Published 30 March 2024

Active Learning Undergraduate Course on UAV Path Planning and Tracking Using Numerical Simulation

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ORIGINAL

Abstract

This paper presents the use of numerical simulation tools developed in MATLAB® and Simulink® for the design and implementation of an undergraduate course, introducing students to the path planning and trajectory tracking of unmanned aerial vehicles (UAV). The course is part of an aerospace engineering emphasis area; however, with minimal flight dynamics background, it is beneficial to students in related disciplines relevant to UAVs. The major classes of UAV path generation and trajectory tracking algorithms are introduced. Significant design issues and their implications are discussed and illustrated through numerical simulation. Course assignments use active and experiential learning approaches encouraging student creativity and initiative. They involve investigating algorithm alternatives and UAV diverse operational conditions beyond nominal, including control surface failures and adverse atmospheric phenomena. Students are required to solve open-ended problems and design, execute, and analyze simulation experiments in the process. Direct assessment by the instructor and student feedback confirm that advanced numerical simulation increases student motivation and facilitates learning. It represents an effective support for active and experiential learning methodologies.

Keywords: Active learning, Simulation-based learning, Unmanned aerial vehicles, Controls

Related ASEE Publications

M. G. Perhinschi, “Undergraduate area of emphasis in unmanned aerial systems,” in *2021 ASEE North Central Section Conference - Engineering Education for Industry 4.0*, University of Toledo, Mar. 2021.

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OPEN ACCESS
Volume
14
Issue
1

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Submitted *29 Apr 2023*

Accepted *23 Jun 2023*

Citation
Perhinschi, Mario "Active Learning Undergraduate Course on UAV Path Planning and Tracking Using Numerical Simulation," Computers in Education Journal, vol 14, no. 1, 2024.

1 Introduction

The continuously growing interest in developing and using unmanned aerial vehicles (UAV) (Sadraey, 2020) and the expanding job market covering a wide diversity of applications (Federal Aviation Administration, 2022), in conjunction with the need for solutions that are more and more systemic and intelligent (Department of Defense, 2018), require the introduction of aerospace engineering undergraduate students to several advanced topics related to the design and operation of autonomous flying systems.

The Department of Mechanical and Aerospace Engineering (MAE) at West Virginia University (WVU) has recently introduced in the curriculum an area of emphasis on unmanned aerial systems (UAS) (Perhinschi, 2021). While design, manufacturing, and operation, including participation in student competitions, represent a major component, numerical simulation is a critical tool. An advanced simulation environment, initially developed for research (Perhinschi et al., 2013), has been modified and customized for specific academic utilization. The course is primarily addressed, as a technical elective, to aerospace engineering undergraduate and graduate students; however, with minimal flight dynamics background, it is beneficial to students in related disciplines relevant to UAVs, such as mechanical engineering, electrical engineering, mathematics, or physics.

Generating the UAV commanded path or trajectory and designing control laws that are capable of following the command accurately are critical processes for UAV performance and safe operation. Depending on the UAV mission objectives and requirements, a large variety of algorithms have been developed (Beard and McLain, 2012; Goerzen et al., 2010) in both areas.

The assignments for the presented course have been designed using active and experiential learning approaches (Silberman, 1996; Kolb, 1984) based on extensive use of numerical simulation tools due to their demonstrated ability for enhancing the effectiveness of the learning process in several other related areas of the aerospace engineering curriculum (Perhinschi, 2020; Perhinschi and Al Azzawi, 2014; Perhinschi and Beamer, 2012).

After this general introduction, the main conceptual aspects related to the dynamics and control of autonomously flying vehicles are briefly presented in section II. As part of the active and experiential learning approach, students must have adequate background in designing experiments and executing and analyzing them, which is outlined in section III. The WVU UAS simulation environment used within the course is described in section IV. The course objectives and learning outcomes are presented in section V. Course assignments are described in section VI, with a more detailed example in section VII. The educational impact and student perception are briefly discussed in section VIII, followed by conclusions and a bibliographical list.

2 Dynamics and Control of Autonomous Flight

An autonomous aerial vehicle is an unmanned vehicle that can perform airborne tasks without direct human intervention, as opposed to being remotely controlled. Several levels of autonomy are identified depending on how much on-board "artificial intelligence" exists, in other words, how much adaptability, flexibility, and decision making is the vehicle capable of. The operation of the system implies two major components: generation of a commanded path or trajectory and the tracking of this command. A large variety of algorithms for both components have been developed depending on the details of the UAV mission. Introducing students to the main classes of these algorithms, their design, and usage is a major objective of the course. Minimal background in aerodynamics, flight dynamics, and aircraft control is required (Etkin, 1982; Stevens et al., 2016). Aerospace engineering students at the junior/senior level acquire this background by taking a typical flight dynamics course. However, a condensed review on these topics is offered at the beginning of the course, such that students in related disciplines can benefit from the course. It is important to note that the design and operation of autonomous systems is an interdisciplinary field involving mechanical engineering, electrical engineering, mathematics, physics, and other disciplines and the course is designed with this extended outreach in mind.

