LEARNING AIRCRAFT DESIGN AND FLIGHT CONTROL SYSTEM DESIGN USING FLIGHT SIMULATION AS A CDIO CONDUIT

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ABSTRACT

Flight stability and control system design are problematic areas for teaching and learning in most tertiary institutions because of limitations in implementation and operation opportunities. Implementation and operation is a critical element of student learning because of the need for students to understand the relationship between design procedures and decisions, and their consequences in flight operation. Motion based flight simulation is a very effective mechanism for students to experience the transient responses and stability of a flight control system in flight, and to relate these back to the design process to reinforce learning. This paper describes how a motion based flight simulation facility has been integrated into a flight control system design course in a way that makes use of the CDIO principles. Students conceive and design a flight control solution for a given aeroplane, and then are able to embed that solution in the simulator and to operate the autopilot so as to experience the dynamics of their solution through the subsequent vestibular and visual stimuli. The paper also addresses how this concept is being expanded into a more thorough implementation in which courses in aircraft design, flight mechanics, and aerodynamics are being unified in a CDIO structure, with flight simulation providing keystone learning opportunities.

KEYWORDS

Flight Simulation, Experiential Learning, Control System Design, Autopilot, Aircraft Design.

INTRODUCTION

The training of student engineers was historically very practically based and trainers were typically industrial practitioners. In more recent decades this profile has changed somewhat with trainers in academic institutions becoming more research orientated. Training of undergraduate engineers has become far more theoretically based with less focus on practical training elements. There is recognition that the preparation of student engineers for industrial postings needs to be more problem based and experientially orientated. In fact a common complaint from employers of control engineers is that students need more laboratory and hands-on experience. Kheir, Astrom et. al. [1] outline the importance of practical experience in learning control systems engineering. They primarily address control engineering in mechatronics, manufacturing, process and electrical engineering applications, though the issues are generic to all disciplines. They particularly stress the pedagogical benefits of experimentation, logic and sequencing training, CAD and the use of simulation as a means of making experimentation more accessible and affordable. Experiential learning through simulated practical exercises appears to be a key element in future engineering education.

In aeronautics in particular, there is a critical teaching gap between theory and practice as many of the concepts taught that relate to the operational significance of design, dynamics and control considerations are difficult to demonstrate to students due to limited access to flight demonstration capability. This is particularly true of smaller aeronautics departments that don't have ready and direct access to a fleet of different aircraft and flight test facilities. For small departments the limitations are imposed by the enormous cost of operating such facilities. In order to address these limitations, a number of institutions have been developing flight simulation capabilities as a cost effective and flexible means of providing virtual practical facilities to enhance engineering training. This sort of facility lends itself to implementation of teaching and learning initiatives that facilitate not only design exercises, but permit the once elusive implementation and operation stages to be integrated into the learning process. They therefore fit nicely into the CDIO teaching strategy.

The CDIO philosophy has instigated a resurgence in practical learning in the engineering academic arena. Its focus on the design process, taking a concept from inception through design all the way to the implementation and operation stages, is an excellent way of fusing the development of generic and discipline specific skills with learning of the operational significance of design decisions and considerations required to make the concept work. The realisation of a working system has a far greater impact on a student's motivation and learning than the disconnected theoretically orientated study of separate disciplines in isolation.

MOTION BASED FLIGHT SIMULATION IN ENGINEERING TRAINING

Historically, flight simulation commenced as a means for pilot training. It is only recently that they have been used for engineering training in an academic environment. Many of these developments address the teaching of handling qualities [2,3,4]. Some have been developed to address the teaching of flight control systems [5,6,7], though most do not involve motion and thus miss out on the important element of vestibular feedback. It is important to note that in these initiatives, the focus is on the learning of engineering concepts and how they relate to flight operations, and not on pilot training.

At the University of Sydney, the School of Aerospace, Mechanical and Mechatronic Engineering provide students with a number of hours of basic pilot training as a separate supplement to their studies. The purpose is to familiarise them with the skills, operational requirements and pressures of flying and aircraft. Simulation exercises are intended to then focus on the importance of the engineering training with this basic flying experience providing a fundamental contextual reference. The first implementation involved experiential learning of aircraft handling qualities by Variable stability Flight Simulation [8]. This initiative was introduced as an experiential learning to supplement to a 3rd year Unit of Study (UoS) called AERO3560 Flight Mechanics 1, in which students undertake thorough learning of flight stability, manoeuvrability and handling qualities. This simulation exercise is used to build upon their flight experience in a single very stable light aircraft by demonstrating the changes in stability and handling qualities that are associated with variations in key aerodynamic (design) parameters (something they cannot observe in a real aircraft). It also allows quick and economically efficient demonstration of the differences in handling qualities exhibited by a range of aircraft types (e.g. light aircraft, transport, training aircraft, fighter etc). The Variable Stability Flight Simulator is depicted in Figure 1 and Figure 2.

