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Undergraduate Area of Emphasis in Unmanned Aerial Systems

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1. Introduction

Autonomous intelligent robots and, in particular, unmanned aerial vehicles (UAV) [1] represent a rapidly growing area within the 4th industrial revolution [2]. The complexity and sophistication of the field create specific challenges for the engineering educational system. They are revolving around the critical need for interdisciplinarity, adaptability, and cybernetics skills [2-4].

An area of emphasis (AoE) focused on unmanned aerial systems (UAS) has been recently designed by faculty in the Mechanical and Aerospace Engineering (MAE) Department at West Virginia University (WVU) and will soon be implemented within the Aerospace Engineering Bachelor of Science (AEBS) Program. This initiative has two main goals: 1) to prepare students for a relatively new and rapidly expanding job market niche [5] and 2) to broaden the content and extend the experiential learning framework for the general AEBS curriculum.

The long term experience of MAE faculty in various aspects of UAS research [6], the availability of in-house developed complex UAS simulation environments [7], as well as the continuous student involvement and interest in competitions of the design-build-fly type [8] have created the premises for an enhanced academic process capable to directly connect theory and practice, causes and effects, engineering design parameters and their impact on system performance.

In this paper, the main elements of designing the AoE in UAS are presented. The role and place of the AoE within the AEBS curriculum are explained in Section 2. The main educational objectives and motivation are outlined in Section 3. The targeted learning outcomes are listed in Section 4. Section 5 includes a brief discussion of the adopted strategy and the main educational tools used for the design and implementation of the AoE. The general curricular structure and academic requirements are described in Section 6. Finally, some conclusions and a list of technical references complete the paper.

2. Integration of an Undergraduate Area of Emphasis in Unmanned Aerial Systems within the Aerospace Engineering Curriculum

Due to the logistical complexity, high risk, and cost of aircraft operation, especially in the context of autonomous flight, the direct exposure of engineering students to the technical systems they are expected to design, build, and exploit is limited. As a consequence, there is a perceived lack of a desirable connection between academic development and the job market needs. This can potentially produce slow learning curve rates and even inefficiency for entry-level employees. Student, alumni, and employer surveys at WVU and other institutions consistently reveal the need and desire for increased hands-on experiences as an integral part of the learning process. At the same time, all constituencies signal the increasing significance of autonomous UAS in the context of modern industry, technology, and commercial applications, as an obvious embodiment of the 4th industrial revolution. This poses specific and high priority challenges to any academic institution hosting AEBS programs relative to workforce education, background, and training. The MAE Department at WVU has identified several academic needs that would have to be addressed in areas such as:

- optimal design of unmanned aircraft for remotely piloted and autonomous missions;
- development and analysis of advanced control systems for specific tasks such as commanded trajectory tracking or close formation flight to be performed under normal and abnormal conditions;
- analysis and design for system survivability, safety, and performance;
- investigation of means to increase system autonomy;
- investigation of synergy between vehicle design, control laws, and environmental conditions;
- assessment of impact of control laws on performance and stability across normal and abnormal operational conditions.

It should be noted that some of these problems involve sophisticated solutions, which should be properly introduced at the undergraduate level, such that a solid background is created for continuing education and/or future workplace training.

Areas of emphasis, as part of the WVU curricular framework, are envisioned as effective tools for in depth focus within an approved major, such that an adequate level of specialization is identified within a major area of study. Undergraduate AoEs may comprise 12-18 credits, 9 of which must be upper-division level. AoEs are noted on the transcript, but not on the students' diplomas. The MAE Aerospace Engineering Curriculum Committee (AECC) decided to initiate the development of the AoE in UAS in response to student interest and the recommendation and support from the MAE Advisory Committee and faculty for enhancing the area of UAS within the curriculum. All courses included in the AoE in UAS are approved technical electives for the general AEBS Program.

The AEBS Program is accredited by the Accreditation Board for Engineering and Technology (ABET). Technical elective courses are typically not considered by the MAE Department for ABET assessment purposes. However, the courses contributing to the AoE in UAS are expected to collectively address all 7 ABET Learning Outcomes.

