Virtual Engineering in Skills Acquisition and Development in the Career of the Rotorcraft Engineer[1]

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Abstract

As the complexity of engineering systems grows, engineers increasingly need to be able to use a range of tools in order to reduce the costs, and associated risks, as they work in the various phases of the engineering life-cycle. In order to help engineers operate successfully within this product life-cycle, there have been significant developments in modelling simulation tools. Integrating these tools in a Virtual Engineering (VE) environment allows engineers to examine the potentially conflicting requirements of the different phases of the life-cycle, to develop a co-ordinated approach to requirements capture and product design through to identifying potential costly problems that could occur later in the development and operations phases. Technical skills development to use these tools is key to this process. This paper presents the experiences, learning outcomes and lessons learned in the development and implementation of bespoke rotorcraft engineering training programmes. The programmes were designed using a Problem Based Learning (PBL) framework where knowledge and skills are gained through solving problems. Four cases studies are presented in the paper, demonstrating how this PBL/VE approach can be used in the training programmes. Consideration of the future use of VE tools is provided together with future challenges for their successful application.

1. Introduction

Computer modelling and simulation provide an efficient and effective method for demonstrating both fundamental principles and complex relationships between system inputs and outputs. With physical properties and processes sufficiently detailed, exercising of simulation models can provide insight and understandings of system behaviours that would be extremely difficult to gain with the 'real' system. The flow of data, information and energy through a system can be illustrated and the consequences of, for example, flow being interrupted by component failures, demonstrated and assessed. Moreover, the impact of changes to the system design on such things as performance or resilience or weight can be explored. These things are at the very heart of the practice of Virtual Engineering (VE) of course, and practising engineers can continue to develop and apply VE skills throughout their careers as the fidelity and capability of modelling and simulation tools increase. The combination of product and process modelling, the creation and refinement of the virtual prototype and its exercise in support of design, development and certification require a special set of advanced engineering capabilities, anchored in sound mathematical practice.

In skills acquisition and development, it is the trainee's direct engagement with problem formulation and problem solving that connects the new ideas and ways of doing things with existing knowledge and abilities. These can then be honed by practice. The combination of this 'problem-based-learning' (PBL) and virtual engineering provide a powerful mix that can accelerate skills acquisition and consequent engineering practices. This is the topic of our paper.

In Section 2 the underlying principles and practices of PBL, in the context of VE, are explained. Section 3 discusses the various tools that are being used in a variety of courses, including continuing

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professional development (CPD), at the University of Liverpool (UoL). This is followed in Section 4 with a number of case studies, illustrating how we have used this approach in the undergraduate, graduate and training classes at Liverpool. In these case studies, the skills acquisition and development are emphasised. Section 5 looks forward to how VE might be further developed for training purposes finishing off with some concluding remarks.

2. Virtual Engineering and Problem-Based-Learning

As the name suggests, PBL involves achieving a series of learning outcomes based on the formulation and solution of problems. This is very much in tune with a professional engineer's daily activities where they are faced with turning a requirement into a design and then on to a product. Engineering creativity and artistry can flourish if the opportunities afforded by 'problems' can be approached in a constructive manner. At Liverpool, this challenge has motivated the development of a number of special courses, built around the PBL concept and based on the theory of experiential learning, expounded by the philosopher and education reformer, John Dewey [1], and the modern interpretations and extensions by David Kolb [2]. Kolb makes the point that "*We are the learning species, and our survival depends on our ability to adapt not only in the reactive sense of fitting into the physical and social worlds, but in the proactive sense of creating and shaping these worlds*. *Our species long ago left the harmony of a non-reflective union with the natural order to embark on an adaptive journey of its own choosing*."

In its broadest positive sense, survival of the human species is about imagining and creating a better world where everyone is safe, has a good quality of life and knows how to life in harmony with the other people and the environment. Kolb introduced the 'cycle of learning' concept illustrated in Figure 1. An obvious starting point is having a concrete experience, from which follows observation and reflection. People naturally reflect on their experiences and PBL helps us to articulate our reflections in a systematic way so that we remember what we thought and build on that experience for next time.

A big step is then taken where we conceptualise the experience. For engineers, this requires analytic and 'visual' thinking, and conceptual or physical modelling skills, used to establish hypotheses and draw conclusions from the experience. In order to plan what we would do differently next time, we also need to think about different options and how to develop our knowledge and skills to address these.

The process is not complete until we have tried out our new understandings, our conceptual models or hypotheses, on a new scenario, creating opportunities for more experiences and so the cycle continues (active experimentation).