Figure 1: Variable Stability Flight Simulator

Figure 2: VSFS Cockpit Learning Environment

A subsequent flight simulation implementation has been introduced into a follow-up UoS AERO4560 Flight Mechanics 2, for experiential learning of flight control system design [9]. This implementation, being in a design based course, is a CDIO based strategy. It is the subject of this paper and is described in the next section. Both of these implementations have been assessed by before and after survey methods for their effectiveness in aiding learning of the key engineering concepts at hand. In each case it has been found that instantaneous knowledge improvements of between 12 and 20% have been achieved via the simulation exercises [8,9].

These achievements motivated a more broadly based CDIO integration into coursework where aircraft configuration design units of study are tightly coupled with units on flight mechanics and component design. In this framework the same flight simulation exercises take on more important learning consequences as they are then providing students with first-hand experience of how their own design products and procedures stand up to requirements, and are a strong provider of experiential and reflective learning experiences. The expansion of the 3rd and 4th year Aeronautical Engineering curriculum to a fully CDIO based structure is also described in this paper. This new structure incorporates links and interactions between students in various 3rd year UoS with the 4th year students in a capstone course involving aircraft configuration design. The Flight Mechanics UoS and flight simulation laboratories are keystone experiential exercises fully integrated into this strategy.

FLIGHT CONTROL SYSTEM DESIGN – CDIO IN A SINGLE UNIT OF STUDY

Outline

The course AERO4560 Flight Mechanics 2 is a final (4th) year unit of study in Aerospace Engineering and builds upon previously developed skills in flight stability and handling qualities developed in the core 3rd year course AERO3560 Flight Mechanics 1 [8]. AERO4560 treats the aircraft as a system and deals with a systematic analytical and design treatment for flight automation. Students study synergies between time and frequency domain representations of the aircraft's dynamics and study the response of an aircraft to control inputs, the response of the aircraft to stochastic inputs (wind gusts), and develop flight control systems to manage the flight path and to reject the effects of wind gusts on the aircraft's flight. The final component of the course is a major project involving the design, implementation and evaluation of stability augmentation and autopilot control systems. The flight simulator laboratory is then used to demonstrate the effects of well-designed, badly-designed and (if available), the student's own control design solutions. As part of the simulation exercise, the students are guided through a structured sequence of test points in which they fly the aircraft and engage the various controllers through the same control interfaces used by pilots. In this way they experience the transient performance characteristics of the closed-loop aircraft response to control system actuation and can connect these characteristics with their observations of their own controller performance from their analysis and design stages. This exercise has the secondary benefit of familiarising engineering students with the avionics equipment and processes used by operational pilots, thus they learn by first-hand experience the roles and functionality of the various cockpit instruments and avionics systems.

A typical major project statement involves the development of longitudinal control systems for the management of the dynamics and flight path in the vertical plane of a turboprop training aircraft. The aircraft model is chosen due to its agility, thus making the dynamics of the aircraft and control systems very observable for students. The goal is to modify the natural pitch characteristics and to control the vertical speed (climb rate) and altitude behaviour of the aircraft with a vertical speed autopilot, and to manage the airspeed with an auto-throttle. This is a multi-loop, MIMO (multi-input-multi-output) system (2 inputs and 2 outputs) with high order dynamics and non-minimum phase behaviour, and challenges students with very real analytical considerations and design decisions. The students design control loops and then analyse the performance of the controllers and the effects of wind gusts using CAD tools (MATLAB). Every second year the control task is alternated with an equivalent lateral-directional problem involving control of the aircraft in the roll and yaw axes using loops to control the bank angle and heading via the roll axis, while implementing a yaw damper to regulate the aircraft's behaviour about the yaw axis. For the purposes of illustration, the longitudinal problem is discussed in this paper.

The experiential learning exercise involves a session in the flight simulator in which students fly the aircraft and engage the autopilot and auto-throttle in order to study the transient behaviour and hence stability of the control solutions obtained. Two standard control solutions are provided, one 'good' controller and one 'bad' controller. These are used to highlight the ramifications of good and bad control design practice on the stability of the closed-loop aircraft behaviour. They are provided with design information that students can use to connect the flight results with particular features or flaws in design practice. If students have their own solutions available, they can be embedded in the simulator and flown so that students can reflect upon their design process after observation of the flight results (relative to the behaviour of the good and bad solutions).