3. Main Educational Objectives

The courses required for the AoE in UAS are expected to collectively address the following academic objectives:

- introducing students to historical and current state-of-the-art information regarding UAS;
- informing students on current domestic regulations and policies on unmanned aerial systems;
- introducing a broad range of technical disciplines related specifically to and within the context of UAS such as: vehicle aerodynamics, propulsion, structures, launch and recovery, mission planning, weapons and sensor payloads, materials, and ground and airborne system data links;
- introduction to and application of fundamentals of unmanned aerial vehicle design, construction, testing, and operation;

- application of numerical tools, computer-aided design tools, and common engineering planning tools (e.g. MATLAB®, SIMULINK®, SolidWorks®, Solid Edge®, MS Project®, and others);
- exposure to effective mathematical methodologies and computational techniques for solving technological problems;
- providing a knowledge basis from which students may identify academic pathways related to UAS;
- preparing students for personal research and/or career pathways related to UAS;
- introduction to algorithms for UAV path planning and trajectory tracking: development, implementation, and testing through simulation;
- introduction to the main objectives, challenges, and tools of the UAV commanded path generation process;
- overview of the main classes of methods for UAV path generation;
- formulation of the autonomous trajectory tracking problem;
- introduction to main methodologies for the development of autonomous trajectory tracking control laws;
- conducting experimental analysis of path generation algorithms and trajectory tracking control laws through simulation;
- introduction to multi-rotor UAV dynamics;
- exposure to basic filters for UAV state estimation;
- introduction to UAV attitude stabilization and altitude holding controllers;
- application of dedicated software within a UAS-focused project targeting one of the major topic areas including: navigation filtering, inner-loop control, or path planning.
- hands-on applications of general aerospace engineering concepts to meet specified flight performance criteria for UAV design and operation;
- integration of multidisciplinary basic concepts within a diverse project team;
- analysis, evaluation, and response to a UAV-specific engineering mission;
- introduction to basic organizational and communicative methods for effective engineering project management and product implementation.

4. AoE Learning Outcomes

The AECC is committed to guide and monitor the design and implementation of courses with learning outcomes that span the entire spectrum of Bloom's taxonomy levels [9]. At the completion of the course requirements for the AoE in UAS, students are expected to be able to achieve at least 80-85% of the following:

1. describe and summarize relevant aspects of UAS in historical and contemporary context;
2. design and analyze components related to fundamental aspects of UAVs;
3. analyze UAVs from the overarching UAS logistics and support network perspective;
4. review the current UAS regulatory framework and interpret flight operations within such a framework;
5. describe and explain the main issues related to the UAV path generation process;
6. develop, implement, and test basic path planning algorithms;
7. describe and explain the main issues related to the autonomous trajectory tracking task;

8. design, implement, and test basic control laws for UAV trajectory tracking;
9. design, execute, and analyze simulation experiments for performance assessments and comparison of path generation algorithms and trajectory tracking control laws;
10. model the dynamics of multi-rotor UAVs;
11. develop simple estimation filters for UAV state estimation;
12. implement basic attitude stabilization and altitude holding controllers in simulation;
13. use advanced mathematical tools, analysis methods, and design criteria for aerospace systems
14. use logical approaches to problem solving by evaluating UAV mission constraints and requirements and generating one or more potential design solutions;
15. describe the fundamental engineering concepts related to UAV design and operation;
16. perform effective team building, management, and communication;

5. AoE Design and Implementation Strategy and Tools

The AECC is actively engaged in a systematic and consistent effort for implementing modern, comprehensive, more effective teaching strategies and tactics [10-14] across the entire aerospace engineering curriculum. These techniques are synergistically combined to develop an academic framework for aerospace engineering education from a student-centered perspective that emphasizes student initiative, creativity, interests, and motivation. Advanced simulation environments as well as infrastructure for building and testing flying platforms are available and are used to support the general AEBS courses and in particular the AoE in UAS. These assets possess the level of complexity, detail, and flexibility that allows them to create an excellent framework for the implementation of innovative educational methods including active learning [15-17], experiential learning [18-21], and collaborative learning [22-24]. The AECC relies on permanent engagement of and interaction between all educational constituencies. The general strategy promoted by the AECC is illustrated in Figure 1.

Two specialized MAE laboratories are particularly supporting the AoE courses. The UAV Design-Build-Fly Laboratory is dedicated to student projects and the participation to AIAA Design-Build-Fly competitions [8] offering an excellent collaborative team environment. It is equipped with a wide range of manual and power tools, general machinery, materials, and supplies necessary for such projects. Student teams have access to a computer design room and an ABS 3D printer for aircraft parts and for the development of molds for composites work. The MAE Flight Simulation Lab includes 18 stations with high-end desktops, accurate joysticks, and advanced graphic cards with dual monitors. Advanced off-the-shelve and in-house developed software are used for the simulation of various types of aircraft and flight dynamics characteristics. Specific in-house developed software for autonomous flight simulation [7,25] is available including extendable libraries of aircraft models, path generation algorithms, autonomous flight control laws, environmental conditions, and models of subsystem abnormal conditions. The computational environment is based on MATLAB® and SIMULINK®, interfaced with commercially available visualization software packages. Figure 2 shows an example of a student build flight testing platform [26]. Figures 3 and 4 show examples of the WVU UAS Simulation Environment interface [7].

