The Use of Modelling and Simulation to Give Students a HEADSTART into Aerospace Engineering

Mark D White[1], Christopher Dadswell and Thomas Fell[2], Roy Coates[3]
The University of Liverpool, U.K.

This paper describes the developments and experience gained with the use of a range of flight simulators to support the Aerospace Engineering undergraduate teaching programs at the University of Liverpool. A range of fixed base and motion simulators have been developed to provide a powerful teaching aid for the undergraduate degree programs. Details of these activities and the evolution of new interactive learning opportunities is described. Such facilities also provide an insight to A-level students who are considering studying aerospace engineering at a University. The HEADSTART Aerospace focus program is presented to show how flight simulators provide a 'vehicle' to reinforce concepts introduced within a more traditional lecture structure, allowing students to investigate flight dynamics and control problems through physics based models and performing real-time piloted simulations trials.

Nomenclature

Ktheta = pitch attitude feedback gain
Kq = pitch rate feedback gain
q = pitch rate
θ = pitch attitude

I. Introduction

A typical academic vision for an Aerospace undergraduate program might be described as follows: "*to develop to Honours degree level, engineering graduates who possess knowledge, skills and competencies (as defined by UK SPEC (Ref. 1) to pursue a successful professional career in engineering that meet the requirements of industry and society. It will provide graduates with deep knowledge of aerospace engineering principles, broad knowledge of technical and non-technical subjects and skills to practice engineering and develop their career to any scientific, technical or managerial level worldwide*" (Ref. 2). Mentioned in the vision statement is the UK Standard for Professional Engineering Competence (UK-SPEC) which has a list of five key competency areas that must be met for registration as a Chartered Engineer (CEng), together will examples of how those competencies should be demonstrated:

1) Knowledge and understanding
2) Design and development of processes, systems, services, and products
3) Responsibility, management, or leadership
4) Communication and inter-personal skills
5) Professional commitment.

Degree programme accreditation bodies, such as the Institute of Mechanical Engineers, also specify the intended Learning Outcomes that are required for an accredited degree programme. Whilst this all provides an overview of the output from the programme it does not provide any details of how that process will be achieved through the curricula delivered. As the vision for the aerospace program is to produce capable graduates for the Aerospace Industry, the students should be provided with the opportunity and environment to develop their technical and inter-personal skills as fully as possible through challenging modules and exposure to active learning methods. As a member of the CDIO

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[1] Senior Lecturer, School of Engineering, University of Liverpool UK, mdw@liverpool.ac.uk, AIAA Member.
[2] PhD Student, Flight Science and Technology Research Group, University of Liverpool, UK.
[3] Computer Officer, School of Engineering, University of Liverpool UK.

Initiative, (www.cdio.org) the University of Liverpool is committed to developing its degree programmes along *C*onceive, *D*esign, *I*mplement and *O*perate guidelines and to developing individual program modules with more interactive teaching and learning. A key part of this learning environment is the toolset available to instil the desire for self-improvement amongst the students.

This paper describes several flight simulation facilities and activities that have been developed for the Aerospace Engineering and Aerospace Engineering with Pilot Studies students at the University of Liverpool (UoL) to provide that learning environment. It focusses on a summer school, HEADSTART, that has been developed to attract students to study Aerospace Engineering. Following this, interactive activities for a range of modules covering the four years of a typical integrated Masters program in the UK are presented together with examples of how undergraduate research activities link with the main simulation research areas.

The paper concludes with some thoughts on the development of future activities and how modelling and simulation might become more embedded in the curricula to enhance the student learning experience.

II. Flight Simulation Facilities

There are 2 full motion simulators, HELIFLIGHT (Ref. 3) and HELIFLIGHT-R (Ref. 4) and 4 fixed base simulators (PA-38, Jetstream 41, FastJet and Flight Deck Assessment Rig) that are used in a range of undergraduate teaching and research activities. This section provides a brief overview of the different simulators at UoL and in particular highlights the input the students have had in their development.

A. HELIFLIGHT

HELIFLIGHT (Fig. 1) was commissioned in the Flight Science and Technology research group at the University of Liverpool in 2000. Key to its procurement was the requirement to use the simulator as part of undergraduate teaching and research activities as well as for post-graduate and industrial research. The ethos was to introduce a tool that would complement ‘traditional’ class room lectures with an active learning environment, where students could formulate ideas and assess them in the simulator (Ref. 5, 6). HELIFLIGHT is a relatively low-cost, turnkey, and re-configurable single seat flight simulator with five key components:

Figure 1 HELIFLIGHT simulator

1) aircraft flight mechanics modelling: the main modelling tool remains FLIGHTLAB (Ref. 7). The MATLAB/Simulink modelling environment has recently been integrated into the simulator to allow the students more open access to the modelling activities but also to enable the simulator to be more openly used in teaching activities
2) a six degree of freedom motion platform
3) four axis force-feel control loading, including controls for fixed and rotary wing aircraft
4) a three-channel collimated display providing 135° horizontal by 40° vertical field of view which is extended to 60° vertical field of view using two flat screen displays in the foot well chin windows
5) a re-configurable, computer-generated instrument display panel.

