Initial Progress in Developing a Predictive Simulation Tool to Inform Helicopter Ship Operations

Wajih A Memon*, Mark D White and Ieuan Owen
wajih.ahmed.memon@liverpool.ac.uk

School of Engineering
University of Liverpool
Liverpool, UK.

The UK's Royal Navy and Royal Fleet Auxiliary regularly perform launch and recovery operations of helicopters to and from their ships. These operations are carried out in challenging conditions, such as confined landing space, irregular ship motion, sea spray and unsteady airflow, posing a high risk to the helicopter, ship and crew. Together, these elements form the Helicopter Ship Dynamic Interface (HSDI) environment [1]. To determine the limitations of the safe operability of helicopters to the ships, a safety envelope is constructed through First-of Class Flight Trials (FOCFT) to determine Ship Helicopter Operating Limits (SHOL) [2], which specify the safe conditions for launch and recovery operations. FOCFTs are performed at sea and are inevitably very expensive, typically taking weeks to construct a SHOL envelope. Very often the required wide range of wind and sea conditions may not be available, resulting in the development of a conservative SHOL [3]. Therefore, Modelling and Simulation (M&S) of the HSDI environment is being developed in flight simulators to mitigate these risks, making SHOL testing safer, quicker and cost-effective. Whilst it is not trying to fully replace at-sea testing, the M&S research aims to inform the key test points of high uncertainty [4,5].

Over the past few years, flight simulators have been increasingly utilised in deriving helicopter/ship operational guidelines and construction of preliminary simulated SHOL envelopes using different techniques [6,7]. The aim has been to offer a wide range of benefits to the at-sea SHOL development process by testing various HSDI scenarios repeatedly with a range of pilots, prior to the FOCFTs. However, flight simulators, despite their utility, still posses limitations such as the fidelity of motion cues and flight models, hardware complexity and the availability of sufficient experienced pilots, all of which may result in compromised task performance and subjective ratings.

This paper reports the further development of a HSDI M&S desktop predictive simulation tool that uses a pilot modelling technique. The research aims to develop a high-fidelity simulation tool which will have the capability to better represent the dynamics of the real pilot when operating in the particularly demanding shipboard environment. It is intended to use this tool in conjunction with the piloted simulations performed using the University of Liverpool's Heliflight-R rotorcraft simulator facility [8] to construct a high-fidelity HSDI simulation environment which will offer a faster, cheaper and more efficient method for operational analysis of shipboard tasks for different combinations of helicopters and ships. Figure 1 shows the predictive tool structure presented in this study that includes a pilot model loop, helicopter dynamics, human sensory equalisation, ship airwake and ship motion driven by sea states, representing the integrated HSDI simulation environment.

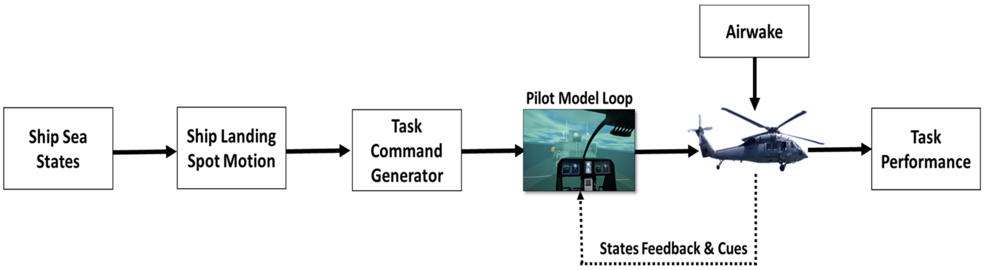

Figure 1: HSDI Predictive Tool Structure

Various desktop helicopter/ship simulation tools have been developed based on a range of pilot modelling techniques. Lee, et al. developed a simulation of a UH-60A GENHEL model operating from an LHA class ship using a compensatory optimal control pilot model [9]. Moon, et al. investigated the operation of a BO-105 helicopter model operating from a ferry using a compensatory optimal control pilot model [10] whilst Jarrett, et al. studied the effect of a ship's airwake on an MRH-90 helicopter model recovering to an LHD class ship using a PID based pilot model [11]. However, these techniques only partially represent the human central nervous system, due to the absence of the additional human modelling elements, particularly the visual, vestibular and proprioceptive systems. The inclusion of these elements adds a significant value to the fidelity of the model by approximating the dynamics of the human sensory systems which are important for multimodality tasks where the pilot may use information from different perceptual modalities [12]. Hess [13] introduced a simplified technique of using a compensatory structural pilot model for helicopter operations near ships which covers all the human sensory information systems. However, whilst the model is capable of representing a compensatory control strategy, in reality, the helicopter shipboard task is a pursuit tracking task where the target (i.e. the ship’s landing deck) is continuously and independently moving [1], adding additional requirements to the pilot task.