Learning Components

The course develops the required system theory, analysis techniques and design tools and implements a hands-on methodology to learning. Table 1 details the core study elements of four assessable computationally based assignments. The first three progressively develop the analytical techniques and skills required to establish a foundation for the control design exercise addressed in the major design project. The table also indicates the relationship of each of these with the core CDIO attributes. The major design project builds upon the collective skills learned and aims to take students through a realistic scenario of system design representative of that which might be experienced in an aerospace system integration company or flight simulator development organisation. In this project the students conceive and design a multi-loop MIMO frequency domain stability augmentation and autopilot system consistent with typical industry solutions. They then consider implementation issues and embed their control solution in the VSFS and will operate their system solution (and others) as a pilot would. The experience can then be used to reflect upon their design decisions, process and analysis for consideration of how the system could be improved.

Table 1
Flight control design UoS: learning components and CDIO attributes

Learning activity	Topics	Objectives	CDIO attributes (see Table 1 in [10])
Assignment 1	Linear system representation, transfer function representation	To develop numerical approaches to linear representation of aircraft response to control inputs via transfer functions (TF's). To develop an understanding of the aircraft's response via the TF only.	2.1 Engineering reasoning and problem solving - 2.1.1 Problem identification and formulation, 2.1.2 Modeling
Assignment 2	Time domain-frequency domain equivalence, time domain response of TF's to specific control input forms, frequency response functions	To develop an understanding of the nature of the time domain response of an aircraft represented by a TF. Develop an in-depth understanding of the links between time and frequency domain representations. Bode plot representation of aircraft frequency response.	2.1 Engineering reasoning and problem solving - 2.1.1 Problem identification and formulation, 2.1.2 Modeling
Assignment 3	Aircraft response to stochastic inputs (wind gusts). Gust power spectral representations.	To develop an understanding of the stochastic nature of wind gusts and their representation via power spectral density (PSD). To develop an understanding of aircraft response to gust inputs. To use analytical statistical tools and representations to quantify an aircraft's response to typical gust sequences.	2.1 Engineering reasoning and problem solving - 2.1.2 Modeling, 2.1.3 Estimation and qualitative analysis, 2.1.4 Analysis with uncertainty
Major Design Project	Classical flight control system architectures. Loop analysis and closed loop stability evaluation. Development of multi-loop multi-input-multi-output (MIMO) autopilot system.	To use analytical and control design tools to design compensators for stability augmentation and autopilot functions. Analysis of closed-loop stability of autopilot designs and assessment of closed-loop sensitivity to wind gusts.	2.3 System thinking - 2.3.2 Emergence and interactions in systems, 2.3.4 Tradeoffs, judgement and balance of resolution 2.5 Professional skills and attitudes - 2.5.2 Professional Behaviour 3.1 Teamwork - 3.1.1 Forming effective teams, 3.1.2 Team operation, 3.1.4 Leadership 4.3 Conceiving and engineering systems - 4.3.2 Defining function, concept and architecture, 4.3.3 System modeling and meeting goals 4.4 Designing - 4.4.2 The design process, phasing and approaches, 4.4.3 Utilisation of knowledge in design, 4.4.4 Disciplinary design, 4.4.6 Multi-objective design
Simulation Laboratory	Operational characteristics of control system dynamic response and stability. Assessment of closed-loop transient response and sensitivity to gusts inputs.	Students operate the cockpit autopilot interface (Mode Control Panel (MCP)) and test the transient response of closed-loop system to autopilot tracking commands. They also assess closed-loop sensitivity to gusts. Students assess a well-designed control solution against a poor design and their own design.	4.5 Implementing – 4.5.1 Designing the implementation process, 4.5.3 Software implementation process, 4.5.5 Test, verification and validation 4.6 Operating – 4.6.2 Training and operations, 4.6.4 System improvement and evolution

Conceive

Students are confronted with a system in which there are two primary control loops with cross-coupling influences and gust disturbance inputs. A typical configuration is shown in Figure 3, (where u and Vs are the airspeed and climb rate, and δ_t and δ_e are the throttle setting and elevator displacements respectively). The students need to decide upon a loop structure and establish the dynamic system representations involved. They must establish the closed loop relationships and the stability and performance characteristics implied. They also need to conceive the most appropriate form for each of the control compensators in the system. The design stage then involves selection of the quantitative characteristics of these components.

