FLIGHT SIMULATION IN AEROSPACE ENGINEERING EDUCATION

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Abstract

Tertiary educational institutions in engineering face great challenges in the 21st century. Accreditation bodies expect such institutions to cover an ever-increasing range of content, provide more real world context and shorten the length of time required to complete an engineering degree (Felder et al., 2000; Engineering Council, 2013).

Flight simulation has been widely adopted in the engineering industry, both as a tool to train pilots and as a tool to design aircraft at all stages of the engineering process (Acklam, 1972; Rolfe and Staples, 1988; Lee, 2006).

This paper examines the literature to discover the history of flight simulation and how flight simulation has been used to educate students studying aerospace engineering. Building from conclusions drawn from the literature, an existing flight simulation software has been adapted by the author for use in an educational setting.

The aim of this work is to initiate a process for the development of flight simulation as an educational tool to resolve some of the increasing challenges facing engineering educators & students. The author has developed a lesson framework tool in JavaScript which provides an easy to use interface to interact with FlightGear and guides students through lesson content.
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## Glossary

### Flight Simulation and Aerospace Abbreviations

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<tbody>
<tr>
<td>COG</td>
<td>Centre of Gravity.</td>
</tr>
<tr>
<td>Damping</td>
<td>Damping is the term used to refer to the effect or reducing or preventing oscillations.</td>
</tr>
<tr>
<td>Damping Ratio</td>
<td>The Damping Ratio is the ratio of a system’s actual damping to a system’s critical damping, where critical damping is the damping in a dynamic system which causes a system to reach the equilibrium fastest.</td>
</tr>
<tr>
<td>DOF</td>
<td>Degrees Of Freedom.</td>
</tr>
<tr>
<td>Dutch Roll</td>
<td>The Dutch Roll mode is a lateral-directional dynamic mode. It is an oscillation of both roll and yaw, characterised by yaw and roll to the right following by a recovery to the equilibrium followed by an overshoot and as a result an elliptical path is followed. It usually has a short period, on the order of 3-15 seconds.</td>
</tr>
<tr>
<td>Dynamic Modes</td>
<td>The Dynamic Modes of an aircraft are the most common patterns of dynamic vibrations of an aircraft system, i.e. they describe how an aircraft responds to a disturbance (either pilot or environmentally introduced).</td>
</tr>
<tr>
<td>FDM</td>
<td>Flight Dynamics Model; a term introduced by FlightGear to describe the different dynamics models which are used to simulate flight.</td>
</tr>
<tr>
<td>HUD</td>
<td>Heads Up Display.</td>
</tr>
<tr>
<td>NTPS</td>
<td>National Test Pilot School.</td>
</tr>
<tr>
<td>Phugoid</td>
<td>Phugoid is a longitudinal dynamic mode, characterised by a variation in airspeed, pitch angle and altitude but not angle of attack. It is caused by the interchange of kinetic energy (the energy due to velocity) and potential energy (the energy due altitude). Phugoid is a very weakly damped oscillatory dynamic mode and as such, the period usually 20-60 seconds.</td>
</tr>
<tr>
<td>Glossary</td>
<td>Description</td>
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<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
<td>Pitch refers to a motion in rotating about the axis perpendicular to the axial direction and to the vertical direction (which, by convention, is known as the y-axis).</td>
</tr>
<tr>
<td><strong>Roll</strong></td>
<td>Roll refers to a motion in rotating about the axial axis (i.e. the axis through middle of the fuselage).</td>
</tr>
<tr>
<td><strong>Short Period</strong></td>
<td>The short period mode is a dynamic mode of oscillation. It is characterised by a rapid pitching of the aircraft about it’s centre of gravity. It is usually a heavily damped oscillation with a period of only a few seconds.</td>
</tr>
<tr>
<td><strong>STOL</strong></td>
<td>Short Takeoff and Landing.</td>
</tr>
<tr>
<td><strong>V/STOL</strong></td>
<td>Vertical and/or Short Takeoff and Landing.</td>
</tr>
<tr>
<td><strong>VTOL</strong></td>
<td>Vertical Takeoff and Landing.</td>
</tr>
<tr>
<td><strong>Zoom Climb</strong></td>
<td>Zoom Climb occurs when an aircraft’s rate of climb is greater than the maximum for a sustained climb, i.e. a climb when the airspeed is maintained during climb. Instead of maintaining airspeed during climb, kinetic energy from the airspeed is traded off for gravitational potential energy, enabling a higher rate of climb.</td>
</tr>
</tbody>
</table>

**Programming Abbreviations and Terminology**

- **API**: Application Program Interface; an API offers a set of tools to a developer in order to create applications.
- **Child Process**: A process is an instance of a program that is being executed on a multitasking OS. A child process refers to a process launched by a parent application, e.g. Google Chrome has a child process for each tab open with a webpage.
- **Command Line Options**: Command Line Options enable you to tell an application how to launch on startup.
- **Commit**: In version control, a Commit refers to adding the latest changes to source code to the repository.
- **Commit ID**: A commit ID is a 40 digit hexadecimal number used by Git to identify individual contributions (commits) to a code repository.
<p>| <strong>DRC</strong>  | Distributed Revision Control, also known as Distributed Version Control or Decentralised Version Control; DRC refers to a type of software for SCM that does not have a single reference of repository, instead, each developer has their own copy of the repository and the changes. Remote servers can be used to share the repository between multiple developers. Developers sync their local repository with this remote repository. |
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hypothesis | Forking refers to the duplication of a source code repository in order to make changes. This may constitute producing a separate piece of software or simply making minor modifications which may be brought back into the source code repository at a later date. |
| <strong>Git</strong>   | A popular DRC-type SCM software. See definitions for DRC and SCM. |
| <strong>I/O</strong>   | Input/Output. |
| <strong>Node.JS</strong> | Node.JS is an JavaScript runtime built using the Google Chrome web browser’s V8 JavaScript engine. |
| <strong>Npm</strong>   | Npm is a software package manager for Node.JS. |
| <strong>Open Source</strong> | In software, a licensing model whereby users are given permission to access the source code; usually such a software license is also free of charge. |
| <strong>OS</strong>    | Operating System. |
| <strong>Poll</strong>  | In programming, Polling refers to actively sampling the status of an external device by a client program. Normally it is used in the context of I/O. |
| <strong>Refactor</strong> | Refactoring refers to restructuring code without changing external observable functionality. |
| <strong>Repository</strong> | A Repository is a data structure that stores metadata for a set of files; usually used in the context of a SCM system. Such metadata includes a history of changes in the repository, a set of Commit objects and references to Commit objects called heads. |
| <strong>SCM</strong>   | Source Control Management; the management of changes to documents or software source code. |</p>
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Submodule</td>
<td>In Git, Submodules allow you to store one Git repository as a subdirectory within another repository.</td>
</tr>
<tr>
<td>Telnet</td>
<td>Telnet is an application layer protocol used over a network which is used to provide a virtual terminal connection. FlightGear provides a telnet server which can be used to interact with their Property Tree over the network when using the relevant Command Line Option.</td>
</tr>
<tr>
<td>XML</td>
<td>Extensible Markup Language; XML can be identified by the use of triangular brackets (&lt;&gt;), and text within them, known as tags (e.g., &lt;mytag&gt; &lt;/mytag&gt;), tags are closed using another tag with a forward slash before the tag name and they can contain content within the tags. Tags are used to describe the structure of a data set.</td>
</tr>
</tbody>
</table>

**Educational Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>EBL</td>
<td>Experience Based Learning.</td>
</tr>
<tr>
<td>PASS</td>
<td>Peer Assisted Study Sessions.</td>
</tr>
<tr>
<td>PBL</td>
<td>Problem Based Learning.</td>
</tr>
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</table>

**FlightGear Abbreviations**

<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>FlightGear</td>
<td>FlightGear is a shorthand for FlightGear Flight Simulator, is a piece of free, Open Source, multi-platform flight simulation software.</td>
</tr>
<tr>
<td>Property Tree</td>
<td>The Property Tree stores the runtime state variables for FlightGear program instances.</td>
</tr>
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**Aerospace Nomenclature**

<table>
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<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$C_D$</td>
<td>Coefficient of Drag.</td>
</tr>
<tr>
<td>$C_L$</td>
<td>Coefficient of Lift.</td>
</tr>
</tbody>
</table>

**Flight Abbreviations**

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AGL</td>
<td>Altitude above Ground Level.</td>
</tr>
<tr>
<td>AMSL</td>
<td>Altitude above Mean Sea Level.</td>
</tr>
<tr>
<td>KTAS</td>
<td>Knots True Airspeed.</td>
</tr>
</tbody>
</table>
PPL  Private Pilots Licence.
1 Introduction

Section 1.1 lays out the project motivation and Section 1.2 sets out the scope. Section 1.3 provides a brief description of the hallmarks of flight simulation. Following this is the literature review, which describes the history of flight simulation (§1.4), how flight simulation is used by engineers (§1.5), engineering pedagogical practice (§1.6) and how the principles of simulation are utilised in other academic disciplines (§1.7).

1.1 Motivation

This project was motivated by the desire to improve students’ understanding of the fundamental concepts within aerospace engineering and to make it easier for students to acquire that knowledge. This paper evaluates whether flight simulation could be used to achieve this goal at the University of Manchester and involves the development of software to enable the use of flight simulation software as a teaching tool.

1.2 Scope

The scope of the project is to address three aims, namely:

1. To provide a brief introduction to flight simulation and its history;

2. To review existing research into the use of flight simulation in aerospace degree classes;

3. To create an initial version of a tool:

   (a) For conveying aircraft design principles, which could be easily adapted for use in other aerospace engineering classes; and

   (b) Which could be used by an entire class of students simultaneously;

   (See §3.1 for the detailed requirements for the tool)

The preliminary design process carried out in Aircraft Design is a simplification and it is expected that utilising flight simulation will allow students to get a feel for the correct answers, as opposed to simply a conceptual understanding. It is for this reason that Aircraft Design is chosen as the subject for this project.

It is extremely important to ensure that the goal 3(b) is met, considering that there are approximately 80 students in each Aircraft Design class and it would be prohibitively expensive or simply impossible to arrange supervised laboratory sessions on professional flight simulators.
1.3 What is flight simulation?

Rolfe and Staples (1988) provide a good definition for what a “faithful simulation requires”; the three requirements are:

1. “A complete model, preferably expressed mathematically, of the response of the aircraft to all inputs, from the pilot and from environment”; and

2. “A means of solving these equations in ‘real-time’, or in other words, of animating the model”; and

3. “A means of presenting the output of this solution to the pilot by means of mechanical, visual and aural responses”.

1.4 History of flight simulation

This section looks at the history of flight simulation. First, the early history of flight simulation (§1.4.1), is explored to find the roots of flight simulation. Following this, (analogue) computational flight simulation (§1.4.2) and developments in flight simulation due to the development of electronic simulators are examined (§1.4.3). Figure 1 shows a timeline with each of these key stages of the development of flight simulation depicted.

