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Development of a Flexible Flight Simulation Design and Test Environment

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Abstract. This paper describes the development and use of a new, flexible flight modelling and simulation environment based on Alsim's engineering pack simulation tool with their AL250 simulators, recently installed at the University of Hertfordshire. This capability provides the necessary performance and flexibility to support the university's aerospace engineering and pilot studies programmes, along with supporting the breadth of ongoing research activities. Two key developments are highlighted: pilot studies assessment, and a modelling framework for general fixed wing aircraft for design testing. Examples of research activities currently in planning and development are also briefly presented, including work on emission modelling for general aviation aircraft. The outcomes from these activities have had notable improvements on previous facility capabilities in all areas.

Introduction

Access to increasingly high-quality and higher-fidelity flight simulation environments is crucial for universities running aerospace degree programmes to be able to provide effective laboratories for active learning. A great amount of flexibility is often required to be able to utilise the same simulator for multiple different learning objectives and avoid the cost and space requirements of multiple specialised systems. This flexibility is also crucial for supporting research and development activities that could encompass investigations in topics ranging from human factors studies to flight control design and testing. The technical performance of many affordable flight simulators is now at the point where they are ubiquitous in most universities running aviation, pilot studies, or aerospace engineering degree programmes [1]. However, not all simulator offerings provide the necessary flexibility for all of these, in addition to requirements for research activity.

As part of a recent upgrade to new facilities the University of Hertfordshire (UH) has recently invested in three Alsim AL250 flight simulators. The AL250 is a reconfigurable single and twin engine piston FNPT II[1] aircraft simulator, designed to meet the training requirements of PPL/CPL/IR/MEP[2]. The cockpit multi-function displays can be switched between traditional instrumentation in a T arrangement and a conventional electronic flight instrument system (EFIS). The base flight models are notably accurate and whilst the simulators can be certified, of more interest to the university is the engineering design and analysis capabilities afforded by its 'engineering pack' (E-Pack) software. These features make it an increasingly attractive tool for many other universities. Waterloo University has used its AL250 extensively for eye tracking, cognitive load, and human factor studies since 2023 [2–5]. A variety of applications in taught programmes have already been explored at Nottingham [6] whilst Portapas [7], also at Nottingham, has used the AL250 with the E-Pack to implement a model of an eVTOL for both teaching and research applications. Such applications are similarly planned at UH throughout the undergraduate and postgraduate programmes. These activities have previously been achieved using a Merlin

[1] Flight and Navigation Procedural Trainer, Level II.
[2] Private Pilot License/Commercial Pilot License/Instrument Rating/Multi-Engine Piston (rating).

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MP520 and X-Plane based simulators. The greater flexibility and accuracy of the AL250 enhances these activities through the integration with MATLAB/Simulink which is also taught throughout the degree programme.

System overview

Two of three AL250 simulators recently installed at the university, shown in Fig. 1, can send and receive data to and from a MATLAB/Simulink client operating from a networked computer running the E-Pack software. This is achieved with a network datastore that acts as a CAN bus to share and push data between each of the simulator's subsystems. This includes, when connected, the client running the MATLAB/Simulink E-Pack software. The E-Pack is implemented as MATLAB and Simulink toolboxes that facilitate the communication with an AL250 unit and its various subsystems. As many of the data variables driving the simulator can be read from and/or sent to the simulator a substantial variety of applications is possible: from simple data logging to flying completely new, bespoke aircraft flight and systems models. Administrators access the simulator configuration controls through an instructor station whilst pilots may access similar controls, particularly for flight data recording, via a tablet device in the flight deck which also serves as an electronic flight bag (EFB).

The simulators have three primary use cases: i) pilot studies training and assessment, ii) aircraft design simulation, iii) research applications. Each of these is briefly discussed in the subsequent sections.