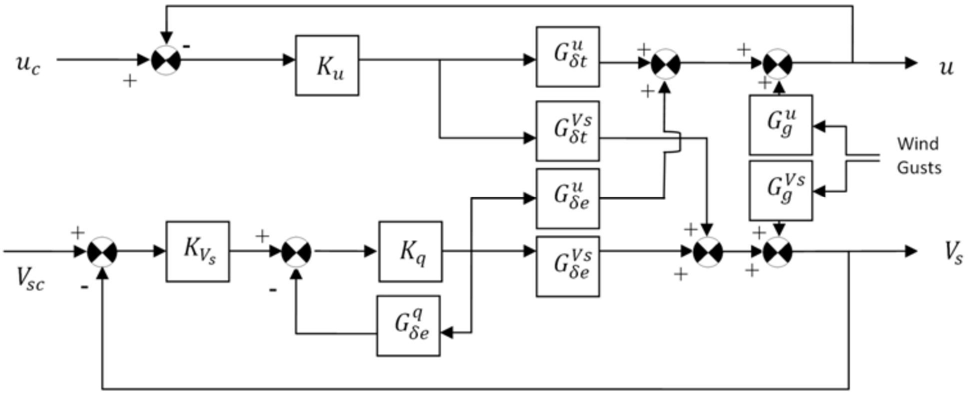

Figure 3: Typical system diagram

Design

Students use the Matlab Control Systems toolbox elements and apply Bode and root-locus design techniques to arrive at compensator design solutions to the problem given. They are expected to meet specifications regarding the transient performance, stability and steady-state tracking performance required. The control solutions are also required to meet certain specifications with regard to gust rejection properties using statistical analysis tools. These requirements are often conflicting and lead to design tradeoffs requiring the application of engineering judgement and intuition. Once their solutions are finalised, students implement them into their analytical nonlinear flight simulation scripts used for the design. This is a process of validation and verification to check that their controllers perform as predicted by the design tools and are robust to off-design conditions and gust disturbances.

Implement

Students study issues of real-time implementation of control system. These include sensing issues of noise and signal conditioning, the implications of discrete time-step on closed loop stability, and time domain implementation of frequency domain compensator designs. Students are given the real-time simulation parameters for the simulator to test with their solutions prior to implementation. They present their solutions in a prescribed format to comply with requirements of the simulator software system. Given that their control solutions are to be embedded in a flight simulator and will be driving a hydraulically actuated motion base, there are issues of occupational health and safety to consider. Each solution is therefore thoroughly checked off-line in an independent simulation environment by staff for stability and performance prior to implementation in the flight simulator so as to verify its safe operation. It is also tested in the simulator with the motion base disabled prior to operation with motion. Once these tests are passed the solutions are integrated into the simulator and made available for operation in the demonstration sessions.

Operate

The simulation session procedure is outlined in a guideline document provided to students in advance so they can familiarise themselves with the procedure as well as the equipment. The session involves a number of scenarios involving the independent operations of the vertical speed autopilot and the auto-throttle, as well as their operation in conjunction. Table 2 details these scenarios and their purposes. The session involves running through this sequence of scenarios four times:

1. At the design condition, e.g. 150Kn at 500ft, with well-designed controllers,
2. At the design condition with badly-designed controllers,
3. At the off-design condition, e.g. 90Kn at 500ft, with well-designed controllers,
4. At the off-design condition with badly-designed controllers.

giving a total of 24 test points.

Note: Test point pairs 1 and 2, or 3 and 4 will be replaced with student's control solution if it is available in the interests of maintaining schedule. The choice is dependent upon a pre-evaluation of stability and effectiveness of the student's solution as to whether it better demonstrates the characteristics of the standard 'good' or 'bad' control solution.

Table 2
Flight Simulation Scenarios

Test Point	Scenario	Purpose
1	Open Loop.	To establish a steady flight condition and a feel for the aircraft's response to the pilot.
2	Vertical Speed mode and Auto-throttle engagement – steady state.	To establish nominal autopilot performance and to hold a steady flight condition.
3	Vertical Speed mode engagement, climb at 1000 ft/min (without Auto-throttle) – no airspeed management.	To observe the transient performance of the vertical speed autopilot. To observe cross-coupling with the airspeed response. Airspeed will not be maintained.
4	Vertical Speed mode engagement with Auto-throttle, climb at 1000 ft/min – constant airspeed climb.	To observe the transient performance of the vertical speed autopilot and auto-throttle. To observe cross-coupling with the airspeed response. Airspeed will be maintained at nominal airspeed after transient response settles.
5	Vertical Speed mode engagement (0 ft/min) with Auto-throttle – level flight acceleration, increase airspeed by 30Kn.	To observe that with the vertical speed autopilot engaged, the airspeed is managed with auto-throttle. Observe performance of the vertical speed autopilot in maintaining level flight as airspeed changes. Observe airspeed transient response. Observe cross-coupling.
6	Auto-throttle engagement (without Vertical Speed autopilot)– level flight acceleration, increase airspeed by 30Kn.	To observe that with no vertical speed autopilot engaged, the auto-throttle will not manage airspeed due to the aircraft's natural flight stability.

