Work in Progress: Feedback Reinforcement of Classroom Learning of Aerospace Design and Performance Concepts Through a Hands-on Design-Build-Fly-Redesign Loop

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Feedback reinforcement of classroom learning of aerospace design and performance concepts through a hands-on design-build-fly-redesign loop – work in progress

Introduction

This is a work in progress, and consequently, various aspects of this approach, including the statistical evaluation of its efficacy need further investigation. The author intend this investigation to continue over a longer period of time and plan to incorporate the findings in subsequent papers and presentations.

In recent years, the use of Unmanned Aerial Systems (UAS) has seen an explosive growth and has shown promise for even more, thanks to the drop in cost of the airframe and associated avionics. Furthermore, the release of Part 107 UAS rules in 2016 and the easing of restrictions on commercial UAS operations by the Federal Aviation Administration (FAA) have resulted in a new landscape for novel and yet to be conceived UAS applications and operations in the National Airspace System (NAS) and it will only grow more diverse in the future.

As it stands today, while major aerospace corporations are still a significant part of this UAS landscape, small businesses and startups drive most of the growth, with novel applications and commercial operations. In this relatively uncharted landscape of UAS operations in the NAS, there is significant competition among UAS designers, manufacturers and end users in coming up with new and novel UAS designs and operations. As with other industries, it is natural to expect that the invisible hand of the market, as well as evolution by natural selection will shape the future of UAS designs and operations – and in a few years, it will result in a small, but proven and well-established set of UAS designs that are used for most of the UAS operations.

Thus, it is not beyond the realm of possibility that during this initial phase, there will be a demand from the industry for aerospace engineers who are capable of designing, building, testing and analyzing the performance of UAS platforms from the ground up, purely from specifications and/or requirements. On the other hand, as time passes, and the designs converge to a small set of proven UAS platforms, the demand for graduates from a multitude of disciplines, including aerospace engineering, sciences and others, *capable of leveraging these UAS platforms* to perform a given goal/mission is only going to grow.

In this setting, it becomes imperative for aerospace engineering departments at institutions of higher education to adapt to meet the demands of this rapidly evolving industry by incorporating flexibility into their curriculum. Towards that, the curriculum should have a

> ***Goal*** *- to incorporate into classes, methodologies that encourage learning and help retain a deep, long term conceptual understanding of the subject material.*

Objective

As it currently stands, on one hand, the wish to provide a broad and well-rounded education for our students and to develop "*the whole person*" leaves little room in a typical aerospace undergraduate core curriculum of most academic programs to provide a comprehensive, multi-disciplinary experience and educate "*the whole engineer*". On the other hand, participation in UAS design/flight test competitions and going up against their peers from other institutions provides a great opportunity for students to express their creativity while applying the knowledge gained in the classroom, without the traditional expectations and pressures of making the "*grade*"; this is an underutilized avenue that has significant potential to provide reinforcement of classroom learning, as well as insights that could be used in classroom lectures. Based on this premise, within the framework of this current effort, the author has the following objectives:

i. *Identify and evaluate methodologies that reinforce undergraduate in-class learning experience in the lifecycle of a systems engineering based Student Unmanned Aerial System (SUAS) competition, particularly as it pertains to concepts of aircraft dynamics, stability and control. Note: This should by no means be interpreted to mean that traditional topics in an aerospace curriculum such as those related to space systems or robotics will/should be ignored.*
ii. *Identify pedagogical methodologies that are not as effective; this can then be incorporated within the "feedback" loop (shown in Figure 3) to be re-evaluated and reframed.*
iii. *Over a longer term, determine how findings from this effort could be applied to other core aerospace engineering courses such as aerodynamics, propulsion and structures to identify pedagogical methods that can be adapted within the scope of those classes.*

Methodology

When it comes to aircraft based competitions, annual events such as the American Institute of Aeronautics and Astronautics (AIAA) sponsored Design, Build, Fly (DBF) competition, the Society of Automotive Engineers (SAE) sponsored AeroDesign competitions, as well as the Association for Unmanned Vehicle Systems International (AUVSI) sponsored Student Unmanned Aerial Systems (SUAS) competitions are ideal outlets for students to complement their classroom knowledge with hands-on experimental experience towards an

> ***Educational outcome*** *- where students develop a deeper understanding of the interconnections and importance of class material, covered over their undergraduate career, as it pertains to achieving a specific goal – in this case, a stable and robust aircraft that reliably achieves an overall mission.*

Prior experience, as discussed by Phillips et. al. in [1] has shown that these competitions also generate and foster important secondary channels of learning, through interaction with peers at other institutions exposed to different pedagogies. Among the competitions, AUVSI's SUAS competition is unique in that it is designed to be a multi-disciplinary "*systems design*" competition – teams are required to execute complex mission scenarios such as aerial photography, target recognition, geo-tagging, geo-referencing, obstacle avoidance and others.