To improve on the fidelity of current HSDI desktop tools mentioned above, the pilot modelling technique adopted herein to design the SHOL predictive tool was first introduced by Hess and Marchesi [14]. The model is a pursuit control tracking model capable of representing multi-loop tasks (two or more control inputs simultaneously) and incorporates all the human sensory equalisation features (e.g. visual, vestibular and proprioceptive system feedback) in an approximate manner [12]. These features make the model more applicable to the HSDI launch and recovery operations.

To initiate the design phase of the tool, firstly, a 6 DoF state-space linearized model of a SH-60 helicopter was extracted from a non-linear FLIGHTLAB model. For simplicity, the hover flight condition was chosen for initial pilot model gains selection and preliminary analysis. Figure 2 shows the comparison of on-axis non-linear and linearized system response to a doublet input in all four channels.

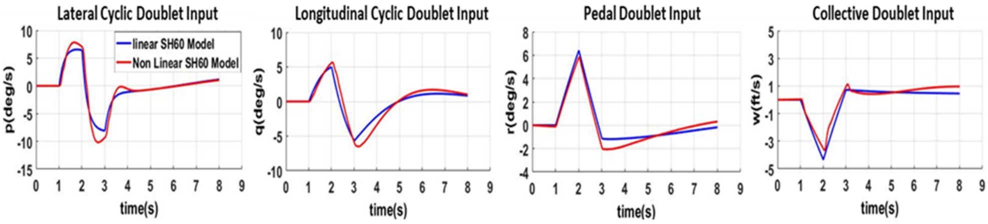

Figure 2: SH60 Linear and Non-linear Model Validation

To design the pilot model loop, a Frequency Domain (FD) technique illustrated in [14] was employed for the successful selection of the appropriate pilot gains. The process involves sequentially closing the loops of the pilot model within each channel (longitudinal, lateral, collective and pedal) separately and then combining all the channels to form a 6 DoF pilot model. Altogether there are fourteen pilot gains to be designed, four in the lateral and longitudinal channel and three in the collective and pedal channel, see Table 1. The bode plots obtained from the lateral channel design process are shown in Figure 3, starting from the inner-most (angular rate) loop having pilot gain ‘k_p’, then inner (attitude) loop having pilot gain ‘k_Φ’, then outer (linear rate) loop having pilot gain ‘k_v’ and finally outermost (translation) loop having pilot gain ‘k_y’. The selection of the gains is based upon the successful achievement of the FD requirements (magnitude difference of 10dB in innermost loop and crossover frequencies of 2rad/s in the inner and outer loop and 0.667rad/s in the outermost loop), as specified in Figure 3 in red.

Table 1: Pilot Model Loop Sequence and Corresponding Channels

Channel	Loop Closure Sequence	Channel	Loop Closure Sequence
Longitudinal	q→Θ→u→x	Collective	ẇ→w→h
Lateral	p→Φ→v→y	Pedal	ṙ→r→Ψ

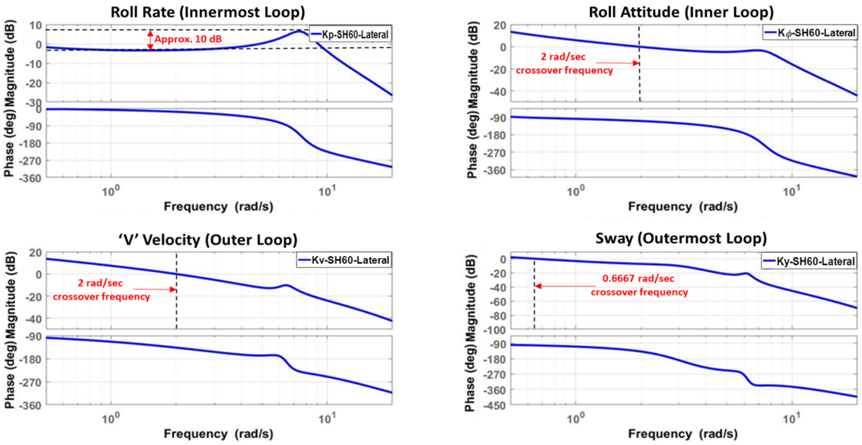

Figure 3: Frequency Domain Approach Lateral Channel Pilot Loop Design (FD design requirement is specified in red font)

Following a successful design of the pilot loop, an initial examination was carried out by performing simulations to compare the response of the tool with piloted simulation flight trials for a simple task. This is useful to aid objective tuning of the pilot gains and analysis of the flight task. The pilot model presented was devised using a command generator to represent a helicopter pilot performing the ADS-33E-PRF Hover task [15]. The commanded task was to initiate the manoeuvre from a hover condition and translate longitudinally 90ft and laterally 75ft and return to stabilized hover, while keeping the heading deviation within ±5° and lateral and longitudinal position within ±3ft. The task performance of the pilot model compared with the piloted flight trials results shows a reasonable agreement, Figure 4. However, it appears that the model gains need a slight tuning in linear velocity loops to further improve the match.