The standard control solutions are designed specifically for the dynamics that the aircraft exhibits at a given flight condition – in this case 150Kn airspeed at 500 ft altitude. One of the major issues with control design is the robustness of controllers to variations in the operating point. Thus the performance of each of the controllers is demonstrated at an off-design condition (in this case 90Kn airspeed at the same altitude) to highlight the robustness (or lack thereof) of the design solutions. This is observed by the student through the inadequacy of the transient behaviour of the controllers, via sensory feedback.

For each scenario, students are given instructions in a guideline document on how to operate the equipment (also delivered verbally by the instructor during the sessions). An example sequence is given in Table 3 for Scenario 4. The instructions pertain to the operation of the control system through the Autopilot Mode Control Panel (MCP) interface shown in Figure 4. They then observe the subsequent transient response through vestibular feedback from the motion, through visual feedback from the outside world display, and through the highlighted instrument readings on the instrument panel shown in Figure 5. The effect of the auto-throttle is also sensed through audio feedback of engine RPM.

At the conclusion of the simulation session, design documents are made available regarding the design of the good and bad control solutions for students to use for comparison to their own design procedure as a means of reflective reinforcement learning.

Table 3
Typical instruction sequence for flight simulation exercise

Scenario 4: Closed Loop – Vertical Speed mode engagement with Auto-throttle – constant airspeed climb	
Instruction	
1	Set 1000 ft/min in the V/S command window using the thumbwheel.
2	Sim will be started. Engage the vertical speed autopilot by lifting the ‘DISENGAGE’ bar, pressing an autopilot button (L will suffice) and then press the V/S button.
3	Engage Auto-throttle as quickly as possible as too much airspeed loss will be difficult to recover. Engage the auto-throttle by lifting the ‘A/T ARM’ toggle switch and by pressing the ‘SPD’ button on the MCP panel. Observe the airspeed to settle at 150Kn.
4	The aircraft will enter a climb. Check for any enduring steady-state error in Indicated Airspeed (IAS) or Vertical Speed (V/S). Take note of the transient behaviour of the V/S needle in reaching 1000ft/min – speed of response, amount of overshoot.
5	Observe the airspeed response – the aircraft will initially lose speed as the thrust increases but it will recover to 150Kn. Note rate of speed loss and amount of overshoot as it reaches the target IAS.
6	Sim will be put on hold (re-set initial condition). Disengage the autopilot by lowering the ‘DISENGAGE’ bar and switching off the ‘A/T ARM’ toggle (down).

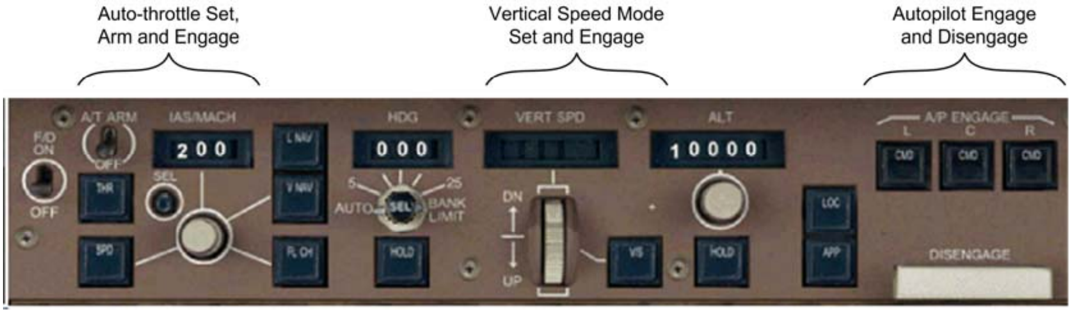

Figure 4: Autopilot Mode Control Panel (MCP)

CDIO-CENTRIC CURRICULUM (RE)STRUCTURE

In order to expand the CDIO-based experiential learning experience in the aerospace engineering education stream at The University of Sydney, the curriculum has recently been restructured. The revised curriculum, which will be implemented from the next academic year onwards, aims for a tighter integration of the various aeronautical units of study to reinforce the links between the different disciplines and to enhance the understanding of the intrinsic tight coupling of all disciplines in the conception, design, implementation and operation of aircraft. Figure 6 schematically represents the links between several units of study in the revised curriculum. The arrows on the figure indicate the flow of knowledge, learning experiences and specifications for the combined design exercises.