The most important requirement to succeed in the competition is that the UAS platform that is designed and fabricated be stable, rugged and reliable as well as be capable of carrying the requisite payload (imaging, processing and radio communication), for the duration of the mission. In order to design a UAS platform satisfying these requirements, students have to leverage their knowledge from classes on structures, propulsion, aircraft stability and control and other classes, as well as their extra-curricular, hands on skills to fabricate the platform. The current curricular structure for students majoring in aerospace engineering at Saint Louis University is shown in Figure 2 (only the Junior and Senior years are shown). As can be seen in Figure 2, students are introduced to aircraft dynamics, stability and control (highlighted in Blue) in the first semester of their senior year, with the pre-requisite/co-requisite class on automatic controls (highlighted in Orange) in the spring semester of junior year and its pre-requisite class on linear vibrations (highlighted in Green) in the fall semester of junior year. This triad of classes forms a critical learning arc, wherein the concepts covered in Linear Vibrations form the basis of material covered in Automatic Controls, which are then applied to particular dynamic system (aircraft) in Stability and Control.

As the class on stability and control progresses, a linear representation of aircraft dynamics is developed and it is shown that the longitudinal dynamics of an aircraft is 2nd order in nature and the lateral direction dynamics is 3rd order in nature. At this time, the students are well aware of the nature of stable 1st and 2nd order dynamics – from the class on automatic controls and the class on vibrations and are able to identify that a 2nd order under-damped system is represented by the following characteristic equation [2].

$$s^2 + 2\zeta\omega_n s + \omega_n^2 \qquad \text{Eq. 1}$$

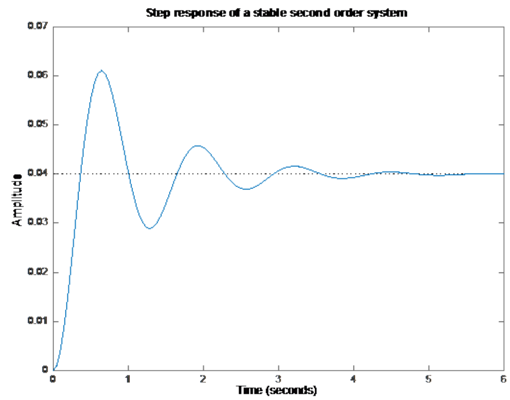

Figure 1: Generic response of a stable second order under-damped dynamic system, such as the short period dynamics of a stable aircraft

and that stable dynamics exhibit the form shown in Figure 2. Also, from the form of the response of a generic 2nd order system, they can determine its natural frequency (ω_n) and damping ratio (ζ). Once they are exposed to the class material on aircraft dynamics, the students will then be able to associate this performance of a dynamic system with the longitudinal dynamics of the aircraft. For example, with respect to the short period longitudinal dynamics of an aircraft, the characteristic equation [3] is given by

$$s^2 - \left(M_{\dot{\alpha}} + M_q + \frac{Z_\alpha}{U_1}\right)s + \left(\frac{Z_\alpha M_q}{U_1} - M_\alpha\right) \qquad \text{Eq. 2}$$

in the same form as Eq. 1, which leads to the expressions for the natural frequency and damping ratio of short period dynamics to be approximated by Eq. 3 and Eq. 4, wherein the terms $M_{\dot{\alpha}}, M_q, Z_\alpha, M_\alpha$ are called the dimensional derivatives.

$$\omega_n = \sqrt{\frac{Z_\alpha M_q}{U_1} - M_\alpha} \qquad \text{Eq. 3} \qquad \zeta = \frac{-\left(M_{\dot{\alpha}} + M_q + \frac{Z_\alpha}{U_1}\right)}{2 * \sqrt{\frac{Z_\alpha M_q}{U_1} - M_\alpha}} \qquad \text{Eq. 4}$$

These equations represent a direct tie in with aircraft design choices that were made and variations introduced during the fabrication process. For instance, in the above equations the derivative M_α given by Eq. 5.