Generating a commanded path consists of establishing a curve in the physical 3-dimensional space that describes the continuous sequence of geometrical points that would take the UAV from a starting location L_s and an initial orientation $(\varphi_s, \theta_s, \psi_s)$ to a goal or final location L_f and a final orientation $(\varphi_f, \theta_f, \psi_f)$.This curve can be expressed analytically or through "waypoints" with the assumption of some type of interpolation between them, such that continuity is ensured. If a velocity profile is imposed, then the commanded path is referred to as a commanded trajectory. Both the commanded path and the trajectory must be “flyable”. This means that the dynamic constraints on the motion of the UAV must be considered. For example, the UAV can only fly at certain velocities and with limited accelerations. The UAV cannot perform very sharp turns; there is a minimum turn radius that the UAV can accommodate. Path and trajectory generation algorithms may attempt to avoid obstacles or collision with other agents and/or achieve “optimality” with respect to various criteria depending on the UAV mission (e.g. minimum time, minimum risk, minimum fuel consumption, etc.).

While remote control is still the predominant mode of UAV operation, current trend is aimed at achieving the highest level of autonomy, where the UAV has the on-board artificial intelligence capabilities allowing it to complete complex missions without human intervention, except for the initial mission/task allocation at the general level and possibly monitoring for safety and verification purposes. Once commanded path or trajectory points are established, the UAV is expected to either follow the path or track the trajectory. Following the path means being on the path regardless of time, while tracking the trajectory means being at the commanded point on the path at the imposed moment. As UAVs claim more important tasks and a larger share of the airspace, the need for sophisticated, fault-tolerant control schemes becomes evident. Such intelligent control schemes are expected to provide enhanced capabilities, safety, and reliability (Wilburn et al., 2013). New control law technologies are expected to increase flight autonomy by maintaining control of the aircraft, not only for long durations without any level of human intervention, but also under abnormal flight conditions caused by extreme weather, damage, equipment malfunction, and/or other unexpected factors. The typically reduced size of the UAVs prevents them from benefitting on a large scale from hardware redundancy, which makes software fault tolerance a very desirable system capability (Moncayo et al., 2013).

Primary aerodynamic control surfaces, such as elevator, ailerons, and rudder, are expected to produce control moments about the three axes of the aircraft body reference coordinate system, which change the attitude of the vehicle. The primary aerodynamic surfaces produce small changes in the lift, which have little contribution to the total lift of the aircraft. However, the moments produced by these small changes are significant and it is these moments that achieve the control of the aircraft. The ailerons bank or roll the airplane about its longitudinal axis. The elevator moves the airplane about its lateral axis, changing the aircraft pitch attitude. The rudder yaws the airplane about its vertical axis.

3 Background in Design of Experiments

The course assignments rely heavily on simulation tests performed on desktop computers. A large number of scenarios may typically need to be considered and simulated. Large amounts of data may need to be recorded, processed, and analyzed. Therefore, all these simulation tests and experiments must be designed carefully to maximize effectiveness, within obvious time constraints.

The term “experiment” can be defined as a systematic procedure performed under carefully controlled conditions in order to reveal cause/effect relationships that can be used to: discover unknown effects, test a hypothesis, demonstrate a known effect, determine relevant variables, optimize process or system parameters, model a process or a system, and/or choose between available alternatives. The comprehensive experimental process includes the following phases: problem definition, objectives/goals determination, analysis of the problem, means and alternatives for solution, design of the experiment, conducting the experiment and data acquisition, data analysis, results interpretation, and verification of results. While the first two components and partially the third are formulated and required by the instructor, the remaining ones are expected to be addressed by the students, as part of the active and experiential learning strategy. The background of the students in these areas may be incomplete and non-uniform necessitating an introduction or a review. In particular, the “design of the experiment” component typically needs a discussion for clarifying the meaning and importance of the experimental “factors”, “levels”, and “outputs” (Montgomery, 2006; Tucker et al., 2010).

Initially exposed to a large number of factors and levels resulting in a full factorial design outside the practical time constraints of the course, the students are encouraged to take the initiative of reducing the experimental grid by using engineering knowledge related to the general aircraft and control surfaces symmetry and basic aircraft aerodynamics and dynamics, such as negligible effects and dynamic decoupling.

