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Project Overview

1.1. Overall goal or purpose

The class was commissioned by a government entity to develop a flight vehicle that will serve as an airborne sensing platform for high precision antenna calibration. The class is a year long (two semesters) and by the end of the spring semester the class designed, built, and tested an aircraft that was delivered to the government entity.

1.2. Societal context and relevance

This project has real world significance because of the collaborators involved, including a government entity and other specialists from local aerospace companies. Demand for the project grew out of the government entity's presently high expenditures from flying manned radar calibration missions and their desire to have a lower cost and more flexible radar calibration system.

From the government entity: We currently do not have any capability similar to what we are proposing. We are relegated to using either fixed towers with limited geometry or very expensive flight missions with general aviation aircraft. We are looking to improve our measurement flexibility as well as reduce our cost, and we believe that a small UAV based system will achieve this.

1.3. Integration (e.g., where project fits in a course, program, or curriculum)

This course focused on the synthesis of a flight vehicle design to meet a given set of design objectives or specifications. It was an opportunity to exercise the individual disciplines taught in Aeronautics/Astronautics (i.e. fluids, structures, control, human factors, etc.), and to explore the complex interactions between these disciplines.

The course is one of three junior/senior capstone design courses. It is the only capstone course devoted to an aircraft project. Each capstone course is two or three semesters long and proportionally devotes the semesters to design, build & test, and operation-related activities. The students are free to "mix and match" amongst these courses as long as they take at least three semesters worth of credits proportioned to design, build & test, and operation-related activities. Thus, the capstone design courses often have a rather transient student composition, which can make it challenging to keep a capstone course's momentum consistent.

Students enrolled in the course must have completed at least four semesters of aerospace courses including courses related to thermodynamics, structures & materials, controls, and basic aerodynamics. Students will also need to know how to use or be willing to learn relevant programming software such as Matlab and computer modeling software such as SolidWorks.

1.4. Description (e.g., complexity, duration, group size and number, budget)

The project involved 36 undergraduate and 8 graduate students, 3 faculty members, 1 technical staff member, 1 research assistant, 1 teaching assistant, 1 communication staff member.

Because of a unique design/build opportunity, the undergraduate and graduate aircraft systems courses were integrated into one major design effort. In general, the core requirements and activities were the same for both student groups who participated as a common team. However, there were some additional requirements for the graduate students. Much of the fall semester work in fell into the conception and design phases. In the spring follow-on course, the flight vehicle was built, tested, and flown.

1.5. Learning activities and tasks (brief summary)

Students will design, build, and test a flight vehicle that will serve as an airborne sensing platform for high precision antenna calibration. The experience gained from the design project will be augmented by lectures on topics that typically arise in aircraft design or are relevant to a specific design problem. The lab activities will include group and individual design activities as well as prototyping as appropriate. Design reviews that will be conducted include:

- **System Requirements Review (SRR)** to present the system requirements which are developed based on analysis of customer and mission objectives and specific customer requirements.
- **Concept Review (CoDR)** to present the driving requirements, technology opportunities, design tradeoff issues which have been identified, and one or more basic vehicle concepts which arose from balancing these tradeoffs. Key issues should be identified along with approaches to resolve these issues.
- **Preliminary Design Review (PDR)** to evaluate the process towards a detailed design. Only one concept should be carried forward at this point. Generally the preliminary design will include a frozen vehicle configuration, preliminary design of major system elements, initial performance, stability and control, mass and cost estimates, as well as test requirements and risk areas.
- **Critical Design Review (CDR)** to review the relatively detailed design, and uncover any areas of difficulty or uncertainty needing further attention. This review should be similar to the PDR with more specificity. It should include the detailed design of key components to be built, consideration of fabrication processes, and refined performance and mass estimates. Any remaining risk areas should be identified.