Pilot studies assessment

A pilot studies pathway of aerospace engineering is offered to undergraduate students who, in addition to core modules on all aerospace engineering pathways, undertake specialised pilot studies modules in topics such as air law, navigation, meteorology, planning, communications, flight performance, avionics, and human factors. Graduating from the programme requires completion of 20 hours of flying (instructed or solo). The flight simulation facilities at the university have long been used to allow students to develop confidence and skills to support this, in addition to more authentic sessions and assessments. This is enhanced with the new flight simulators which provides a highly accurate flight model, high-fidelity flight deck and controls, and easier access to data logging commands through the EFB.

An example of one of the more complex assessments on the programme is a flight planning exercise requiring students to plan a route via multiple local waypoints, including two short-stop landing/takeoffs, avoiding class D airspace (Fig. 2). Students must then fly a minimum 20 nautical

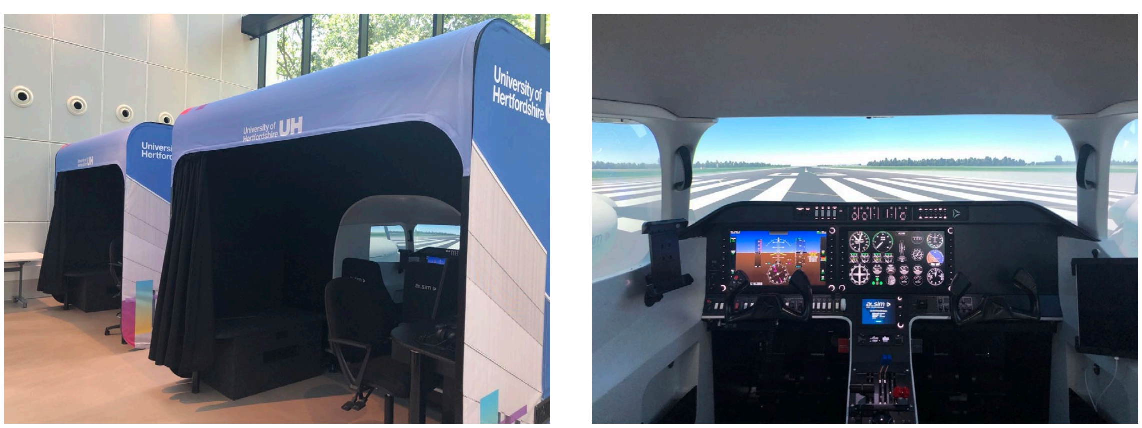

Figure 1. Alsim AL250 simulators.

mile portion of this route to demonstrate sufficient flight control and navigation skill. A significant enhancement with the AL250 compared to previous simulators is an integrated, physical GPS navigation unit for the students to use.

Other notable enhancements with the AL250 simulators are greater weather setting controls and a higher fidelity flightdeck which provides a more realistic environment for radio communication lessons and tests (Fig. 3). This enables both the actual flight and radio equipment to be used as part of the assessment to enhance the training transfer.

Aircraft design tool

Many aerospace degree courses will incorporate some form of aircraft design capstone project [8–11]. One of the fundamental aims of this kind of project is to replicate the industrial working environment of (and subsequently build students' skills and confidence in) cooperative design and systems integration. Consequently, these projects are typically undertaken as group work which reflects the nature of industrial work. An important element of the design process, or more generally as part of the feedback loop for developing students' knowledge and understanding, is for students to quickly generate a flight model of their design to analyse and evaluate it.

Fast generation of flight models from preliminary design parameters is a relatively mature topic owing to the wealth of knowledge and information on this topic. As such, there is a wide variety of methodologies that can be programmed to generate these flight models (Fig. 4), which trade accuracy for complexity and timeliness. The requirements of a tool for student-focused aircraft design activities are:

1. Fast generation of flight models from a basic geometry and mass specification.
2. Generation of simulated flight data to support performance, stability, and control analysis.

