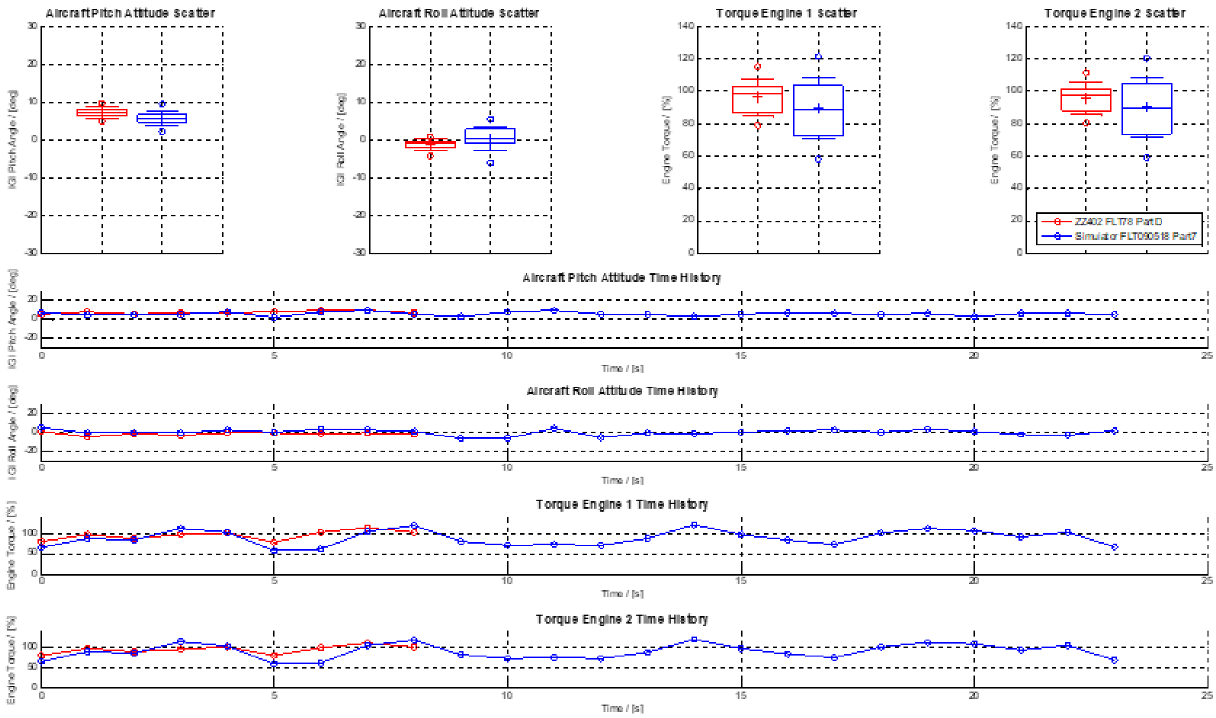

Figure 4: Key aircraft parameters for side-hover

Good alignment of both plots, seen by comparing the SE trial data and real SHOL trial data, provides quantifiable evidence that there is a strong basis for validation of the SE created. The average values of the simulator roll and pitch attitudes where generally within 2 deg of the SHOL data for the corresponding conditions. The stick positions and engine torques are mostly within 5-10 percentage points of the SHOL data. The variability of the simulator data is higher than the variability of the SHOL data. This is consistently shown also in the DIPES rating, explaining the higher workload rating on the simulator.

2.6. SAIF System Integration

After the initial integration of the airwakes and pilot in the loop evaluations, the ESF ship DI capability was substantially improved by the addition of the UK Ship/Air Interface Framework (SAIF). This section provides a description of the SAIF system.