2. Learning Objectives (1 page)

2.1. Technical objectives (e.g., basic math, science and engineering knowledge, skills, processes and procedures)

At the completion of the fall semester, students will be able to:

- Summarize the mission requirements and develop a set of system and subsystem requirements that define a vehicle that meets the mission requirements
- Develop a set of Figures of Merit (FOM) that quantitatively characterize the performance of the system to meet the mission requirements.
- Develop a system architecture which provides a “best solution” to meet the mission requirements based on the FOM

- Based upon the chosen system architecture, design a vehicle which: “closes” technically, i.e. satisfies the laws of nature; is build-able within the time and cost constraints; can be tested to verify that it meets the mission requirements; is operable in the mission environment.
- Complete the detailed vehicle design with analysis and drawings to a level that the vehicle could be produced by someone else

At the end of the spring semester students will be able to

- Fabricate or acquire subsystems and assemble the complete system to prepare for testing and evaluation
- Execute system and subsystem level test to demonstrate that the vehicle can be operated safely and achieve the mission requirements
- Report the outcomes of the vehicle performance and resulting lessons learned

At the completion of the fall and spring semesters, students will be able to:

- Apply project management methods to execute the project on schedule, with resource constraints, and to deliver the technical performance measured by the FOM
- Keep records of work done and document progress made to achieve the design project objectives
- Practice effective technical communication skills---both oral and written---for a range of professional situations: informal team work, formal design reviews, written portfolios and formal written reports.
- Evaluate progress towards team and class goals.

2.2. CDIO outcomes (e.g., personal and professional skills and attributes teamwork, communication, conceiving, designing, implementing and operating skills)

2.1.5 Solution and Recommendation
2.2.4 Hypothesis Test, and Defense
2.3.4 Trade-offs, Judgment and Balance in Resolution
2.4.4 Critical Thinking
2.4.7 Time and Resource Management
3.1.2 Team Operation
3.2.3 Written Communication
3.2.5 Graphical Communication
3.2.6 Oral Presentation and Inter-Personal Communications
4.3.3 Modeling of System and Ensuring Goals Can Be Met
4.3.4 Development Project Management
4.4.1 The Design Process

3. Project Description and Student Instructions

3.1. Project description (e.g., brief description of project purpose and context)

The flight vehicle system will assist in open-air measurements of as-installed antenna patterns of ground radar and other sensor systems. Specific system objectives include:

1.) Autonomously fly a 1 to 3 hour mission with a flight profile suitable for collecting the required antenna measurement data. The primary objective is controlled flight through the desired altitudes and sampling locations. The threshold design requirements call for flight operations at altitudes of 2,000 to 10,000 feet and a ground range of 2 to 10 km from the ground based radar site. Furthermore, the design goal is to allow for operations at altitudes of up to 25,000 feet and a ground range of 25-50 km from the radar site

2.) Execute the specified mission (e.g. conduct power measurement) without requiring any significant infrastructure (e.g. other than a generator for powering any ground component, no other power, communication, or facilities are to be required). As a result of this objective, minimum size and weight are also desired. Payload size, weight, and power will be provided by the government entity and will be modular in design.

3.) Return the data collected. This data must include accurate vehicle position and the time corresponding to each measurement. Depending on the payload, data collected may include received power measurements.

4.) Be able to conduct another mission within 24 hours.

3.2. Learning objectives

At the completion of the fall semester, students will be able to:

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- Develop a set of Figures of Merit (FOM) that quantitatively characterize the performance of the system to meet the mission requirements.
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- Based upon the chosen system architecture, design a vehicle which: “closes” technically, i.e. satisfies the laws of nature; is build-able within the time and cost constraints; can be tested to verify that it meets the mission requirements; is operable in the mission environment.
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- Fabricate or acquire subsystems and assemble the complete system to prepare for testing and evaluation
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At the completion of the fall and spring semesters, students will be able to:

- Apply project management methods to execute the project on schedule, with resource constraints, and to deliver the technical performance measured by the FOM
- Keep records of work done and document progress made to achieve the design project objectives
- Practice effective technical communication skills---both oral and written---for a

range of professional situations: informal team work, formal design reviews, written portfolios and formal written reports.
- Evaluate progress towards team and class goals.