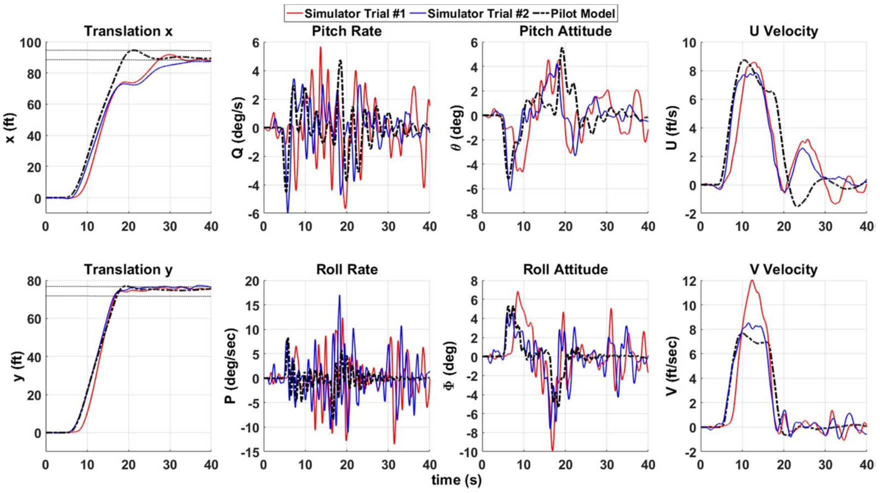

Figure 4: Developed Pilot Model Overpotted on Heliflight-R Simulator Flight Trials for ADS-33 Hover Task

In addition to the land-based task, a preliminary HSDI simulation of a representative SH-60 model helicopter operating to a UK Type-45 destroyer ship was developed to perform the hover MTE using the developed tool. Ship motion was calculated at the c.g of the ship and transformed to the landing spot. To account for the ship motion integration, the landing deck's lateral and heave motion serves as a command to the pilot model. To account for the airwake integration, a simplified Control Equivalent Turbulence Input (CETI) model was used which represents the effect of airwake on the helicopter using the relationship between turbulence and pilot control inputs [16]. It was assumed that the helicopter can land safely on the ship's deck if the pilot is capable of following the relative position and maintain altitude difference within the safe boundary for a given time. Since the ship was given a forward speed of 12kts, a forward flight linear helicopter model was trimmed at the 25kts airspeed and a 13kts headwind to represent a 25kts Wind Over Deck Condition. The CETI model was obtained using the Comprehensive Identification from Frequency Responses (CIFER) analysis tool [16]. A turbulence intensity of 15.5ft/s was calculated at hover point from Type-45 airwake computed at 25kts headwind condition [17] and used as an input to the CETI model. The turbulence intensity was used to generate equivalent control inputs to represent the airwake disturbance. Figure 5 shows the initial simulation results from the pilot model primarily tracking the position of the landing spot with and without the airwake.

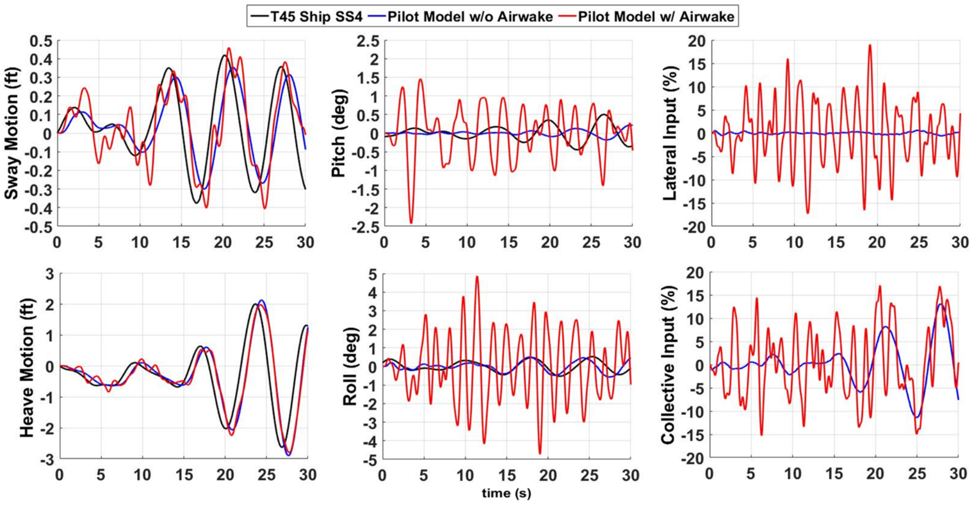

Figure 5: Approximated HSDI Simulation Results using Developed Pilot Model

For this preliminary HSDI setup, the task performance can be evaluated by determining the position tracking errors [13]. The maximum tracking errors determined in lateral and vertical axis are ±0.85ft and ±3.45ft, respectively, which are well within the desired task performance boundary (Lateral ±5ft and Vertical ±9ft) as specified in reference [13] for a similar task. The final step in this study is to compare the obtained results with the piloted simulation trials.

The paper will extend the initial results obtained in this research. Also, a dedicated piloted simulator trial will be conducted to objectively tune the pilot model gains and validate the predictive tool for various helicopter/ship combinations and HSDI conditions using the UK's Royal Navy deck landing approach.

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