B. HELIFLIGHT-R

HELIFLIGHT-R (Fig. 2) was commissioned in 2008 to provide more capability and to increase the capacity in terms hours available on the flight simulators for both research and teaching. It is a full motion research flight simulator which has:

1) a three channel 220 x 70 degree field of view visual system, now using a Rockwell Collins pixel management system to provide image warping
2) aircraft flight mechanics modelling: the main modelling tool is also FLIGHTLAB, but as with the HELIFLIGHT Facility, the MATLAB/Simulink modelling environment has been integrated into the simulator
3) a six degree of freedom motion platform
4) four axis force feedback control loading, with controls for rotary wing aircraft, a side stick and overhead throttle quadrant and switches
5) an interchangeable 2-person crew station together with a rear Instructor Operator Station
6) a re-configurable, computer-generated instrument display panel using Presagis' VAPS XT prototyping software to produce aircraft specific instrument panels
7) outside world imagery generated using Presagis' Creator Pro software to produce either geo-specific or custom visual databases.
8) a UoL developed run-time environment *LI*verpool *V*irtual *E*nvironment (LIVE) using Presagis' VEGA Prime software, 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 Ref. 8)


Figure 2 HELIFLIGHT-R simulator

The current aircraft library features a range of fixed wing, rotary wing, and tilt-rotor aircraft. These models are integrated into the simulator, together with realistic audio cues, to provide an immersive environment for a pilot.

C. Pilot Studies Laboratory

UoL offers two undergraduate degree programs, Aerospace Engineering with Pilot Studies (B.Eng. and M.Eng) for students who are considering a commercial or military flying career. The programs have the same structure as the Aerospace Engineering programs but have additional modules to cover elements of the Private Pilot's License (PPL) and Airline Transport License (ATPL) ground school. In addition, in the first year of the program the students undertake 20 hours of flight training at Liverpool John Lennon International Airport, flying Piper Tomahawk PA-38 aircraft.

To provide the students with an interactive learning environment three fixed base simulators have been developed in house by staff and undergraduate students to create a new Pilot Studies Laboratory. The laboratory also features several workstations that house Computer Based Training software to support the ground school modules.


Figure 3 PA-38 Simulator

To support the students in the first year of the Pilot Studies program a PA-38 Simulator has been developed. The aircraft originally belonged to a local flight training organization before being donated to UoL. The PA-38 simulator was originally conceived as a cockpit procedural simulator enabling students to become familiar with the cockpit of the aircraft prior to any flying lessons. Over the last two years, staff and students have upgraded the simulator to allow it to be used to rehearse flying lessons, undertake post-flight reviews and to provide a research environment for undergraduate research projects.

The PA-38 simulator consists of a genuine aircraft cockpit interfaced using a range of readily available interfaces to the X-Plane flight simulator program (from Laminar Research). Instrumentation is provided by Flight Illusion units. A simple projection system currently provides the 'out of the window' views and a separate instructor console allows for control of the flight environment from outside the cockpit.

In the second year of the Pilot Studies program the students start to look at commercial airline operations and study parts of the ATPL ground school syllabus. This introduces the students to multi-crew operations concepts, global meteorology, and operation of complex aircraft systems. The JetSim, a simulation of a Jetstream 41 aircraft, was developed to provide the students with a learning environment where they can explore these new concepts.

The JetSim (Fig. 4) consists of a custom-built shell which houses hardware from a Hawker 125 aircraft. This is also interfaced to the X-Plane flight simulator program using commercially available interfaces. Instrumentation is provided by bespoke software written in-house and is displayed on screens installed behind the instrument panels. Sufficient switch-gear and software emulation is in place to allow actual Jetstream 41 check-lists to be used in the simulator.

A separate instructor console allows for comprehensive control of the flight environment from outside the cockpit, including changes in weather or equipment failures.