3.3. Learning activities including specific procedures, tasks, etc.

Design reviews are an important part of the design process which mark the culmination of various design phases. They provide the opportunity for a critical review of the design to evaluate its viability and to identify areas of concern. It is expected that design reviews will include (at least) a description of the vehicle (e.g. 3 view, budgets and margins, master equipment list, weight and balance, etc.), a rationale for the choices and decisions that were made with regard to the design of the vehicle, and a discussion of issues. It is normal to have issues emerge in the design reviews. These issues should be resolved before the next major review or in some cases a "delta" review will be conducted shortly after the major review to resolve specific issues. There will be four design reviews. Design reviews follow periods of peak activity and students should plan ahead accordingly. It is expected that each student will present in at least 1 design review. If a student presents in more than 1 review, the best grade will be used. The design reviews that will be conducted include:
- **System Requirements Review (SRR)** to present the system requirements which are developed based on analysis of customer and mission objectives and specific customer requirements.
- **Concept Review (CoDR)** to present the driving requirements, technology opportunities, design tradeoff issues which have been identified, and one or more basic vehicle concepts which arose from balancing these tradeoffs. Key issues should be identified along with approaches to resolve these issues.
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The CoDR, the PDR and the CDR will have "dry runs" with a communication instructor and a TA several days before the review in order to help students and teams refine their oral presentations. It is strongly encouraged that the students practice their SRR presentations prior to the SRR.

Effective reporting and documentation are absolutely indispensable in any large engineering project. Support will be available for presentations and written communication. The reporting activities are:
- **Notebooks** - Each team member must keep some record of his/her work on the project, whether it is in the form of handwritten notes, disk-stored spreadsheets, or computer printouts or graphics. Eventually, all relevant material must be condensed

into the oral progress reports and the final written report, so early organization will pay off later. If someone else can go through your raw documentation and follow it, you are more organized than most people.

- **Portfolio** - Each student will create a portfolio that will document their work and contributions throughout the semester. This is an ongoing, continuously expanding, and revised document. It is useful to think of the portfolio as a digested form of the raw material from the notebook. It is expected that parts of the portfolio will be used as a portion of the final design document. The portfolio shows the individual work of each student as a contribution to the larger project. An example will be provided in the wiki. The portfolio should be continuously updated but will be submitted for review 3 times during the semester. In some cases the staff may make an interim request to review specific portfolios.
- **Design Document** - This is the main documentation of each team's efforts. It typically is a collection of chapters or sections written by individual team members. Each chapter will have a student responsible for its integration. One team member will be responsible for integrating the entire report. A draft version of the design document will be due 9 days before the final delivery date to allow feedback from the course staff. More specific guidelines for the written report will be given later.
- **Peer Assessment** - Twice during the semester (at the time of the CoDR and PDR), each student will electronically submit a colleague assessment of six other students in the class as well as themselves. You will be graded based upon how insightful and constructive your reviews were of others as well as on how others perceived your contributions to the project.

3.4. Assessment criteria and standards

Activities	Points	Team/Individual Grade
System Requirement Review (Presentation)	5	Team
Concept Review (Presentation)	5	Team
Preliminary Design Review (Presentation)	5	Team
Critical Design Review (Presentation)	10	Team
Draft Design Document (Report)	5	Team
Final Design Document (Report)	20	Team
Individual Contribution (Technical & Program)	20	Individual
Portfolio	20	Individual
Peer Review	5	Individual
Individual Briefing	5	Individual
Subsystem Lecture (Graduate students only)	15	Individual

This class does not have a weekly mechanism for helping students track their grade. There will be prolonged periods during which students not be given quantitative feedback about performance.

3.5. Equipment, tools, supplies and/or materials

Fully equipped lab and machine shop. Composite materials including foam, fabrics, epoxy, and resins.

3.6. Safety and risk mitigation procedures

Standard lab and shop safety procedures with the addition of special handling and care for fuel and batteries. Precautions were taken during the testing phase in particular when operating the aircraft engine since the spinning propeller poses a serious risk of injury. When operating or testing the aircraft, it was required that at least two students be present to help reduce incidents due to oversight. Since the aircraft is autonomous, it cannot be flown in public airspace.