The SAIF system is a distributed simulation that is able to provide time accurate ship air-wake data to real-time simulators. LHUK understand that SAIF is and will be the standard for the provision of airwake data sets and will be updated and expanded to incorporate all RN ship types to facilitate the vision of the greater future application of SEs for MOD and industry. The SAIF system is also capable of providing ship motion data according to the wave spectrum defined by the flight simulator. Table 3 shows the Air wake and Ship Motion models available for use in the ESF version of SAIF. Internal to SAIF are the High Level Architecture (HLA) Federates which model and simulate the following systems:

- Ship air wake federate: the air wake federate is responsible for serving airflow data for the requested sample points around the aircraft.
- Ship motion federate: this federate is responsible for serving ship motions data to the flight simulation. Current ESF implementation of SAIF does not have this configured .i.e. the source of the ship motion is the flight simulator.
- Stealth visualisation federate: This federate is responsible for the visualisation of airflow vectors at the requested sample points along with a visualisation of the simulated ship and the aircraft.

Table 3: List of Airwake and ship motion data avaialble in the ESF version of SAIF

Ship Type	Airwake	Ship Motion
T23	Limited WOD azimuths	None
QEC	23 WOD	High Fidelity hydrodynamic Model
Tide Class (MARS Tanker)	23 WOD	High Fidelity hydrodynamic mModel
Albion Class Landing Platform (LDP)	23 WOD	High Fidelity hydrodynamic Model
RFA Argus Primary Casualty Receiving ship (PCRS)	23 WOD	High Fidelity hydrodynamic mModel
Bay Class Landing Ship Dock (LSD)	23 WOD	High Fidelity hydrodynamic Model
T26	23 WOD	High Fidelity hydrodynamic Model

3. UN-CREWED SYSTEMS SYNTHETIC ENVIRONMENT

Having established a SE for the crewed AW159 and AW101 within the RWUAS CCD2 programme, the focus was switched to the un-crewed systems to establish a roadmap of activities that will grow simulation and SE capability for direct exploitation to RWUAS development.

A strand of work was undertaken to integrate a simulated model of an unmanned rotary wing circa 200kg helicopter (AWHERO) designed and built by Leonardo’s Sistemi Dinamici based in Pisa Italy. This model was integrated into the ESF at LH Yeovil. The flight dynamics model was created in FLIGHTLAB (Refs 9 and 10). A model of the Flight Control System and Flight Management System that integrates with the Aircraft Ground Control Station was integrated with the ship motion and air wake models, to simulate ship landings of AWHERO on to a Type 23 Frigate

The SE for the AWHERO included the following elements and was applied in the context of the AWHERO SHOL simulation, as per Figure 5 below.

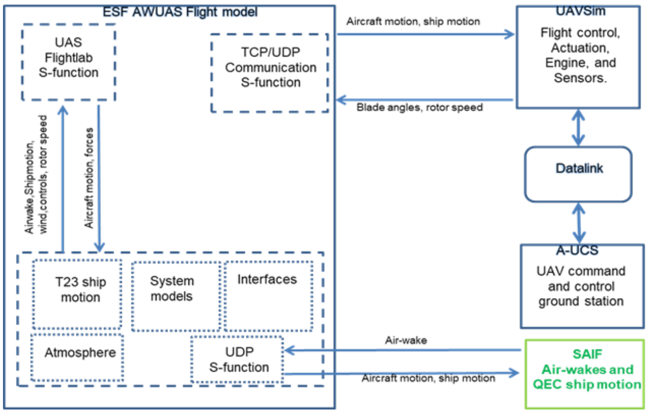

Figure 5: ESF AWHERO simulation architecture (mission components excluded)

3.1. UAVSim

This application hosted AWHERO control laws, provisions for the engine model, motion sensor models and air sensor models. The current version of UAVSim does not have a realistic engine simulation of the AWHERO and a constant rotor speed simulation is assumed. The fidelity of the motion and air sensors (AHRS and ADU) is also at a basic level. UAVSim models the flight control actuator dynamics including rate and range limits and outputs main and tail rotor blade pitch angle demands. The UAVSIM also models the AWHERO's Flight Control Sim and Flight Management System. It communicates to the A-UCS via the STANAG 4586 datalink. Communication between the ESF flight model and the UAVSim was performed via a TCP communication software component wrapped up in a Simulink S-function.

