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Engaged Student Learning in Dynamics of Flight and Control Classes

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Active Learning and Student Engagement in Flight Dynamics and Control Classes

Abstract

The next big challenge in STEM education is envisioned to come from curricular change. This paper aims to assess the best-practice model in student learning that was developed and demonstrated in Flight Dynamics and Control courses between 2011 and 2014 and 2017. The best-practice model was developed when a team research component was included into the undergraduate aerospace engineering courses of Flight Dynamics and Control I and II. By taking advantage of the unmanned aerial system fleet owned by the Department of Aerospace Engineering at the University of Kansas (KUAE), students were tasked with developing a physics-based model for one of eighteen different unmanned aircraft platforms, comparing the dynamic models to actual flight test data for the platform, and writing papers and presenting them to a panel of KUAE Faculty. As a result, forty-eight independent research projects were conceived, designed, built, and tested by teams of juniors in the aerospace engineering department. Since 2011, eight research projects were selected to be submitted to the American Institute of Aeronautics and Astronautics conferences. Six papers were accepted for the Professional Sections and three more are currently under internal review for future submission. In addition to the publication records, student evaluations, KUAE Industrial Advisory Board exit poll reports, and post-graduation survey results consistently show the effectiveness of project oriented collaborative learning.

1. Introduction

Some undergraduate STEM education disciplines provide hands-on design, manufacturing, and structures laboratories. These courses mainly cover undergraduate capstone courses with design and build components that support the design portion of the curriculum. However, in Flight Dynamics and Control I and II courses, there are typically no hands-on laboratory or co-curricular elements that demonstrate engineering and scientific principles/theories using real-world problems [1-2]. Such conventional curricula norms in Flight Dynamics and Control I and II courses are challenged in this work.

KU student evaluations from 2005-2010 consistently point to the lack of real-world experiences in many fundamental engineering disciplines. Many laboratory and design experiments unfortunately take place within the confines of closed space, using pre-defined inputs and outputs, and a monotonous approach to the completion of an experiment. The majority of class projects are limited to theories and mathematical analysis that are repeated year after year with no significant changes. Such courses are widely considered by students as being "dry", "boring", and "disconnected" [3]. In most Flight Dynamics and Control courses, objectives are drowned in numerous technique and example problems. For students to learn and better retain knowledge, they must be engaged at the objective level. Students must be able to apply their knowledge, skills, and creativity to problems in unfamiliar situations [4]. After all, this is the basis of all inventions, patents, and great engineering accomplishments [5].

The primary objective of teaching engineering courses is to empower engineers with analytical and technical capabilities so that they can contribute to society through industry, and be successful in research and continue to push the frontiers of knowledge. Developing problem-solving is one of the fundamental educational goals for STEM students. Reference [6] shows that only teaching mathematical methods will not develop problem solving skills. Students must shape their own thought processes and they must be deliberate and reflective about the principles and strategies they select for problem-solving [7]. The best way to develop problem solving skills is to challenge students with real-world problems where students learn to solve problems through applying analytical methods, establishing criterion, applying new approaches, using both formal and compiled knowledge, and verifying and validating the effectiveness of applied methods. A recent report by the Royal Academy of Engineering on the quality of Engineering Education in the United Kingdom highlighted the need to change both the scope and quality of engineering education to meet "industry-relevant skills" and "experienced-led" learning [8].

Class projects can be the most important tools teachers have to engage and prepare students in developing in-depth knowledge [9-10]. Class projects provide students the opportunity to solidify engineering and scientific principles and to reinforce teamwork aspects through a collective and synergistic efforts within the group. The effort envisioned herein seeks to integrate co-curricular elements in undergraduate STEM programs to maximize education and research outside typical classroom environments. The National Research Council research found that "engineering students will better grasp the relationship between the laws of physics and the construction of effective supports for a bridge if they see some examples of well-designed bridges, accompanied by explanations for the choices of the critical design features" [11]. Reference [8] shows that the "single most desirable attribute in new recruits" is the ability of students to apply their theoretical knowledge to real-world problems.

This philosophy was the motivation to restructure and improve undergraduate education in the Flight Dynamics and Control I and II classes. Unmanned aerial systems (UASs) and autonomous robots are emerging technologies of the 21st Century. When compared to the least expensive manned aircraft (e.g. general aviation aircraft), UASs are orders of magnitude less expensive. Their inexpensive cost and availability make them very effective replacements for manned aircraft in a broad range of scientific and military missions. By adopting UAS cutting-edge technologies and taking advantage of the UAS fleet owned by the KU Department of Aerospace Engineering, predominantly theoretical classes in Flight Dynamics and Control are transformed into laboratory-rich and discovery-based courses.