$$M_\alpha = \sqrt{\frac{c_{m_\alpha}\bar{q}_1 S\bar{c}}{I_{YY}}} \qquad \text{Eq. 5}$$

is a function of a number of design parameters including:

i. the size of wing, affecting the surface area S and mean aerodynamic chord $\bar{c}$
ii. the choice of wing airfoil, affecting the pitching moment coefficient c_{L_α}
iii. the length of the fuselage, affecting the pitching moment coefficient c_{m_α}
iv. the size and choice of the tail airfoil, affecting the pitching moment coefficient c_{m_α}
v. the weight and its distribution, affecting the moment of inertia, I_{YY}

A similar association can be made between the lateral-directional dynamics of the aircraft and the design choices in the sizing of the vertical tail surfaces of the UAS, their location and the distribution of the weight during fabrication. By applying the knowledge gained from the class on aircraft dynamics, stability and control, students can predict how their choices affect the performance of the UAS they designed and conduct a sensitivity analysis to determine which of their design choices would affect the performance of their platform the most. By observing and analyzing the performance of the UAS through data from flight tests, and correlating it to the subject material encountered during this arc of classes (linear vibrations, automatic controls and aircraft stability and control), the underlying learning is reinforced, and can serve as a viable path to a redesign/revalidation of their UAS platforms.

Assessment: This effort is a work in progress, and the author anticipate to continuously assess the efficacy of classroom teaching and learning in the three courses through well-spaced surveys, and regular classroom assessment (quizzes and tests). The author intends this to be a long term study, covering multiple cohorts of students and anticipate that over a period of years, sufficient data would be generated, from which trends in student learning could be extracted. The planned assessment methodologies include the following:

i. The fact that only a small portion of students in each cohort participate in UAS competitions, could be advantageous in testing the hypothesis stated in this study by naturally generating two groups of students to test against each other in terms of retaining information and knowledge - students participating in the competitions and those who do not.
ii. A statistics based assessment methodology using exit surveys and/or questionnaires, potentially including voluntary information about their performance in the triad of classes.
iii. The surveys will be based on established assessment techniques [4] and tailored to gather as much information as possible regarding the avenues of learning the participants used – classroom, peer-peer in the same institution, peer-to-peer learning from outside the institution. Additionally, surveys will also incorporate questions designed to assess the effectiveness of the "*hands-on*" experimental work, such as "*what is your observation on the sensitivity of precise fabrication techniques on the dynamic stability and performance of the SUAS*".
iv. This self-assessment will be validated across quantitative performance measures of the students in the class (through tests) as well as the performance of the SUAS in meeting the stated goals, as well as the assessment of the class against the stated ABET goals [4].

Results

Based on an informal survey of 6 students participating in the 2015-16 AUVSI SUAS competition cycle, and on a review by the author, the following observations were made:

What worked?

i. In the classroom: The systematic approach to the development of a mathematical model of an aircraft was received quite well by the students and helped in predicting/analyzing the stability and dynamic performance of their aircraft designs.
ii. Hands-on experience: Fabrication and flight test evaluation of the UAS design was perhaps the most valuable lesson that the student team gained; at this scale, few finished products turn out in line with designs and projections. The team encountered this apparent discrepancy at various stages following the initial design, including component weight during fabrication, as well as the final weight of the finished aircraft, which was about 30% more than the design specification, affecting its dynamic performance. <u>Lesson Learned</u>: Analysis of aircraft designs need to account for potential variations in parameters during the fabrication/repair process to still be able to satisfy design and performance requirements.

iii. A systematic approach to flight testing activities. The team was able to plan each flight experiment, and maximize the returns during time the aircraft was in the air by piggybacking additional experiments. This involved high level coordination between sub-groups, working on various tasks towards the overall mission of autonomous UAS flights for specific missions.

What did not work?

i. Following initial flight tests, *ad hoc* solutions were adopted to try and improve the dynamic performance of the UAS – without the benefit of detailed analysis; the result was a crash and a total loss of the UAS. Lesson learned: reliable tools for simulation and validation of aircraft dynamics, using data from flight tests (for example, using pilot inputs in a playback simulator, to validate flight performance) could be developed as in class modules in the senior level class on stability and control.

Conclusion

This is a work in progress, and the evaluation aspects of this work need further investigation. A conceptual representation of the "*Feedback reinforcement of classroom learning of Aerospace design and performance concepts through a hands-on design-build-fly-redesign loop*" approach is shown in Figure 2.