1.4.1 Early flight simulation

Flight simulation originated as a tool to aid pilots learning to fly aircraft. Page (2000) reviews the history of flight simulation. Page (2000) suggests that the origins of flight simulation can be seen in “flight training devices” for pilots. One of the earliest such training devices was the “Sanders Teacher” (Haward, 1910). Figure 2 from Haward (1910) shows the static training device;
the configuration is similar to modern aircraft designs, with the same primary control surfaces and even the same names for them. One distinguishing feature is the fore-plane at the front of the aircraft (sometimes referred to as a canard configuration), which is much like that of the Wright Brothers Flyer I (Library of Congress, 1908). Clearly, this trainer was of limited value, it was constrained by the wind speed and direction of the surrounding environment (Page, 2000).

Rolfe and Staples (1988) describe how flight trainers developed in the 1920s utilised compressed air actuators to simulate the effects of speed, aileron, elevator and rudder input, although they were simulated independently. Rolfe and Staples (1988) note that in the early 1930s the US Army Air Corps used Link Trainer devices, which were developed to introduce rudder/aileron coupling, a stall feature and various mechanical/pneumatic instruments; these features improved the simulation, however, the simulation was still a far cry from modern full flight simulators which can be used by pilots in place of actual flight hours (Lufthansa Flight Training, 2015).
1.4.2 Computational flight simulation

Page (2000) notes that the “first known discussion of the computer method of simulation is believed to be that of Roeder in his 1929 German Patent Specification” (Roeder, 1929) and that the “dynamic simulation of an airship height control system” described in the patent was designed to utilise “a fluid operated analogue computer”. The German patent did not result in any successful training devices (Page, 2000). Mechanical flight trainers suffered from “instability of adjustment due to humidity, temperature and ageing” (Rolfe and Staples, 1988), which led to the development of electronic flight simulators.

1.4.3 Electronic flight simulation

Rolfe and Staples (1988) describe in detail how the analogue electronic flight simulator soon made way for the digital flight simulator, beginning with “fixed-base” systems such as UDOFT (Universal Digital Operational Flight Trainer), which was a project that began in 1950 and was completed in 1960. Lee (2006) describe the digital computer developed for this flight trainer and explain that it was capable of solving its flight model within “35 msec”, this response time marked a turning point in flight simulation, as a means for solving detailed flight dynamics equations in near real time had been developed. Initially most digital flight simulators were static, however, in 1958 flight simulation incorporated motion again when “Redifon received a contract from BOAC for the production of a pitch motion system as part of the Comet IV simulator” (Page, 2000).

1.5 Engineering flight simulation

In 1972, Acklam noted that there “is, however, an equally important but less publicised branch of simulation, the design and development simulator” (in addition to the widely recognised branch of flight simulation concerned with training pilots). Acklam (1972) specified the key distinguishing characteristics of these flight simulators, specifically that they “must be capable of being changed quickly from one configuration to another in order to study the many possible variations in the proposed aircraft” and that “it must be capable of being set up to represent actual aircraft with which the pilot is familiar”.

Acklam (1972) described six specific design scenarios within which this type of simulator was used. First, Acklam (1972) explained how flight simulation was used to position aircraft spoilers. Specifically, Acklam (1972) said that, in order to compensate for the nose-up pitching moment induced by conventional location (i.e. behind the COG), the impact on downwash and the impact
of their design on the pitching moment, flight simulation was used to investigate a variety of flight profiles (e.g. “formation flying, ground attack and landing”) to ensure the best handling results. Second, Acklam (1972) explained that the dynamic mode known as lateral phugoid, which is due to “spiral and roll mode roots” (in high-speed aircraft), was discovered in a flight simulator. Third, Acklam (1972) noted that, “as the wings of variable geometry aircraft are swept the aerodynamic centre shift causes the handling characteristics to alter drastically and extensive simulator work [had] been performed to study the severity of the effects and the changes that must be made to the feel system characteristics to compensate”. Fourth, Acklam (1972) noted that “as commercial aircraft grow larger and some military aircraft grow longer the response to elevator movement [became] slower” and hence “much better glide path control” could be achieved by utilising “direct lift control” which uses spoiler or flap variations to control pitch. Fifth, the simulator was used in order to “optimise the aircraft systems” by creating an accurate feel model, thereby modifying stability augmentation systems; specifically, the simulation was used where there were not “firm criteria to define what is optimum” and the desired results were described by pilots in a simulator. Finally, Acklam (1972) explained that engineering design simulators were used extensively by test pilots before their first flight in order to gain hands-on experience, without the risk of crashing real aircraft. This allowed test pilots to give feedback to the engineers to improve their simulation.

However, it is worth noting that there are limitations to using a flight simulator as a design tool, specifically that “the first flight [in] the simulator can only be as good as the data supplied to it” (Acklam, 1972).

Lee (2006, pp. 122-123) describes other areas where flight simulation has been utilised in research, namely, “cockpit design” and “avionics”. Furthermore, advances in microprocessors, “visual display technologies” cockpit automation led to the elimination of the requirement for a flight engineer, reducing the flight crew (Lee, 2006, p. 122). Lee (2006, p. 122) explained that “flight simulators were instrumental” in doing so, due to their ability to enable safe and efficient evaluation of new cockpit systems (namely “layout alternatives”, “avionic systems”, “flight management” and “diagnostic systems”).

Engineering flight simulation also led to the development of in-flight simulation devices, variable stability aircraft, which are aircraft designed to vary their “apparent stability and control response” in-flight in order to test different design variations (Rolfe and Staples, 1988, p. 214). Table 1 shows a list of variable stability aircraft (used for in-flight simulation) and lists the work that they are used for. This table (§1) makes it clear that there are numerous uses for in-flight simulation, and as such, that higher fidelity ground simulators are extremely valuable. Rolfe and Staples (1988, p.
215) noted this, saying that “with improving standards of ground-based equipment, the need for extensive testing on variable stability aircraft has been reduced”.

Table 1: Research facilities - Variable stability aircraft (adapted from Rolfe and Staples, 1988, p. 210)

<table>
<thead>
<tr>
<th>Country</th>
<th>Organisation</th>
<th>Location</th>
<th>Aircraft</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Calspan</td>
<td>Buffalo NY</td>
<td>Lockheed T-33A; Convair C-131H; Bell X-22A</td>
<td>Fighter flying qualities; Total In-Flight Simulator (TIFS); VTOL research</td>
</tr>
<tr>
<td>Princeton University</td>
<td>New Jersey</td>
<td>Navion</td>
<td></td>
<td>Aircraft flying qualities (6 DOF)</td>
</tr>
<tr>
<td>NASA Ames</td>
<td>Moffett Field</td>
<td>Boeing CH 47B</td>
<td></td>
<td>Helicopter control displays (4 DOF)</td>
</tr>
<tr>
<td>NASA Ames</td>
<td>Moffett Field</td>
<td>D-H QSRA</td>
<td></td>
<td>Powered-lift STOL performance and control</td>
</tr>
<tr>
<td>Canada</td>
<td>NAE Ottowa</td>
<td>Ontario</td>
<td>Bell 205</td>
<td>V/STOL flying qualities controls/displays</td>
</tr>
<tr>
<td>West Germany</td>
<td>DFVLR</td>
<td>Braunschweig</td>
<td>Hansa-jet; VFW 614; BO 105</td>
<td>Flying qualities; displays; fly by wire; fly by light; Helicopter flight control</td>
</tr>
</tbody>
</table>

1.6 **Engineering pedagogy**

Section 1.6.1 reviews the history of engineering pedagogy from the early 20th century through to the 21st century. The major challenges that educators face in the 21st century are discussed in Section 1.6.2. Section 1.6.3 then looks at what educational objectives are and how they are relevant to engineering pedagogy. Section 1.6.4 looks at problem and experience-based learning methods, which are popular learning methods used in many engineering programmes worldwide.

1.6.1 **History of engineering pedagogy**

Historically, engineering pedagogy has not changed significantly. Felder et al. (2000) concur, noting that “although [engineering class] content has changed in some ways and the students use calculators and computers instead of slide rules, many engineering classes in 1999 are taught in exactly the same way that engineering classes in 1959 were taught”. The most significant issue with this is that “instructors often start a course by presenting totally new material without putting it in any context” (Felder et al., 2000).
1.6.2 Challenges facing educators in engineering

Felder et al. (2000) clearly described the problems that are facing educators in engineering:

“The Accreditation Board for Engineering and Technology [says] that [educators] must strengthen [their] coverage of the fundamentals; teach more about ‘real-world’ engineering design and operations, including quality management; cover more material in frontier areas of engineering; offer more and better instruction in both oral and written communication skills and teamwork skills; provide training in critical and creative thinking skills and problem-solving methods; produce graduates who are conversant with engineering ethics and the connections between technology and society; and reduce the number of hours in the engineering curriculum so that the average student can complete it in four years”.

The UK equivalent, the Engineering Council (2013) has similar objectives, with design elements expected to integrate “knowledge and skills to the solution of real problems”, engineering practice into “operations and management” and students to be taught “an understanding of different roles within a team” and about “social, environmental, ethical, economic and commercial considerations”. As a result, it seems that educators are facing great challenges which will require new approaches to teaching.

It is hypothesised that flight simulation may be able to help educators to achieve these goals, specifically, “problem-solving methods” and “‘real-world’ engineering design”.

1.6.3 Educational objectives

Bloom’s *Taxonomy of Educational Objectives* (1956) describes six different classes of “instructional objectives” (Felder and Brent, 1999) that engineering programmes have for students, namely, “knowledge (repeating verbatim)”, “comprehension (demonstrating understanding of terms and concepts)”, “application (solving problems)”, “analysis”, “synthesis (creating something, combining elements in novel ways)” and “evaluation (choosing from alternatives)” (Bloom and Committee of College and University Examiners 1956, p. 18; Felder and Brent 1999). The order is significant; each objective class is “built on the behaviours found in the preceding classes” (Bloom and Committee of College and University Examiners, 1956, p. 18). Felder and Brent (1999) also note that most of the students cannot stay focussed throughout a lecture, particularly that after 10 minutes student attention begins to drift. McKeachie (2002, p. 62) claims that Hartley and Davies’ (1978) review on student attention notes “that attention typically increases from the beginning of the lecture to ten minutes
into the lecture and decreases after that point”, however, this could not be verified after reading their paper. Felder and Brent (1999) assert that “students’ attention can be maintained throughout a class session by periodically giving them something to do” and that “the most common [activity] is the small-group exercise”. As a result, an active learning exercise such as utilising simulation would be significantly more engaging than traditional lectures.