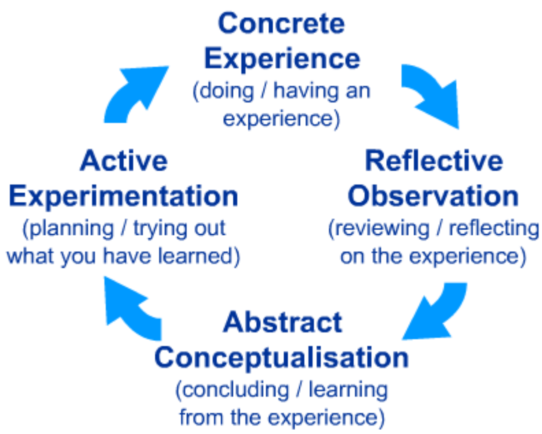

Fig 1 The Kolb Cycle of Learning [2]

The Kolb cycle has a strongly intuitive flavour and fits naturally with the PBL approach. For PBL activities developed at Liverpool, an aircraft with its operational deficiencies is often the focus for knowledge acquisition (e.g. handling qualities [3]). This method of learning helps the trainee to garner transferable, technical and interpersonal skills that will serve them throughout their careers. Critically, in PBL the tutor acts as a facilitator rather than a teacher, encouraging useful lines of questioning rather than providing explicit answers, and, when appropriate, provides problem-solving structures or methodologies. So the trainees take responsibility for their own learning, engaging in active learning through critical self-reflection, self-assessment and collegial learning.

One additional aspect of Liverpool's PBL approach worth highlighting is the use of the Personal Learning Journal (PLJ). The aim of the PLJ is to record the conduct and completion of required tasks. The Journal also aims to encourage self-reflection on what has been learned and how things could be done differently. The journal should provide a rich source of information about a trainee's self-assessed knowledge and competence in the exercise of skills. The journal also provides the basis of an external assessment of competence in terms of technical knowledge and understanding, intellectual skills and abilities, ability to apply these skills in practical situations and generally transferable skills, particularly relating to teamwork. A good understanding of what is required in terms of content in the PLJ is important. A PLJ is not a list of facts but is a reflection by the person on how their understanding and thinking has changed over a period and why.

So how do VE and PBL go together? In the following two sections this question is answered in some detail but, first, some general points. The use of M&S to formulate and solve problems is, of course, not new but rather integral to engineering practice in the form of predicting and revealing behaviour. Nowadays the detail in state-of-the-art simulations is so fine that only experts in the mathematical assembly processes can have a full and complete understanding. However, a larger number of engineers are likely to be 'users' of virtual engineering tools and therefore need to be sufficiently confident in the modelling that they can use the tools intelligently. This 'validation' provides an excellent theme for PBL; what is wrong with the model? The search for and eventual discovery of, a flaw can be a profound learning experience. Of course, such a PBL exercise would feature evidence that led to suspicions of a modelling flaw, rather than the flaw being known. Another example might be the use of simulation to aid understanding of how an aircraft's performance or handling qualities are limited; this is likely to require pilot assessment, hence real time piloted simulation. In all PBL exercises, problem formulation is a critical element to finding a solution; too simple and the problem may not evident, too complex and the problem may be hard to find. PBL training needs to emphasise this aspect, and the need to take time with this early formulation stage. These aspects will be brought out more descriptively in the case studies of Section 4.

3. Virtual Engineering Tools

Central to the development of the rotorcraft engineer are the tools sets available for them to maintain and acquire skills in support of their engineering careers. A wide range of VE tools are available from Computer Aided Design software, structural design, Computational Fluid Dynamics and flight mechanics codes. This paper will concentrate on a small number of software and hardware tools that have been utilised at the Liverpool to facilitate the use of VE in training activities.

UoL operates two motion research flight simulators; HELIFLIGHT [5,5] a single seat simulator and HELIFLIGHT-R [6], which features a three channel 220 x 70 degree field of view visual system, a 6 degree of freedom motion platform, a four-axis force feedback control loading system and an interchangeable crew station. Figure 2 shows both simulators, with HELIFLIGHT-R in the foreground and HELIFLIGHT in the background.

Figure 2 HELIFLIGHT-R simulator – internal and external views

Flight mechanics models are developed in either FLIGHTLAB or Matlab/Simulink and the current aircraft library features a range of fixed-wing, rotary-wing and tilt-rotor aircraft. The outside world imagery is generated using Presagis' Creator Pro software to produce either geo-specific or custom visual databases. Using Presagis' VEGA Prime software, the Liverpool group has generated its own run-time environment, LIVE (Liverpool Virtual Environment), which allows the simulator operator to change environmental effects such as daylight, cloud, rain and fog along with maritime effects such as sea state, ship's exhaust and rotor downwash on the sea's surface. A heads-up display can either be generated using an LCD screen with a beam splitter located above the instrument panel or projected directly onto the dome. The motion and visual cues, together with realistic audio cues, provide an immersive environment for a pilot. Data from the flight models, e.g. aircraft accelerations, attitudes etc., together with pilot control inputs can be monitored in real-time and recorded for post-flight data analysis.

4. VE and PBL in practice - Case Studies

The following case studies are taken from a number of different training courses given by the authors over the last 15 years. They are necessarily presented in summary form but with sufficient emphasis on the skills acquisition and development to enable the reader to appreciate the depth and breadth of the training.