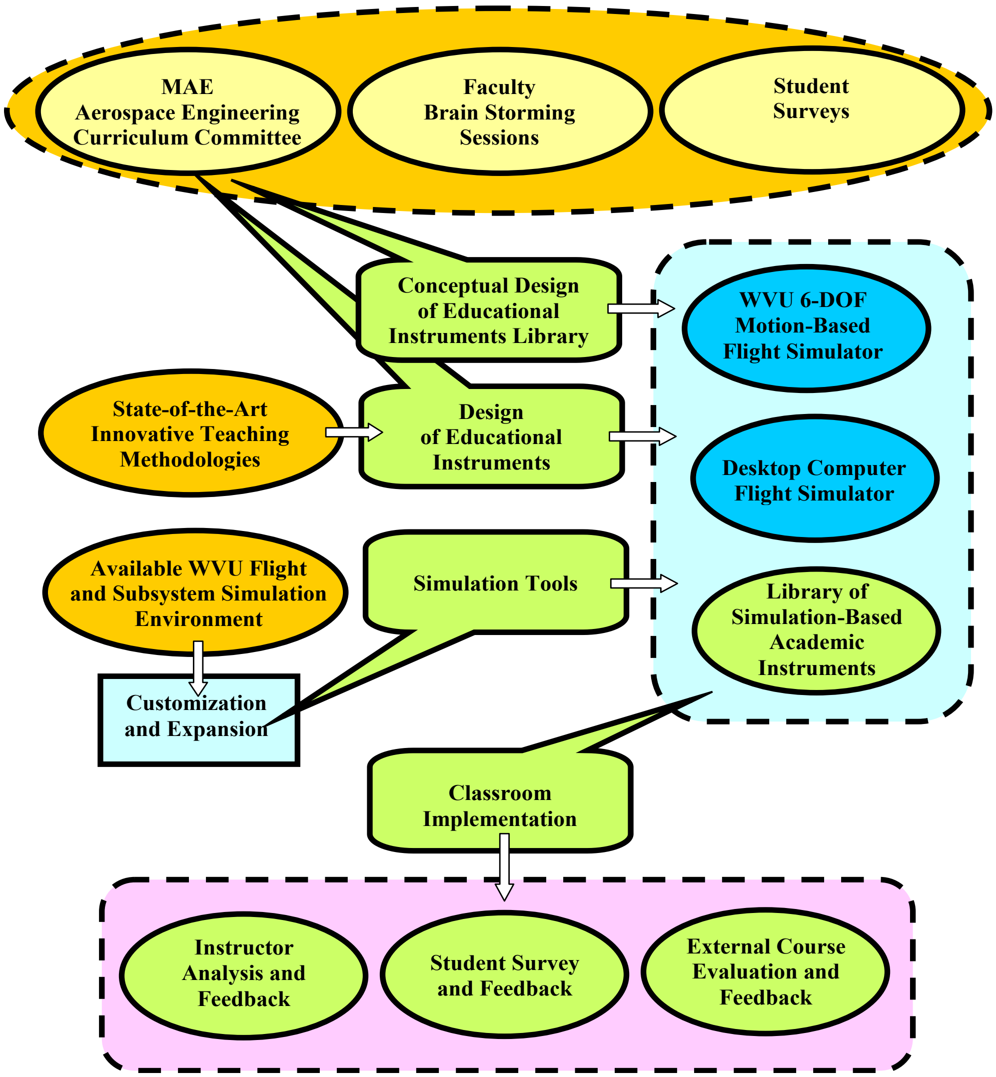

Figure 1. AECC Strategy for the Development of the AE Educational Environment

Figure 2. Student-built Reduced Size Flight Test Platform [26]