1.6.4 Problem and experience-based learning

Adams et al. (2007) argues that “one of the most, if not the most important skill an engineer must possess is that of problem solving” and that “another desirable” skill is “being able to think creatively” and claims that “the development of problem-solving skills, and the encouragement of creativity in the classroom shows a clear link with the philosophies of Problem Based and Enquiry Based Learning (PBL/EBL)”.

It is because of this, that capstone courses utilising PBL/EBL are now common in universities worldwide (Dutson et al., 1997). Dutson et al. (1997) describe a survey (which took the form of questionnaire) of “capstone-type engineering courses of 360 departments representing 173 schools in North America”, conducted by Todd et al. (1995), which examined the courses, project information and both faculty and industrial involvement in capstone education. Dutson et al. (1997) note a variety of different categories for the capstone courses including first, those that involve “simulations” and those that involve “authentic involvement” (Harrisberger and al, 1976) and second, those that “design for economic evaluation” and those that “design for construction” (Kabel, 1988).

1.7 Simulation in university programmes outside engineering

Deshpande and Huang (2011) look at how “simulation games have been applied in various education domains”. In an architecture class, a simulation game is used to “deliver management, practise and law subjects” using a “web-based game” which allows students to “observe the transformation of designs into buildings with the use of the contract management process” (Deshpande and Huang, 2011). In a business ethics class, students “experience the problems involved in making tough business decisions and the ethical issues involved” (Deshpande and Huang, 2011). Deshpande and Huang (2011) describe a “graduate level course” which aids students with their “interviewing skills” by helping them “identify their strengths and weaknesses” and covering “the interviewing process, hypothesis generation and testing”. Gordon, Oriol and Cooper (2004) claim that patient simulators used in medicine are “often described as ‘flight simulation for doctors’” and suggest a process which can be integrated into existing curricula in medical schools and teaching hospitals. Deshpande and
Huang (2011) further describe a series of physics simulation games, including “Spectrum” which is used to “explain the concept of energy and its relation to light” and “Frantic Physics” which looks at “mechanics, electromagnetic [sic], optics, sound, and calculus”.

2 Existing engineering programmes utilising flight simulation

This section looks at how flight simulation is utilised in aerospace engineering degree programmes.

Flight simulation has been used in undergraduate education for more than 25 years. Russell, Mouch and Yechout (1990) describe ‘students being provided with the opportunity to ‘fly’ and evaluate their unique aircraft designs and perform a variety of flying tasks as part of their capstone design course” and Yechout et al. (1997) review 10 years of flight simulation in aeronautical education (see §2.1).

In recent years, interest in this area has grown substantially. Done (2000), Done and Neal (2012) and Altman (2015) describe their use of engineering flight simulators created by the Merlin Simulation Group, which are specifically targeted at universities, to teach elements of their courses in flight mechanics, dynamics and aircraft design (see §2.2). In addition to the Merlin Simulation Group’s solution, many educators have described their solutions which utilise commercial software (see §2.3) or simulation software developed in-house (see §2.4).

Section 2.5, looks at the use of flight simulation at the University of Manchester and the potential for future growth in the use of flight simulation. Section 2.6 summarises the existing uses of flight simulation in engineering pedagogy. Section 2.7 summarises how those existing uses of flight simulation were assessed and what the results of that assessment were.

2.1 United States Air Force Academy (USAFA)

Russell, Mouch and Yechout (1990) explained that “recent innovations in the teaching of aircraft design at the United States Air Force Academy [had] demonstrated the utility of flight simulation in ... [the endeavour to] ... enhance the engineering education process”. Russell, Mouch and Yechout (1990) used the flight simulator in their second-semester design course to allow students to account for “handling characteristics” in their designs, which were “compared to the appropriate military specification (MILSPEC)”.

Yechout et al. (1997) described how the USAFA used flight simulation in “aircraft performance and static stability, aircraft dynamic stability and feedback control, flight [sic] test techniques and aircraft design”. Yechout et al. (1997) and Russell, Mouch and Yechout (1990) described the Genesis
2.2 EXISTING ENGINEERING PROGRAMMES UTILISING FLIGHT SIMULATION

2000 flight simulator utilised in their programmes. Yechout et al. (1997) emphasised that it offers “flexibility [which] may be used for [the] development of aircraft and flight control system designs as well as [the] evaluation of performance and stability characteristics”.

Yechout et al. (1997) used the “Genesis model of the T-38” in his aircraft performance class, as it provided “a good platform to evaluate [the aircraft] at subsonic airspeeds so that the peak of the specific range and specific endurance versus velocity curves [could] be determined” and hence it was used to help undergraduate students to learn about specific range and specific endurance. In the aircraft dynamic stability and feedback control class, Yechout et al. (1997) explained how they used their flight simulator to “illustrate concepts like damping ratio, damped frequency and overshoot”. Yechout et al. (1997) also used the Genesis 2000 flight simulator in teaching aircraft design and explained that “in most cases, the initial designs are unflyable”, but that students utilise “reasoned trial and error” to achieve a “flight simulator-refined” aircraft design.

Bossert and Yechout (2002) describe how the USAF utilises the newer “MATLAB-based Genesis 3000 built by Veridian Engineering” (note that this is a static simulator much like the Genesis 2000 preceding it) in “three undergraduate flight mechanics courses - Aircraft Dynamics Stability and Control, Aircraft Feedback Control, and Aircraft Design”. Much like the earlier teaching scenarios suggested by Yechout et al. (1997), Bossert and Yechout (2002) used the simulator to illustrate concepts like Damping Ratio (also see Damping), Short Period, Dutch Roll and employed the simulator in an aircraft design programme as well. In addition, Bossert and Yechout (2002) utilised the simulator to teach the “Aircraft Feedback Control” unit, which differed significantly from past uses in that it involved designing a feedback control system and testing it in the simulator.

2.2 Merlin Simulation Group

Done (2000) used an engineering flight simulation developed by Merlin Simulation Group as a multi-purpose tool for teaching and research (in coordination with Merlin Simulation Group). Done (2000) argued that while flight tests and wind tunnel testing helped students gain a practical understanding of some elements of flight dynamics from their lectures, they were insufficient. Done (2000) used the Merlin MP520-T flight simulator to teach students an intuitive understanding of the results of shifting the aircraft’s COG. Done and Neal (2012) further demonstrated the development of Merlin flight simulators (in the intervening 12 years) and established uses in flight mechanics, dynamics and aircraft design. Specifically, flight dynamic modes such as Phugoid, Short Period oscillations and Dutch Roll were investigated. Furthermore, students worldwide, including those at the University
of Manchester, now use the simulator to flight test aircraft designs and enter a competition run by Merlin Simulation Group (Done and Neal, 2012).

Altman (2015) uses Merlin MP521 simulator to “close the loop on an initial conceptual sizing”. Altman (2015) describes how students develop an initial conceptual sizing and then enter their data into the simulator in order to evaluate whether their design has merit. Following students’ development of the flight simulation model, “volunteers from the local section of the Society for Experimental Test Pilots fly the students’ designs” in order to provide them with feedback. Students are able to modify their conceptual designs to meet pilot expectations more closely in a similar manner to how flight simulators are used in industry, where aircraft designs are modified using the flight simulator to match pilot expectations before the first flight (Acklam, 1972; Altman, 2015).

The use of Merlin’s flight simulators are relatively widespread1 and a vast majority of universities which own such simulators have not published academic papers describing their utilisation of those simulators (Merlin Simulation Group, 2014, 2016). It appears that either flight simulation is being underutilised at these universities or they are not publishing papers describing their use.

2.3 Flight simulators utilising commercial flight simulation software

Jumper and Baughn (1991) described the use of “Microsoft Flight Simulator” (specifically “FS4.0”) as a “substitute for actual flight test experience” at the University of Notre Dame and in conjunction with “actual flight test data taken in a Cessna 182” at the University of California at Davis. Jumper and Baughn (1991) lamented that they “had an opportunity to examine the Genesis 2000 first hand” but that “the price per unit [was] approximately $100-150 thousand, which, in [their] case, [was] prohibitive”. Jumper and Baughn (1991) primarily used their flight simulator to evaluate aircraft performance. For example, they asked students to “cross plot $C_D$ against $C_L^2$ and fit a linear curve to this in a least-squares sense” in order to “determine the drag polar” (see nomenclature for the definition of $C_D$ and $C_L$).

Baughn and Wolf (1998) described the use of “Jeppesen FS200 PCATD and Microsoft Flight Simulator 98” in a similar manner to Jumper and Baughn (1991), but also considered “manoeuvring flight”, specifically, looking at “rate-of-turn (ROT) and the turn radius, $R$” of aircraft.

White and Padfield (2006) describe the use of the HELIFLIGHT flight simulator operated at the University of Liverpool. This flight simulator is a commercial product sold by Advanced Rotorcraft Technology Inc. and is the only flight simulator used in an educational setting that known to the author at the time of writing simulates rotorcraft. The HELIFLIGHT simulator

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1The University of Manchester has one MP521 motion, one MP520 motion and two static MP500 flight simulators.
runs software developed by the supplier which is known as FLIGHTLAB. However, White and Padfield (2006) note that the “simulation environment has undergone a number of hardware and software upgrades carried out in-house”, namely, “implementation of BAE’s run-time environment Landscape” (which allows for “moving visual models or entities”), application of “a range of visual conditions at run-time” and the addition of “a new C++ communication bridge”, which enables users to “integrate MATLAB/Simulink models or other flight models e.g. X-Plane, FlightGear into the simulation environment”. White and Padfield (2006) explain that their university has “10 undergraduate degree programmes which have an aerospace theme” and that “four modules” utilise their flight simulator.

Arnaldo et al. (2011) use a flight simulator (utilising “X-Plane”) to familiarise students with different aircraft, instruments and flight procedures, specifically to ensure students can “understand and internalise the principles of flight and air navigation”, “various systems” such as “radio air navigation aids, communications and surveillance systems” and that they can “work with different airspace structures and instrument flight procedures”.

Van Heerden et al. (2011) describe the construction of a motion flight simulator for educational use, utilising “off-the-shelf PC equipment and flight simulation software and hardware, together with commercial actuators and drive systems”. Van Heerden et al. (2011) note that the flight simulator was constructed for the “science exploratorium (SciEnza) of the University of Pretoria” and was designed to be used as a platform to aid mechanical engineering classes in “dynamics and control”. Van Heerden et al. (2011) say that “flight simulators that have four or more degrees of freedom are usually prohibitively expensive and complex” and hence, a system with “two degrees of freedom (pitch and roll)” was developed with the intention of keeping it “low-cost”. While Van Heerden et al. (2011) discuss the possible application of the simulator to undergraduate and graduate degree programmes, they had not used the simulation in such a way by the date of publication.