2. Project Oriented Collaborative Learning

For training competitive, creative, and capable students, the engineering education should provide the opportunity for learning fundamental knowledge but also provide a realistic, industry motivated, and relevant experience. The course material and research applications provided should be up to date and practical for strong curriculum. The best practice model was developed when a team research component was included in two undergraduate aerospace engineering courses of Flight Dynamics and Control. Several different UAS platforms with different sizes and configurations were provided to students and they were asked to create a dynamic model for the UASs. Students generated a geometry model of an actual aircraft by collecting physical measurements and mass characteristics of the aircraft. As shown in Figure 1, they performed oscillation tests to experimentally calculate the aircraft moment of inertia. Next, by using an industrial standard software called Advanced Aircraft Analysis (AAA), estimates for the stability and control derivatives of the aircraft were generated [11]. Important concepts for flight dynamics such as aircraft mass, moment of inertia, control surfaces and hinge moments, planform shapes and their impact on the aspect ratio and consequently lift-curve slopes, impact of aircraft size and geometry on the dynamics modes, and many other important subjects are given new meaning to the students since they have collected their data off of actual aircraft.

These derivatives are then used to simulate aircraft flight and can be validated with actual flight test data of the same aircraft platform. By comparing results with those from the actual flight tests, students have shown that the physics-based model developed is an accurate representation of the UAS dynamics. To vary the research projects different from year to year, secondary research objectives were assigned. These research tasks were varied based on the on-going research in the KUAE Department. For example, one class was asked to investigate the effectiveness of split aileron control surfaces to provide more robust control of the aircraft [15]. Another team was asked to investigate the effectiveness of winglets on the aerodynamic performance and to quantify their effect on the handling qualities of the aircraft [16]. Such secondary objectives make these projects open-ended. As a result, 48 independent UAS research projects were conceived, designed, built and tested by teams of juniors in the aerospace engineering department. Considering time constraints for a semester-long research project, UAS instrumentation and flight test were conducted by the faculty, graduate teaching and research assistants, and department staff. The classical approach of theory-based mathematical development was transformed into a laboratory-based, collaborative-learning, and an application-oriented discovery course. A faculty panel reviewed student results, selected high quality research papers, and encouraged students to submit them to American Institute of Aeronautics and Astronautics (AIAA) conferences. Out of the forty-eight UAS projects since 2011, eight papers were submitted to the AIAA for review. Out of the eight submitted, six papers were accepted for presentation in various AIAA professional conferences and are in press [13-18]. Additionally, three more are currently under internal review for AIAA submission. Considering the total number of projects done by different teams (48), approximately 17% of student projects were chosen for submission to the AIAA conferences. The following projects are examples from successful research efforts done by the juniors in the Flight Dynamics classes.

Figure 1: Swing Tests for Measuring Aircraft Moment of Inertia

a) Dynamic Analysis of the Meridian Unmanned Aerial Vehicle

The aerodynamic, stability, and control characteristics of a large fixed-wing UAS, known as the Meridian, was developed using Advanced Aircraft Analysis (AAA). The Meridian is a 1,100 lb UAS that was designed, manufactured, and flight tested by the KUAE department. The dynamic model of the Meridian was investigated over a broad range of Mach numbers and flight altitudes. The dynamic model for the UAS was verified with actual flight tests [14].

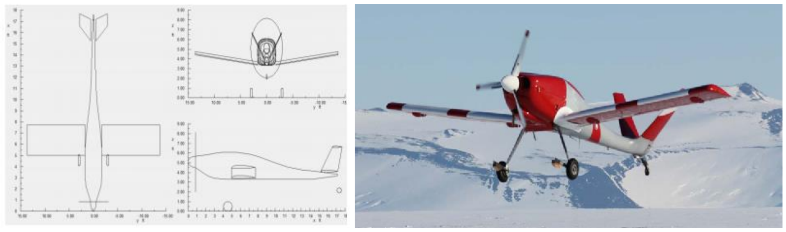

Figure 2: Dynamic Modeling of Meridian UAS (Ref. 14)

b) Effects of Winglets on Small Unmanned Aerial Systems

Although the benefits of winglets on the fuel efficiency, takeoff, and climb performance of large transportation aircraft have been extensively investigated and documented, their impact on small UASs have not been widely modeled. This project investigated the effect of adding winglets with various dihedral angles to a 55 lb UAS with an 11 foot wingspan. Students not only conducted the dynamic analysis but also manufactured the winglets and integrated them into the existing wing structure. The aircraft was then flight tested and the flight test data was used to validate the dynamic model developed from AAA.