4 WVU UAS Simulation Environment

The MAE Flight Simulation Laboratory includes 18 stations with desktop computers, accurate joysticks, and advanced graphic cards with dual monitors - one that can typically be used for cockpit and out-of-windows display and one for simulation control and management. These resources were already available, supporting other courses within the MAE curricula. Several sets of complex simulation tools are available in MATLAB® and Simulink® , for both education and research purposes. Among these tools, the WVU UAS simulation environment (Perhinschi et al., 2013) is dedicated to the design, testing, demonstration, and evaluation of advanced control laws for UAVs operating autonomously under normal and abnormal flight conditions. It was designed for maximum portability and flexibility and it is interfaced with FlightGear® (***, 2023) for aircraft and environment visualization. It includes customized map generation and visual feedback environment created in C#. The simulation scenario can be setup to include the following features: single or multiple UAVs, manual or autonomous flight, different types of aircraft, different path planning and trajectory generation algorithms including a formation flight option and pre-recorded trajectories, different conventional and adaptive trajectory tracking algorithms with fault-tolerant capabilities, normal and abnormal flight conditions, different failures of aircraft sub-system, atmospheric upset conditions, and mission and environment setup through definition of zones of interest and threats. For the purposes of the presented course, a subset of the described features is used. A typical view of the 2-monitor interface is presented in Figure 1.

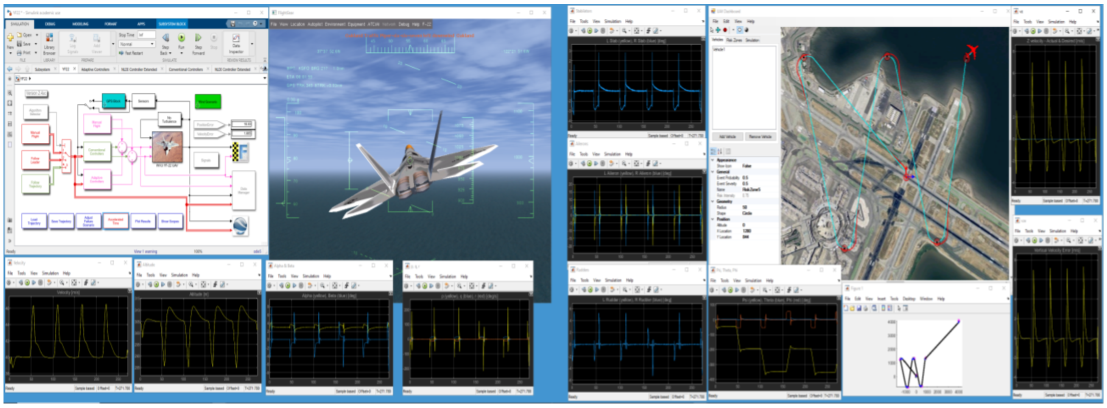
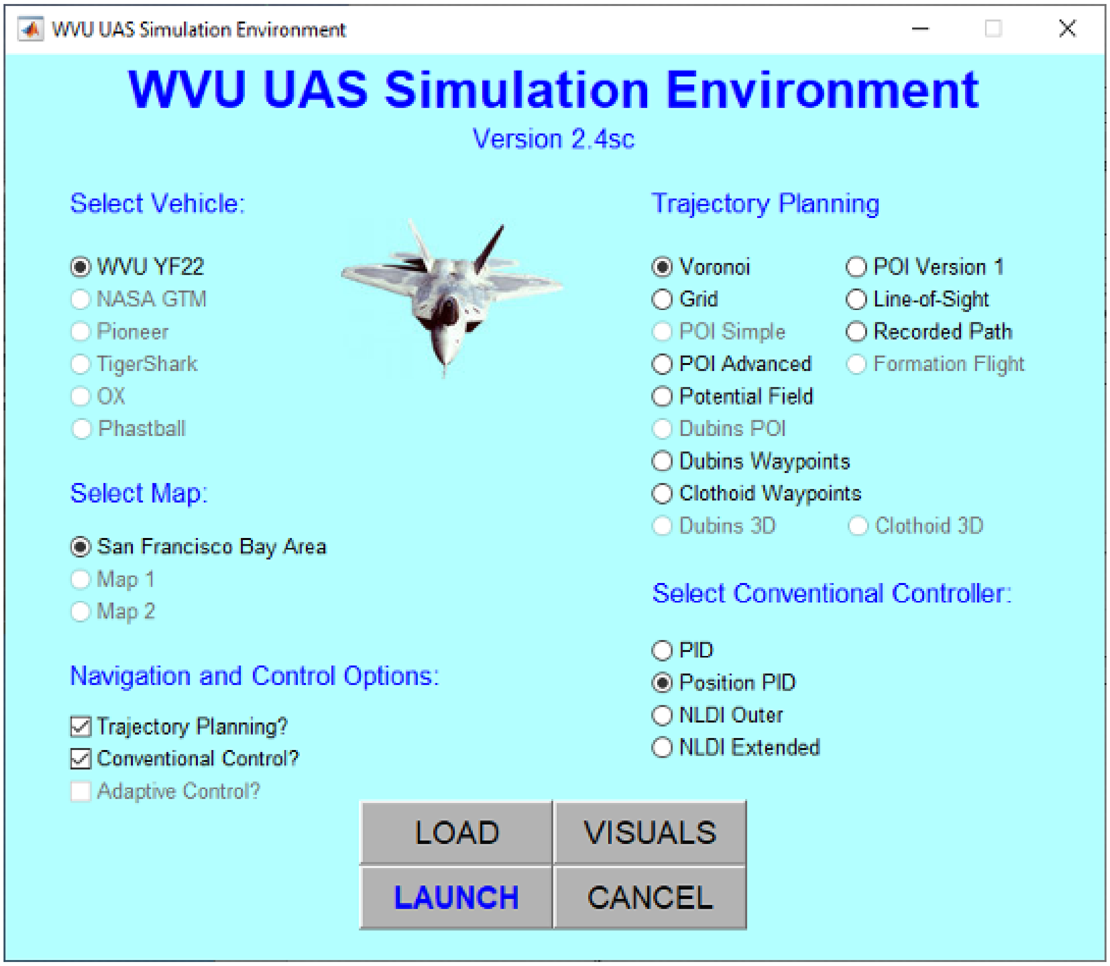


