Capstone Senior Design Projects
in Aerospace Engineering

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Abstract:

All undergraduates in Aerospace Engineering Sciences (AES) are required to take a two semester capstone projects course sequence. This sequence includes *ASEN 4018 Senior Projects I: Design Synthesis* (Fall semester) and *ASEN 4028 Senior Projects II: Design Practicum* (Spring semester). In this course senior students will develop a requirements-based design project in self-directed teams. The course is taught by a team of 10 faculty members and two staff members forming the Project Advisory Board (PAB).

This document describes the scope of a typical Aerospace Enginereing Sciences Senior Design project. A list of recent projects sponsored by faculty members or proposed by students is given in Appendix #2.

Background

In the time-frame of 1995 to 2000 the AES department, under the leadership of A.R. Dick Seebass, started a reorganization of the undergraduate curriculum. Perceptions about what a quality education in aerospace engineering is and should be was gathered from employers, alumni, students and faculty. Key elements of that research suggested that there is a major need for hands-on learning through experimentation and design. The fundamental sciences should not be taught solely as theory but theory should have a laboratory component. Concepts learned in class had to be translated into experimental labs with a design component. The approach was termed “active learning.”

In the same time frame the College of Engineering has developed a new building dedicated to active learning: the Integrated Teaching and Learning Laboratory (ITLL). That building was equipped with facilities to support experiments and design laboratory exercises. The AES department took advantage of that opportunity and redesigned its undergraduate curriculum from sophomore to senior level in such a way that most courses include at least several weeks of laboratory activities in ITLL. This focus on design early on in the curriculum lead to a redevelopment of the capstone senior design course at the senior level.

The undergraduate courses became proactive learning courses while establishing technical fundamentals. The implicit curriculum develops engineering skills in analysis, computing, design, experimentation, writing, and public speaking. Design components and team work are essential components of all sophomore courses and of many junior courses. Sophomore and several junior courses are co-taught by two faculty members with differing expertise and/or experience.

Senior Projects Course

Aerospace Senior Design provides students with a high-quality, first-hand experience in the practice of aerospace engineering, producing a prototype to satisfy a specific need or to serve a particular purpose. The curriculum provides senior undergraduate students with a mentored experience working on a requirements-based design project in self-directed teams.

Project ideas can be of two types: design of a new device, vehicle, or system, or design of an experiment to develop new technology or design principles. Both of these projects utilize established technology and design principles. All projects must begin with a requirements definition phase and must include components of a) mechanical, b) electrical and c) software subsystems.

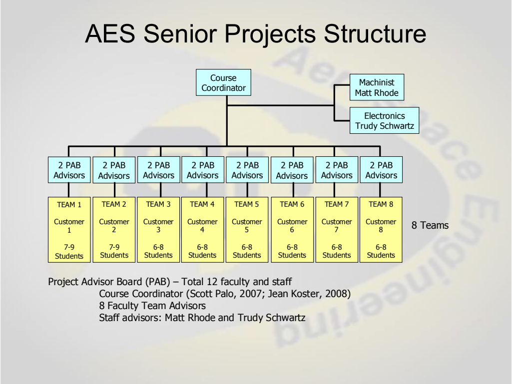
Fundamentals, techniques and tools learned in sophomore and junior courses will be applied in a team environment to carry an engineering idea through to a testable prototype, and to develop an understanding of the technology which would enable the idea to be further developed. Students integrate knowledge from the prior coursework in a practical design analysis based on systems engineering. They evaluate physics concepts and integrate them into engineering which requires an understanding of the impact of changing some parameters on the system. Students learn about systems engineering methodologies*,* design requirements*,* objectives and constraints*,* and assumptions for developing a project. They learn how to make trade studies and sensitivity analysis while developing engineering reasoning and teamwork skills. A major component of the course are several oral presentations where all students develop their communication skills.