3.2. A-UCS

The Unmanned Control System architecture for AWHERO is shown in Figure 6 below and is comprised of:

- Command & Control Station (A-UCS)
- Payload Operator Station (P-UCS)
- ADS-B system with dedicated display
- Termination control panel
- Deck Pilot Control Unit

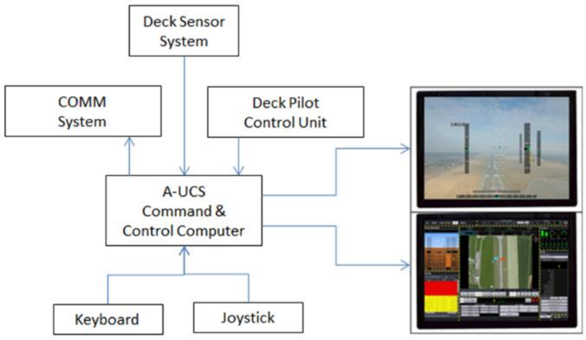

Figure 6: A-UCS functional schematic

The Graphical User Interface (GUI) on the lower monitor above, allows the operator to command and control the air vehicle, the higher monitor enables mission based control. The Deck-Sensor provides the air vehicle with ship position, speed, course, ship attitude (roll and pitch angles) in real time. The data allows the air vehicle to perform Automatic take-off and landing.

Figure 7 shows the GUI displays on the A-UCS software application for one of the SHOL test cases at the ESF. The aircraft is waiting for acknowledgement from the operator to transition across to the deck from the Waiting Point.

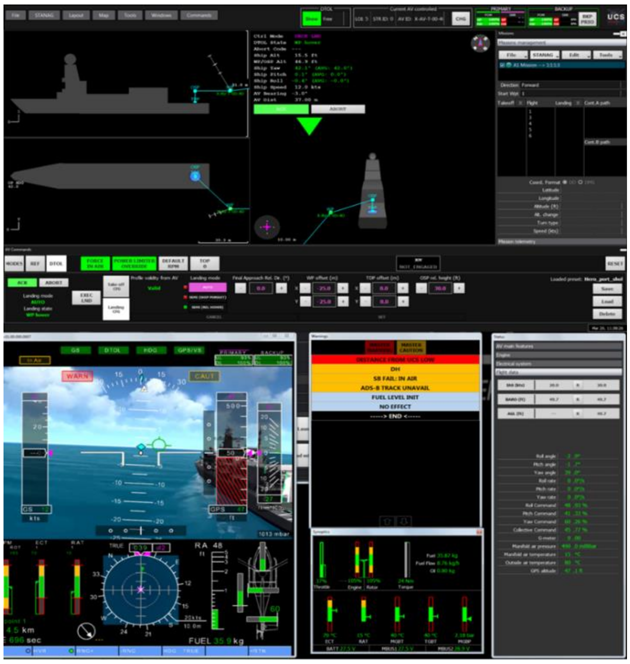

Figure 7: A-UCS displays: AWHERO deck landing simulation (Aircraft at Waiting Point)

3.3. AWHERO Preliminary SHOL

The objective of the work has been to prove successful integration of the components of the AWHERO unmanned system model into the ESF. This step is a precursor to enable SHOL testing which could be developed and used in the future to support airworthiness and ship integration programmes. This would require additional SE validation activity, application of a full Systems Engineering process and phased investment for the ESF. Preliminary results of this integration for the selected set of airwakes and ship motion have been generated, indicating the type of data that may be generated in the future through the SE. Figure 8 shows the touch-down position from the simulation of the deck landings performed for a set of 20kt WOD cases. The harpoon area (blue circle) and ship's deck are also plotted.