Figure 4 JetSim Flight Deck

The Fast-Jet simulator (Fig. 5) was donated to the University by BAe Systems as an empty shell. To date, basic flight controls have been installed and work is now underway to add sufficient hardware and software to the simulator to emulate the operation of the BAe Hawk T2 training aircraft. In addition to commercially offered interfaces, advantage is being taken of low-cost microprocessors such as Arduino's to create bespoke hardware.

The simulation software for the Hawk will again be X-Plane with additional software developed in-house to emulate the Hawk's various systems.

Figure 5 FastJet Simulator

One of the key design points for the Pilot Studies laboratory was to provide the students with open access to flight simulation hardware and software that they can use to develop their interest in Aerospace Engineering. The simulators provide an excellent “vehicle” for the acquisition and development of new knowledge of flight controls, flight dynamics, mechatronics, and software integration. The fixed base simulators are good examples of how low-cost devices utilizing commercial off the shelf hardware can provide a learning landscape for students.

III. HEADSTART Aerospace Focus Program

Headstart is an activity of the Engineering Development Trust and forms part of the Royal Academy of Engineering’s Best Programme that aims to provide high quality Year 12 students, who are interested in science and engineering, an opportunity to spend up to a week at University exploring appropriate degree courses prior to making their University applications. The courses are designed to demonstrate what science and engineering disciplines are about, provide opportunities to meet university lecturers, recent graduates, and engineering organizations and to show that engineering is a worthwhile and dynamic career.

The University of Liverpool has been running the Headstart Aerospace Focus program since 2003. The course is a 5-day residential summer school attended by forty 17-18 year old students from across the UK. The course was influenced in the early years by the research activities that were underway at the time with students being involved in the handing qualities assessment of the Wright brothers' 1903 aircraft and later with tilt-rotor operations. This gave the students a valuable insight into the ongoing research but did not fully capture the student experience offered by the degree programs. Hence a new course was developed, that blended "traditional" lectures with hands-on laboratory and flight simulation exercises to give the students a more rounded experience of studying aerospace engineering.

Working in teams of 5 (assisted by mentors who are either PhD students or previous HEADSTART students), the students take on different roles to design, simulate and flight test an aircraft that is suitable to fly a Red Bull Air Race format course based around the city of Liverpool's various landmarks (Fig. 6). The course is marked out through a number of gates (balloons) such that there are a number of performance requirements that need to be tackled on the course (Fig. 7) such as knife edge turns (position 1), roll reversals (position 2), steep climbs (position 3), target tracking in a dive (position 4) and a low speed fly past over an aircraft carrier's deck (position 5).

Figure 6 HEADSTART "Red Bull Air Race"

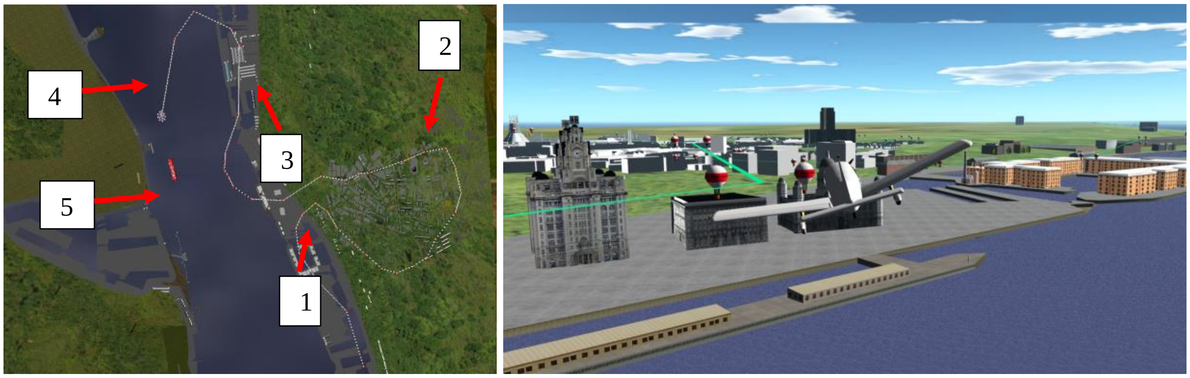


Figure 7 (a) Plan View of Race Track (b) Chase View of Race Track

Teams are given a notional budget of £200,000 for their aircraft, which they can spend on major components and additional upgrades, the choice of which will be informed by a range of laboratory exercises and desktop simulations.

