A&AE 451
Aircraft Design
Professor Dominick Andrisani
Fall Semester 2000

Objectives of this course

The objective of this course is to learn about the art and science of aircraft design through first hand experience with a semester long aircraft ***design, build, and test*** project.

Class schedule and procedures

The class meets in "lecture" format at 12:30-1:20 P.M. on Tuesday and Thursday unless otherwise noted. The Tuesday "laboratory" session will meet from 1:30 till 4:20 P.M. Classroom discussion, sharing ideas and group effort are vital to the success of the course. It is absolutely important that you attend class and be on time. Attendance is recorded and will be figured into your grade.

Final grades will be assigned on a competitive basis with point totals assigned for class exercises, participation, team work and contributions to the Preliminary Design Report and the Thiokol Design Report (final report). Creativity, interpersonal skills, intuition, and enthusiasm will effect your grade in this course. Of course, these same skills and traits will determine your professional success as well. Not all persons on the same design team can expect to get the same course grade. Each member of a design team will have the opportunity to grade the performance of every other member of the team. This will also be figured into your course grade.

The Professor and the TA

Professor Dominick Andrisani, Grissom Room 328, Phone 494-5135, e-mail: andrisan@ecn.purdue.edu. Professor Andrisani is available most hours in his office. If you are making a special trip to campus to consult with him, please call to make an appointment to insure that he is available.

Professor Andrisani has been at Purdue for 20 years and has taught A&AE 421 (29 times), A&AE 574 (9 times), A&AE 474 (7 times), A&AE 565 (8 times), A&AE 203 (5 times), A&AE 451 (4 times), and A&AE 421L (4 times). He has been a contributor to the research fields of state estimation, target tracking, aircraft handling qualities, and missile guidance. He is the author of over 100 journal papers, conference proceedings and reports in these areas.

Teaching assistant - Tulin Kayir, office: Grissom Hall Room 350 Desk #23 phone 494-5153, e-mail: tkayir1@purdue.edu.

Required Textbooks

Dr. Jan Roskam, *Airplane Design*, *Volumes I and II*, Roskam Aviation and Engineering Corporation, (All volumes in this 8 volume series are helpful although only the first two are required.). [Some students find the following book helpful. Dan Raymer, *Aircraft Design: A Conceptual Approach*, AIAA Education Series.]

The Art of Design

Design is the art of putting things together to create an object. Dictionary definitions - "to plan - to contrive - arrangement of parts, detail and forms" - don't quite capture the essence of the design process. Design has several well-defined steps and uses scientific processes. Still - design is an art and there are elements of design that defy exact description and cannot be taught, only learned. Our purpose this semester is to learn the essential steps in the design process by creating an object - an unmanned aerial vehicle. During this process, the artistic values of design will be seen - we hope.

Although this course is called "aircraft design," what we learn during the semester will have broad uses ranging from engineering to political science to personal behavior this course will change the way you think and approach all of your problems. A major goal for this course is to blend together traditional aerospace subjects with management skills to create the ability to handle multi-disciplinary problems.

This course is designed to integrate material taught in other courses. Very little new material will be presented. Students are expected to determine on their own what is needed, where to find the required resources, and how to determine the required answers.

New designs appear because of one of four reasons. The first is the functional failure of current technology to provide a need. For instance we might need a new road to provide high speed traffic. The second reason is to extrapolate past successes. This might be a new, slightly better airplane to haul a few more passengers. The third reason for a new design is the threat of potential failures of current designs. We might want a new stealth fighter to counter projected advances in radar defense systems. Finally, a new design might appear because we have imbalance between technologies in current designs. This might arise when we have new engines powering old designs. The turbojet engine changed aerodynamic and structural design. These reasons for new designs will affect our discussions about the exact details of our small airplane design objective.

Design, Build, Test

Design, build, test is a hands on educational approach that allows Mother Nature to both confirm and qualify the analysis and design methodologies taught in the classroom.

The approach starts with a single piece of paper, the mission specification, and involves twelve weeks design work conducted by multidisciplinary teams. The design process is monitored in twelve major design reviews.

Students have three weeks to build the aircraft.

The design process ends in flight testing within the Mollenkopf Athletic Center during the fourteenth week of the semester when we see whether the aircraft system meets the mission specification.

Required written and oral reports

During the semester we will generate homework assignments and reports. The two major team reports are the Preliminary Design Report and the Thiokol Design (Final) Report. The Preliminary Design Report is due in early November, while the Thiokol Design (Final) Report is due at the end of classes. These reports are 25 pages (maximum) with unlimited appendices and attachments. Further details of these reports will be given in class.

In addition to these major reports, you will give oral reports to the class during the semester and provide written team progress reports. We will also have individual and team homework assignments that will contribute to your grade.

Elements of design - aircraft and otherwise

Understanding how wings, tails, fuselages, engines and landing gear work together is a systems level operation. Analysis emphasizes taking objects apart and isolating them. Design emphasizes understanding how to put concepts together.

Devices that engineers design will address and solve some human related problem. The most unusual (and annoying) feature of design activities is the requirement that we clearly define the problem that the device is intended to solve as well as design the device (our airplane) itself. Unless there is a clear identification of the customer needs and the goals of the device, coupled with the knowledge that the design effort has a reasonable probability of success, no acceptable design will be found.

All design efforts have six essential steps.

- Identification of a market/user needs - this is called listening to "the voice of the customer"

- Development of a Mission Specification that defines the purpose of the device and has clearly defined measures of goodness or performance.

- Generation of possible design concepts. At this stage we need to identify which disciplines must be included/excluded in a preliminary design effort? Problem parameter definition (e.g. wing span, taper ratio) must be included. The question is - What is important and what is not?