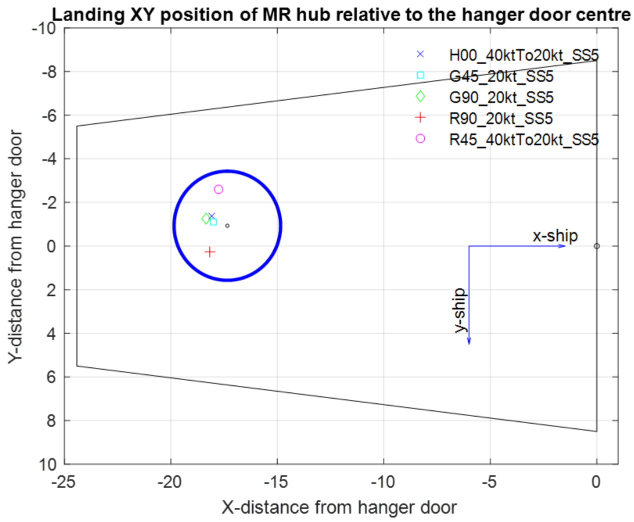

Figure 8: Automatic touch-down position of AWHERO for a 20kt WOD for various WOD azimuths on the ESF Simulator

Figure 9: AWHERO on T23 Frigate on ESF Simulator

4. RWUAS TECHNOLOGY DEMONSTRATIONS PROGRAMME (PROTEUS)

RWUAS Technology Demonstrator (TDP) is a collaborative programme between Leonardo and the UK MOD to deliver an aircraft known as Proteus, designed for the future of maritime aviation roles, prove the viability of large VTOL UAS and advance technologies in autonomy. The programme requirements are not only to design, build and fly the demonstrator aircraft in summer 2025, but to develop Concept of Operations (CONOPS) for a large number of mission types and be an incubator for the development of aircraft and mission autonomy. The development of a representative 'digital twin' is essential in understanding and testing the Uncrewed Air System physical and functional behaviours prior to flight test. Extensive efforts are being made to develop a 'digital twin' of the aircraft and all its systems to enable virtual testing of aircraft systems and their integration. This simulation activity uses flight physics based models developed in FLIGHTLAB, control laws in Simulink and the ship environment developed under the MoD Ship Air Interface Framework to gain an early understanding of aircraft system requirements and operating limitations.

4.1. Proteus Flight Model Integration

For the Proteus Flight Model, the methodology adopted was similar to the AWHERO where the flight dynamics component of the simulation is performed in FLIGHTLAB. Other aircraft systems were applied using the established ESF Simulink model with legacy components and UAVSim retained for control law hosting. The ESF Simulink based Flight Model hosted SAIF communication programmes for air-wake and ship motion, environment models and interfaces for the various components of the ESF (see Figure 5). The Proteus Flight Control System were in hosted in UAVSim.

The FLIGHTLAB model was supplied with time accurate airwake velocities representing the aerodynamic flow field around a ship. The interface control between the ESF Simulink model and FLIGHTLAB is as generic as possible to support modular "plug and play" aspects where different modelling elements (sensors, engine and FCS models) can be replaced, offering flexible integration. The ESF model has an option to model the undercarriage (ground dynamics) either in FLIGHTLAB or within the host ESF Simulink model. The ICD has provision to send external forces and moments to the FLIGHTLAB model, which allows the modelling of the undercarriage externally to FLIGHTLAB.

The most effective means to integrate the FLIGHTLAB flight dynamics model was to wrap the model into a Simulink S-Function with a predefined Interface Control Document (ICD) for input/output control. The FLIGHTLAB model was auto-coded into a set of API calls using a FLIGHTLAB supplied utility called 'fcmdump'. 'fcmdump' creates a complied library of API calls to initialize (start of simulation), update (every time step) and finalise (end of simulation) the simulation. A C++ s-function wrapper programme was written to use these API calls to interact with auto-coded FLIGHTLAB model and perform simulations with a predefined integration time step.

A key requirement of the integration task was to host the airwake and ship motion models within the ESF simulation framework (outside of FLIGHTLAB). Modelling airwake and ship motion outside FLIGHTLAB also allowed the integration of the UK MoD SAIF into the FLIGHTLAB Flight Mechanics model. This requirement meant that air wake velocities for a set of predefined sampling points around the aircraft are passed to the FLIGHTLAB model at each simulation step. Provision for two individual blade (blade-element) rotor aerodynamic models and several aerodynamic surfaces (including a wing) are included in the ICD between the ESF and FLIGHTLAB. This should allow the easy integration of a tandem helicopter or a tiltrotor model without any ICD changes in future. The ICD also contains ship motion data so that the aircraft can be landed on a moving ship.