High fidelity models are not crucial for this task so analytical and semi-empirical models for computing the aerodynamic and stability parameters can be readily computed in MATLAB/Simulink for easy implementation with the E-Pack software. This is being done using methods from DATCOM, ESDU datasheets, and various well-known texts [12,13] to create a general template to model a generic fixed wing aircraft.

For example, Fig. 5 shows an electric-powered acrobatic aircraft designed by one group of students on the final year capstone group design module. In previous years we have used parametric modelling tools using a Merlin MP520 two-axes motion simulator and/or X-Plane software, both requiring some geometric data as well as propulsion performance data. Propulsion

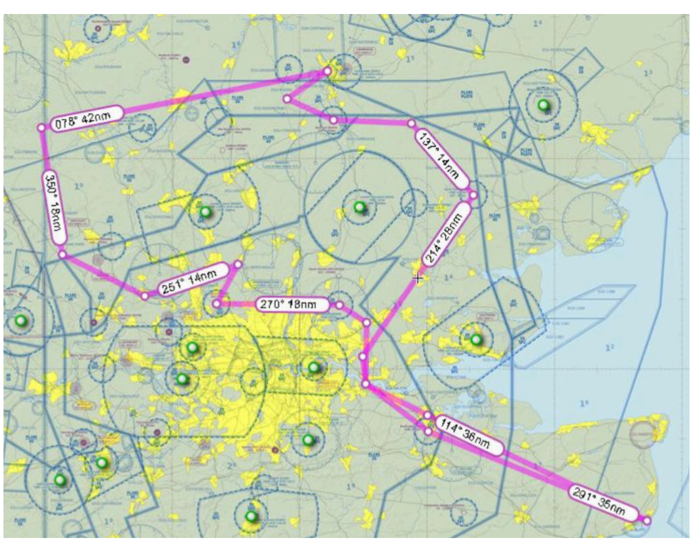

Figure 2. Example flight planning exercise.

Figure 3. Radio communication test.

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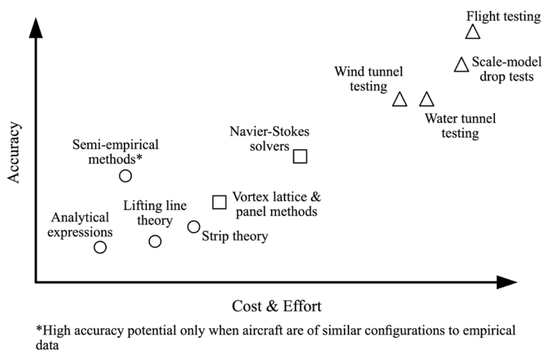

Figure 4. Aerodynamic model estimation methodologies.

Figure 5. Example design from the capstone aircraft design module: A two-seat sport electric aircraft.

system models with these systems were limited to conventional types (piston and gas turbine-based), with limited capability of electric propulsions systems in X-Plane. With the flexibility offered by the MATLAB/Simulink environment detailed models of more modern and advanced propulsion systems can now be explored and implemented. This includes more comprehensive modelling for batteries and hydrogen-based fuel cell systems for a variety of electric and hybrid propulsion models. This is in addition to the capability of modelling more complex systems, e.g., variable cycle engines.

The use of MATLAB/Simulink also means that higher fidelity models and different vehicle configurations with the design tool can be supported with an inherent modularity in its implementation. Additional functionality is planned as future module updates.

Research applications

Research capabilities with the new AL250 simulators include:

1. Nonlinear and unconventional configuration flight dynamics modelling.
2. Control inceptor evaluation.
3. Human-machine interaction studies.
4. Flying and handling qualities evaluation.
5. Flight control design and analysis.
6. Designing flight recovery techniques.

Most of these rely on the flexible modelling and data-reading functionality provided by the E-Pack software. The use of the simulators to enhance two example research projects are described below.