Because every project is different, the course will teach students about the engineering process using a "mentoring" approach, as opposed to the familiar "lecture/lab" method. Each team will have two faculty advisors who will meet weekly to guide students through the process, offer advice as needed, and evaluate individual student contributions to the team effort. Workshops will be conducted, as needed, to provide technical assistance that benefits multiple projects. Typical workshops are on systems engineering, electronics/measurements, machining, composite manufacturing, intellectual property, and others as needed. It is important to note that the conduct of each project is the responsibility of the student team. Also, each project must have a specific "customer" who can evaluate the degree to which the project achieves the stated goals. The project may be originally proposed by a customer or students may actively recruit customers to pursue their own ideas. The customer (Faculty, corporation) may propose an exploratory or proof-of-concept project as an undergraduate capstone senior project. Projects which are in the customer's critical path are not accepted as Senior Design projects.

The customer provides a one page project idea description on the Project Proposal (PP) form to the AES Senior Projects Coordinator and presents a detailed Customer Project Definition Document (CPD2) to the students in April. That initial contact with our students gives the potential industrial customer also the opportunity to select summer interns from among the interested junior students. During the two semester senior projects course the customer has the opportunity and charter to mentor a group of up to ten students, which may be an efficient variety of on-the-job training.

During the first week in the fall semester (mid-August) students will select teams around proposed project ideas. The department has set a limit of eight different projects because of resource limitations. Once the team has formed students will meet with the selected customer to fully understand the project which shall allow them to define a set of top level requirements.

Students work in self-directed teams. A typical team consists of between 6 to 10 Aerospace Engineering students of senior standing (Figure 1). Students are required to understand the common purpose of the team, its values, its vision, its goals, its operating procedures, and the roles of each member. Students are encouraged to develop teams with pertinent complimentary skills. Members are required to take select leadership positions such as program manager, systems engineering, safety engineer, specialty lead (e.g. manufacturing, aeronautics), and chief financial officer. Each team is assigned two faculty advisors from the 10 faculty members of the Project Advisory Board (PAB) pool. These faculty members cover a wide range of technical skills. The individual team advisors are generally chosen to match critical needs of select teams and will meet with their teams at least for one hour each week.



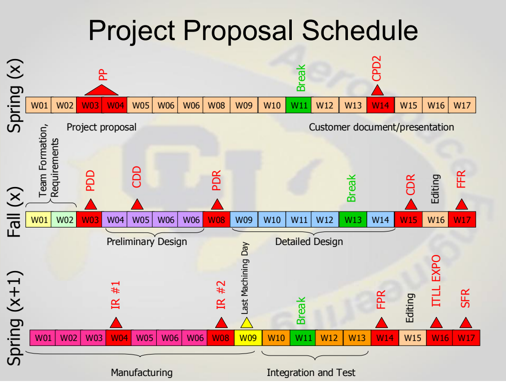
AES Senior Projects Structure

Project Advisor Board (PAB) – Total 12 faculty and staff
Course Coordinator (Scott Palo, 2007; Jean Koster, 2008)
8 Faculty Team Advisors
Staff advisors: Matt Rhode and Trudy Schwartz

Figure 1: Project organizational structure

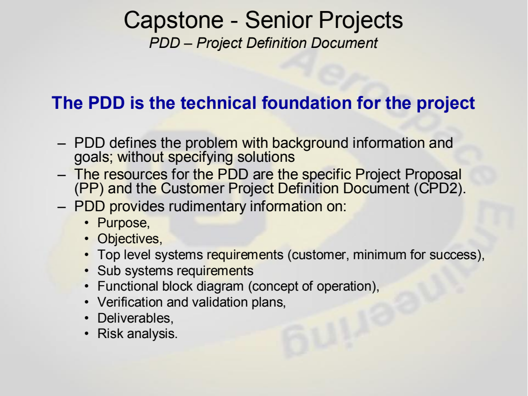
At the beginning of the first semester (fall) of the course (ASEN 4018) students receive a customer provided Project Proposal (PP) and a Customer Project Definition Document (CPD2) which were negotiated in the previous semester (Figure 2). With this start-up package students begin analyzing the design of the proposed system, starting with design concepts and assessing design requirements. This work will be documented in a Project Definition Document (PDD, Figure 3) and followed by a systems architecture analysis documented in a Conceptual Design Document (CDD). Key components in the engineering process learned in this phase are:

- Defining project objectives and scope
- Developing a concept of operation
- Establishing top level requirements
- Identifying key technologies and required skill sets