Domínguez, López and Gonzalo (2013) also describe an exercise using the commercial flight simulation package “X-Plane” to aid the “acquiring and developing of knowledge in flight mechanics”. Domínguez, López and Gonzalo (2013) used a virtual cockpit that mimics a Beechcraft Baron 58 aircraft to verify the impact of the flight simulation exercise by asking students to complete a multiple choice test both before and after completing the exercise. Thirty-one students from their class of 41 participated in this research, of which, 10 were a control group, who sat the test twice, but did not partake in the flight simulation exercise. Surprisingly, on one of the questions, students actually performed worse after the simulation than before (and worse than the control group); this illustrates the risks of flight simulation exercises. Domínguez, López and Gonzalo (2013) attribute
this and the limited improvement in student performance to students being distracted by the entertainment aspect of the simulator and therefore suggest that students should be offered more time in the flight simulator. No further research was carried out by the authors of this paper, and hence, this theory remains unsubstantiated.

### 2.4 Proprietary flight simulation solutions

Twigg and Johnson (2003) note that Johns Hopkins University and Pennsylvania State University utilise simulation software in their control classes. Twigg and Johnson (2003) employ a flight simulator representing the “Lockheed Martin F-16 jet aircraft” in order to aid their class in “flight control system design”. The flight simulation software empowers students to design their own control system (Twigg and Johnson, 2003). The F-16 “was chosen because it is very difficult to fly without stability augmentation” (Twigg and Johnson, 2003). First students fly the F-16 aircraft with an open loop controller (i.e. with “no stability or control augmentation”), in order to demonstrate the need for a more advanced control system and then students begin to implement such a control system (Twigg and Johnson, 2003).

Virginia Polytechnic Institute and State University (Virginia Tech) utilises an Operational Flight Trainer (OFT) for the A-6E Intruder, which was donated by the United States Navy after the A-6E Intruder was retired (Scalera and Durham, 1998; Cotting, McCue and Durham, 2007). Scalera and Durham (1998) described how the flight trainer was adapted to “simulate dynamic response characteristics of aircraft other than the now retired A-6E”, specifically, the software developed for this purpose was designed to be compatible with “CASTLE (Control Analysis & Simulation Test Loop Environment)”, which is the United States Navy’s architecture. The “real-time data viewing tool” IADS was later added to their configuration after it was donated by “Symvionics Inc. of Arcadia, CA” (Cotting, McCue and Durham, 2007).

Cotting (2010) asserts that “modern use of remote control aircraft in the aerospace curriculum aids students by giving them some practical experience, but it only gives students an experience by proxy” and that as a result “an aerospace engineering curriculum attracts students with great mathematical prowess and often excludes students with more practically based engineering skills”. As such, Virginia Tech utilises it’s A-6E Intruder in a course entitled “Flight Test Techniques” (Cotting, McCue and Durham, 2007; Cotting, 2010). Cotting, McCue and Durham (2007) describe 23 objectives that the course has for students to achieve, which are described using the six objective types within Bloom’s taxonomy (see §1.6.3), which range from applying concepts taught to students...
in control, performance and stability classes to classification of “both qualitative and quantitative aircraft characteristics in terms of MIL-F-8785C” and interpreting “gathered flight test data and [presenting it] in a standard, technical form”. Cotting, McCue and Durham (2007) asked students to evaluate their course and received an “overwhelmingly positive response” and furthermore, they note that attendance at the class (which was “held at 8:00 AM”) was rarely “less than 100%”, and “optional laboratory times were filled 75% of the time with students”.

Tarantino, Fazio and Sperandeo-Mineo (2010) describe a simple 2-DOF flight simulator that they have written using “Interactive Physics”, which “applies the traditional Runge-Kutta 5 integration method”. The simulator can be used in two different modes: first, an automatically piloted mode and second, a piloted mode which uses “all the available longitudinal controls to improve the flight performance” (Tarantino, Fazio and Sperandeo-Mineo, 2010). There is no cockpit window type visual in this software.

Gibbens, Dumble and Medagoda (2010); Gibbens and Verstraete (2011) describe the use of a “decommissioned Link 707 simulator acquired from the RAAF” in order “to enhance engineering training in aircraft flight stability, handling and control concepts". Gibbens, Dumble and Medagoda (2010) make the case for “simulation motion”, by contending that it “gives the student the most immediate appreciation of the dynamic responses”. The Link 707 flight simulator is used for “experiential learning” including exercises during which students “engage the autopilot and auto-throttle” and test “two standard control solutions” in control systems engineering (Gibbens, Dumble and Medagoda, 2010). This exercise was assessed both by the students, who graded their “understanding of key concepts on a scale of 1-5 where 1: Very poor” and “5: Excellent” and by assessors, who graded students using a questionnaire which involved “six-part multiple choice responses to a set of 18 questions that target specific knowledge concepts” (Gibbens, Dumble and Medagoda, 2010). The outcomes suggested a significant overall improvement, but the absence of statistical analysis and the lack of any mention of the sample size, mean that the results are not reliable (Gibbens, Dumble and Medagoda, 2010). Gibbens, Medagoda and Dumble (2009) also recorded the data for those with and without flight experience and found that it appears that, experienced pilots gain less from this flight simulation tool. Furthermore, Gibbens, Dumble and Medagoda (2010) compared women’s and men’s scores and found that women appeared to have a better understanding of the topics after using the flight simulators, but this may be an irregularity due to the sample size, which is not specified.

Shankar et al. (2015) describe a pair of software tools used to aid teaching of “aircraft dynamics and control”. First, a tool which employs a SolidWorks 3D design model and MATLAB, and
second, a tool which uses a “SIMULINK linear model” to drive a FlightGear visual flight simulation (Shankar et al., 2015). Shankar et al. (2015) carry out extensive statistical analysis of the results and found that there is a statistically significant improvement in student understanding and confidence in their knowledge.

2.5 Flight simulation at the University of Manchester

The University of Manchester utilises flight simulation in a variety of different ways:

First, the flight simulator is currently utilised by two different undergraduate degree classes: Aircraft Performance & Stability and Flight Dynamics. The first class, Aircraft Performance & Stability, employs the University’s four Merlin flight simulators to familiarise students with flight control devices (such as the joystick, throttle levers and yaw pedals), the principal instruments and to put the course content into context. Students are required to perform a circuit (utilising banked turns) and to record the data from this flight in order to produce a poster. The second class, Flight Dynamics, uses the flight simulators in order to give students a physical understanding of the Dynamic Modes; students are tasked with plotting data recorded for the Phugoid and Short Period in order to get a physical understanding of these modes, as opposed to the mathematical expressions which are derived in class.

A questionnaire was designed and sent out to students of Aircraft Performance & Stability following their laboratory. The abridged results can be found in Appendix A. Students were overwhelmingly positive regarding the flight simulation element of the assignment and all but one student claim to be confident in their answer to a specific assignment question. All students claim to be more confident in the content following the assignment. In addition to the numerical sections, students were asked if they would like to provide a comment; here is a selection of the responses:

- “I also enjoyed lab activity as it was a very useful hands-on experience”;
- “Using the simulators is always good”;
- “A good mixture of group work, individual demonstration and practical work which really helped me to grasp key concepts”;
- “Very helpful towards understanding the theory learned in lectures”; and
- “Simulator activity was great as always”.

Second, students formed a Flight Simulation Society in 2012, which enters a pair of competitions run by the Merlin Simulation Group, known as IT Flies and IT Flies USA. The society has weekly
lectures throughout semester one, during which senior members present to new first-year members, 10-15 minute lectures covering aircraft design principles. These lectures are highly targeted and each week the first year students are expected to produce another segment of their aircraft design, from establishing their aircraft weight and weight make-up (known as mass breakdown) through to finding their minimum wing area and thrust requirements and designing a suitable wing layout. These lectures are reviewed by the senior members before presentation and as a result, each year the presentations improve significantly. The society has been hugely successful at the two competitions, coming away with either first or second place five times (this year, the society entered two teams that won joint first place) in the last four years at IT Flies USA. Additionally, in the past two years, the society has opened a new branch dedicated to developing a flight simulator utilising a Hawk cockpit facsimile which was kindly donated by BAE Systems to the Society.

Third, the members of the Flight Simulation Society run a variety of other events in the flight simulators including Open Day visits and PASS flight simulation sessions. These sessions allow the Society’s members to share the flight simulators with a wider audience.

2.6 Summary of pedagogical flight simulation tools

In Table 2, there is a brief summary of the universities which is using the tools, description of the software, hardware and concepts being taught by each of the papers discussed in §2.1, §2.2, §2.3 & §2.4.

<table>
<thead>
<tr>
<th>Reference</th>
<th>University</th>
<th>Software used</th>
<th>Hardware</th>
<th>Pedagogical concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>University</td>
<td>Software used</td>
<td>Hardware</td>
<td>Pedagogical concepts</td>
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<tr>
<td>----------------------------</td>
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<td>----------------------------------------------------------------</td>
</tr>
<tr>
<td>Bossert and Yechout (2002)</td>
<td>U.S. Air Force Academy, USA</td>
<td>MATLAB</td>
<td>Genesis 3000 (static)</td>
<td>Aircraft performance, static and dynamic stability and feedback control; flight test techniques; aircraft design, control system design.</td>
</tr>
<tr>
<td>Done (2000); Done and Neal (2012)</td>
<td>City University, UK</td>
<td>Excalibur</td>
<td>Merlin MP520-T (motion)</td>
<td>Aircraft performance, static and dynamic stability and feedback control; flight test techniques; aircraft design.</td>
</tr>
<tr>
<td>Altman (2015)</td>
<td>University of Dayton, USA</td>
<td>Excalibur</td>
<td>Merlin MP521 (motion)</td>
<td>Aircraft design and flight test techniques including test pilot feedback.</td>
</tr>
<tr>
<td>Jumper and Baughn (1991)</td>
<td>University of Notre Dame, USA; University of California, Davis, USA</td>
<td>Microsoft FS 4.0</td>
<td>Custom, with yoke and rudder pedals (static)</td>
<td>Aircraft performance.</td>
</tr>
<tr>
<td>Reference</td>
<td>University</td>
<td>Software used</td>
<td>Hardware</td>
<td>Pedagogical concepts</td>
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<tr>
<td>White and Padfield (2006)</td>
<td>University of Liverpool</td>
<td>FLIGHTLAB; FlightGear and X-Plane capable</td>
<td>HELIFLIGHT</td>
<td>Flight handling qualities; flight control systems; rotorcraft flight.</td>
</tr>
<tr>
<td>Arnaldo et al. (2011)</td>
<td>Universidad Politécnica de Madrid, Spain</td>
<td>X-Plane</td>
<td>AV-IFR (static)</td>
<td>Familiarity with aircraft, instrument and flight procedures to aid flight control design</td>
</tr>
<tr>
<td>Van Heerden et al. (2011)</td>
<td>University of Pretoria, South Africa; North-West University (Pretoria campus), South Africa.</td>
<td>Microsoft Flight Simulator X</td>
<td>Custom, low-cost 2-DOF (motion)</td>
<td>None yet. Plans for use in aircraft dynamics and control.</td>
</tr>
<tr>
<td>Scalera and Durham (1998); Cotting, McCue and Durham (2007); Cotting (2010)</td>
<td>Virginia Polytechnic Institute and State University</td>
<td>CASTLE &amp; IADS</td>
<td>Operational Flight Trainer (OFT) for the A-6E Intruder</td>
<td>Flight testing; Flight control, performance and stability</td>
</tr>
</tbody>
</table>
2.7 Evaluation of flight simulation in aerospace engineering pedagogy

Existing research into teaching aerospace principles with the aid of flight simulation falls into two categories, first, research that evaluates relevant solutions using rigorous analytical methods and second, research that relies on lecturer and student feedback. Table 3 shows the different papers discussed in this literature review, the evaluation type and the evaluation techniques used.