Flight Handling Qualities (FHQs). VE and PBL are uniquely suited to developing knowledge and skills in FHQs for both pilots and engineers [7]. Example learning outcomes are listed in Table 1. Simulation models of sufficient fidelity are required to derive the predicted HQs (metrics, e.g. bandwidth, control power) and a flight simulator is required to derive the pilot-assigned HQ Ratings (HQRs). A comprehensive training includes such things as mission analysis, from which mission task elements (MTEs) can be defined, performing trim and stability analysis on the simulation model, computing HQ parameters and establishing the predicted HQ levels throughout the flight envelope. Understanding the physics behind the HQ predictions is important and can be enhanced by developing skills in using reduced order linear models of the flight dynamics [3]. Trainees might be asked, for example, to derive an expression for the effect of the pitching moment changes with speed derivative, M_u, on the phugoid damping; this is important as it is the source of a helicopter's instability in hover. Or they might need to understand better the impact of the yawing moment due to roll rate, N_p, on Dutch roll damping, as it can affect the level of gain used in the yaw damping element of the stability and control augmentation. Developing proficiency in working with reduced order models to aid enlightenment, is likely to raise the confidence of the trainee as he or she moves on to acquiring skills working with the full non-linear flight model.

Table 1 Example Learning Outcomes in FHQ PBL Course

Knowledge and Understanding

- *Handling qualities standards for different classes of aircraft and missions*
- *How aircraft design parameters affect handling qualities*
- *Do's and Don'ts in the use of HQ rating scales*

Skills and Abilities

- *Proficiency in Modelling and simulation of aircraft flight dynamics*
- *Design and conduct of HQ experiments*
- *Improvement of HQs through control system or airframe design*
- Maintaining a learning journal

Designing the (simulated) flight test is a core VE activity where the trainee engineer must focus on engaging the pilot with the problems exposed through the predicted HQ analysis. In this sense the activity is very much a collaboration between pilot and engineer, particularly if the aim is to improve the HQs where constant dialogue is needed to refine the improvements. Skills developed here include how to establish the task performance standards based on operational requirements, communication protocols during testing and how to conduct a de-brief session. Pilots will learn how to use the HQ rating scale and engineers will learn how to measure and present the performance and workload data to inform the de-brief discussions. It is in this area that the training might also provide opportunities for conflict resolution; the pilot might be adamant that they perceived a good performance but the data shows otherwise; or the engineer might interpret the control activity during a task as high workload but the pilot disagrees and returns a rating corresponding with low workload. Such situations are likely to result in extensive learning opportunities in non-technical communication skills.

FHQ was initially developed as a module for 4th year undergraduate and postgraduate Masters students at Liverpool [7]. The class would typically be divided into teams of 5 students. Each team would be given an aircraft (simulation model) and a mission definition with operational requirements. They would discover that the aircraft did not meet the performance and handling qualities requirements and the first task was to understand why and quantify the magnitude of the 'problem'. The second task was about finding ways of modifying the design and developing a HQ augmentation system to fix the problem and demonstrate operational readiness in terms of performance and HQs. The students starting point was the knowledge and skills gained from 3 years of their aerospace degree programme and a key point made in the module specification was that, as a team, they would likely be required to draw on all of this background to achieve success in the FHQ module.

An example from the FHQ VE training is given by the case of a helicopter that was required to perform agile manoeuvres at low level in confined spaces. The students selected a set of ADS-33 mission task elements (MTEs) [8] including the hover-turn, that required desired performance standards achieved in a 180 degree turn in 10 seconds. The team identified one of the critical deficiencies as a lack of yaw attitude response quickness in the basic aircraft (magenta in Fig. 3). Through the combined use of feedback (damping) and feedforward (quickening) control they were able to improve the response and measured this in terms of the ADS-33 attitude quickness parameter. Figure 3 shows that the team was able to increase the quickness to reach the Level 1-2 HQ boundary (blue in Fig. 3). This improvement in agility was achieved without a penalty to stability. According to the pilot HQRs, the assigned HQs improved from Level 3 (adequate performance not attainable) to Level 1 (desired performance achieved).

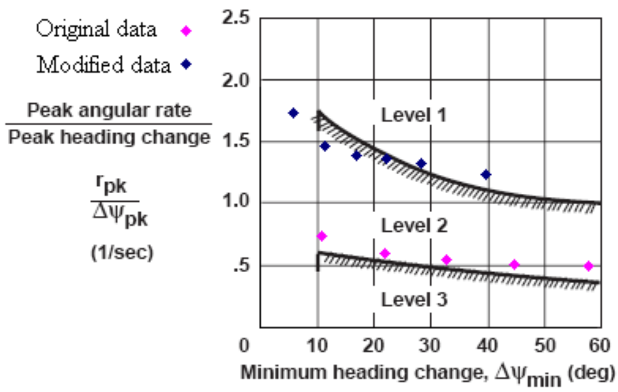

Fig 3 Yaw Attitude Quickness
(◊ original aircraft ◊ with yaw quickening)

In all, the team designed 5 MTEs to exercise the HQs in the low speed phase of the mission. The improvements resulted in Level 1 HQs in most areas. Their control system upgrade required relatively straightforward technology, although the team recognised that new dual-port actuators would be required to accept the electronic inputs from the augmentation system.

The combination of the use of VE tools and the PBL framework enabled students engaged in the FHQ module to apply and build on their previous knowledge and understanding and, significantly, learn from their team colleagues; mirroring what they will likely find in Industry as they tackle 'real' engineering problems.