Figure 3: Effects of Winglets on small UASs (Ref. 16)

c) Hawkeye UAV Dynamic Analysis

A dynamic analysis of the Hawkeye UAS which was designed, manufactured, and flight tested by the KUAE department was performed by a team of juniors. Geometric data was collected through measurements of the aircraft and its control surfaces, and the dynamic model of the aircraft was developed for several trim velocities. The linear time invariant models were created and a modal analysis of the aircraft was conducted to investigate the stability of the UAS between various cruise speeds.

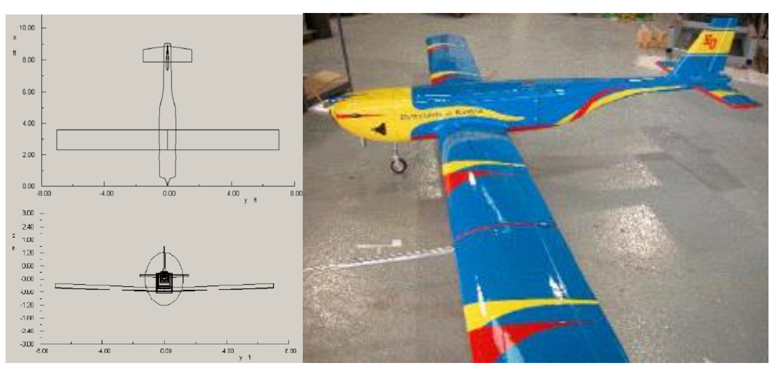

Figure 4: Dynamic Analysis of Hawkeye (Ref. 17)

3. Relation to the Longer-Term STEM Teaching

Integration of UAS dynamic modeling in the course curriculum develops highly engaging learning environments as a best practice model for STEM education to improve learning outcomes including student engagement, increased retention rates, and number of awarded degrees in STEM fields. In addition, the projects are constructed in such a way as to improve student independent research skills, innovative problem-solving skills, team-based leadership, communication skills, and knowledge of post-graduation options that prepare them for graduate school and professional careers in STEM fields. Out of the nineteen students whose papers were accepted, presented, and published in the AIAA conferences, twelve pursued graduate degrees (63%), of which seven pursued PhD degrees (37%) and five pursued Master's degree (26%).

In order to develop a data-driven best-practice model, starting in the Fall 2018 semester, student demographic data will be collected by the educational assessment staff from the KU Teaching Excellent to track participation, retention, and graduation of under-represented student groups within STEM fields, and compare the institutional data with the students who participated in the Improving Undergraduate STEM Education (IUSE) program data.

4. Assessment of Student Learning Outcomes

In addition to the published papers in the AIAA conferences [12-17], the KUAE Department's Advisory Board (KUAE-AD) collects senior exit polls on a yearly basis. Undergraduate senior exit polls in AE from 2012-2014 strongly confirmed the effectiveness of this approach. Students in the program described their experience as "life changing".

In a period between 2014 and 2016, students were taught the Flight Dynamics and Control using a more classical approach and no projects where assigned by the faculty. When seniors were asked "Is there any specific area, related to the previous question where you feel you are not properly prepared? If yes, please identify and describe", they consistently appreciated professors' efforts, however expressed their concerns on their struggle when it comes to real-world applications for "how to apply their knowledge". Since Fall 2017 and after reinstating the active learning and the best practice approach, students evaluations have improved significantly and are comparable with years 2012-13. Figures 5 and 6 show number of students who participated in the evaluation process and results from their evaluations between years 2012-2017. A dramatic change can be observed in the acquired knowledge as a function of teaching methods (classical versus active learning). Evaluations results were consistently better in years when the active learning approach was implemented and students were engaged with class projects (2012-13 and 2017). The standard deviations of class evaluations were found to be much larger in years that classical approach were used in teaching Dynamics of Flight I.