Shankar et al. (2015) carried out the most extensive evaluation techniques. However, it should be noted that Shankar et al. (2015) did not use the flight simulator for aircraft design or use the software in an interactive environment (i.e. he did not use a motion system or even pilot input).
Overall it is evident that flight simulation was seen in a positive light by both lecturers and students. This is unsurprising given that Shankar et al. (2015) demonstrate that flight simulation tasks improve students’ desire to learn, confidence in their understanding and their actual understanding of the topics at hand. The quantitative data available for the impact of flight simulation is lacking compared to the qualitative and particularly anecdotal notes, however, the limited research that does exist suggests positive results.
Table 3: Table of techniques used by educators to evaluate the benefit to students’ understanding of the content in their programme due to the utilisation of flight simulation

<table>
<thead>
<tr>
<th>Paper</th>
<th>Evaluation Type</th>
<th>Evaluation Techniques</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russell, Mouch and Yechout (1990); Yechout et al. (1997)</td>
<td>Qualitative</td>
<td>Assessor oversight.</td>
<td>Positive</td>
</tr>
<tr>
<td>Bossert and Yechout (2002)</td>
<td>Qualitative</td>
<td>Assessor oversight.</td>
<td>Positive</td>
</tr>
<tr>
<td>Altman (2015)</td>
<td>Qualitative</td>
<td>Student feedback, assessor oversight.</td>
<td>Overwhelmingly positive</td>
</tr>
<tr>
<td>Domínguez, López and Gonzalo (2013)</td>
<td>Qualitative and quantitative</td>
<td>Student feedback, student self-analysis and assessor analysis both before and after.</td>
<td>Moderately positive; limited value believed to be due to “distraction hypothesis”</td>
</tr>
<tr>
<td>Scalera and Durham (1998); Cotting, McCue and Durham (2007); Cotting (2010)</td>
<td>Qualitative and quantitative</td>
<td>Student comments &amp; self-assessment survey, assessor oversight and student attendance.</td>
<td>Overwhelmingly positive</td>
</tr>
<tr>
<td>Gibbens, Medagoda and Dubble (2009); Gibbens, Dubble and Medagoda (2010)</td>
<td>Quantitative</td>
<td>Student self-analysis, assessor analysis both before and after.</td>
<td>Positive, limited improvements</td>
</tr>
<tr>
<td>Shankar et al. (2015)</td>
<td>Qualitative and quantitative</td>
<td>Motivated Strategies for Learning Questionnaire (MSLQ), Engineering Self-Efficacy Survey (ENGSE), Student Perceptions of Classroom Knowledge-building (SPOCK) and examination data analysed using statistical multivariate hypothesis tests.</td>
<td>Overwhelmingly positive, significant evidence of improvements in students perceived and true understanding</td>
</tr>
<tr>
<td>White and Padfield (2006)</td>
<td>Qualitative and quantitative</td>
<td>Assessor analysis before and after.</td>
<td>Positive, limited analysis</td>
</tr>
</tbody>
</table>
3 Development of the flight simulation tool

Section 3.1 sets out the requirements for the development of the flight simulation tool. Following this, a survey of different flight simulation platforms was carried out to find the platform most suitable for development (§3.2). Section 3.3 describes the software development methodology used, which incorporates best practice in software development.

The software be obtained and set up as follows:

- The entire code repository for the project can be found at https://bitbucket.org/ukblewis/simulation-tool-for-teaching and the release (i.e. the built project, not the source code) can be downloaded as a ZIP file from https://bitbucket.org/ukblewis/simulation-tool-for-teaching/get/release/Windows.zip for Windows and from https://bitbucket.org/ukblewis/simulation-tool-for-teaching/get/release/OSX.zip for OS X;

- The FlightGear data is also required to run the project, and this can be downloaded from https://bitbucket.org/ukblewis/fgdata/get/release/3.6.0.zip;

- To set up software, copy the contents of the FlightGear data into the path %APPLICATION_ROOT%/FGFS/fgdata where %APPLICATION_ROOT% is the location which you extracted the Windows or OS X release to; and

- Following this, you can run the software either from the shortcut in %APPLICATION_ROOT%, or going to %APPLICATION_ROOT%/FGFSNodeLauncher/bin and clicking on the executable, i.e. PedagogicalSim.exe for Windows and PedagogicalSim.app for OS X.

The documentation for the project can be read by clicking on %APPLICATION_ROOT%/FGFSNodeLauncher/JSDoc/index.html or visiting this link.

3.1 Requirements for development

The software must be:

1. Simple:

   Simplicity is paramount; the project must be simple because undergraduates and educators are already under great pressure with their degree programme work and do not have the time to learn to use an obtuse platform.

2. An open project, Open Source, with publicly available, well documented and easily accessible code:
What is needed is an Open Source platform, given that the majority of flight simulation tools developed have been either proprietary products developed by individual institutions solely for their use, or commercial products (such as Merlin Excalibur and FLIGHTLAB) that many institutions may not be able to afford. Furthermore, both proprietary and commercial products have the added disadvantage that it is often hard for universities to develop on top of or modify them due to limited documentation, support and sometimes contractual issues.

3. Able to run on low cost hardware while maintaining maximum possible functionality and the most engaging experience possible:

Advanced simulators, such as Merlin’s MP521, focus on motion or require specialist hardware (such as flight simulation servers and custom joystick hardware). This would cost a vast amount to deploy at a large scale, such as that required for use by an entire Aircraft Design class, since each flight simulator can cost tens or even hundreds of thousands of pounds. As such, the goal of this project is to adapt existing flight simulation software, which can be run on mainstream computing hardware, for use in an educational setting, in order to overcome the challenges of cost and scale.

4. Capable of being run on multiple Operating Systems and a wide range of hardware:

Students use different OSs, with recent Windows and OS X releases covering over 80% of the laptop/desktop market (StatCounter, 2016). The university may not be able to procure specific hardware for this particular project and, even if they are able, they may desire to upgrade to improved hardware in the future. Accordingly, this project is designed to be compatible with an array of different hardware (e.g. joystick and throttle devices) in addition to both the latest Windows and OS X releases.

5. Intuitive:

Additionally, it was ascertained that it would be hugely beneficial to develop a piece of software that is intuitive enough that students can use it without requiring assistance, thereby reducing the costs of running laboratory sessions and enabling students to use the software at home for additional practice. The software that guides students through the simulation tasks (and potentially offers additional interactive content) will be known as the “tutor”.

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3.2 Flight simulation platform chosen

In order to minimise the time required to develop a fully featured flight simulation solution for teaching, it was decided that instead of developing entirely new flight simulation software, existing software would be adapted. A comparison of a variety of commercial, free and Open Source flight simulation software is shown in Table 4. FlightGear 3.6\(^2\) with JSBSim was chosen, since the combination has been used in teaching before, JSBSim has a detailed model of atmospheric flight and JSBSim’s Open Source licence means that the source code can be easily edited to add new functionality.

Table 4: Table comparing flight simulation software, adapted from Cetyrkovskis (2014), adding documented use in teaching, FDM and OS columns and updated software versions

<table>
<thead>
<tr>
<th>Software</th>
<th>FDM</th>
<th>simulation of atmospheric flight</th>
<th>Custom aircraft models</th>
<th>Supported platforms</th>
<th>Licence</th>
<th>evidence of use in engineering education(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excalibur II and III</td>
<td>Internal</td>
<td>Yes, simplified panel method</td>
<td>Yes, simplified</td>
<td>Windows</td>
<td>Commercial</td>
<td>Yes</td>
</tr>
<tr>
<td>FlightGear 3.4 and 3.6</td>
<td>JSBSim</td>
<td>Yes, flexible coefficient build up method (Berndt, 2004)</td>
<td>Yes</td>
<td>Windows &amp; OS X</td>
<td>Open Source</td>
<td>Yes</td>
</tr>
<tr>
<td>YASim</td>
<td></td>
<td>Yes, simplified geometric method (FlightGear Wiki, 2014)</td>
<td>Yes</td>
<td>Windows &amp; OS X</td>
<td>Open Source</td>
<td>No</td>
</tr>
<tr>
<td>X-Plane 10.42</td>
<td>Internal</td>
<td>Yes, panel method</td>
<td>Yes</td>
<td>Windows &amp; OS X</td>
<td>Commercial</td>
<td>Yes</td>
</tr>
<tr>
<td>PREPAR3D v3</td>
<td>Internal</td>
<td>Yes, stability derivative method</td>
<td>Yes, difficult to model</td>
<td>Windows</td>
<td>Commercial</td>
<td>No</td>
</tr>
<tr>
<td>Orbiter 100830</td>
<td>Internal</td>
<td>Basic</td>
<td>Yes, basic lift and inertia</td>
<td>Windows</td>
<td>Freeware</td>
<td>No</td>
</tr>
</tbody>
</table>

\(^2\)Version 3.6 was never actually released, it was skipped. The project is based upon the latest version 3.6 source code. It is compatible with version 3.4 aircraft models. It would also be straightforward to compile a more recent FlightGear version with the JSBSim code change if necessary.

\(^3\)Includes documented use of a similar software version, not necessarily the version indicated.
FlightGear is made up of a series of components (shown in Figure 3), which allow it to provide rich functionality. This project will focus on the FDM, JSBSim and the core simulation environment, SimGear. FGCom, the voice communication package, will not be used since the “tutor” software is to be designed to be operated by a single student; however, coordinated tasks involving multiple students could be designed utilising this component in the future. TerraSync, the scenery package, can be enabled or disabled by the tutor. If the software is to be used offline, it should be disabled and instead scenery should be pre-downloaded. Scenery is both visually appealing and a requirement for the correct operation of the FDM in FlightGear; as such, either TerraSync must be enabled or scenery pre-downloaded.

![Figure 3: FlightGear components](image)

### 3.3 Software development methodology

In order to develop software applications, it is important to maintain best practice principles to ensure that code is easily maintainable. The consequence of utilising best practice principles is that software can be easily read by those who have not been involved in the development process or those who were involved but have not been active in development recently.