Each team member is assigned a role, for which there is a corresponding exercise:

1) Team Leader - Organize the group in order to complete the aircraft design within the assigned time. Settle any disagreements within the group. Analyze the performance of any aircraft designs to determine whether it will be fit for purpose. Create and test FLIGHTLAB models of the aircraft using the tools provided.
2) Aerodynamics, Wing Design - Design the whole wing section. This will require selection of an appropriate aerofoil section to be used and determination of the wingspan, chord length and surface area. Design decisions must also be made with regard to the wing taper, dihedral and sweep characteristics
3) Flight Dynamics, Aircraft Configuration - Make decisions on the placement of aircraft components including the wing, tail, undercarriage, and cockpit. Analysis of aircraft stability for different configurations will be necessary.
4) Control - Required to design a control system augment the longitudinal dynamic behavior of the aircraft.

5) Propulsion and Propeller Design
6) Decide on an engine to use in the aircraft and suggest placement. Also required to test different propellers and decide on the most appropriate for this purpose.

An evaluation of the ability of a Grob G115E 'Tutor' aircraft to fly the race course is first undertaken by a former test pilot during a "live flying session" in the HELIFLIGHT-R simulator to establish a baseline performance for the students to improve against. A live feed from the simulator cockpit, including various telemetry, is broadcast to the students in a lecture theatre. During this session, the test pilot demonstrates the handling and performance deficiencies of the simple aircraft in the flight simulator and then participates in a question and answer session with the teams so they can identify problems with the aircraft that they can improve on in their own design. The final design is flown by a test pilot around the race course where the time penalties in Table 1 are applied for any infringements whilst flying the course. Their design choices are informed by the laboratory activities described in the following sections.

Table 1 Headstart Race Course Penalties

Infringement	**Penalty (seconds)**
Failing to pass through a gate or approaching a gate from the wrong direction	20
Flying more than 50 ft above or below a gate	5
Hitting balloons (gates)	10
Crashing	Disqualification

A. Glider Design Exercise

Prior to the students engaging with any detailed aircraft design, the students undertake a basic glider design, build and test activity. At this stage in their schooling the students will have learned some basic mechanics but will not have taken any aerospace courses so the exercise introduces them basic aircraft terminology and performance parameters e.g. lift, drag, drag polar, glide ratio, chord, ailerons but also to the concepts of basic engineering design e.g. defining problems and understanding constraints, understanding the mathematics/physics of the problem, being creative to identify potential solutions, deciding on the "best" solution, testing their design and reflecting on the success of their design. It is at this stage that the students are introduced to the concept of problem based learning (PBL), where knowledge and skills are gained through solving problems.

The constraints for the design are that it will be made of balsa wood (different thicknesses are made available) and must have a wing span of no more than 0.7 m and a length of 0.6m. The design is assessed against the distance travelled, time of flight and mass of the aircraft. The students are introduced to concept of stability, c.g. effects on performance and the neutral point. Instead of burdening the students at this stage with the underlying mathematics, the AERY Glider Design Software was used to allow the students to investigate the design space of fuselage length, wing location, stabilizer (Horizontal) location, vertical tail (Stabilizer) location, and nose mass using several tabs in the software. After making several design decisions the students can use the built in "Will it Fly?" analysis tool to analyze the flight stability of their design enabling improvements to be made if necessary. The students then construct the glider, test the design, and reflect on the success of their design. The exercise allows the teams to experience the benefits of working in a team, to start to use software tools to help in the design process and to understand the potential requirements conflicts that they may face in the design process.

B. Wind Tunnel Laboratory

In this laboratory class the students are introduced to the role that wind tunnel testing can play in the design of an aircraft. Preliminary model tests normally concentrate on measuring the lift, drag, and pitching moment over an incidence range that would include the stall condition; measurement of these parameters together with an error analysis is the focus of the experiment. The students use AF100 open circuit suction wind tunnel and associated AFA3 three-component balance (Fig. 8) to conduct tests on NACA 0009, NACA 0012, NACA 0015, NACA 23012 and Eppler 694 airfoils to demonstrate the effect of airfoil design on aerodynamic performance. Following the experiment the students take the data back to their teams to make an informed decision on the choice of airfoil section for their group's design.

Figure 8 AF100 Demonstrator Wind Tunnel

C. Propeller Laboratory

Students in this laboratory are introduced to the different design parameters that can be used to design a propeller e.g. twist, airfoil section and how performance is affected by flight phase, advance ratio, number of blades, diameter, and tip speed.

In the experiment the students use a small-scale wind tunnel built in-house by the undergraduates (Fig. 9) to show the students that in order to undertake a comparative study, low cost test tools can be used. 3-D printed 2, 3, 4 and 8 bladed propellers are tested at a range of advance ratios. Thrust and power measurements are taken at each test condition to determine the propeller efficiency. A comparison with the underlying theory is made before the students return to their teams to make a recommendation on their final design.