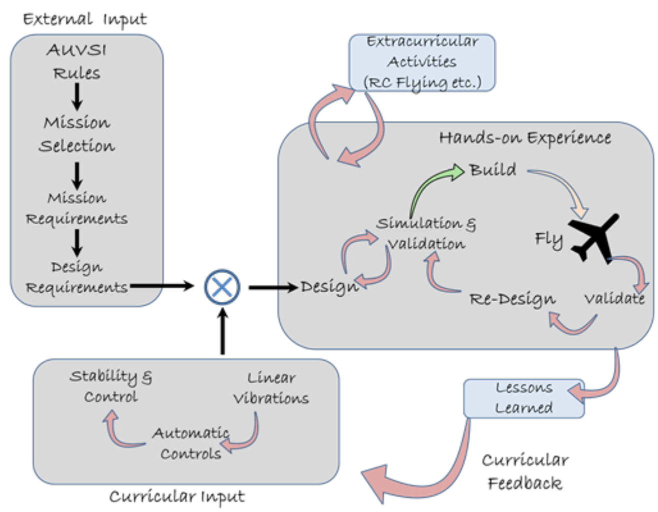

Figure 2: Conceptual representation of a "*Feedback reinforcement of classroom learning of Aerospace design and performance concepts through a hands-on design-build-fly-redesign loop*" approach

At this stage, the author has informal and anecdotal evidence of the usefulness of the hands-on experience in reinforcing classroom learning in the context of a flight dynamics, stability and controls class. During the upcoming fall semester, (fall 2017), when the course on aircraft dynamics, stability and control is scheduled to be taught and the next cycle of the AUVSI's SUAS competition begins, the author intends to include formal surveys (beginning of class, mid-semester, end of the semester and end of the competition in summer) and short, in-class assessments (such as quizzes). This will provide data at various stages of the classroom learning process. In the longer term, it is the author's vision that the mix of classroom and hands on experience pedagogical methodologies that help with the learning and retention of information, as identified through this effort could be tightly integrated into core classes of a typical aerospace curriculum, by other instructors. This could include the use of short experimental modules that immediately complement the introduction of the theoretical background, with minimal modifications to the curriculum.

Considering that this effort is a work in progress, it is reasonable to expect that the efficient implementation of this approach will take more than one academic cycle.

Junior Year					
Fall Semester			**Spring Semester**		
Course Num.	**Course Title**	**Hrs.**	**Course Num.**	**Course Title**	**Hrs.**
AENG 3000	**PERFORMANCE** (p-AENG 2000)	3	AENG 3210	GAS DYNAMICS (p-ESCI 2300, p - ESCI 3200, cc- MATH 3270)	3
ECE 2001	ELECTRICAL ENGR (p-MATH 1520, p-PHYS 1610)	3	AENG 3220	AERODYNAMICS (p-ESCI 3200, cc- MATH 3270)	3
ECE 2002	ELECTRICAL ENGR LAB (c-ECE 2001)	1	AENG 3150	ASTRODYNAMICS (p-AENG 2000, p-ESCI 2150)	3
ESCI 3100	MECH OF SOLIDS (p-ESCI 2100, cc-MATH 2530)	3	AENG 3100	COMPUTER AIDED ENGG (p-CSCI 1060, p-ESCI 3100)	3
ESCI 3101	MECH OF SOLIDS LAB (cc-ESCI 3100)	1	ESCI 3410	LINEAR SYSTEMS (p-ESCI 3110)	3
ESCI 3110	LINEAR VIBS (p-ESCI 2110, p-MATH 3550)	3		MATH /SCIENCE ELECTIVE %	3
MATH 3270	ADV. MATH FOR ENGINEERS (cc-MATH 3550)	3			
	Total			**Total**	
Senior Year					
Fall Semester			**Spring Semester**		
Course Num.	**Course Title**	**Hrs.**	**Course Num.**	**Course Title**	**Hrs.**
AENG 4110	FLIGHT VEHICLE STRUCTURES (cc-AENG 3100)	3	AENG 4014	DESIGN II/Lab (p-AENG 4004)	3
AENG 4210	PROPULSION (p-AENG 3210)	3	PHIL 3400	ENGINEERING ETHICS	3
AENG 4111	AEROSPACE LAB (p-AENG 3000, cc- AENG 4110)	1		CULTURAL DIVERSITY ELECTIVE ##	3
AENG 4400	STABILITY & CONTROL (p-AENG 3000, cc- ESCI 3410)	3		TECH ELECTIVE %	3
AENG 4004	DESIGN I/Lab (p-AENG 3000, cc AENG 4400)	3		TECH ELECTIVE %	3
MENG 4300	HEAT TRANSFER (p-CSCI 1060, p- ESCI 2300, p-ESCI 3200)	3			
	Total			**Total**	

Figure 3: Current Aerospace Engineering Curriculum at Saint Louis University (junior and senior year classes shown)