In order to meet this requirement, the code was developed utilising an SCM, specifically, the Open Source DRC tool Git. Atlassian Bitbucket was configured as a remote Repository for Git.
The software application Atlassian SourceTree was used to interface with Git to make tracking the Repository and Commits easier. Remote repositories offer a series of benefits, in particular, they enable:

- Lost data to be recovered;
- Historical work to be easily reviewed, at any location (especially using Atlassian Bitbucket’s web interface); and
- Multiple developers to work collaboratively.

Additionally, the code is commented and documented using the documentation tool JSDoc.

### 3.4 Software developed

![Development flow diagram](image)

**Figure 4: Development flow diagram**

Figure 4 shows an overview of the new components and how they communicate with FlightGear.

In order to accelerate development of the guiding “tutor” software, it was decided that this software would be developed separately from FlightGear and either use modifications to JSBSim.
to change the aircraft being modelled while flying (§3.4.1) or using the Telnet interface to the FlightGear Property Tree (§3.4.3) to control FlightGear’s operation. In addition, it was ascertained that the FlightGear HUD would have to be adapted for use in teaching in order to make it easier to use (§3.4.2). Following this, a preliminary lesson was constructed to evaluate and improve the tool (§3.4.4).

### 3.4.1 Changes to the existing flight dynamics model (JSBSim)

![JSBSim flow diagram]

Figure 5: JSBSim flow diagram

JSBSim is limited in that it can only simulate a single aircraft model at any one time, which requires a user to restart FlightGear to change a single aircraft design variable. Preferably a user would be able to reload an aircraft model without restarting FlightGear. This functionality was added by modifying the source code of JSBSim.

The minor code modifications required to add this functionality can be found in the Git commits “Add latest code from CVS for JSBSim”\(^4\) and “Create simple wrapper for model reloader ...”\(^5\).

The implementation uses a file named `flush`, which is read to verify if the aircraft should be updated or not. If the file named `flush` contains 1 then the aircraft would be reloaded by JSBSim.

---

\(^4\) Commit ID: 63d1cccd118e009dc7502806691ef292a548d52ce
\(^5\) Commit ID: bee32b1c478826ac2ab313b79908e9d80602f80d
3.4 DEVELOPMENT OF THE FLIGHT SIMULATION TOOL

and the file would be updated to contain 0. If the file contained anything else, JSBSim would continue execution without changing any parameters. Figure 5 shows a flow diagram to illustrate this flow.

In order to integrate this change into FlightGear, the change to the source code was applied to FlightGear and the FlightGear repository was forked (see Fork) and was configured as a Submodule inside the project Git repository.

3.4.2 Development of the HUD for FlightGear

In order to create a flight simulation tool for pedagogical use, it was determined that full simulation of the cockpit interior including the panels would be distracting and detract from the experience. As such, work focused on producing a highly-readable HUD.

Figures 6 and 7 show the three default HUD options available in FlightGear. In option one (default) there are a lot of indicators, none of them are appropriately labelled, which makes it extremely difficult to guess what they display on the first use. Option two (NTPS) does not have enough of the relevant information, and once again none of the items are labelled. Option three is the cleanest, but still does not label anything and is hard to read relevant data at a glance (because tapes and indicators are used so sparingly).
The HUD in FlightGear is configured using a series of XML files which allow the user to define the type of visual element (e.g. indicators, tapes and gauges) being shown, what property it should display and the format with which to display it. Furthermore, it can be used to implement elementary mathematics such as multiplication, so that variables stored in the Property Tree in feet per second can be converted to feet per minute. The full XML code for the final HUD can be found in the FlightGear data repository inside the folder \texttt{Huds}.
Figure 7: Default HUD options in FlightGear (FlightGear Wiki, 2015)
Figure 8, shows the first full revision of the HUD design; notable changes include removing all of the indicators for trim and control deflections (the double arrow-headed bars in the centre on the bottom and left) and the radio altimeter tape to reduce clutter. The trim status was shown by using a percentage deflection indicator at the bottom centre of the display which makes it clear which tab was deflected in which direction while maintaining the minimal look.

Incrementally, a second full revision (see Figure 9) was designed utilising feedback from students in the Aircraft Design class (see 3.4.4) and Gautam Gorasia, a qualified PPL holder and one of the leaders of the Flight Simulation Society at the University of Manchester. Some major changes were made, including introducing a rate of climb tape to the right of the AMSL tape and adding a bank indicator. Additionally, the thrust indicator was moved down and labelled for clarity, as was the AGL indicator. Angle of attack and KTAS indicators were introduced and all of the tapes now have readouts.
3.4.3 Development of the lesson environment

Initially, a survey of major programming languages was undertaken in order to find the most appropriate one to use for the lesson environment tool. The different programming languages each have many major implementations, supported platforms and features; a summary of these details can be found in Appendix B.

JavaScript was chosen as the programming language to use for this project. JavaScript uses Prototype-based Object-Oriented Programming, which means that new methods and properties can be added extremely easily. Moreover, JavaScript is an implicit and dynamic programming language, which means that variables do not need to be initialised by specifying their type, and their type can be changed if necessary. This makes JavaScript an extremely flexible language, which means that developing new software in it is extremely quick. Beyond this, some significant unique features led to JavaScript being chosen amongst the list. JavaScript can be run on a Windows, Linux or OS X computer natively using Node.JS and Node.JS offers extremely easy to use APIs (see API) for file system I/O and for networking.

An IDE called WebStorm was used to aid development. The lesson environment tool utilises web pages to show students lesson content. In order to offer a live link between FlightGear and the
web page, Socket.IO was used to open a web socket between the Node.js server (which launches FlightGear in a Child Process), and the web page. For more information on the implementation of the “tutor”, known as PedagogicalSim, see Appendix C. An additional benefit of serving the application’s UI as a web page is that, if the students are sharing a network, a tablet, smartphone or other another computer can be used to read the lesson content and control FlightGear on the primary computer. To test this, simply launch the application on the primary computer, connect the other device to the same network and then look for the “Local IP” listed in the top corner of the primary computer. Then navigate on the other device to http://THE LOCAL IP HERE:3000/ and you should see the PedagogicalSim interface.

By utilising FlightGear’s Command Line Options (known as launchProps in the code base), it was possible to create code that launches a certain aircraft at trim in a particular location, orientation and speed. Furthermore, it was possible to create code that launches FlightGear with the simulation clock frozen such that students would be able to set their throttle lever position and verify their joystick controls before flight. By utilising the Telnet interface to FlightGear, it was possible to create code that starts the clock again dynamically in FlightGear after starting the simulation with the clock stopped.

```javascript
socketLaunchFG(aircraftName,flightConditionName,disableTerraGear)
// Obtain the flight condition data
=> launchFG(aircraftName,flightConditionData,socket,disableTerraGear)
// Launch FlightGear in a child process, with TerraGear enabled or
// disabled as specified, aircraft specified, in flight condition
// specified with telnet enabled and frozen clock using
// Command Line Options and write errors to web page using socket
=> pollThrottle(socket)
// Every 200 ms use telnet to read the throttle lever and joystick
// position values and read the trim value. Take the value received
// and convert the decimal value and turn it into an integer percentage
=> telnetConnect()
// Open a telnet connection handle or retrieve the existing one
=> telnetWriteRead(telnetCommand)
// Write to the telnet connection the FlightGear Property Tree values
// to retrieve
=> socketEmitData()
// Use the socket to emit throttle and joystick position values and
// the trim value
```

Figure 10: Core application functionality code skeleton

The application uses the Telnet network connection to Poll the requested throttle value provided to FlightGear and the trim value, from the FDM, to help students match the two values. Addition-
3.4 DEVELOPMENT OF THE FLIGHT SIMULATION TOOL

ally, the application polls the input from the joystick in order to plot the current requested Pitch and Roll inputs. The code skeleton for the core application can be found in Figure 10.

The application can also retrieve and edit properties from FlightGear’s Property Tree using Telnet and by utilising Socket.IO. This data can be sent to the web page or modified by the web page. Finally, the application may also be used to log aircraft data from FlightGear. This feature is enabled by utilising the file `propertyList.json` which maps human readable names for properties to FlightGear Property Tree entries. This is used to build an XML file which specifies to FlightGear how to log data. FlightGear is then launched with the relevant Command Line Option to log to this file. Logging is currently fixed at one entry per second, but this could be modified at a later date and logging cannot currently be started after FlightGear has been launched, FlightGear must be restarted. The file `propertyList.json` is also used by the property retrieval/editor feature. To test these features, once you have launched the application, visit `http://localhost:3000/development`.

3.4.4 Sample lesson

![Constraints Analysis: Task 1](image)

In order to utilise the tool and provide an example for future development, a sample lesson was created in the “tutor”. This sample lesson focussed on constraints analysis, a topic covered in Aircraft Design. The lesson was shown to two students of the Aircraft Design class who volunteered to try the software.
Their feedback was generally extremely positive, but they noted some bugs and found some HUD elements hard to distinguish, particularly, AGL. One of the students provided the following comment:

“The flight simulation software is a more interactive way of grasping the concept of the driving factors in the design process (constraints analysis) and would provide a better visualization [of] how each constraint determines the final design of an aircraft. In terms of the experience it was quite enjoyable, interactive and educational, requiring you to use the data from the GUI at different flight stages to determine the ‘category’ to which the aircraft belongs to on the constraints diagram design space. Some minor improvements could be made to the interfaces used for a more fluent launch of the program and added functionality (For example, changing from climb to cruise without relaunching the program), and there were some minor issues /bugs that arose from time to time (program crashing/ multiple sessions open at the same time, etc.). Other than that it was an enjoyable experience”.

This feedback led to the incorporation of the label in the second full revision of the HUD. Appendix D contains the plan developed for the sample lesson including the answers to the problems set. A version of this lesson plan without the answers was provided to the students.