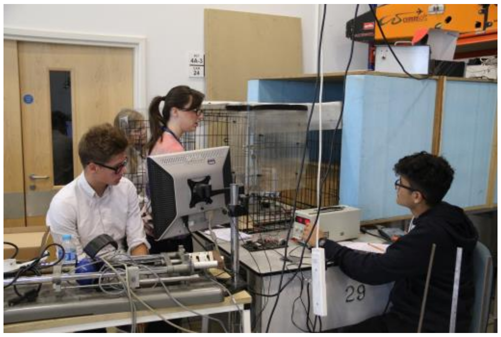


Figure 9 Propeller Laboratory

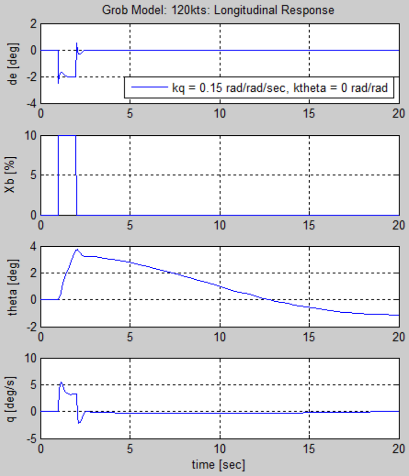


Figure 10 Example Pitch Rate Response for Controller Design

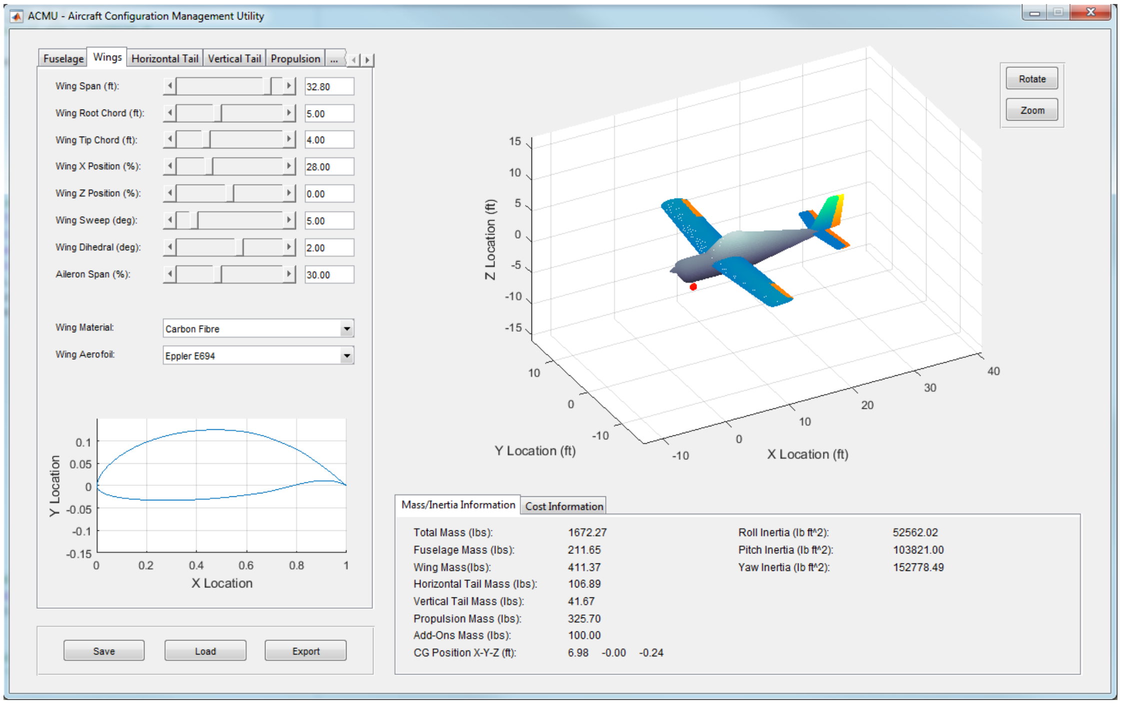
D. Flight Control Laboratory

During the initial flight test evaluation, the test pilot indicated that during the dive and target tracking phase of the course, they experienced significant difficulties in the pitch tracking task with the baseline aircraft exhibiting a poorly damped response when attempting to point the nose of the aircraft at a target at high speeds.