Conceptual Design: Early conceptualisation of a new rotorcraft configuration to meet a design requirement can only be achieved through VE. This task therefore lends itself well to a PBL based training exercise to provide the required learning outcomes, as listed in Table 2. Creation of a virtual prototype (VP) requires the engineer to first design the aircraft 'on paper' to establish the configuration; however, the exact form of the VP does not need to be known, only its functional data. On completion of the conceptual design exercise, the data is transferred to an appropriate template within the FLIGHTLAB modelling and simulation software package. This allows for a handling qualities and performance assessment to be conducted to determine any deficiencies against the requirements. These can be validated using pilot-in-the-loop simulation to establish the impact of performance shortcomings and the assigned HQs. Any deficiencies are identified and improvements explored through airframe re-design or system augmentation to deliver the requirements.

Table 2 Example Learning Outcomes in Rotorcraft Conceptual Design PBL Course

Knowledge and understanding

- Aircraft configuration parameters for a range of rotorcraft sizes and shapes
- How aircraft design parameters impact requirements, e.g. performance and handling
- Requirements analysis

Skills and abilities

- Conceptual aircraft design trading for an intended mission profile
- Design and conduct of pilot-in-the-loop simulation trials
- VP verification and validation processes

The design exercise is the core activity where to progress the design, students must gain knowledge and understanding of the design attributes of a range of aircraft configurations and develop understanding of the physical impact of phenomena such as disc loading or how the advancing blade tip might enter the transonic flow region if not carefully designed. The trainee engineer is then invited to trade-off design characteristics based upon knowledge of existing rotorcraft designs analysed throughout the case study.

This case study was implemented as part of an aircraft design, performance and HQ module and provided trainee engineers with the skills to develop a tilt rotor virtual prototype with Level 1 HQs from a mission requirement document. An example task is to develop a virtual prototype of a civil tilt rotor for an Emergency Medical Services (EMS) role. Since a tilt rotor can operate in both helicopter and fixed wing modes, the design addresses both these type of aircraft. The process leads the trainee engineer through one possible rotorcraft design methodology, where the rotor is designed using equations representing the fundamental principles of helicopter flight while the wing and the airframe are scaled based upon fundamental fixed-wing parameters.

The first step in the process is to determine the payload required for the mission. In this case, no information is given other than aircraft size and maximum take-off weight. The trainee engineer will need to undertake a literature study to configure the mass and composition of an EMS payload based upon current EMS helicopter specifications. The rotor design is where significant learning outcomes are achieved. The equations used are deceptively simple but are unlikely to be applied successfully without an understanding of basic rotor physics. An example of this can be seen when selecting the disc loading, rotor radius and rotor speed. The relationship between these parameters is shown in Figures 4 and 5.

The engineer is faced with the question of how to determine these parameters when the only information available is mass. The approach presented in this case study is that the trainee students must again revert to a literature study to develop a bounded range of values typical to a given aircraft type. For example, there is no clear relation between disc loading and gross weight of a rotorcraft, but a literature review shows that helicopter or tilt rotor disc loading values are typically within narrow bands. Nevertheless, this still doesn't allow the designer to select a disc loading, merely to say that experience suggests it is within a set of bounds and that not enough information is currently available. It does, however, allow the disc area and rotor radius to have typical bounds applied.

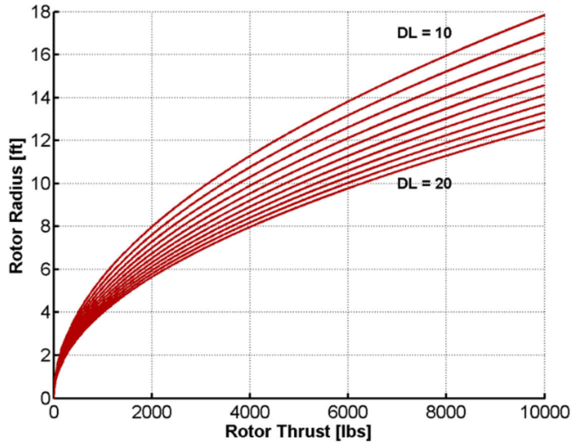

Figure 4 Rotor Disc Loading

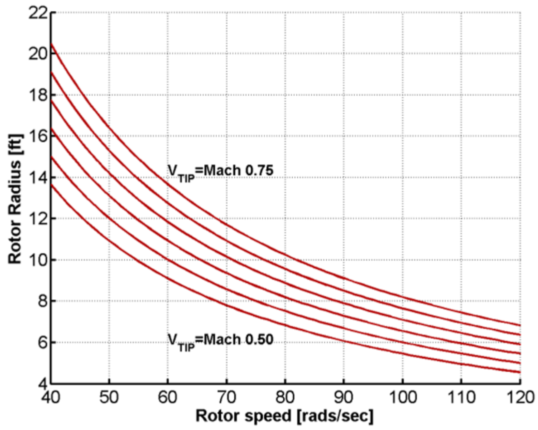

Figure 5 Rotor Tip Speed

Knowledge and understanding of rotor aerodynamics can be introduced to further refine the design. For example, students can utilise knowledge of rotor radius, rotor speed and blade tip speed with the effects of operating in the transonic regime to refine the rotor radius and determine a maximum operating speed. When the vehicle maximum speed and hover tip speed have been designed, the max and min rotor radius boundaries found previously can be applied to the representative rotor tip speed line illustrated in Figure 5 which in turn defines a rotor speed range. At this point, the designer can look at the engines needed and select one which has an appropriate power and size. If this information is not available, enough limitations have been set to allow the designer to choose an appropriate combination of rotor speed and radius, thus determining the rotor disc area and disc loading.