- Definition of preliminary design concepts and measurement of these concepts against the requirements of the Mission Specification and other "measures of goodness" using appropriate analytical techniques and previous experience (manufacturing, cost, etc.). This stage identifies conflicts and interdisciplinary issues. This leads to the baseline concept in the next step.

- Definition of the baseline concept and optimization of this concept. How do the individual disciplines interact? When and in what sequence is each discipline to be considered? Trade studies examine interactions (e.g., effect of cruise Mach number on wing weight, empty weight and take-off gross weight). Interdisciplinary conflict resolution - measures of system performance. Development of interdisciplinary synergism - making interaction work (e.g. location of the canard plane to get favorable wing downwash interaction)

- Communication of results to a variety of audiences in written and oral formats

Topics to be covered in this course

To design an .... aircraft we need to know how the airplane operates and then understand how to organize an effective design effort. We also need to know where to find information sources. Some of this information will be distributed in class. Additional information is available in our design library in Grissom 100. We also need to know how to organize a project. Here are some of the major areas we will cover.

Teamwork - TQM and industry - The initials TQM stand for Total Quality Management. TQM provides an organizational methodology to help designers understand and define objectives and to understand the process by which that objective will be achieved.

The majority of our work will be done by teams. This is a very uncomfortable concept at first, but it is the way things are done in industry and is essential to the design process. A manager of a major aerospace group once commented that "...if Albert Einstein worked for (company X), he'd be among the first to be laid off. We don't appreciate lone wolves here because we work in teams. When a project succeeds, we can't name the one person who developed the idea because so many people contributed as a team."

Economics - Aircraft production is justified only by economic drivers. We must be aware of the type of business that our products will serve. The air transportation industry and the military establishment have specific economic requirements and a language all of their own.

The aeronautical engineer must understand why the aircraft exists and where costs and revenues come from and understand the complexities of the economic system to understand why we need to build a new design. We need to understand economic reasons and exercise analytical models to predict costs of a new aircraft. We need to develop an interactive model to permit examination of the sensitivity of the economy to changes in aircraft economics and manufacturing economics and to present this model to students and engineers.

Manufacturing and structures - Manufacturing is closely coupled with costs and structures, although most structural design emphasizes least weight designs to the exclusion of issues in manufacturing complex shapes. Seemingly minor issues like the shape of a panel and the weight of the panel influence manufacturing and acquisition cost. While some shapes of load bearing structure may be superior for load bearing ability, they may cost more and as a result they will not be chosen for design.

The choice of materials is cost driven by manufacturability, reliability, maintainability and inspectability. The primary material considerations are manufacturability, which relates to acquisition cost, and service operation, which relates to direct and indirect operating costs and is related to fatigue and fracture characteristics of the materials used.

Operational loads and weight estimation - Structural loads define the structure and the structure defines the loads. Generating estimates of structural loads quickly and feeding them into a structural design process is not easy. Weight estimation and estimating the cost of structural weight is an art as well as a science. For conventional designs weight trades can be simulated with well-known formulas for component weights in terms of geometrical and operational design parameters such as wing aspect ratio, sweep angle and take-off gross weight. These formulas were generated from least-square curve fits of published data for existing aircraft.

Trade studies - Analysis supports design efforts. Designers need to fit all of the pieces together into an efficient system where system requirements like range or cost dominate over disciplinary requirements such as aerodynamic elegance. We must identify quickly which design features are important and what is least important to the success of the design effort. What is necessary and what is "nice?" Typically these questions are answered by trade studies where major disciplinary parameters such as wing span are displayed against empty weight or fuel weight to judge their importance.

The "what if" decisions are important to design. Computing the formal derivatives of design output variables, such as fuel weight, with respect to input variables, such as wing span or materials choices, constitute a measure of the sensitivity of the system to changes in disciplinary variables. On the other hand, because changes in wing span, for instance, affect several disciplines at once, the computation of sensitivity derivatives is not a simple matter.

Sensitivity analysis will support good design judgment and help to develop intuition or else student designers will be presented with yet another bewildering array of numbers generated for a class grade. Optimization, by itself, may be useless unless the student designer understands fully what the important performance indices are in a design. A course in multi-disciplinary optimization, its objectives, organizational structure, and examples to illustrate its use will provide this guidance.

Modeling, analysis and organization for design- The differences in terminology in the various areas of engineering and the different levels of analytical fidelity are barriers to interdisciplinary cooperation. The decomposition of a large system for analysis is not obvious.

The organization of the data flow (data transmission links) from one team member to another and the sequence of design/analysis operations is very important. It is not obvious how we should organize the design of an operation with many different interacting parts. This organizational structure will determine critical data paths and the importance of one discipline with respect to another.

Development of communication skills - Interdisciplinary interaction during the design process requires the generation of large volumes of unorganized data. This information must be organized and exchanges among team members with different disciplinary responsibilities. Needs of one group should not be unrecognized by others.

Communication of results and issues is an essential element in design. There is a feedback process between understanding and communication that allows the communicator to more completely understand the design process. Communication (oral or written) has several purposes:

- to explain design and progress of design effort to others (including the writer),
- get feedback early in the design stage,
- improve chances of synergistic breakthroughs to improve the design.

As part of the communication process, we will learn to organize data and to display it effectively. Each of you will maintain a design notebook that includes all your work, initial concept, preliminary results, final details about your design. Oral and written reports will be required throughout the semester. A major written assignment that is done by teams is participation in the Thiokol Design Communication Competition. Each team will prepare a 25-page report that will be evaluated for technical writing content by a panel of Thiokol engineers and managers. We will have seminars on technical writing during the semester.