Figure 1. WVU UAS Simulation Environment – Visual Interface

Basic background on working with MATLAB® and Simulink® is needed for simulation setup, data recording, and results processing. However, a brief introduction to the platforms is provided, such that students who lack previous exposure can easily reach the level necessary for successfully completing all assignments. Several graphical user interface (GUI) menus facilitate the general management of the simulation. In Figure 2, the main GUI for the selection of the path generation algorithm and the trajectory tracking laws is presented, as an example.

5 Course Objective, Learning Outcomes, and Topics

The catalog description of the course emphasizes the focus on introducing the students to algorithms for UAV path planning and trajectory tracking, including their development, implementation, and testing through simulation.



WVU UAS Simulation Environment

WVU UAS Simulation Environment

Version 2.4sc

Select Vehicle:

● WVU YF22
○ NASA GTM
○ Pioneer
○ TigerShark
○ OX
○ Phastball

Select Map:

● San Francisco Bay Area
○ Map 1
○ Map 2

Navigation and Control Options:

☑ Trajectory Planning?
☑ Conventional Control?
☐ Adaptive Control?

Trajectory Planning

● Voronoi
○ Grid
○ POI Simple
○ POI Advanced
○ Potential Field
○ Dubins POI
○ Dubins Waypoints
○ Clothoid Waypoints
○ Dubins 3D
○ POI Version 1
○ Line-of-Sight
○ Recorded Path
○ Formation Flight
○ Clothoid 3D

Select Conventional Controller:

○ PID
● Position PID
○ NLDI Outer
○ NLDI Extended

Figure 2. WVU UAS Simulation Environment – GUI Menu for UAV Control Algorithms Selection

Along with the growing complexity of missions carried out by UAVs, comes an increased need for better performance, versatility, and robustness of trajectory tracking algorithms (Federal Aviation Administration, 2022; Department of Defense, 2018). The attempt to integrate UAVs within the national airspace raises critical issues regarding operational safety and reliability. Safe operation is directly related to the capability to maintain adequate performance under abnormal conditions, either external, such as extreme atmospheric conditions, or internal, such as faults and failures of aircraft sub-systems. While inherent robustness of the control laws is desirable, robust control techniques alone are not sufficient and it is expected that adaptive control techniques must be used to provide a comprehensive and integrated solution to the problem of fault tolerant autonomous flight.

The course main objectives are summarized as follows:

- Introducing students to the main objectives, challenges, and tools of the UAV commanded path generation process;
- Over viewing the main classes of methods for UAV path generation;
- Formulating the autonomous trajectory tracking problem;
- Introducing students to the 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.

The design of the course was aimed at ensuring that student learning outcomes adequately cover the cognitive domain in terms of complexity and specificity according to Bloom's taxonomy (Bloom et al., 1956). Upon completion of the course, the students should be able to:

- Describe and explain the main issues related to the UAV path generation process.
- Develop, implement, and test basic path planning algorithms.
- Describe and explain the main issues related to the autonomous trajectory tracking task.
- Implement and test basic control laws for UAV trajectory tracking.
- Design, execute, and analyze simulation experiments for performance assessments and comparison of path generation algorithms and trajectory tracking control laws.