Although the equations are rudimentary, combined with knowledge of existing rotorcraft designs, they provide students with a powerful technique for estimating and assessing a rotor configuration. Further design composition can then be determined such as solidity, chord, thrust coefficient and blade loading coefficient using simple relationships, when the designer defines the number of rotor blades, but again the user requires knowledge of the impact of the variations in these design parameters.

On completion of the VP design, trainee engineers use modelling and simulation tools, typically FLIGHTLAB, to create a real time version of the simulation. Even though a minimal set of design parameters has been established, many parameters in the VP will use default values to create the structure and aerodynamic data for the rotor blades and fixed wing aerodynamic surfaces. Again a default control schedule is included to allow inputs to the model and to convert between helicopter and aeroplane modes.

The handling qualities and performance of the bare airframe VP can then be assessed in the same manner as discussed in the previous FHQ case study, through off-line predicted handling qualities and performance assessment followed by assigned handling qualities assessments from pilot-in-the-loop simulation. These results allow the designer to identify and address any shortcomings and repair deficiencies, e.g. by developing a Stability Control Augmentation System (SCAS) to deliver Level 1 HQs for the defined mission.

Ship-Helicopter-Operating Limits (SHOLs): The objective here is to transfer knowledge and understanding of generic maritime helicopter operational constraints through the simulation and assessment of ship-helicopter operating limits (SHOLs) and handling qualities. It is also the purpose to transfer to the trainees, knowledge and skills that provide a synthetic view of the ship take-off & landing constraints from the pilot's point of view and to identify constraints for one of the most complex and complicated developments prior to commencing a maritime helicopter development program.

Traditional lectures cover:

i. helicopter on-shore testing to establish predicted and assigned handling qualities, including the rational for mission-task-element design, e.g. super-slide tracking, lateral re-position and precision hover (see Fig. 6).
ii. The Dynamic Interface (DI) between helicopter and ship embracing the launch from and recovery to the ship i.e., approach, line up, descent and deceleration to alongside ship, hover, fly over deck, landing.

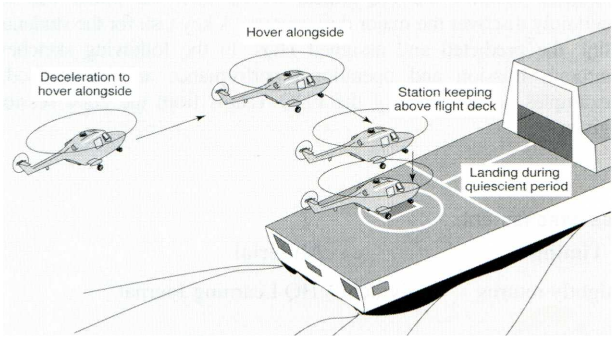

Figure 6 Deck landing mission task elements

iii. The ship environment, including wind and wave generation (Beaufort and sea state scales), ship and flight deck motion, air wake (air flow over flight deck due to ship superstructure), natural wind effects (maritime atmospheric boundary layer, turbulence) and types of degraded visibility (night, mist, fog, snow, spray, windscreen interface).
iv. The helicopter/ship recovery including locating the ship, controlled approach (ship controlled, helicopter controlled, emergency low visibility approach), non visual guidance for approach and landing; various DI technologies including search radar, precision approach radar, instrument guidance systems, ship visual aids, future guidance systems (emission controlled conditions – EMCON), recovery profiles/cockpit displays and automatic recovery.

The learning derived from the lectures is then applied to the development of the SHOL for a particular ship-aircraft combination using piloted flight simulation with ratings based on the deck interface pilot effort scale (DIPES; from 1 (deck landing easy to 5 (dangerous))

Learning outcomes

Knowledge and understanding: The trainees should be able to demonstrate a wide knowledge and understanding of the SHOL process and the difficulties of achieving the ultimate limits due to a range of factors. The lectures are interspersed with team exercises designed not only to test the trainees' absorption of the information but also to test their application and their ability to resolve issues and problems during such operations, both as individuals and as a team. The trainees are encouraged to ask questions, related or not to the lectures, during and any time after and to maintain their personal journals.

Practical skills: On completion of the PBL training, the trainees will be able to conduct VE SHOL exercises, planning the programme, acting as the flight engineer during the VE SHOL flight simulator exercises, or as the project engineer on board the ship directing operations, modifying the programme as required by the results and the conditions. The trainees will also have the opportunity to develop skills in modifying the design of the aircraft, implementing these in the VE simulation and evaluating the results of the upgrades on the SHOL.