4.2. Proteus FLIGHTLAB Model Development and Accuracy

FLIGHTLAB (Refs. 9 and 10) is a component based, selective fidelity modelling and analysis tool developed by Advanced Rotorcraft Technology for modelling and simulation of rotorcraft. The Proteus FLIGHTLAB model consists of the following top-level components:

- Blade element rigid main rotor with Peters-He three state inflow
- Blade element ducted fan tail rotor with non-linear unsteady airloads, enhanced Peters-He finite state induced velocity and duct airloads with respect to collective pitch and inflow velocity
- Rigid fuselage airloads from CFD and wind tunnel data
- Empennage aerodynamic surfaces
- Skid landing gear auxiliary body
- Ideal engine
- Sensor Dynamics
- Simplified control system modelling hydraulic actuator response

The Proteus model has its foundations in an existing LH FLIGHTLAB model, which has followed the design of prototype vehicles throughout the development process and has been validated against iteratively expanding flight test data on each prototype variant. The design modelling of the dynamic system is unchanged in the Proteus TDP model, allowing for existing flight test data to be used to assess the model accuracy at hover and within the low speed envelope, where the changes to the fuselage aerodynamics have no significant impact. An indicative comparison of the model accuracy is presented in Figure 11 for quartering flight conditions within the slow speed envelope, with good accuracy of top-level Flight Mechanics parameters observed. The conclusion of this validation activity was that the model is suitable for Flight Mechanics activities including usage for real time simulation, with the tail rotor performance tuned based on duct forces recorded in low speed and quartering flight. Further refinement of the tail rotor duct/fan interference will be performed using future testing campaigns to improve the robustness and to widen the domain of validation which will be required for SHOL testing.