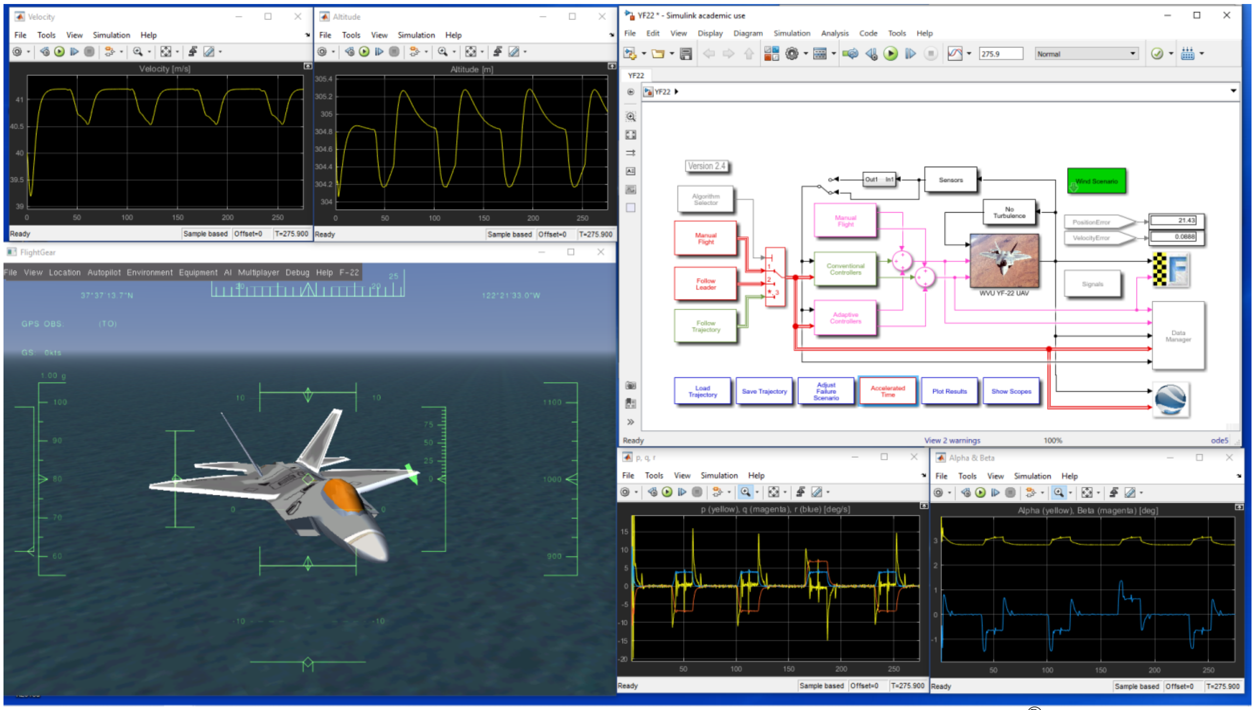

Figure 3. Interface of the WVU UAS Simulation Environment - SIMULINK® Model, Time History Displays, and Aircraft and Scenery Visualization