An example was the determination of the SHOL of a conceptual embarked helicopter which had level 1 HQs for land based MTEs but potentially level 2 characteristics in the DI when operating with small power margin (<10%) in high seas and strong ship air wakes from some quarters of the proposed SHOL envelope. The basic SHOL with the ship in sea state 3 was derived which proved to be severely restricted (Figure 7). As a consequence, a stability and control augmentation system (SCAS) was designed for the heave, yaw, pitch and roll axes incorporating collective/yaw coupling. During the subsequent phase of the training, the characteristics which led to the limited SHOL were investigated, the handling characteristics improved to level 2 and the re-testing of the modified aircraft SHOL with the ship airwake incorporated is shown in figure, expanding the SHOL by 20%.

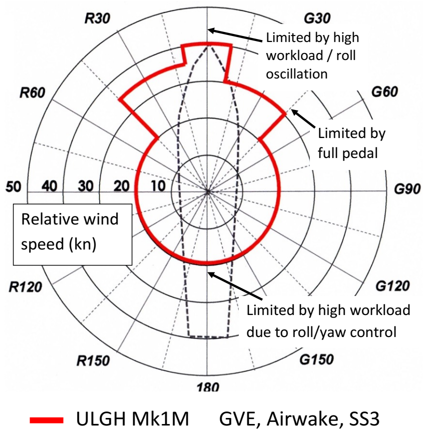

Figure 7 Typical SHOL envelope in good visual conditions, sea state 3 with airwake

Another example from the training exercises involved evaluation of ship visual aids in degraded visual environments. In Figure 8 (left), the SHOL of the original model (in red) is compared with the new model (hashed red) in good visual conditions. This was not a significant advance although the yaw departure was eliminated. Figure 8 also shows the reduction caused by a daytime degraded visual environment. The ship featured a fixed horizon bar on top of the hangar with deck floodlighting. The new model expands the SHOL for direct headwinds and tailwind. Figure 8 (right) shows the reduction in the SHOL in degraded visual conditions at night and the further reduction as the sea state increased to 5, although the ship was then equipped with a suite of enhanced visual aids, incorporating electro-luminescent panels on the deck and forming deck centreline line up poles, stabilised horizon bar and deck floodlighting. These aids clearly reduced the impact of the high sea states and resulting ship motion.

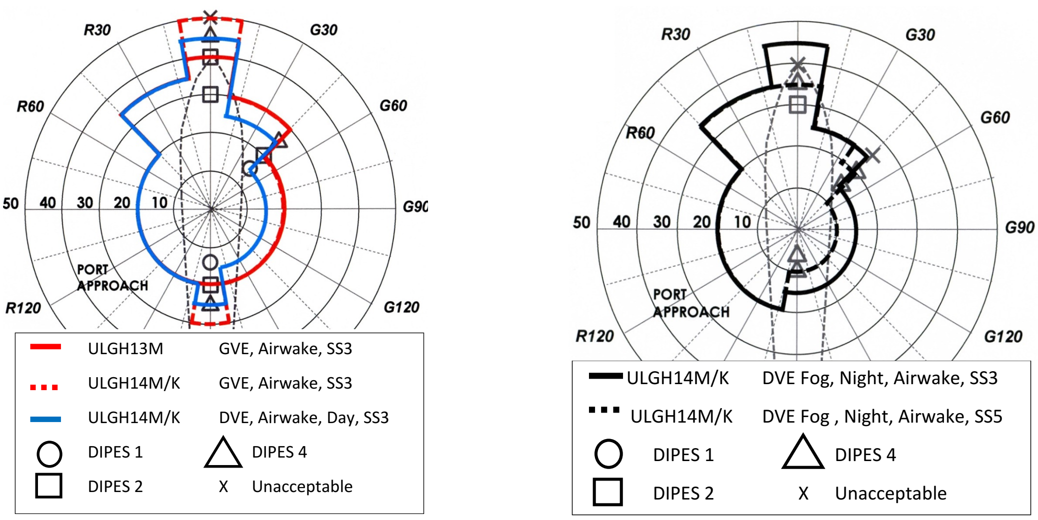

Figure 8 Comparison of SHOLs of two helicopters with different levels of visibility and ship motion

Following the SHOL tests, the trainees analysed the data and provided verbal and written reports on the exercise, in the form of the helicopter release recommendations together with the outstanding issues associated with pedal margin, roll oscillation and roll/yaw control together with the unexplained yaw departure for G90 winds. The tests therefore revealed further design issues with the helicopter itself which required attention and which would need retesting.

Overall Outcomes

The principal earning outcomes were that the trainees would be able to conduct real SHOL tests with confidence, and be able to identify potential issues and pitfalls. Outcomes were assessed by the trainees' ability to plan and conduct the SHOL tests efficiently, maintaining a good dialogue and relationship with the test pilot conducting the tests. Secondly, it was tested by their ability to analyse the results and to determine the reasons for shortfalls in the SHOL envelope, expected or otherwise. Thirdly, their ability to communicate with the end customer was assessed by presentation of the results from the SHOL tests in a way which showed their understanding of the processes involved and the relative importance of the facts presented. By the end of the training, they should have comprehensive know-how and means to further analyse, define, develop and build for themselves their own helicopter-ship dynamic interface capabilities, using simulation, to the benefit their navies. In addition, they will have an appreciation of the complex nature of maritime operations.