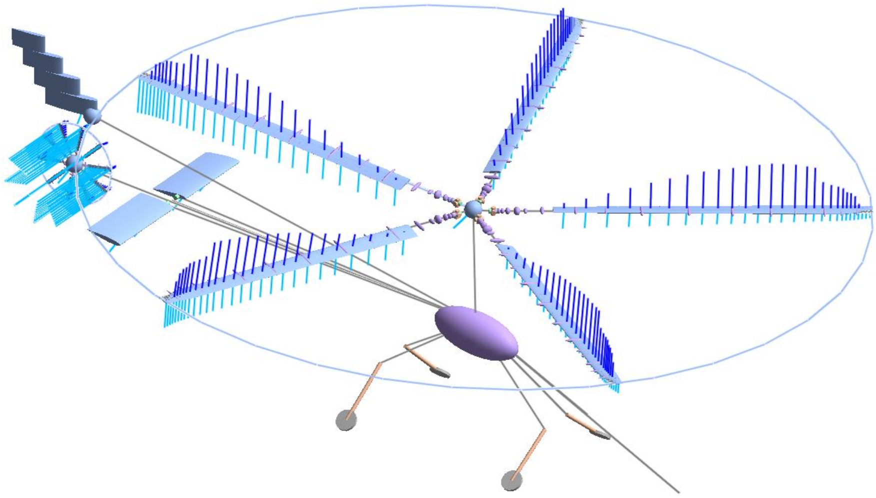

Figure 10 : FLIGHTLAB Model Viewer (FLMV2) Representation of Proteus TDP

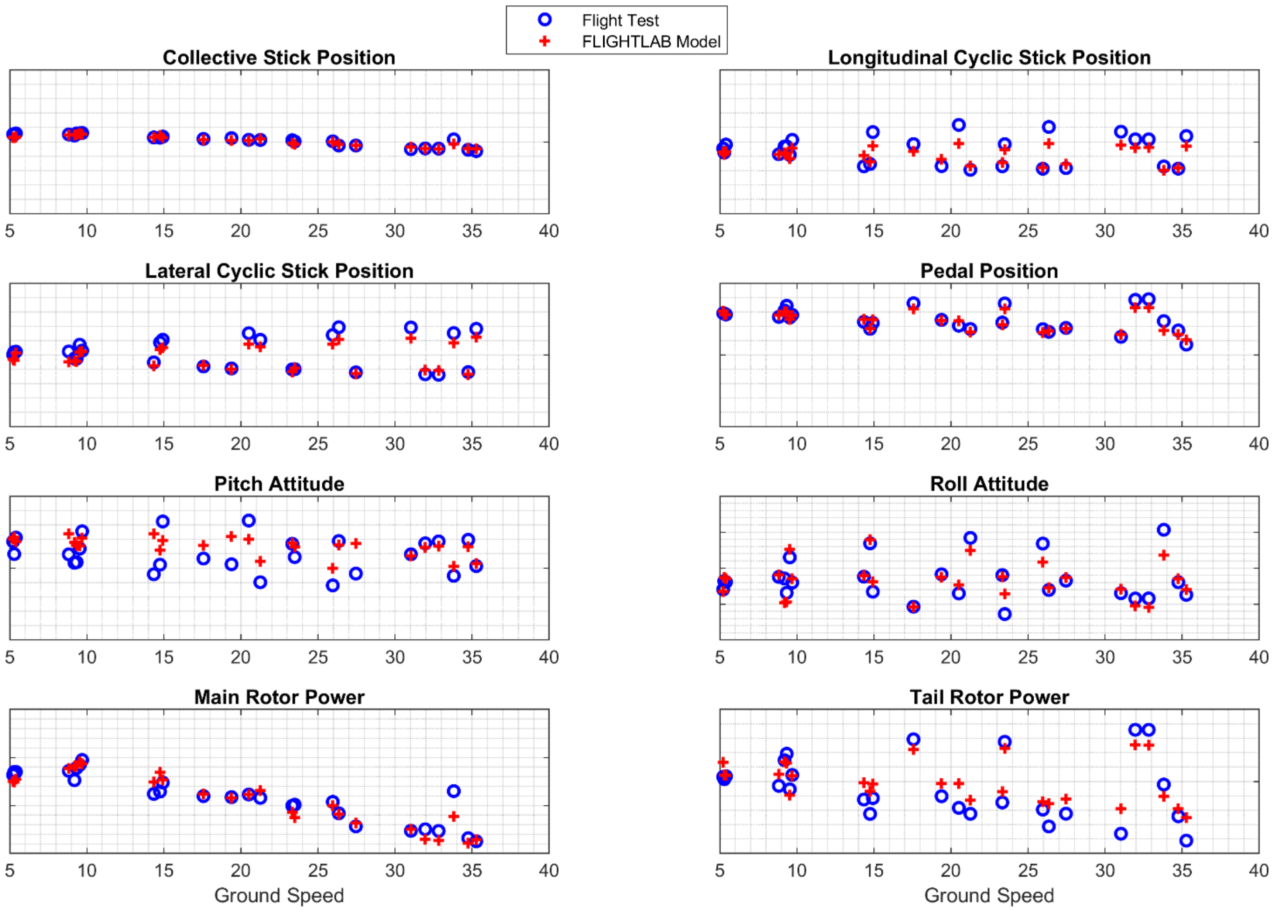

Figure 11: FLIGHTLAB Model Accuracy in Low Speed Quartering Flight

4.3. Simulation control Functionalities

One of the key benefit of modelling the air system in FLIGHTLAB is the wide range of comprehensive rotorcraft modelling capabilities that it offers. These modelling options include vortex wake models of the rotor inflow and the aerodynamic interactions between the vortex producing sources (main rotor/tail rotor), in addition to the blade element (rigid or aero-elastic) structural modelling options for the rotor systems. Whilst FLIGHLAB offers a comprehensive modelling capability, the main limitation of the code-generated FLIGHTLAB model (approach used in this work) is the lack of flexibility in terms of simulation control that are typically required for the deployment on a simulator (crewed or un-crewed). A code-generated FLIGHTLAB model is often restricted to the configuration (all-up-mass, CG locations, etc.) and initial conditions (airspeed, altitude and atmospheric conditions) around which the model is trimmed and auto-coded. Ability to change these conditions at the start of a simulation (or on the fly) is essential for simulation operations. The ability to reset model states such as initial heading and altitude are needed for ship DI or for the integration with a Rig designed for avionics or flight control system (a flight control computer or a re-hosted AFCS) in the loop. An extensive amount of modelling and programming efforts have been made within the FLIGHTLAB model and the Simulink model hosting the auto-coded FLIGHTLAB model to achieve these functionalities. The following functionalities have been implemented so far:

- Ability to externally supply airwake and ship motion.
- Ability to externally supply ship geometry parameters so that simulation can be performed for any ship.
- Ability to send external engine torque so that the engine can be modelled outside of FLIGHTLAB.
- Ability to send undercarriage forces to FLIGHTLAB so that undercarriage can be modelled outside of FLIGHTLAB.
- Ability to set terrain height and atmospheric conditions externally.
- Ability to re-trim, reposition and freeze the model when necessary.