4 Conclusions

An investigation of the literature uncovered the history of flight simulation, its place engineering and found that past research suggested that there could be great value in utilising flight simulation in engineering pedagogy. Following the investigation into the existing work, it was found that there was no flight simulation software targeted specifically at academia which could be used by students outside of a flight simulation laboratory. Therefore, the author decided to modify the existing open source flight simulation platform known as FlightGear to meet the needs of academia. A summary of the aims and the outcomes is shown in Table 5.
### Table 5: Aims and outcomes

<table>
<thead>
<tr>
<th>Aim</th>
<th>Sub-aim</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Provide a brief introduction to flight simulation and the history of it.</td>
<td>Completed successfully; the introduction is in Section 1.3 and the history is in Section 1.4.</td>
<td></td>
</tr>
<tr>
<td>2. Review existing research into the use of flight simulation in aerospace degree classes.</td>
<td>Completed successfully; a summary of the results can be found in Tables 2 and 3.</td>
<td></td>
</tr>
<tr>
<td>3. Create initial version of a tool:</td>
<td>(a) For conveying aircraft design principles, which could be easily adapted for use in other aerospace engineering classes.</td>
<td>Completed successfully; a tool known as the “tutor” was devised and created. The tool is modular and so easy to adapt. A sample lesson was developed.</td>
</tr>
<tr>
<td></td>
<td>(b) Which could be used by an entire class of students simultaneously.</td>
<td>Completed successfully; additionally, the requirements set out in Section 3.1 were also met.</td>
</tr>
</tbody>
</table>

## 5 Future work

The software developed as part of this project suggests many opportunities for future work. A few examples of areas that could be explored in the future include:

1. Development of further web page lessons and flight simulation tasks for Aircraft Design, for example, tasks involving shifting aircraft centre of gravity;

2. Development of flight simulation tasks for Aircraft Performance & Stability classes, utilising high-performance aircraft to demonstrate Zoom Climb;

3. Development of flight simulation tasks for Flight Dynamics classes, utilising the property logging features, enabling students to explore the dynamic modes in depth at home;

4. Thorough testing of content produced for the three classes mentioned above, by assessing students’ understanding before the simulation tasks and after the simulation tasks; and

5. JSBSim could be modified to enable partial aircraft model refreshes rather than refreshing all data, which could significantly improve the performance when changing the aircraft model.

It is envisioned that another student will continue the work undertaken in this project next year and that as a result, it will be possible that this software will be used in the Aircraft Design class by all students the following year, in place of the current coursework task undertaken utilising the 3D computer aided design software SolidWorks. Discussions with the lecturer for Aircraft Performance & Stability suggest that it is likely the software will be used in this unit. A vision for future work
is shown in Figure 12. Evidently, there is significant potential for future work and the development of the strong, modular base program should ensure that future work progresses quickly.

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 2016</td>
<td>Pedagogical engineering flight simulation &quot;tutor&quot;, PedagogicalSim, developed.</td>
</tr>
<tr>
<td>March 2016</td>
<td>First lesson for PedagogicalSim developed.</td>
</tr>
<tr>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>September-June 2016</td>
<td>PedagogicalSim utilised in Aircraft Performance &amp; Stability laboratory.</td>
</tr>
<tr>
<td>September-December 2016</td>
<td>PedagogicalSim lessons developed for Aircraft Design.</td>
</tr>
<tr>
<td>December-April 2016</td>
<td>PedagogicalSim lessons tested with significant segment of Aircraft Design cohort.</td>
</tr>
<tr>
<td>September-June 2016</td>
<td>PedagogicalSim replaces existing SolidWorks coursework task in Aircraft Design.</td>
</tr>
</tbody>
</table>

Figure 12: Timeline for future work
Bibliography


LIBRARY OF CONGRESS (1908) Wright brothers aeroplane - patented plans, 1908. Available at: http://loc.gov/pictures/resource/cph.3c27779/.


Oracle (no date) OpenJDK. Available at: http://openjdk.java.net [Accessed: 2016-04-05].


Appendix A  Questionnaire provided to Aircraft Performance & Stability

Here are the questions that were asked:

1. How much did you enjoy the group activity? [Scale 0-10, with zero as did not enjoy it];

2. How difficult did you find the group activity? [Scale 0-10, with zero as really easy];

3. Are you confident that you understand what aircraft trim is? [Yes/No];

4. Were you confident that you calculated the bank angle in step 7 of the group activity correctly? [Yes/No];

5. How many hours did your group spend producing the poster assignment (collectively)? [Number];

6. How much did you enjoy producing the poster? [Scale 0-10, with zero as those who did not enjoy producing it];

7. Did you enjoy this method of assessment? [Yes/No];

8. Do you feel more confident in your understanding of this content following the laboratory? [Yes/No];

9. Please estimate how well you think you performed in this activity: [Scale 0-10, with zero as a “I scored extremely low”];

10. Please rate this coursework assignment: [Stars 1-5, with “5 being the best and 1 being the lowest”];

11. Please enter any additional feedback that you would like to provide: [Text area].

Looking at Table 6, we can see that, from the twenty-seven respondents, the average score for their enjoyment of the activity was greater than 75% (i.e. it was 7.63/10) and an even higher 85% said that they enjoyed this method of assessment, which is encouraging. However, the average score for the difficulty of the assessment was rather low at 3.96/10, which suggests that the task could be made more difficult without students struggling. All students claimed to be confident in knowing what aircraft trim is, which is encouraging, this should however, be compared with the...

---

Question 11 has been redacted to prevent the document from being excessively large, full results available on request.
assessment results. 96% of students said that they were confident in the bank angle that they calculated, which is also encouraging. What is also interesting to note, is that the student who claimed to be unsure of their bank angle, also noted that they found the task to be 7/10 on the Question 2 (the difficulty question). The average number of hours spent on the poster assignment collectively was 4.30, although there may have been some confusion, leading some respondents to be unsure whether to input their own time dedicated or all member’s time added up. The average score for enjoying producing the poster was only 5.19, which suggests that this element of the task was less enjoyable than the hands-on elements. All the respondents claimed said that they felt more confident in their understanding of the content following the laboratory, which is extremely encouraging. The average score that students assigned to their performance in the activity, was 7.30. The average star rating for the coursework assignment was 4.44 out of 5, which is extremely encouraging. Students noted that “use of the simulators was good”, but that the poster was “a bit annoying to do because some of my group did not have the best excel skills” and that the “only bad thing is that sometimes activities and assignments in groups are bot [sic] the best thing since some end up doing more work than others”. Meanwhile, a student noted that they found “the interview to be a particularly good way to assess [them]”. 
Table 6: Results of Aircraft Performance & Stability laboratory questionnaire

<table>
<thead>
<tr>
<th>Question:</th>
<th>Q1</th>
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<th>Q3</th>
<th>Q4</th>
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<th>Q7</th>
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<td>85% Yes</td>
<td>100% Yes</td>
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</table>
Appendix B  Choice of programming language

In order to produce the lesson framework tool, the application had to be written in a programming language. In order to decide which programming language to choose, a table comparing popular programming languages was produced (see Table 7).

Table 7: Programming languages compared

<table>
<thead>
<tr>
<th>Programming Language</th>
<th>Major implementations</th>
<th>Platform</th>
<th>Object-Oriented Programming</th>
<th>Functional</th>
<th>Data typing</th>
<th>Easy to use on multiple platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>C++</td>
<td>LLVM Clang (LLVM, n.d.a); GCC (Free Software Foundation, 2016); Microsoft Visual C++ (Visual C++ Team Blog, 2015); etc.</td>
<td>Windows, OS X, Linux + (LLVM, n.d.b)</td>
<td>Class-based (McNamara and Smaragdakis, 2000)</td>
<td>Yes (McNamara and Smaragdakis, 2000)</td>
<td>Explicit, static and strong (McNamara and Smaragdakis, 2000)</td>
<td>No</td>
</tr>
<tr>
<td>Programming Language</td>
<td>Major implementations</td>
<td>Platform</td>
<td>Object-Oriented Programming</td>
<td>Functional</td>
<td>Data typing</td>
<td>Easy to use on multiple platforms</td>
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</tr>
<tr>
<td>JavaScript</td>
<td>Chakra; SpiderMonkey; V8 Lane et al. (2012, p. 161)</td>
<td>Web browsers (e.g. Google Chrome), natively via Node.JS on Windows, OS X, Linux</td>
<td>Prototype-based (Turbak, Gifford and Sheldon, 2008, p. 380)</td>
<td>Yes</td>
<td>Implicit, dynamic and weak (Turbak, Gifford and Sheldon, 2008, p. 623)</td>
<td>When using Node.JS or only supporting modern web browsers</td>
</tr>
<tr>
<td>MATLAB</td>
<td>MATLAB</td>
<td>Windows, OS X, Linux + (MathWorks, n.d.b)</td>
<td>Class-based (MathWorks, n.d.b)</td>
<td>No</td>
<td>Implicit, dynamic and weak (MathWorks, n.d.a)</td>
<td>Yes</td>
</tr>
<tr>
<td>Programming Language</td>
<td>Platform</td>
<td>Major Implementations</td>
<td>Data Typing</td>
<td>Easy to use on multiple platforms</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>PHP</td>
<td>Windows, OS, +X, Linux</td>
<td>Zend Engine (Zend, n.d.); HHVM</td>
<td>Implicit, dynamic and weak (PHP Group, n.d.a)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Python</td>
<td>Windows, +X, Linux</td>
<td>CPython; Jython; PyPy</td>
<td>Implicit, dynamic and strong (Turbak and Sheldon, 2008, p. 623)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruby</td>
<td>Windows, OS, +X, Linux</td>
<td>Ruby MRI; Rubinius; JRuby</td>
<td>Implicit, dynamic and strong (Ruby, n.d.b)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruby MRI</td>
<td>Windows, OS, +X, Linux</td>
<td>Ruby MRI; Rubinius; JRuby</td>
<td>Implicit, dynamic and strong (Ruby, n.d.b)</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruby MRI</td>
<td>Windows, OS, +X, Linux</td>
<td>Ruby MRI; Rubinius; JRuby</td>
<td>Implicit, dynamic and strong (Ruby, n.d.b)</td>
<td>No</td>
<td></td>
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</tr>
</tbody>
</table>
Appendix C  “Tutor” development information

The application was created using WebStorm to create a template project to run on Node.JS containing Express.JS, Handlebars and LESS packages and boilerplate (starting) code. Some major additions were made to the environment during development:

1. The web UI toolkit Bootstrap was installed (and it’s dependency jQuery) from Npm, which enabled the UI to be developed quickly while still ensuring that it was clear and aesthetically appealing;

2. Socket.IO, a library for real-time web applications, was employed to send data live between the FlightGear interface and the web page, eliminating the need to refresh the web page;

3. A custom interface was written to interact with FlightGear over the Telnet network interface to allow the tool to control FlightGear;

4. The package “open” was installed from Npm to make it easier to open the web browser on application launch on Windows and OS X;

5. The package “tree-kill” was installed from Npm to enable killing the FlightGear process tree;

6. The package “node-jsxml” was installed from Npm to enable reading of XML strings to JavaScript objects, modifying them and saving of them as strings;

7. The package “xml-escape” was installed from Npm to enable escaping of the XML strings exported to XML files.

The application was refactored (see Refactor) following development in order to reduce duplication and make it easier to re-use the core helper functions; this means that it should be relatively straightforward to create a new lesson now.
Lesson 1 plan: Constraints analysis

22nd April 2016

1 Requirements

1. PC running Windows or OS X with:
   (a) A screen with a high resolution display: 1024 x 768;
   (b) A 3D video card with at least 1024-2048 MB of dedicated gDDR3+;
   (c) At least 2-4GB of free RAM;
   (d) Preferably a quad core processor with ~2 GHz each with a 64bit architecture (although code is compiled as 32 bit on Windows and I’m testing it on my MacBook Pro which is dual core);
   (e) At least 6.5GB of free HD space (files to run it are relatively large; I will try to streamline it by removing unneeded files for future lessons);
   (f) A two or three button mouse with a scroll wheel AND a joystick/yoke and/or pedals - Gameport or USB (HID compatible) - large array supported by FlightGear - Saitek X52 Pro has been tested on Windows and OS X and works out of the box (although, it can be remapped relatively easily);
   (g) Ideally two displays/large display so that you can run “tutor” and FlightGear side by side.