The content of the course is aimed at introducing student to the main concepts, objectives, and challenges related to UAV path generation and trajectory tracking. This list of topics summarizes the particular algorithms and approaches addressed:

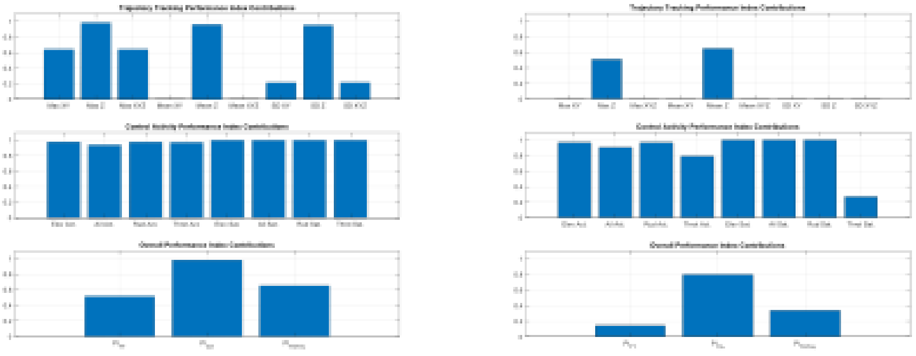
- Formulation of the path generation problem;
- Line-of-sight path generation;
- Waypoint-based path generation – Dubins and clothoid methods;
- Voronoi path generation algorithm for obstacle avoidance and risk mitigation;
- Potential field methods for path generation;
- Formulation of the trajectory tracking problem;
- Inner/outer loop control laws architecture;
- Proportional, integral, and derivative control;
- Other control methods with fixed parameters and adaptive parameters;
- Impact on UAV performance of abnormal conditions such as actuator failures and excessive atmospheric phenomena.

6 Course Assignments

Course assignments include four midterm tests, ten homework, and two team projects. The final grade for the course is calculated as a weighted average of all assignments, as follows: midterm tests 10% each, homework 22%, project #1 20%, and project #2 18%. The tests use a more traditional format with questions and problems relative to general aircraft dynamics, response to controls, behavior under wind and turbulence conditions, effects of actuator failures, path generation algorithms, and trajectory tracking control laws.

The homework and the team projects were designed with the expectation of ensuring maximum student immersion into the course material through open-ended formulations, requiring an experimental design process that includes system analysis, objective definition, decision making, and resources assessment. After a brief review of the main theoretical aspects, students start working on most of the homework in class within a laboratory-like format. Students are encouraged to take initiative in organizing the simulation experiments, adopting simplifications, identifying the most significant aspects, and optimizing the path for reaching the objectives. Stimulating student creativity and initiative, in conjunction with the hands-on experience facilitated by the simulation environment, proved to be effective for successful active and experiential learning.

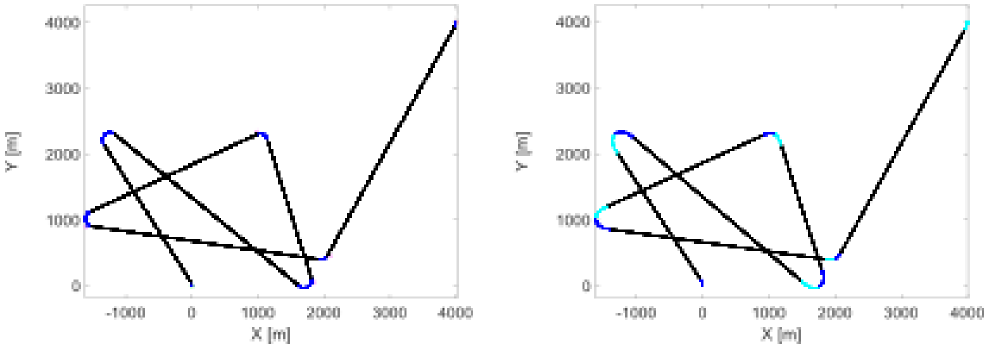
The first two homework assignments address general concepts and issues related to flight dynamics, including definition of states and controls, reference systems and sign conventions, stability and control derivatives, and aircraft dynamic response. Homework assignments #3 and #4 introduce students to using the WVU UAS Simulation Environment and analyzing autonomous flight performance under nominal and adverse flight conditions, such as wind and turbulence and failures of the aerodynamic control surfaces. Different performance metrics are proposed and the students are expected to conduct the analysis within a multi-criteria framework. An example of performance metric interface and values for wind effects analysis is presented in Figure 3.



(a) **(b)**

Figure 3. Performance Indexes for the “No Wind” Case (a) and for the “30 Knots Wind” Case (b)

Homework assignments #5 through #8 are dedicated to the implementation and analysis of path generation algorithms, investigating their design challenges and performance relative to different alternatives. Figure 4 shows an example of commanded paths obtained using the Dubins and the Clothoid approaches.



(a) **(b)**

Figure 4. Waypoints and Commanded Path Obtained with Dubins (a) and Clothoid (b) Algorithms

Homework assignments #9 and #10 require testing and comparing two different sets of autonomous flight control laws from the point of view of robustness to adverse conditions. An investigation of the effects of different controller gains is also part of these assignments.

