A&AE 451
Aircraft Design
Professor Dominick Andrisani

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 in Armstrong Hall Room 1021 at 1:30-2:20 PM. on Tuesday and Thursday unless otherwise noted. The Tuesday "laboratory" session will meet in the ARMS 1-21 at 9-11:20 AM. 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 often recorded and may be figured into your grade.

The Professor and the TA

Professor Dominick Andrisani, Armstrong Hall Room 3203, Phone 494-5135, e-mail: andrisan@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.

Teaching assistant – Stephan Lehner (slehner@purdue.edu)

Grading

Final grades will be assigned on a competitive basis with point totals assigned for class exercises, participation, teamwork and contributions to the Preliminary Design Report and the Thiokol Design Report (final report). Please refer to the handout entitled "Behavioral Dimensions of Grades." Not all people on the same team will get the same grade. Creativity, interpersonal skills, intuition, and enthusiasm will affect 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 two opportunities to grade the performance of every other member of the team. This will also be figured into your course grade.

Required Textbook

Dan Raymer, *Aircraft Design: A Conceptual Approach*, AIAA Education Series. [Some students find the following book helpful. Dr. Jan Roskam, *Airplane Design, Volumes I-VIII*, Roskam Aviation and Engineering Corporation].

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 open ended 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.

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 ten weeks design work conducted by multidisciplinary teams. The design process is monitored in roughly twelve major design reviews. After the third week students do most of the talking in this course.

Students have three weeks to build the aircraft.

The design process ends in flight-testing just before Thanksgiving when we see whether the aircraft system meets the mission specification. **Students in this course must be present for the flight testing of their aircraft on the Tuesday before thanksgiving.**

Required written and oral reports

During the semester we will generate individual and team homework assignments and reports. 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 the final report, you will give oral reports to the class during the semester and provide written team progress reports.

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 - 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.

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.

Design, what is it?

1. To conceive in the mind; invent: designed his dream vacation.
2. 2. To form a plan for: designed a marketing strategy for the new product.
3. To have as a goal or purpose; intend.
4. To plan by making a preliminary sketch, outline, or drawing.
5. To create or execute in an artistic or highly skilled manner.

Design is ...

Design is creating the geometric description of the thing to be built.

Design is not the same as drafting. In a good design everything needed is there, everything fits, everything is in the right place.

Good designs will survive detailed analysis with minimal changes.

Design is the analytical process used to determine what should be designed and how the design should be modified to better meet the requirements.

The design process begins with ....

(this is hard to complete)

the design concept,

or the initial weight estimate,

or the requirement.

All are correct.

Design is an iterative effort.

Phases in the life of an aircraft

– 1. Planning and conceptual design(the primary focus of this course)

– 2. Prelim. design and system Integration

– 3. Detail design

– 4. manufacturing and Acquisition

– 5. Operation and support

– 6. Disposal

Conceptual design

Basic questions of configuration arrangement, size, weight, and performance are answered.

Will it work?

What does it look like?

What requirements drive the mission?

What tradeoffs should be considered?

What should it weigh and cost?

Trade off studies are considered to…

determine the sensitivity of some aspect of the design to a particular requirement, e.g., the sensitivity of gross weight to required range,

the effect of one design parameter on another design parameter, e.g. what combinations of thrust to weight ratio and wing loading will satisfy the design requirements.

Preliminary Design

(begins when the major changes are over)

Freeze the configuration,

Develop lofting (mathematical modeling of the outside skin of the aircraft),

Develop and test analytical base,

Design major items,

Develop actual cost estimate, ("You-bet-your-company").

Detail Design

- Design the actual pieces to be built, e.g. individual pieces of the wing box are separately designed and analyzed,
- Design the tools and fabrication process,
- Test major items - structure, landing gear,…
- Finalize weight and performance estimates.

BEHAVIORAL DIMENSIONS OF GRADES IN THIS CLASS

'A' or OUTSTANDING STUDENTS	'C' or AVERAGE STUDENTS
1. Ability (Talent)	
...have special aptitude, motivation, or a combination of both. This talent may include either or both creativity and organizational skills.	...vary greatly in aptitude. Some are quite talented but their success is limited by a lack of organizational skills or motivation. Others are motivated but lack special aptitude.
2. Attendance (Commitment)	
...never miss class. Their commitment to the class resembles that of their professor. Attending class is their highest priority.	...periodically miss class and/or are often late. They either place other priorities, such as a job, ahead of class or have illness/family problems that limit their success.
3. Attitude (Dedication)	
... show initiative. Their desire to excel makes them to more work than is required.	...seldom show initiative. They never do more than required and sometimes do less.
4. Communications Skills	
...write well and speak confidently and clearly. Their communication work is well-organized, covers all relevant points, and is easy to listen to/read.	...do not write or speak particularly well. Their thought processes lack organization and clarity. Their written work may require a second reading by the professor to comprehend its meaning.
5. Curiosity	
...are visibly interested during class and display interest in the subject matter through their questions.	...participate in class without enthusiasm, with indifference, or even boredom. They show little, if any, interest in the subject matter.
6. Performance	
...obtain the highest scores in the class. They exhibit test-taking skills such as an ability to budget their time and to deal with test anxiety. They often volunteer thoughtful comments and ask interesting questions.	...obtain mediocre or inconsistent scores. They often do not budget their time well on exams and may not deal well with test anxiety. They are rarely say much during class discussion and their answers indicate a cursory understanding rather than mastery of material.
NOTE: Performance is a joint function of a student's native ability and motivation. Punctuality, attendance, attitude, curiosity, effort or time commitment, and preparation all indicate motivation.	
7. Preparation	
...are always prepared for class. They always respond when called on. Their attention to detail sometimes results in catching text or teacher errors.	...are not always prepared for class. They may not have fully completed the assignment, have completed it in a careless manner, or hand in their assignments late.

'A' or OUTSTANDING STUDENTS	'C' or AVERAGE STUDENTS
8. Retention	
...learn concepts rather than memorize details so they are better able to connect past learning with present material.	...memorize details rather than learn concepts. Since they usually cram for tests, they perform relatively better on short quizzes than on more comprehensive tests such as the final exam.
9. Time Commitment (Effort)	
...maintain a fixed study schedule. They regularly prepare for each class no matter what the assignment. They average 3-4 hours of study for every hour in class.	...study only under pressure. When no assignment is due, they do not review or study ahead. They average no more than 2 hours of study for every hour in class. They tend to cram for exams.

Source: Standards, Assessment and Testing Committee—Dr. Paul Solomon, Chair, College of Business, San Jose State University, April 1995. Adapted from John H. Williams, "Clarifying Grade Expectations," *The Teaching Professor*, August/September 1993, re-published in *The Teaching Professor*, February 1996 by Paul Solomon and Annette Nellen.

A&AE-451 Survey Sheet
Fall 2008

The purpose of this survey is to determine your areas of interest and how you can contribute to a design team effort. Please carefully evaluate your own capabilities and interests before completing this survey form.

Name ______________________________

E-mail address: ____________________________________

Technical interest area (Please rank your interest in each of these areas, place the number 1 in front of your first choice, 2 in front of your 2nd choice, etc.)

__ aerodynamics/system identification from flight data

__ structures/materials/weights/c.g./strength/strength testing

__ propulsion/engines/speed controller/propellers/batteries/

__ dynamics and control/stability/trim/control power/ /EOMs/feedback

Overall GPA range (circle one category)

2.0-2.5

2.5 - 3.0

3.0 - 3.5

3.5 - 4.0

List any experience you have with model aircraft.

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List classmates you would like to have on your team.

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