2. Web browser to run the “tutor”;

3. Software package:
   (a) Software will be provided in a .ZIP compressed file;
   (b) Extract the ZIP and run the executable labelled “RUN ME”.

Appendix D  Initial lesson plan
## 2 Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Repeating information verbatim</td>
</tr>
<tr>
<td>Comprehension</td>
<td>Demonstrating understanding of terms and concepts</td>
</tr>
<tr>
<td>Application</td>
<td>Solving problems</td>
</tr>
<tr>
<td>Analysis</td>
<td>Examination of the element or structure of something</td>
</tr>
<tr>
<td>Synthesis</td>
<td>Creating something, combining element in novel ways</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Choosing from alternatives</td>
</tr>
</tbody>
</table>
Civilian aircraft design is driven by cost and hence, by causation, reduction in aircraft wing size and engine size is the primary goal.

Aircraft design is driven by the constraints. Constraints can be derived from aircraft equations of motion. Constraints can be derived for any relevant flight profile. Constraints tend to use the axes thrust to weight ratio \( (T/W) \) and wing loading \( (W/S) \) to normalise plotting aircraft with different weight.

Fly two aircraft - aircraft A and aircraft B. Which do you think has the higher thrust to weight ratio \( (T/W) \) and which do you think has the higher wing loading \( (W/S) \)? Answer: Aircraft 2 has the higher \( (T/W) \).

What additional constraints could you come up with? Answer: Rate of climb, descent, rate of descent, rate of turn, etc. Can you derive one of these?

In civilian aircraft, the most important constraints tend to be takeoff, climb, cruise and landing conditions.

The most important constraint equations: takeoff, climb, cruise and landing. Answer: See the software.

Can you plot the cruise constraint for a Boeing 737? Answer: See Figure 1 for the solution.

Which do we expect to be the driving (key) constraints for a De Havilland Canada DHC-3 Otter aircraft? Answer: Since it is a Short Takeoff and Landing aircraft (STOL) - Takeoff/landing.

<table>
<thead>
<tr>
<th>No</th>
<th>Objective</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Civilian aircraft design is driven by cost and hence, by causation, reduction in aircraft wing size and engine size is the primary goal.</td>
<td>Know</td>
</tr>
<tr>
<td>2</td>
<td>Aircraft design is driven by the constraints. Constraints can be derived from aircraft equations of motion. Constraints can be derived for any relevant flight profile. Constraints tend to use the axes thrust to weight ratio ( (T/W) ) and wing loading ( (W/S) ) to normalise plotting aircraft with different weight.</td>
<td>Comprehend &amp; Apply</td>
</tr>
<tr>
<td>3</td>
<td>Fly two aircraft - aircraft A and aircraft B. Which do you think has the higher thrust to weight ratio ( (T/W) ) and which do you think has the higher wing loading ( (W/S) )? Answer: Aircraft 2 has the higher ( (T/W) ).</td>
<td>Analyse and Evaluate</td>
</tr>
<tr>
<td>4</td>
<td>What additional constraints could you come up with? Answer: Rate of climb, descent, rate of descent, rate of turn, etc. Can you derive one of these?</td>
<td>Synthesize and Apply</td>
</tr>
<tr>
<td>5</td>
<td>In civilian aircraft, the most important constraints tend to be takeoff, climb, cruise and landing conditions.</td>
<td>Know</td>
</tr>
<tr>
<td>6</td>
<td>The most important constraint equations: takeoff, climb, cruise and landing. Answer: See the software.</td>
<td>Comprehend</td>
</tr>
<tr>
<td>7</td>
<td>Can you plot the cruise constraint for a Boeing 737? Answer: See Figure 1 for the solution.</td>
<td>Apply</td>
</tr>
<tr>
<td>8</td>
<td>Which do we expect to be the driving (key) constraints for a De Havilland Canada DHC-3 Otter aircraft? Answer: Since it is a Short Takeoff and Landing aircraft (STOL) - Takeoff/landing.</td>
<td>Evaluate</td>
</tr>
</tbody>
</table>

3 Assessment

- Objectives 1, 2, 5, 6 & 8 will be assessed by an online multiple choice quiz (thereby reducing instructor time required);
- Objective 3 will be assessed as a A/B question by an assessor;
- Objective 4 will be assessed by an assessor in a brief chat (limited to 10 minutes);
Objective 7 will be assessed by an assessor as a simple graph comparison to pre-provided plot - students would be provided working and plot after submitting answers.

4 Risk assessment

- Students could break joysticks;
  - Low-cost joysticks will be used and students will be asked to pay for any damage caused.

- Students could break computers:
  - Students will only be allowed to use computers and joysticks in limited sessions during which they would be supervised.

- Students could be unable to use the software at home:
  - Sufficient lab time would be provided for those students that need it.

- Software could crash or otherwise fail:
  - Software will be tested thoroughly on lab computers.
<table>
<thead>
<tr>
<th>Consent Form</th>
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</thead>
<tbody>
<tr>
<td><strong>Name of Researcher:</strong> Ben Lewis</td>
</tr>
<tr>
<td><strong>Title of study</strong> Constructing a flight simulation tool for pedagogical aircraft design</td>
</tr>
</tbody>
</table>

Please read and complete this form carefully. If you are willing to participate in this study, ring the appropriate responses and sign and date the declaration at the end. If you do not understand anything and would like more information, please ask.

I, the undersigned, confirm that (please tick box as appropriate):

1. I have read and understood the information about the project, as provided in the Participation Information Sheet dated 18/12/2015. □
2. I have been given the opportunity to ask questions about the project and my participation. □
3. I voluntarily agree to participate in the project. □
4. I understand I can withdraw at any time without giving reasons and that I will not be penalised for withdrawing nor will I be questioned on why I have withdrawn. □
5. The procedures regarding confidentiality have been clearly explained to me. □
6. The use of the data has been explained to me. □
7. I understand that other researchers/supervisors will have access to this data only if they agree to preserve the confidentiality of the data and if they agree to the terms specified in this form. □
8. I freely give my consent to participate in this research study and have been given a copy of this form for my own information. □

**Participant:**

<table>
<thead>
<tr>
<th>Name of Participant</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>

**Researcher:**

Ben Lewis

<table>
<thead>
<tr>
<th>Name of Researcher</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>
Participation Information Sheet

You are invited to participate in an empirical research study as part of an MSc Dissertation project in the University of Manchester, Management of Projects programme. Before you make your decision whether you wish to participate, it is important for you to understand why the research is being done and what it would involve for you. Please read the following information carefully. Ask questions if anything you read is not clear or would like more information. Take time to decide whether or not to take part.

Who will conduct the research (contact information)?
Ben Lewis
School of Mechanical, Aerospace and Civil Engineering (MACE)
University of Manchester
Oxford Road
Manchester
M13 9PL
e-mail: bxxs
mobile: +44

Title of the Research
Constructing a flight simulation tool for pedagogical aircraft design

What is the aim of the research?
The aim of this research project is to improve learning in aerospace engineering, and to investigate the potential for flight simulation to aide such learning.

Who is organising or sponsoring the research?
The research is instigated by the University of Manchester.

Why have I been invited?
You are a student at the University of Manchester whom it may benefit.

Do I have to take part?
It is up to you to decide to join the study. We will describe the study in this information sheet. If you agree to take part, we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason. If you change your mind after you have participated in the research, please contact Ben Lewis (see contact information provided).

What will I be asked if I take part?
You will be asked questions to assess your knowledge of key concepts in Aerospace Engineering before and after using a flight simulation learning tool.

What is the duration of the research?
If no mitigating circumstances arise, Ben Lewis will submit his work on 24th April 2016

What happens to the data collected?
The data will be analysed by Ben Lewis. The results will be used in the qualitative analysis in the dissertation.

How is confidentiality maintained?
All information which is collected about you during the course of the research will be kept strictly confidential. All data will be anonymised and kept securely. Any other researchers/supervisors that will have access to this data agree to preserve the confidentiality of the data and they agree to the terms I have specified in this form.

Expenses and payments?
No remuneration is envisaged for your participation in the research

What are the possible disadvantages and risks of taking part?
No particular risks or disadvantages in your participation are foreseen. The research will be conducted strictly following ethical rules and professional conduct. Your personal and professional
reputation will be protected by all means. 

**Will the outcomes of the research be published?**

Potentially. The outcomes of the research will be used within a 3rd year individual project submission. If this project is useful, it may be condensed and published in a journal.

**What if something goes wrong?**

If you have a concern about any aspect of this study, you should ask to speak to the researcher who will do his best to answer your questions (see contact information provided). If you wish to complain, you should contact the supervisor named above in the first instance.

**Further information and contact details:**

*Researcher:*
Ben Lewis  
e-mail: benjamin.lewis-3@student.manchester.ac.uk  
mobile: +44 (0) 7956385643

*Supervisor Dr. Hollingsworth*  
e-mail: peter.hollingsworth@manchester.ac.uk
Appendix F  Project management

This section of the report details how the project was planned and managed. Initially the project management for the first semester work is discussed and following this, the Gantt chart for the final project is presented.

During the first month of the project, early research into flight simulation was carried out, particularly with a focus on flight simulation in university programmes and other educational settings and research was carried out into suitable flight simulation software. In the last two weeks of this first month, a development environment was set up and a development strategy was enacted to ensure the quality of the software development. Following this, research into the literature of flight simulation in university programmes and other education settings started to deliver many more results, due to the limited amount of research into this area, work can be hard to find, for example, there are no pre-existing literature reviews and different works often used different language to describe the same ideas. As such, the second month of literature review research delivered many more papers and the first draft of the review was drawn up. The discovery of literary papers towards the end of the six week period allocated for research of the literature review did not, however, result in significant delays, this was because greater time was devoted to researching and beginning software development during the earlier weeks. However, this did lead to some research not being included in the literature review by the deadline for the Interim Report. This research was added in the second semester. The status of the project history and plan at the end of semester one is shown in a Gantt chart that can be found in Figure 13.

The second semester led to many changes to the plan. Specifically, due to such a small number of students volunteering, it was ascertained that further lessons and testing was a lower priority than development of additional enabling functionality, such as logging of flight simulator variables. The final project plan, as it occurred, is shown in the Gantt chart in Figure 14.
Figure 13: Gantt chart produced during first semester
Figure 14: Final project Gantt chart