Figure 5: Typical instrument panel showing airspeed, vertical speed, altitude and direction indicating instruments

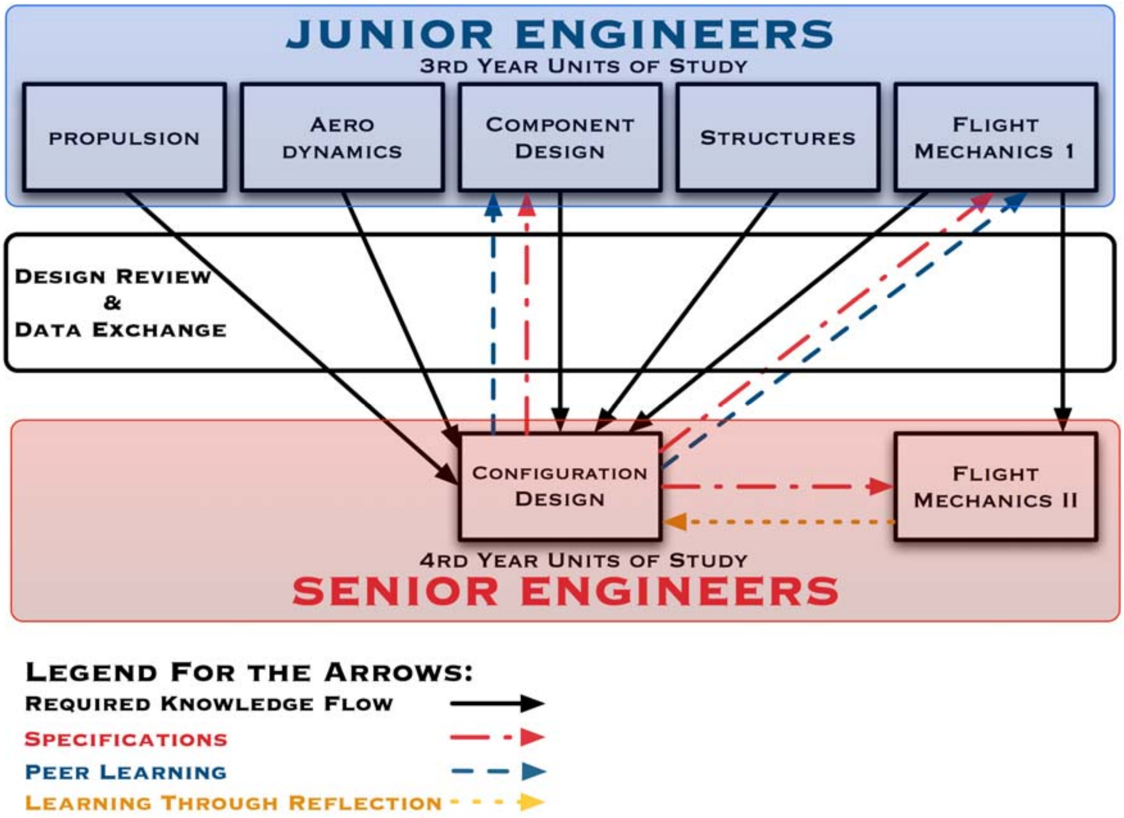

Figure 6: Flow chart of the “junior/senior” units of study in the revised curriculum

As shown on Figure 6, some of the third and fourth year units of study are organised as a junior/senior engineering experience to better match the university environment with the future work environment of our students. Due to practical and semester limitations, several of the third year units of study only serve the traditional role of providing required knowledge (indicated by the black arrows on Figure 6). A much closer interaction has however been set up between the third year component design and flight mechanics unit of study and the fourth year capstone configuration design and flight mechanics units of study.

During their capstone design project, the “senior” engineers outsource the design and analysis of some aspects of their aircraft to the “junior” engineering component design teams by providing them with the detailed specifications that are required for the particular analysis (as indicated by the red arrows on Figure 6). In order to better understand the specific nature of the process, a short description of the contents and procedures of the design units of study involved in the close collaboration is given in the next subsection. A very succinct overview of some of the other prerequisite courses is given too. The details of the specifications exchange are then given in the following subsection.

Unit of study descriptions

The third year propulsion unit of study (AERO3261 – Aerospace Propulsion) provides the students with an overview of the different types of engines used on aerospace vehicles. Students are introduced to the performance of turbojet, -prop and –fan as well as rocket engines. The aerodynamics unit of study (AERO3260–Aerodynamics 1) covers both 2D and 3D subsonic aerodynamics as well as airfoil theory. Two other third year units of study are considered prerequisites for the capstone design course. In Aerospace Structures 1 (AERO3360), students are taught stress, strain, and displacement relationships for thin walled beams as well as shear panels, ribs and cut-outs. Bending and torsion effects are covered and energy methods are introduced. The Aerospace Technology 2 unit of study (AERO3465) on the other hand covers fatigue and damage tolerance of shear flow dominated structures. The students design a wing box structure for a given load set under tight weight constraints. The wing box is designed, built and tested to destruction, which allows a comparison between the calculated and the actual load carrying capability.