In the first example, an autonomous take-off system is implemented as an assistive autopilot. Such a system has potential applications in autonomous short takeoff/landing aircraft and in single pilot operations. A section of the system is presented in the Stateflow state machine of Fig. 6. This is combined with a low-level attitude autopilot as well as a thrust asymmetry control law which regulates the lateral deviation in engine-out scenarios. This system has been assessed in a purely software environment but the added benefit of running it on the AL250 simulator, via the E-Pack, means the human interaction with the system can be evaluated through the representative flight deck and autopilot panel controls.

The second example relates to the modelling of aircraft emissions of fixed wing aircraft to support a research project in the decarbonisation of general aviation airports. The project aims to define the exemplar framework for small airfields to approach and achieve decarbonisation and sustainability targets through a variety of approaches. One approach is better understanding and management of airfield emissions from the aircraft that operate from it, which are predominately training school flights. One approach to emission modelling is to consider the fuel consumption multiplied by the specified emission species index. To achieve a baseline model a set of simulated training sorties are flown in the AL250 simulator, with the fuel consumption extracted and recorded through the E-Pack. In particular, the fuel consumption at different phases of flight is obtained from the simulated aircraft and used to obtain flight phase benchmarks for the emissions. Fig. 7 illustrates the simulated fuel consumption and mass of various emission species (carbon monoxide, CO; carbon dioxide, CO_2; Hydrocarbons, HC; Nitrogen oxides, NO_x) throughout a circuit for a twin-engine aircraft flight model, using emissions factors derived from [14]. The trends are consistent with experimental measurements from literature [14,15]. The data is also useful to compare the accuracy of metamodels that rely solely on flight hour date from trainer flights.

Conclusions

An overview of recent developments and uses with Alsim AL250 flight simulators in university taught and research programmes has been presented. These simulators provide improvements and capabilities for the three key uses: i) pilot studies assessments, ii) modelling for aircraft design activities, and iii) a wide range of research activities. Examples of these have been presented. The greater fidelity of the simulated flight deck environment, along with the wide-ranging capabilities from the MATLAB/Simulink E-Pack, has enabled more authentic piloting assessments, more

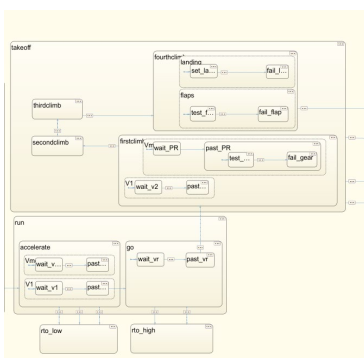

Figure 6. Section of a Stateflow model for the autonomous takeoff system.

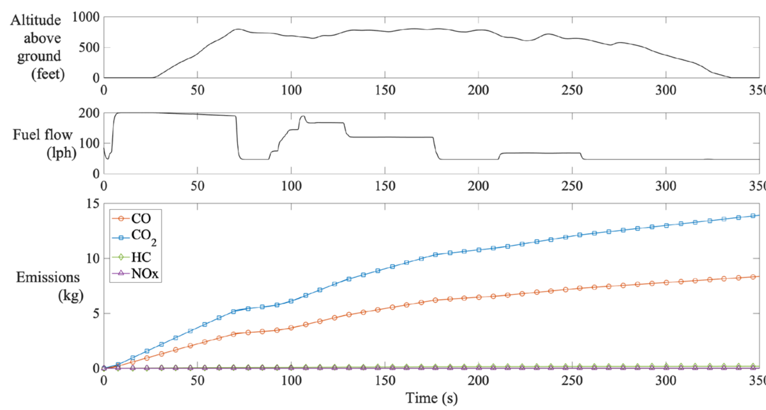

Figure 7. Estimated emission profile during simulated flight (fully rich mixture).

detailed aircraft system modelling capabilities, and more accurate simulation environments for research, compared to previous facilities. This is achieved in a smaller footprint than previously possible due to the flexibility of the Alsim simulators.

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