- A dynamic trimming algorithm that allows to re-trim the flight model within seconds (typically less than 20 seconds of simulation time) on to a new flight condition is implemented. The auto-coded FLIGHTLAB model can be re-trimmed to a forward airspeed (above 40kts) or to a low ground-speed (including hover) in-flight above ground. The model can also be trimmed on (on-ground) to a moving ship or on a terrain with a non-zero terrain height allowing the simulation to be started from either a moving ship or from a runway/helipad. The trimming algorithm works by taking control of the model states (only the six body-degree-of-freedom states) of the FLIGHTLAB model during the trim phase and then sending to the FLIGHTLAB model at every time step via the interface. The trimming algorithm also calculates the blade pitch angles necessary to achieve the trim. At the end of the trimming phase, FLIGTLAB model takes control of the model states. Details of the trimming algorithm is outside of the scope of this paper.

4.4. Proteus Autonomous Maritime Mission Demonstrations

As part of the TDP, one of the strategic challenges was for LH to demonstrate autonomous capability in their key maritime missions of Anti-Submarine Warfare missions and the demonstration of a visual based ship landing system. The autonomy development and demonstrations to the customer were successfully conducted at the ESF in April 2025 (Figure 12). The ship DI synthetic environment models described in this paper were key for the maritime missions in these demonstrations.

Figure 12: Proteus on the QEC for the Autonomous Maritime Mission Demonstration on the ESF SE.

4.5. Proteus Full Systems Integration Rig (FSIR)

In addition to the ship DI synthetic environment development, hardware test rigs are being developed to allow any combination of hardware systems and virtual systems (digital twins) to be tested together The Proteus FSIR is designed to enable the avionic components of the Proteus to be tested using either real or emulated equipment. The simulation of the Proteus system consists of a set of desktop based simulation models that provide a physics based representation of the primary functions of the aircraft including flight dynamics, aircraft systems and navigation sensors – effectively modelling the behaviour of the aircraft to dynamic stimuli (such as blade angle and engine demands) to enable the vehicle to be virtually flown. For the FSIR integration of the Proteus, the same (as described previously) FLIGHTLAB auto-coded flight mechanics model is used. Proteus specific navigation sensors, engine and the actuator models were developed in the hosting Simulink model (see **Error! Reference source not found.**).