The third year component design unit of study (AERO 3460–Aerospace Design 1) introduces the students to practical detailed design projects of non shear stress dominated structural components. Throughout the course the students work on 3 major design problems of varying degrees of complexity. For the first assignment/design project of the unit of study, the students need to investigate the structural integrity of a camera mount and design the attachment fittings of the different components of the mount. The mount consists of a steel boom held in place with two aluminium struts, mounted on the roof of the cockpit. In a follow-up assignment students are asked to identify more suitable materials for the boom and the struts. In a second project, the complexity of the component is increased and detailed load cases for an engine mount of a motored glider. The mount is designed and analysed completely and a simple mock-up is built out of straws to assess the functionality of the design. The third design project of the course consists of a specific component of one of the fourth year configuration design projects as detailed in the next subsection.

The fourth year configuration design unit of study (AERO 4460–Aerospace Design 2) is set up as a completed aircraft design competition for student design teams consisting of 5 to 6 members. As in most capstone design courses a request for proposal (RFP) is provided to the students and each of the teams creates a unique aircraft design that meets or exceeds all of the requirements of the RFP in a competitive environment. The RFP is intentionally set up so that creative designs are needed to be able to meet the specified requirements boosting the students to think “outside the box”. During the course of the unit of study there are 3 major decision gates that are intended to represent industry design practices. After roughly a third of the semester, a preliminary design review is organised where each of the teams present their configuration/concept, the main innovative aspects of their approach and how these help them meet the requirements of the RFP. At the two-thirds mark, an intermediate design review is set in place where design details are presented for some of the major components. Finally, at the end of semester, a critical design review is held. At this point each team presents their final design to peers, faculty, and industry guests. Each of the reviews serves multiple purposes. First of all they stand as milestones for the project development. They furthermore allow students to gain experience with professional public speaking and finally force students to defend their work against criticism. At each review milestone the teams hand in a report and give a presentation.

Specification exchange between the units of study

As indicated previously and as shown on Figure 6, some of the detailed analysis work of the senior capstone design project is outsourced to the junior teams. This setup provides several mechanisms to engage in deeper learning and reinforces the strong focus on both experiential learning and CDIO in the aeronautical engineering education stream at The University of Sydney. It furthermore leads to a much closer resemblance between the university environment and the future industry environment our graduates will work in. Not only will they be experienced in the industry practise of junior and senior engineers, the students are also exposed to the procedure of outsourcing and delegating work to subordinate design teams or external contractors, which is common practise in the current highly specialised and global aerospace industry. Finally, the students are also trained in writing out detailed specifications for other teams.

The primary aim of the closer integration of different units of study is to enhance learning by offering several opportunities to promote the so-called deep learning approach. As the fourth year students guide the third year students throughout their work on the outsourced components, a significant amount of peer learning is embedded in the process. This process works both ways, as the third years will also question the choices that lead to the particular configuration of the aircraft they are analysing and designing components for in order to understand the nature and details of the specifications provided to them. This will serve as an additional review in the capstone design unit of study and will force the fourth years to justify their selection and hence promote reflection. Finally, as the fourth year students use the aerodynamic parameters of their own aircraft from the capstone design unit of study to develop a stability augmentation system and autopilot in the final assignment of Flight Mechanics 2, a mechanism of reflection is introduced between the two units of study.

The specifications that are passed between the senior and junior team require a substantial amount of detail to allow the junior teams to work out their component design or stability analysis respectively. The senior team who writes out the specifications is as such responsible for providing all the required information in a suitable format. The specifications that are passed on to the groups for the component design course consist of geometrical details of the different mounting points of the structure to be analysed as well as all the load cases that need to be considered to comply with the appropriate Federal Airworthiness Requirements (FARs). Examples of structures that are analysed by the juniors are struts for a high wing strut braced general aviation aircraft or cantilevered spring type main landing gear. For the data exchange with the flight mechanics unit of study, senior students provide all the aerodynamic and inertial parameters for a critical condition in the flight envelope.

Additional CDIO opportunities in the revised curriculum

Figure 7 illustrates the functional interactions between the primary units of study in design and flight mechanics. It highlights the key areas in which the Conceive, Design, Implement and Operate functions are distributed amongst the units of study. It also summarises the nature of the key design data that are created and how they are exchanged and implemented in this scheme. When the different component specifications are exchanged between the third and fourth year students, the third year students are exposed to the conception and development phases of the capstone design course before they implement and operate their own part of the particular design. The interactions with both the third and fourth year flight mechanics units of study allow both student groups to implement and operate the aircraft they have worked on and fly it real time in the VSFS. These interactions between fourth and third year groups take on the added feature of providing a forum for students to be subjected to realistic design specification/review processes typical of industry practice.