Simulation Fidelity: The benefits of using virtual environments to provide a safe and reliable tool for pilot training are well established. In order to have confidence in the utility of the training device its level of fidelity must be quantified in some way. The objective of this training activity is to enable simulation engineers to be able explore the simulator design space, within a VE environment, to examine the impact of component fidelity requirements e.g. motion base, field of view, flight/simulator model tolerances, on the overall fidelity of the simulation. Simulation engineers will be familiar with current qualification standards such as CS-FSTD(H) [9]. Whilst the standards provide a useful regulatory framework detailing, for example, the tolerances for the proof of match between flight and simulation data and what might be considered as the functional fidelity of the system, i.e. levels of replication of the cockpit layout, they do not provide a robust methodology for the fidelity assessment of the overall simulator system. Further, they do not cover the full range of rotorcraft operational training requirements e.g. ship-borne landings or research simulators. The activity will provide the engineers with a methodology for improving current standards or developing new standards where they do not exist.

The training activity would begin with a review of recent research regarding simulator fidelity standards and the need for further research. For example, GARTEUR Action Group HC/AG-12 [10] showed that the relationship between overall fidelity and the "*predictive fidelity*" tolerances prescribed by CS-FSTD(H) is sensitive to the nature and duration of the manoeuvre. These *predictive fidelity* metrics are formulated using tolerances, typically +/- 10% against which simulation data must match flight test data and previous studies have shown that satisfying these tolerances does not necessarily guarantee that the simulator is fit for purpose.

The focus within these standards is related to the definition of component level fidelity rather than the training benefit that can be derived from the simulator. Existing standards do not provide details of the level of fidelity required for individual training tasks, nor a methodology for assessing that fidelity requirement. The Royal Aeronautical Society's ICAO 9625 advisory document [11], has made a significant step to providing such a framework and can be used to introduce to the trainees the concept of task specific fidelity. At its heart however, the document contains the same tolerances that exist in the current standards and the trainees would be introduced to the need for a new methodology for assessing the overall fidelity of a synthetic training device.

Research at UoL has produced a fidelity assessment framework, based in part on the assessment of *predictive fidelity* requirements using a Handling Qualities (HQ) approach and also *perceptual fidelity* requirements, and the training activity will explore these concepts [12, 13]. The use of HQ metrics to complement existing time-domain criteria within CS-FSTD(H), in order to identify the effect of model deficiencies on overall fidelity, will be introduced and the methodology for developing new criteria demonstrated. For *perceptual fidelity* assessments, a Simulator Fidelity Rating (SFR) scale has been developed at UoL, and its utilisation for subjective fidelity assessment will be a key part of the training. The SFR scale is fundamentally driven by two components: adaptation of task strategy and relative task performance either between the simulator and flight or between a simulator baseline model and a "variation". The following illustrates how these predictive and perceptual fidelity metrics can be used to examine flight model fidelity [14].

CS-FSTD(H) requires that, following a longitudinal step input, the on-axis response - the pitch rate (and pitch attitude) from longitudinal cyclic - should be within the tolerances shown as the broken lines in Figure 10, and the off-axis response (e.g. roll response) should be of 'correct trend and magnitude'. The on-axis response tolerances in CS-FSTD(H) are either ±10% of the achieved peak attitude, or ±3 deg/sec of the rate, whichever is less restrictive. The off-axis responses in Figure 9 all exhibit the correct trend so it becomes a matter of interpretation whether the magnitudes are ‘correct’ and it is at this point the trainees will apply one of the complimentary HQ metrics, inter-axis couplings, to examine the impact of model “deficiencies” on the fidelity of the model.

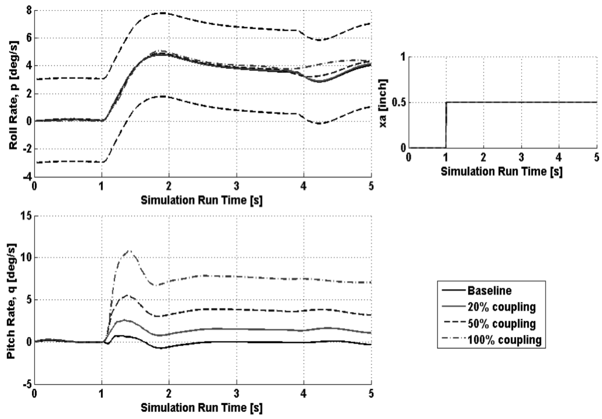

Figure 9 – On and off-axis rate responses to a 0.5 inch, 4s lateral cyclic input for cross coupling variations

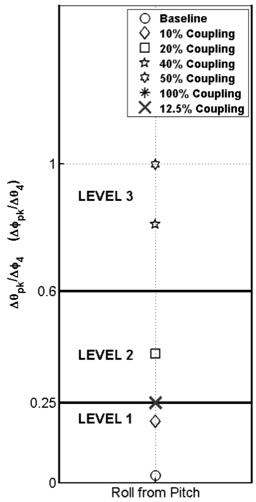

Figure 10 - ADS-33E-PRF Pitch/Roll Coupling Requirements for Aggressive Agility

Whilst the responses shown in Figure 9, satisfy the qualification requirements, increasing the pitch/roll cross coupling to 12.5% in the model degrades the handling qualities into Level 2, suggesting that, beyond this, the fidelity of the simulation may be compromised.