In this laboratory exercise, students are introduced to aircraft flight dynamics modes, and how these modes can be altered by use of a flight control system to improve the aircraft's handling qualities. The students examine the effect of pitch rate (q) and pitch attitude (θ) feedback loops on the short period dynamics of a linear aircraft model. Using MATLAB, the students carry out a tuning exercise to examine the effect of pitch rate feedback gain (Kq) and Pitch attitude gain (Ktheta) on the aircraft's pitch attitude and rate response (Fig. 10). The students then apply this control system to the non-linear FLIGHTLAB model using a desktop simulation to examine the pitch response requirements for the race to determine: the level of agility achieved, how quickly the maximum pitch rate is achieved, how sensitive to small control inputs is the pitch response and finally can the students now point the nose of the aircraft precisely at a ground target? The controller design is then taken back to the teams for consideration in the final design.

E. Virtual Prototyping the Final Design

Each of the laboratory exercises was designed to introduce new aerospace concepts to the students. The challenge for the students in the final activity of the course is to apply that knowledge and understanding to develop a new aircraft design. In order to facilitate this a unique set of modelling tools have been produced that enable the students to virtually prototype their designs using desktop simulations prior to final evaluation on HELIFIGHT-R with a test pilot. The virtual prototyping tool is comprised of a MATLAB based graphical user interface, shown in Figure 11, for creating an aircraft configuration, and an export utility to rapidly create FLIGHTLAB models for instant assessment of aircraft changes. The geometry of aerodynamic surfaces, fuselage dimensions, component materials, propulsion options and control systems can all be modified. Numerical values are only modifiable within certain ranges that are defined in a configuration file to avoid giving the students an overwhelming amount of choice. Mass, inertia and cost estimates are provided within the software, as well as a visual representation of the aircraft. Configurations can be saved and recovered for future modification. The export utility creates a copy of an existing baseline FLIGHTLAB model and then modifies the design parameters to reflect the desired aircraft configuration. The model can also then be directly launched from the utility so that students can quickly evaluate design changes using a joystick and the FLIGHTLAB Pilot-Station interface.



Wing Span (ft): 32.80
Wing Root Chord (ft): 5.00
Wing Tip Chord (ft): 4.00
Wing X Position (%): 28.00
Wing Z Position (%): 0.00
Wing Sweep (deg): 5.00
Wing Dihedral (deg): 2.00
Aileron Span (%): 30.00

Wing Material: Carbon Fibre
Wing Aerofoil: Eppler E694

Total Mass (lbs):	1672.27	Roll Inertia (lb ft^2):	52562.02
Fuselage Mass (lbs):	211.65	Pitch Inertia (lb ft^2):	103821.00
Wing Mass(lbs):	411.37	Yaw Inertia (lb ft^2):	152778.49
Horizontal Tail Mass (lbs):	106.89		
Vertical Tail Mass (lbs):	41.67		
Propulsion Mass (lbs):	325.70		
Add-Ons Mass (lbs):	100.00		
CG Position X-Y-Z (ft):	6.98 -0.00 -0.24		

Figure 11 Aircraft Virtual Prototyping Tool

The students work with the tool, assessing a range of candidate designs via a desktop real-time simulation before completing and submitting their final design for assessment by the evaluation test pilot. The students design a 30-minute flight test slot in which they brief and de-brief the test pilot and carry out a piloted assessment of the aircraft around the race track.

F. Final Presentation and Student Feedback

On the final day of the course, each group present their design and race track results to all other groups, members of academic staff, mentors, and parents. The 15-minute presentation includes a justification of the parts used in the design process and a summary of the group's performance in the final flight simulation trial. The students are encouraged to reflect on the success of their design and to consider how they would address the any deficiencies if they were to re-design the aircraft again.

The aim of the HEADSTART course is give the students an insight into a subject they might like to study at University. The students complete a questionnaire at the end of the course to see how helpful the event was in helping them to make an informed choice of University degree program. Feedback has been very positive throughout the years the course has been run. When asked "How has Headstart influenced your choice of STEM discipline?", 97.5% indicated that the course helped them with making their minds up either re-enforcing their choice or helping them to change their choice of University degree program. Regarding the elements of the course that the students enjoyed the most, the use of the flight simulators, both desktop and motion simulators, were top of the list. The students liked the way they could explore and test their designs and get an almost immediate feedback regarding the success of their designs.

IV. Undergraduate Teaching and Research Activities

As mentioned previously, use of the flight simulators to provide an interactive learning environment was one of the key drivers in their procurement. This sections describes several aerospace modules that provide that interactive learning environment.