There are two projects to be performed in teams of 2 or 3 students, formed by the students. One project involves the testing through simulation and analysis of path generation algorithms and the other, the testing through simulation and analysis of trajectory tracking algorithms. The projects are assigned in the 3rd and 13th week of classes, and are due in the 10th and last week, respectively. The second project is typically easier and faster to complete because the students are required to use the same general approaches for organizing the tests, processing data, and analyzing results, as for the first project. The first team project is presented in more detail in the next section.

7 Course Assignment Example

The first team project involves a comparison of two waypoint path generation algorithms, Dubins and clothoid, using the WVU UAS simulation environment with the implemented “Position PID” control laws. The mathematical apparatus behind the Clothoid algorithm is of higher level and only general conceptual aspects are addressed within the course. On the other hand, the Dubins algorithm is well aligned with undergraduate level and one homework addresses actual implementation and analysis, in preparation for this team project.

The factors and levels of the simulation experimental design should be selected such that the comparison is based on different commanded trajectories, presence and absence of constant wind, and presence and absence of actuator failures affecting the elevators, ailerons, and rudders of the UAV. At least 2 commanded waypoint routes with at least 5 waypoints each must be considered. The wind conditions must include “no wind” (which will represent the “normal” or “reference” situation) and a set of different values for main characteristics of the constant wind: magnitude, pitch angle, and yaw or heading angle. At least 3 different levels should be considered for the constant wind magnitude, a “low”, a “medium”, and a “high” value. For the wind pitch angle θ_W, at least the value “0”, a positive “medium” value, and a symmetric negative value should be considered. For the wind heading angle ψ_W, at least the four main directions: N-S, S-N, E-W, and W-E should be considered.

The actuator failure conditions must address all 3 channels of the aerodynamic control (rolling, pitching, and yawing moments, that is aileron, elevator, and rudder deflections). Only the case of a locked aerodynamic control surface must be considered. The surfaces must be locked (one at a time) at “current” position, at a “small” off-set and at a “large” off-set position. These values are supposed to capture the “severity” of the failure. The off-set positions must be positive and negative. For establishing “low”, “medium” and “high” values for all these parameters, students are recommended to use the following procedure. Consider the worst case scenario (assign by inspection “high” values for all the parameters) and make sure that the aircraft is still controllable, that is, it can complete or barely complete the commanded trajectory. Once these “high” values are determined, the “low” and medium” values may be selected between these high values and the reference condition.

The effects of wind and actuator failures must be first considered separately (wind present and no failure and then no wind, but actuator failure present) and compared to the reference or “normal” flight condition when there is no wind and actuators function properly. The combined effects of wind and failure should be addressed in the following manner. For one of the commanded trajectories, consider the “medium” wind magnitude with a positive pitch angle and the most disadvantageous heading angle. The effects of this wind scenario must be analyzed when failures of different severity (as described above) are present on each of the three channels (one at a time).

The performance metrics implemented and calculated within the WVU UAS simulation environment should be considered as the starting point in establishing a set of metrics for the performance evaluation and the comparison of the two path generation algorithms. Students may use all the implemented and calculated metrics (see Figure 3), a subset, or may define additional ones, if considered necessary. The selection of the performance metrics must be explained and justified in detail. These metrics will determine directly the list of the experimental design “results” or “outcomes”.

Students are required to address in detail the following elements in the project report:

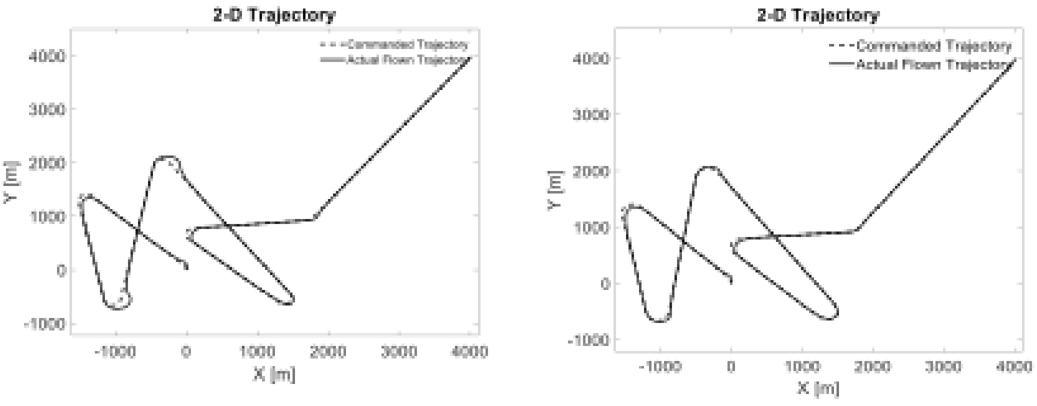
- formulating the problem and specifying assumptions, simplifications, and adopted approaches;
- describing in detail the experimental design process (list all experimental factors, levels, and outcomes);
- justifying/explaining all selections made, including rationale for reducing the experimental grid;

- describing the data acquisition, the organization of the files, and processing of data for analysis and display;
- analyzing and presenting results using detailed discussion, plots, and tables;
- drawing conclusions regarding the performance of the two path generation algorithms and their relative ranking correlated with UAV mission, objectives, and priorities;
- submitting all simulation raw data separately from the report;
- sharing interesting aspects/issues/challenges and lessons learned.