3.7. Deliverables (e.g., products, oral and written reports, and/or reflective journals)

PRODUCT ITSELF (the flight vehicle)

DESIGN REVIEWS

- **System Requirements Review (SRR)**
- **Concept Review (CoDR)**
- **Preliminary Design Review (PDR)**
- **Critical Design Review (CDR)**

REPORTING

- **Notebooks**
- **Portfolio**
- **Design Document**
- **Peer Assessment**

4. Instructor Guide

4.1. Commentary on conducting the project keyed to the Student Instructions

A school-provided site will be available and used for posting lecture notes or announcements to the class.

A wiki site will also be set up for the class. Students will be required to upload all their written materials to the wiki including: the design documents, individual portfolios, and presentations. Permissions have been set so that students can add material to most pages, but are not able to delete material. The wiki will be set-up to maintain privacy of the information within each team. Individual work will be managed so that it is made public only when complete.

Course Flow

Lectures were held on Tuesday and Thursday from 2:30-5:00pm. Typically, there was a 30-40 minute class-wide meeting at the beginning of each class to address problems/challenges that spanned more than one subsystem group. This meeting was sometimes eliminated if there was a lecture that day. Following the meeting, students went directly to the lab. While the students met and performed most of their work outside of the formal course time block, it was important that they were all in the lab from 3:30-5:00pm on Tuesday and Thursday to guarantee at least some working sessions in a given week where students and instructional staff could rely on *everyone* being there.

The following is provided to students in the syllabus:

The following are lessons learned from previous capstone classes. Please read these carefully because they were learned through hard work and experience. By understanding the cause, effect, and solution, this class will be able to work more productively which leads to a better product and learning experience and possibly less overall work.

- Students (and faculty) often get into the mindset that they cannot perform their work until they get information from others. This inevitably leads to a drawn out, sequential process that consumes precious time. It is important to search for tasks that can be done concurrently or on a "first pass" using preliminary estimates. Once the needed information becomes available, utilize it to complete your work.
- Lead through example, not orders. Sometimes the quietest person can be the best leader. The person who identifies and solves problems, and helps others to do the same, is a natural leader.
- Seek multiple views and opinions on questions. Unlike standard homework problems, design choices have many possibilities. It is often hard for a single individual to think of multiple approaches. This is where the team approach becomes valuable. Always take a moment to consider opposing arguments during discussions. Often trying to actually argue in favor of the opposition will help provide a new perspective which leads to a better design. Avoid rejecting suggestions "out of hand" without pausing to reflect. Often "one thing leads to another" and positively thinking about a suggestion will lead to yet a new idea.
- Designing, building and operating a product requires a working appreciation for hardware fabrication and testing techniques. Acquire this experience as early in the program as possible. A spiral approach is effective whereby the team goes through a complete cycle, knowing it doesn't yet have the final design or answer, but in the process gaining valuable experience.
- Unlike classes with tests and problem sets that provide weekly updates on performance, this class is more open-ended and representative of the "real world." Learn to self assess. Develop the skills to recognize when you are doing well and when your performance is sub-par. Do teammates look to you for guidance? Are you on time with deliverables and attend all scheduled meetings, both inside and outside of class? Are you a major contributor during "crunch times?" Has the class started to pass you by?
- Analysis saves time and money. Guessing and building prior to analysis wastes resources.
- The largest amount of wasted effort occurs during the first third of the first semester. Think about what you need to accomplish. Envision the end state. Define deliverables and interfaces with your teammates and other teams. Organize. Get traction.

4.2. Team Organization and Management suggestions (e.g., number of groups and group size, initial organization, and ongoing management)

2-4 teams were created by course staff during the design phase. After the design-phase, course staff created several specialty teams (of at least 4 students) based on student interests and expertise when possible.

4.3. Assessment –

4.3.1 Criteria (e.g., to judge the quality of student products, processes, or performances relative to the learning outcomes and activities)

Students were evaluated based on completion of requirements, including design reviews and reporting documents. Course staff also considered student's investment regarding effort and time.