A. Flight Awareness

The Flight Awareness laboratory exercise forms part of the first year "Introduction to Aerospace" module. This module serves as an introduction to the principles of flight and basic aerodynamics, while the laboratory aims to give the students a hands-on experience of flying an aircraft, and how some of the science the students learn in the associated module impacts the pilot at the controls. The learning outcomes of the tasks are knowing and explaining the functions of all the main aircraft components, knowledge of common aircraft instruments, and how to fly a simple fixed wing aircraft. As a group of 4 or 5, the students will also assess the basic performance of the aircraft, a Grob G115E 'Tutor', to gain an appreciation of common operational speeds and capability.

The exercise begins with a briefing that recaps some basic flight principles including aircraft axes of motion, lift and drag generation, aircraft control surfaces, stability, and covers some basic instructions for take-off, maneuvering and landing of an aircraft. Each student then completes a full flight using a simulation model of the Grob Tutor in the HELIFLIGHT simulator, performing a take-off, climb to altitude, some maneuvers, and finally an approach and landing, all performed in a visual representation of the city of the Liverpool. The student is guided in each flight by an instructor in the simulator control room (Fig. 12) and the student then examines different elements of the aircraft performance including take-off speed, stall speed, maximum speed, the effect of flap deflection on these speeds, primary and secondary effects of control surfaces, and stability characteristics with each student investigating 3 or 4 factors.

The students then undergo a debriefing session where they are challenged to use the knowledge gained in the module lectures to explain some of the aircraft behavior observed in the simulator, such as the secondary control effects like adverse yaw, and the factors influencing longitudinal and lateral stability. Finally, they complete a brief test on the materials covered in the lab, which forms part of their final grade for the module.

Figure 12 Instructor station for Flight Awareness laboratory

B. Flight Dynamics and Control

Flight Dynamics and Control is a 3rd year undergraduate module which introduces the undergraduate students to the core concepts of static and dynamic aircraft stability and modes. This culminates in a coursework exercise requiring the students to design a stability augmentation system (SAS) using a combination of linear models in MATLAB and flight simulation to test their final design. The objective of using flight simulation is to reinforce their understanding of the common dynamic modes exhibited by aircraft in flight and the effects of feedback control on both the aircraft stability and maneuverability.

The coursework exercise is spread over 8 weeks with the students first building a linear state space model of a F-104 Starfighter in MATLAB. The students are then tasked with breaking the aircraft modes down into their longitudinal and lateral-directional parts and augmenting the dynamic modes using proportional rate feedback and full state feedback control techniques learnt during the module. The linear models built by the students are interfaced with the HELIFLIGHT simulator and the student “pilots” are given the challenge to track a refueling probe in flight whose movement is designed to excite the different modes of the aircraft (Fig. 13). During the flight simulator session, the students are invited to compare their offline analysis including root locus and time history plots (Fig. 14) with their experience in the simulator and are given an opportunity to rapidly explore both optimal and sub-optimal feedback control designs.