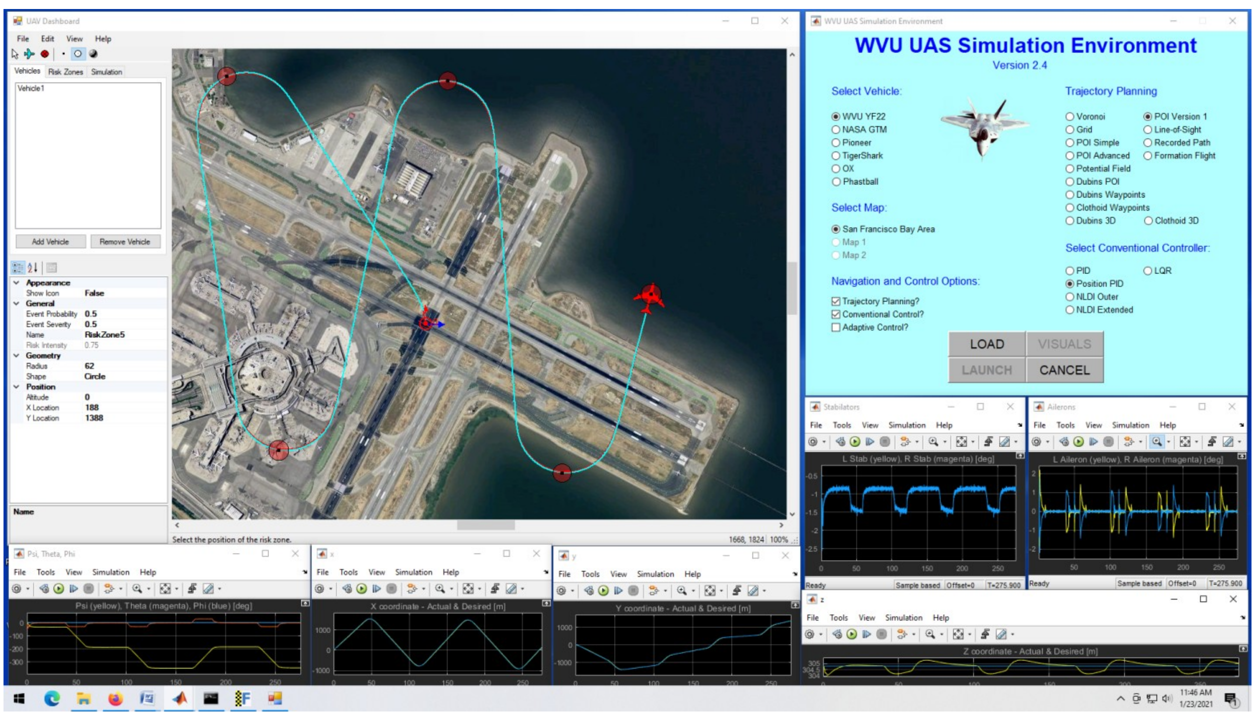

Figure 4. Interface of the WVU UAS Simulation Environment - Simulation Scenario Setup Interface, Time History Displays, and Map for Navigation Setup

The interface module comprises four main components: simulation scenario setup interface, time history displays, aircraft and scenery visualization, and the map for navigation and environment setup. The MATLAB®/SIMULINK® main portal for simulation setup interface (see Figure 4) allows the user to select the aircraft to be simulated, the desired trajectory planning algorithm, and the desired trajectory tracking control laws. Further graphical user interface menus allow setting up of atmospheric conditions and failures affecting actuators and sensors, including the Global Positioning System. The SIMULINK® scope displays allow convenient monitoring of relevant variables during and after the simulation (Figures 3 and 4). The aircraft and scenery visualization is provided by FlightGear®, a free simulation package (see Figure 3). An interactive map interface, the WVU UAV Dashboard (see Figure 4), was developed using the Microsoft Visual C# programming language. It allows the user to load an aerial map, define a coordinate system, place vehicles into the simulation, define threat zones and obstacles, and add waypoints or points-of-interest that are used for path planning purposes [7].

6. General Curricular Structure of the AoE in UAS

For the optional AoE in UAS, students must take and pass at least 3 technical electives (TE) courses from the Primary Course List A, presented in Table 1, and one course from the Secondary Course List B, presented in Table 2. Students may choose to take all 4 courses from List A. Other approved TE courses (MAE 493) or selected graduate courses (MAE 593) may be used as substitutes with ad-hoc approval by the MAE AECC. Both List A and B are open and subject to periodical revision and extension by the AECC.

The curricular structure has been designed such that the learning outcomes of the AoE are achieved as desired. Table 3 presents how the courses in List A are connected to the expected learning outcomes.

Table 1. Primary Course List A for the AoE in UAS

Course #	Course Title
MAE 361	Introduction to Unmanned Aerial Systems
MAE 457	UAV Path Planning and Trajectory Tracking
MAE 469	UAV Guidance, Navigation and Control
MAE 474	UAV Design-Build-Fly Competition 1 and 2

Table 2. Secondary Course List B for the AoE in UAS

Course #	Course Title
EE 327	Signals and Systems 1
EE 463	Digital Signal Processing Fundamentals
MATH 441	Applied Linear Algebra
CS 453	Data and Computer Communications
MAE 446	Composite Materials
MAE 478	Guided Missile Systems

Table 3. Learning Outcomes Addressed by Primary Courses

Course #	Learning Outcomes
MAE 361	1, 3, 4, 15
MAE 457	2, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16
MAE 469	2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15
MAE 474	1, 2, 4, 8, 13, 14, 15, 16

7. Conclusions

It is envisioned that the new AoE in UAS will have a significant impact on the current state of education and workforce development at WVU and more generally due to the following considerations:

- the adopted conceptual approach of synergistically and systemically blending advanced simulation with hands-on hardware building and modern highly effective educational methods are expected to represent a significant qualitative advance with respect to current academic practice;
- the integration of advanced simulation tools and hands-on practice as primary means for developing an educational environment focused on active and experiential learning with a high level of student centered customization will lead to successful and effective education in the targeted technical area, with wide dissemination capability;
- the development of this AoE responds to the need to transform undergraduate education into a more student-oriented process that provides the framework for and encourages active student participation and motivation;
- the design of the educational activities and instruments is focused on bringing real-world problems and experiences into the classroom and providing the students with a framework for creative search for solutions, investigative analysis, and independent inquiry-based study;
- the implementation of the AoE in UAS is responding to current and future job market needs and trends in the context of the 4th industrial revolution and the specific challenges that it triggers.

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