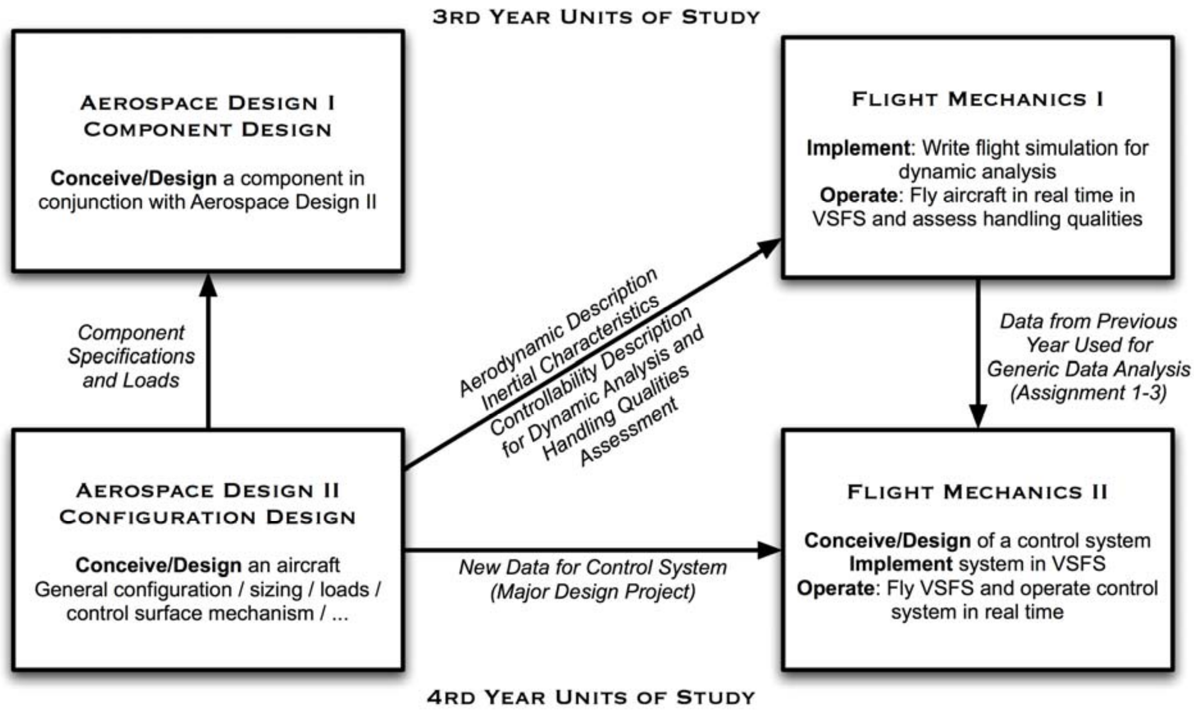

Figure 7: CDIO implementation in the design and flight mechanics units of study

CONCLUSION

A deeply embedded CDIO application has been established in which motion based flight simulation provides a real-time implementation and operation conduit for a capstone course in flight mechanics. The course involves the use of a specified aircraft's aerodynamic, inertial and controllability description to conceive and design stability augmentation and autopilot control systems for that aircraft. The resulting systems are implemented in the simulator and operated in real-time by the students as a means of reinforcement learning. It has been found that this immersive environment with a full complement of sensory feedback mechanisms is very effective in enhancing learning of the key concepts involved.

Building upon the success of this initiative, a broad based course curriculum has been formulated in which Aircraft Design units of study are tightly coupled with units in Flight Mechanics. The basic disciplinary content of junior units involving propulsion, aerodynamics and aircraft structures feeds into the capstone unit involving aircraft configuration design. The senior students conceive a complete aircraft configuration and specify component parts of their design to students in a junior unit of aircraft component design and facilitate a mechanism for design groups to undertake design review roles that closely mimic those frequented by aerospace engineering contractors. The senior students assess the aerodynamic characteristics of their aircraft and use this description as the basis for their own autopilot design in their capstone Flight Mechanics unit of study. By this means students can undertake the complete design of a new aircraft configuration, including designing it for acceptable handling qualities and designing its flight control system. They are able to implement the aircraft dynamics for flight in real-time in the simulator with a full range of sensory feedback mechanisms to reinforce the learning. This key element of operation completes the learning loop and provides a strong link for reflective re-assessment and re-evaluation of their design experiences

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