Figure 13 Air-to-air Refueling task

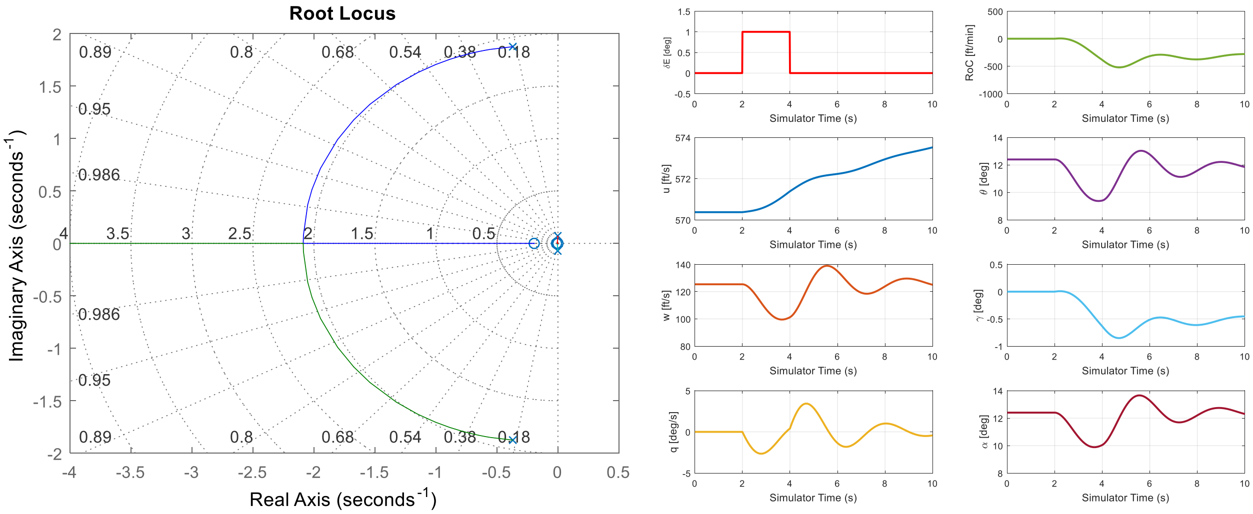


Figure 14 (a) F-104 Root Locus Plots **(b) F-104 Aircraft State responses**

C. Flight Handling Qualities

Flight Handling Qualities (FHQ) was initially developed as a module for 4th year undergraduate and postgraduate Masters students at UoL (Ref. 9). In its current form the class is divided into teams of 6 students and each team is presented with an aircraft (simulation model) and a mission definition with operational requirements. The students work to discover whether or not the aircraft meets the performance and handling qualities requirements. The students starting point was the knowledge and skills gained from three years of their aerospace degree program 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.

In its current form, six “test” aircraft are used:

1) Bell 412 – two teams looking at a utility transport role, hot and high operating in a degraded visual environment
2) SH-60 – maritime reconnaissance role, operating to/from a frigate in high sea states with a Green 45 wind
3) XV-15 – Hover and conversion mode teams, operating in a Search and Rescue role
4) FastJet – fast jet training role operating at low level, nap of the earth flight

and the students are required to use the relevant handling qualities standards e.g. ADS-33, MIL-HDBK-1797 (Refs. 10, 11), to undertake an assessment of the predicted handling qualities of the aircraft using desktop flight simulations. Based on this, the students design a flight simulation trial, working with test pilots to expose any deficiencies of the aircraft in the assigned role.

The combination of the use of Virtual Engineering tools and the PBL framework enables 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 (Ref. 12).

D. Final Year Projects

During the third year of their studies, undergraduate students are required to undertake an individual supervised research project. This provides the students with the opportunity to develop new general research skills and if the project outline is informed by ongoing academic research, can also encourage students to “*acquire new knowledge through independent learning and thought and provides an environment for them to develop critical thinking and* *problem solving skills*” (Ref. 13). This approach of research-led teaching is recognized by the UK’s Quality Assurance Authority in their recommendation that Universities should “*develop a research environment that provides a context for taught courses*” (Ref. 14) something echoed at UoL in their Framework for Learning and Teaching that achieving excellence in the student experience can be derived by “*designing, delivering, and refining internationally relevant, research-enriched curricula*” (Ref. 15). Flight simulators can provide the learning/research landscape that the students can use to achieve these goals in a range of ongoing projects that include research themes such as human factors, flight control, novel aircraft configurations and operations of aircraft in harsh environments.

An example student project involved the development of a pilot aid for light unstabilised helicopters who inadvertently fly into Degraded Visual Environments (DVE). The student first identified a representative scenario based on a helicopter accident involving a Gazelle helicopter near Honister Slate Mine located in the Lake District, Cumbria (Ref. 16). The location was selected to present a suitably complex terrain problem with rising ground, narrowing valleys and limited space to maneuver.

The student built the visual database in the flight simulator using the Presagis suite of tools and invited pilots from the local flying school to fly to Honister Slate Mine experiencing similar meteorological conditions, of low cloud and strong wind, to those experienced by the Gazelle. The flight tests demonstrated the applicability of the scenario with the pilots becoming disorientated, struggling to stabilize the aircraft or experiencing Controlled Flight into Terrain (CFIT) typical of light helicopter accidents in these conditions.

The next part of the project involved developing a pilot aid for this scenario. The student designed an augmented reality head down display driven by a fast path searching algorithm based on optimal route finding with potential field corrections based on the aircraft kinematic constraints (Ref. 17). The end result was a real-time generated highway in the sky route which the pilot could then fly through to return to visual flight avoiding the terrain (Fig. 15). Subsequent flights in the simulator finished the project exposing both benefits and limitations of the algorithm and display. Although, limited in scope, the project was greatly enhanced by the ability to test a conceptional algorithm using trained pilots in a realistic scenario otherwise untestable in the real-world at this level.

Figure 15 (a) Highway in the Sky Display (b) Augmented Reality Display

V. Conclusion

Flight simulation, either at a desktop or motion simulator level, provides a valuable learning environment for students. It provides a "vehicle" for them to take ownership of their learning and encourages them to develop reflective engineering skills through a PBL approach to knowledge acquisition. Introduction of modelling and simulation activities earlier in the curricula would provide the students with tools and skills they can utilize throughout their studies, something that should be encouraged in the re-design of current modules.

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