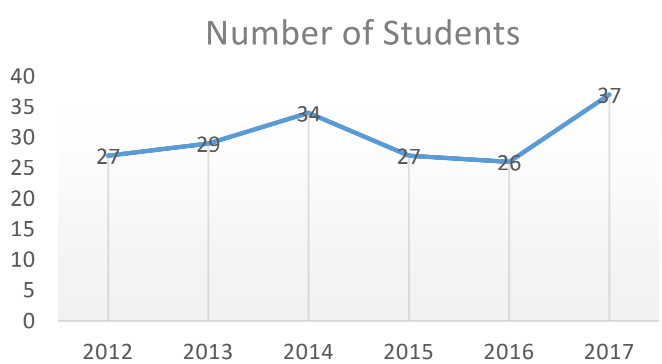

Figure 5: Number of Students Who Participated in the Evaluation Process

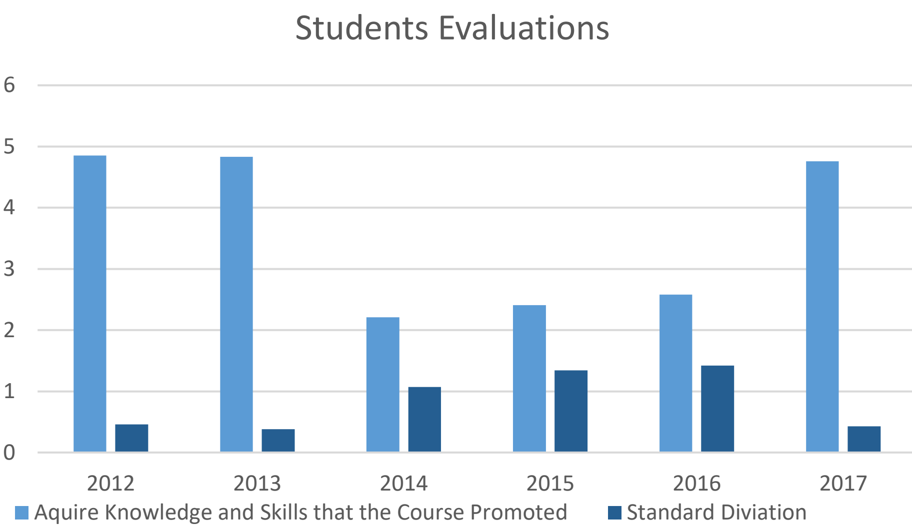

Figure 6: Comparison of Acquired Knowledge in Flight Dynamics I Course between 2012-17

To quantify improved student performance over the years, two surveys were conducted to assess the effectiveness of class projects on the outcome of Flight Dynamics and Control classes.

a) Survey I

Survey I was conducted among the current students in the Flight Dynamics II class. These students were assigned eight dynamic modeling project in the Fall 2017. Thirty-five students were asked to evaluate the impact of the class projects on their understanding of flight dynamics, dynamic modeling, and aircraft systems. The survey showed that the majority of students (85%) found the projects very helpful or extremely helpful. The average evaluation score was 4.25 out of 5. A similar trend can be seen in their overall evaluation of class projects (85%), that found their experience was either very or extremely positive.

b) Survey II

Survey II was conducted on former students who graduated prior to Spring 2014 and have already started their professional careers. Twenty-one former students responded to the survey, and although the sample size was 40% smaller, a similar trend was observed. 76% of former students found that the class projects were very/extremely effective tools in learning mathematical concepts in flight dynamics. The average evaluation score was 4.29 out of 5. Of the former students polled, 80% evaluated their experience as very or extremely positive. Considering the fact that the level of complexity from one project to another one was very similar, it is very important to determine why a large percentage of students were unable to reach to the expected level of excellence and were not asked to submit their work to the AIAA conferences. Important factors like the impact of the percentage of proficient and driven students versus average students in a team or dissimilar interests between teammates must be studied more carefully before any conclusion can be drawn. Currently, students pick their own teammates however it *might* be more efficient if team members are carefully assigned.

5. Conclusions

Unmanned aerial systems and autonomous robots are 21st century emerging technologies and the KUAE Department is a pioneer in adopting these cutting-edge technologies in various courses in the KUAE program. Integrating UAS related projects in Flight Dynamics and Control classes has motivated students to more fully understand fundamental concepts and has transformed these Engineering courses from predominantly theoretical to laboratory-rich and discovery-based courses that help students to learn engineering concepts using real-world experience. Surveys, class evaluations, and student achievements consistently show the effectiveness of the proposed methods.

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