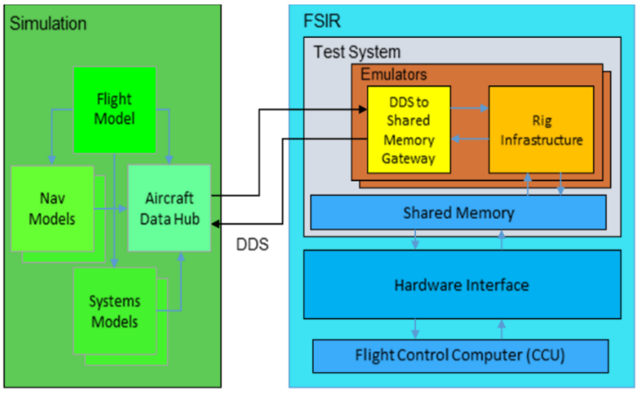

Figure 13: Proteus FSIR schematic

One of the key aircraft component being currently tested on the FSIR is the CCU (Core Computing Unit) which hosts the Vehicle Management System software and the flight control laws. The CCU commands the actuator demands for a given flight condition determined by the auto-pilot modes and these actuator commands are converted to blade angle demands and sent to the FLIGHTLAB model. Integration of a high fidelity flight dynamic model within the FSIR environment running the CCU computer hosting the vehicle management and control laws is an extremely valuable step towards the understanding of the physical and functional behaviours of the Un-crewed Proteus Air System prior to the flight test. The FSIR is also equipped with an 'outside world visual' of the aircraft being simulated. Figure 14 shows the Proteus on the runway where the initial flight testing is planned to be performed.

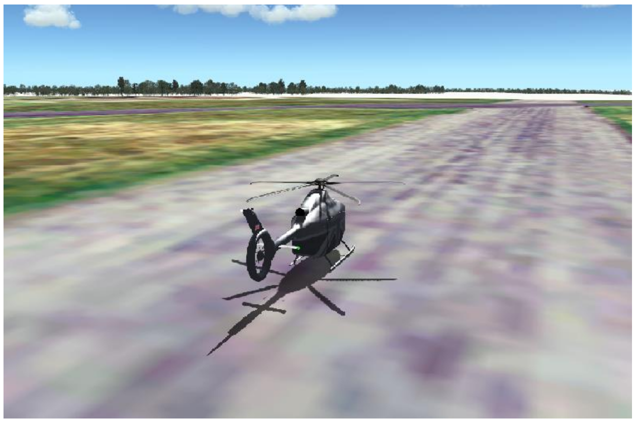

Figure 14: Proteus (visualisation) waiting for the take-off command from the CCU at the FSIR

5. CONCLUSIONS

This paper has given an overview of the work carried out towards the development of a ship Dynamic Interface for rotorcraft (crewed & un-crewed) at the Engineering Simulation Facility in Yeovil, UK over the past 7 years. Considerable progress have been made starting from a well-established Engineering Simulation Facility in conjunction with industry partners who are leaders in ship DI technology and alongside LH's wider capabilities in ship DI analysis and testing. The paper presented how the UK Ship Air Integration Framework (SAIF) for ship airwake and ship motion modelling was implemented on the synthetic environment. The paper described the development and validation of the ship DI from a crewed AW159 helicopter perspective and further development on to RWUAS, especially AWHERO and later on to the Proteus configuration. The ship DI synthetic environment models described in this paper formed fundamental building blocks for the Proteus maritime missions demonstrated to the Royal Navy customer in April 2025.

The primary focus of the paper was on the development of the flight models starting from an in-house developed flight mechanics code and moving on to the deployment of the wider LH used FLIGHTLAB rotorcraft modelling tool. The paper discussed how FLIGHTLAB flight mechanics model has been successfully ported to a more flexible Simulink environment – an environment where a wide variety of validated and tested helicopter system models were available. One of the key outcomes of this work was the development of the simulation control functionalities of the auto-coded FLIGHTALB model at run-time from a more widely used industry standard Matlab/Simulink environment. The Simulink flight model hosting high fidelity FLIGHTLAB flight mechanics models are being used in the AFCS/Avionics integration rig for testing the control laws used for the Proteus Technology demonstrator aimed for a first flight later in the summer of 2025.

The LH UK based Engineering Simulation Facility has developed into a highly capable, high value asset. Our partner industrial organisations have developed significant mature capabilities in the fields of ship air wake and ship motion simulation. By leveraging these joint capabilities coupled with high fidelity flight dynamics models, LH will be able to offer a unique facility within which the current and future ship DI environment may be explored.

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7. CLASSIFICATION & COPYRIGHT