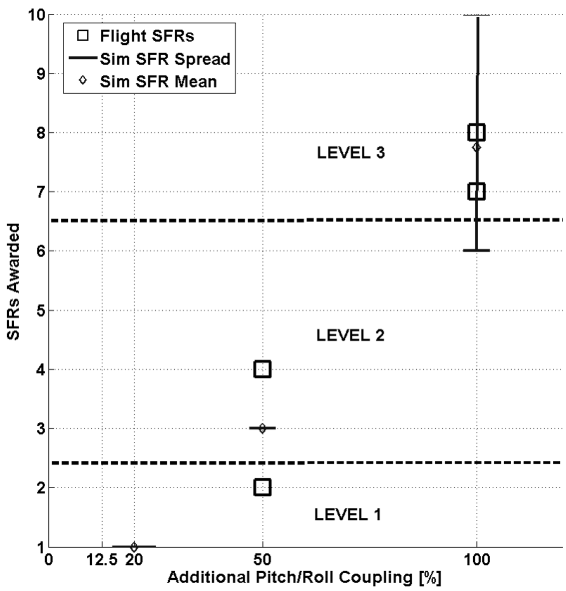

Figure 11 - SFRs awarded for cross coupling tests HELIFLIGHT-R and ASRA –Precision Hover MTE

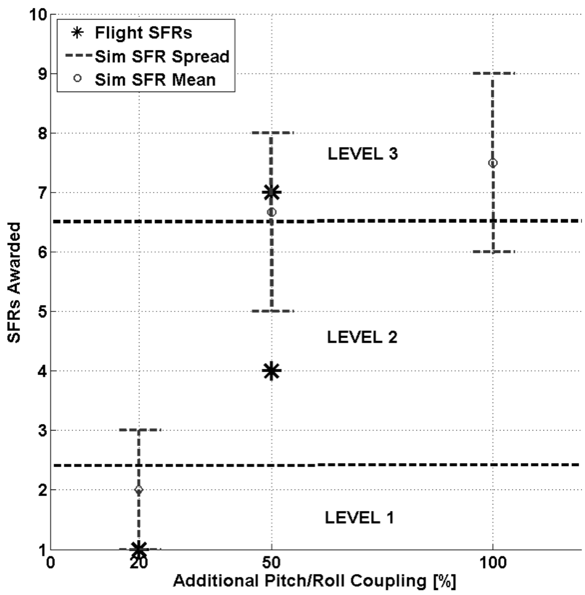

Figure 12 - SFRs awarded for cross coupling tests HELIFLIGHT-R and ASRA – Accel-Decel MTE

The results in Figures 11 and 12 were obtained from flight and simulation trials where the same methodology was applied; an incremental change in the coupling response and use of the SFR scale to examine the effect of the change on overall fidelity for two ADS-33E-PRF manoeuvres, a precision hover and an accel-decel. The flight tests were conducted using the National Research Council of Canada’s Bell 412 Advanced Systems Research Aircraft (ASRA, in-flight simulator), which has a fly-by-wire flight control system enabling user-defined control laws to be flown. The results show that the SFRs degrade as coupling strength increases, as might expected. A methodology can thus be derived to identify an acceptable parameter variation, in this cross-coupling to derive fidelity tolerances. From the results presented, it is expected that the tolerance on pitch/roll cross coupling for Level 1 fidelity for the Precision Hover task may lie between 30% and 40% cross coupling (an inter-axis coupling of approximately 0.7 - see Figure 10), but this value would be smaller for the accel-decel at approximately 20% cross coupling (inter-axis coupling of approximately 0.4). This result illustrates that fidelity is task dependant, which is not currently considered in the CS-FSTD(H) standards, and will allow the trainees to develop new task specific criteria for their training applications.

5. Looking Forward and Concluding Remarks

The aim of this paper has been to highlight a number of VE tools and processes available to rotorcraft engineers to enable them to develop new skills to address future rotorcraft design, development and operational challenges. It should be noted that whilst the case studies presented in this paper were aimed at enabling the acquisition and development of personal skills in a particular area this should not occur in an isolated fashion. The strength of the VE-PBL approach to knowledge acquisition and development for rotorcraft engineers is that a variety of technical disciplines can collaborate effectively together to assess and understand the impact of design changes in one domain upon another, which is key to reducing costs, time to market and ensuring the design is 'correct first time'.

In terms of software developments, more capable, higher fidelity tools are available to be used by engineers to address current and future requirements for rotorcraft designs. However, there needs to be a reality check in this process, the question of how good is good enough needs to be addressed in all aspects of the use of VE tools. Adding complexity to the tools does not necessarily equate to improving fidelity in the application stage. VE tools need to be developed to allow the sharing of design information across technical disciplines to assess the impact of changes on one domain on another. In addition tools are needed to also preserve corporate lessons learned for the next generation of engineers. It is hoped that this paper demonstrates that the career of a rotorcraft engineer can be enhanced through the availability of VE tools coupled with an understanding of the capabilities of the tools and how they might best be employed in support of the end goal.

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