Only minor adjustments to the Simulink® model may be needed or desired if additional data must be saved and/or visual scopes are needed for monitoring and analysis support. Post simulation runs, a simple MATLAB® script must be developed for loading and plotting data to support the analysis and the project report.

Over the duration of the project, two open sessions are dedicated to interacting with the instructor and other teams for answering questions, discussing alternative ideas and challenges, and sharing experience. Each team is expected to submit a weekly progress report describing the activities and progress made towards completing the project. Each student must submit a peer contribution form evaluating their own and teammates contributions to the project. Individual project grades may be affected by peer evaluation and instructor confirmation. A team project report, professionally written, must be submitted on or before the project due date.

The Dubins path generation algorithm uses circular and straight segments producing a minimum distance commanded path with a discontinuous command in bank angle in-and-out of the turns. The Clothoid algorithm uses the so-called clothoid curves instead of circles producing longer commanded paths, but with smooth bank angle transitions, hence lower tracking errors. However, there are exceptions to this pattern depending on the actuator failure, direction and orientation of the wind, and direction and frequency of turns. The students are expected to identify these cases and explain the dynamics behind them. For example, Figure 5 shows the horizontal commanded and actual path, when the two algorithms are used. A locked left elevator failure is induced 5 seconds into the simulation. Figures 6 and 7 show a 3-dimensional view, showing the better trajectory tracking when the Clothoid algorithm is used. It can also be seen how the side of the actuator failure in conjunction with the side of the turn affects the horizontal and vertical trajectory tracking errors.



(a) **(b)**

Figure 5. Horizontal Projection of the Commanded and Actual Path for the “Dubins” Case (a) and for the “Clothoid” Case (b)