4.3.2 Methods and materials (e.g., rubrics for oral/written reflection methods, peer/team self-evaluation, assignments, lab reports, and standard quizzes embedded in the learning activities)

5. Resources

5.1. Budget (e.g., recurring and non-recurring expenses)

Funding required to support 3 full TAs, 3 faculty members, 1 technical support staff member. Roughly $50,000 was budgeted for materials

5.2. Equipment and tools

Fully equipped lab and machine shop. Composites (including foam, fabrics, epoxy, resins)

5.3. Materials and supplies (e.g., reusable and consumable including hazardous materials)

Batteries and fuel resources used in this project are considered hazardous materials.

5.4. Staffing (e.g., describe particular skills and scope of commitment)
Instructors
technical staff
others (e.g., additional expertise or licensure)

Included 3 faculty members, 1 technical staff member, 1 research assistant, 1 teaching assistant, 1 communication staff member

5.5. Spaces (e.g., minimum feasible space requirements per student or per student team, whether space is dedicated or used only during student activity, and use of space for design, build, operate, and storage)

Shared design lab, shared machine shop, lecture hall, and testing area.

5.6. Other resources (e.g., computer hardware and software)

Athena Vortex Lattice (AVL) XFOIL
Matlab & Simulink Maple, Mathematica Tecplot
LaTex
SolidWorks

References

- Raymer, D. P., Aircraft Design: A Conceptual Approach, AIAA Education Series, 1990. (on reserve)
- Stinton D. The Design of The Aeroplane, BSP Professionals Books, 1983, (on reserve)
- Roskam, J. Airplane Design, Parts 1-8, 1990.

- Torrenbeek, E., Synthesis of Subsonic Aircraft Design, Delft University Press, 1986.
- Kuchmann, D., The Aerodynamic Design of Aircraft, Pergamon Press, 1978.
- Bertin, J.J., Simth, M.L., Aerodynamics for Engineers, Second Edition, Prentice Hall, 1989. (on reserve)
- Kuethe, A. M., Chow, C.-Y., Fondations of Aerodynamics, Fourth Edition, John Wiley and Sons, 1986. (on reserve)
- Hoerner, S.f., Fluid Dynamics Drag, Bricktown, N. J., 1956. 9.
- JANE'S All the World Aircraft, published yearly and available online via VERA 10.
- Papers and notes to be handed out and posted on the course website.

6. Safety and Risk Mitigation

6.1. Operational safety

Testing autonomous vehicles requires additional safety considerations. From an operational standpoint, there must a fail-safe mechanism to bring the aircraft down if it enters a pre-specified "no fly" zone and there must always be a manual operator override capability.

6.2. Governing policies and regulations (e.g., governmental and institutional)

Depending on the characteristics of the aircraft, it may fall under Federal Aviation Administration (FAA) regulations. Testing will require special provisions if this is the case.

Due to the use of radar in this project, Federal Communications Commission (FCC) regulations should also be considered.

Model aircraft rules and regulations can be found at: http://www.modelaircraft.org/documents.aspx.

7. Other information, for example:

7.1. Possible variations in the project

In previous years, the course project was an entry for the Cessna/Raytheon Missile Systems Student **D**esign/**B**uild/**F**ly competition. More information about the competition is available here: http://www.aiaadbf.org/.

7.2. Supplementary multi-media and other resources

Web references:

- FAR Part 23 Airworthiness Requirements: Google "Electronic Code of Federal Regulations", Title 14 – Aeronautics and Space, Part 23

7.3. Sample student products from previous iterations of the project

Appendix I

Table of Contents from Final Design Document

References

Appendix II

Outline for Portfolio

- Purpose and Intended Audience
- Outline
- Main Message
- Personal Role and Responsibilities
- Relevant System and Requirements
- Analysis
    - Models
    - Items, Masses, and Cost
    - Approach
    - Test Plan
    - Test Results
- Future Work
- Schedule List of References