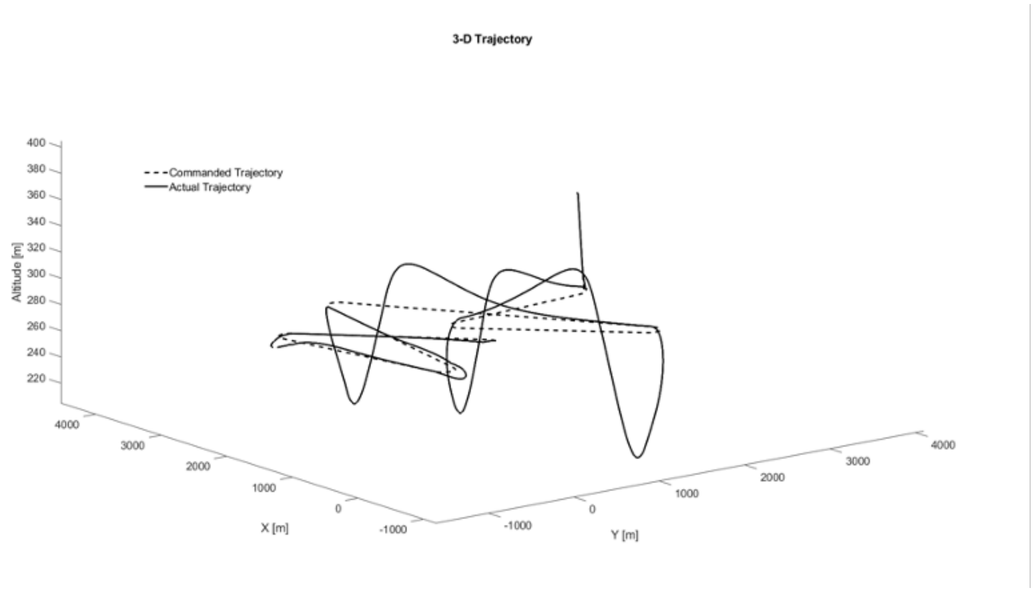


Figure 6. Three-dimensional Commanded and Actual Path for the “Dubins” Case

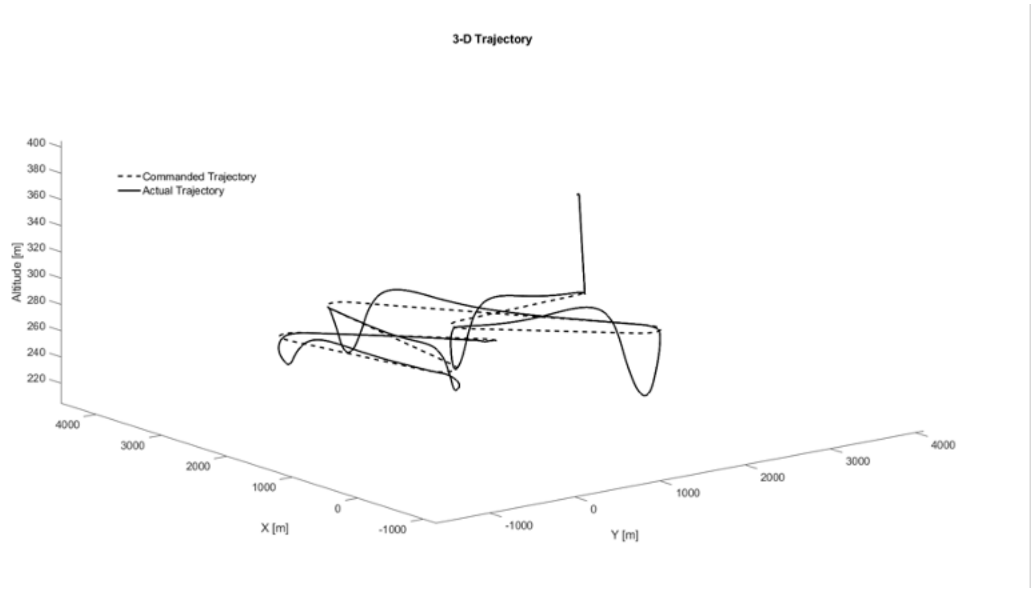


Figure 7. Three-dimensional Commanded and Actual Path for the “Clothoid” Case

8 Educational Impact and Student Perception

The course has been taught in Fall 2021 and Fall 2022 as a technical elective with a total enrollment of 29 students. The same student evaluation of instruction (SEI) questionnaire has been administered in both semesters. All questions and the ratings weighted averages based on the number of students, are listed in Table 1. Over the two semesters, average scores per question vary between 4.33 and 5.00, with total averages of 4.67 in the first semester that the course was taught and 5.00 in the second semester. The historical SEI average ratings within the MAE department at WVU range between 4.00 and 4.25, slightly higher for a subset of courses with related topics. Therefore, the rating of 4.93 is very high from this perspective confirming that the course was well received by students and found to be valuable.

The WVU SEI survey provides students with the opportunity to make comments in addition and support of their ratings. These comments confirm the high ratings and emphasize the value of simulation as an academic tool for the flight dynamics general area. In response to the generic question: "What helped you learn in this course?", students say:

- *Dr. Perhinschi's notes, and going through the use of the simulator in class and using it for assignments to see what happens with a UAV in flight.*
- *Discussion in class clarifying and solidifying material within the notes. The notes were very in depth, complete, and helpful. Overall, great course where I learned a lot of interesting things about UAVs with a good instructor*.
- *Mario is awesome. He gives us everything we need to do well, especially in 457. Assignments are clear and it's easy to understand what you need to do and how to do it correctly.*
- *Utilizing the course handouts as well as the simulation environment and attending lectures.*
- *The simulation was a great tool to implement theory to application.*
- *I believe using the sim to show the topics in discussion in lecture was very helpful.*

To summarize, one student says: *"The course is great the way that it is currently".*

Table 1. Student Evaluation of Instructor Ratings (2012-2022)

	SEI Question	Overall Weighted Average
1	The overall quality of the course	4.93
2	Course content was related to graded assignments	4.78
3	Course content was thought-provoking	5.00
4	The course materials were useful to course objectives	5.00
5	Overall my learning in the course	4.92
6	The instructors overall teaching effectiveness	4.93
7	The instructor fostered a positive learning environment	4.89
8	The instructor was well organized	4.89
9	The instructor provided helpful feedback	5.00
	Total Average	4.93

Based on direct interaction with students, the instructor can confirm that teaching complex topics in the broader area of flight dynamics can be significantly facilitated by using flight simulation. The dynamic and kinematic equations of motion come to life and their meaning, somewhat obscured by the dry mathematical formulation, becomes more accessible and sensical. Access to flight simulation tools and delegated responsibility for open-ended experimental design, test execution, and data processing and analysis allow students to exercise initiative, enhance creativity, relate cause and effect, and connect theory to practice. In particular, important concepts can be more effectively and rapidly communicated and understood, such as aerodynamic and dynamic coupling, aircraft six degrees-of-freedom control, control robustness, adaptive control, and off-design conditions impact.

9 Conclusion

An advanced UAS simulation environment has been used successfully to support an undergraduate introductory course on UAV path planning and trajectory tracking, as part of an active and experiential learning educational approach.

The open-ended assignments relying on simulation have been demonstrated to increase significantly student interest, motivation, and learning.

Despite of the challenging technical complexity and sophistication of the autonomous flight area, the general course design and implementation methodology has been demonstrated to be attractive to students facilitating and enhancing significantly the learning process.

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