Project Proposal Schedule

Figure 2: Project time line



Capstone - Senior Projects

PDD – Project Definition Document

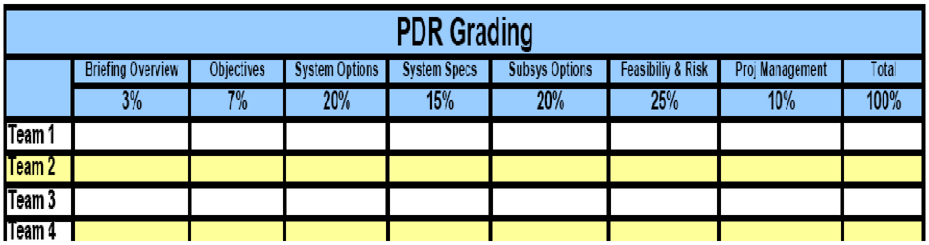
The PDD is the technical foundation for the project

- PDD defines the problem with background information and goals; without specifying solutions
- The resources for the PDD are the specific Project Proposal (PP) and the Customer Project Definition Document (CPD2).
- PDD provides rudimentary information on:
  - Purpose,
  - Objectives,
  - Top level systems requirements (customer, minimum for success),
  - Sub systems requirements
  - Functional block diagram (concept of operation),
  - Verification and validation plans,
  - Deliverables,
  - Risk analysis.

Figure 3: Expectations for the PDD

The teams are required to defend their designs at a Preliminary Design Review (PDR) and at the end of the first semester in a Critical Design Review (CDR). The one-hour (total) presentations during PDR and CDR with questions-and-answers period are held before the Project Advisory Board (PAB) and any customers, who evaluate the project according to a set of predefined grading metrics (Figure 4). It is a course requirement that each student must present at one of these two oral presentations. The key components of the PDR are:

- Developing major design alternatives
- Identifying and assessing risk
- Selecting a baseline design
- Developing subsystem requirements
- Developing evidence of feasibility
- Developing a top level project plan, including contingencies

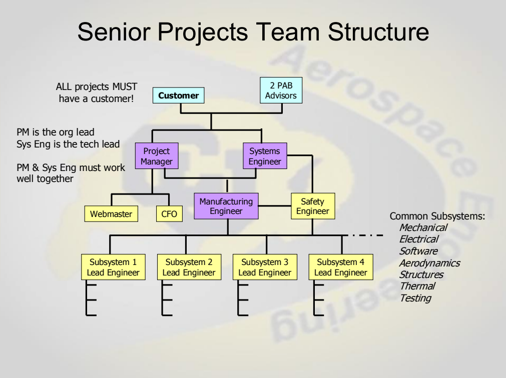


PDR Grading

	Briefing Overview	Objectives	System Options	System Specs	Subsys Options	Feasibiliy & Risk	Proj Management	Total
	3%	7%	20%	15%	20%	25%	10%	100%
Team 1								
Team 2								
Team 3								
Team 4								

Figure 4: PDR grading matrix

By PDR teams are required to have a team organization chart (Figure 5) which details responsibilities of individual students. Each student must assume one kind of leadership position. As the teams are small, individual students have to assume multiple technical functions. After the PDR presentations each PAB member may submit a Request For Action (RFA) form to teams on issues that need special attention. These RFAs need to be formally addressed by a defined date and at CDR.



Senior Projects Team Structure

ALL projects MUST have a customer!

PM is the org lead
Sys Eng is the tech lead

PM & Sys Eng must work well together

Common Subsystems:
Mechanical
Electrical
Software
Aerodynamics
Structures
Thermal
Testing

Figure 5: Suggested team organizational structure

At CDR (at the end of the first semester) teams have to present results from prototyping a critical component of their design and fully understand and document all safety issues encountered in manufacturing and testing of their project. For CDR the key components in the study of the systems engineering process are:

- Detailed modeling and analysis
- Preliminary testing and prototyping
- Design trade-off and selection
- Detailed component specification
- Test planning
- Plans for off-ramp design alternatives
- Costing

- Detailed subsystem and integration planning

The first semester is concluded with a comprehensive Fall Final Report (FFR) which is the CDR in all details. The following topics need to be addressed:

- Project Objectives and Requirements
- Systems Architecture
- Development and Assessment of Systems Design Alternatives
- Systems Design-To Specifications
- Development and Assessment of Subsystem Design Alternatives, including prototyping efforts
- SubSystem Design-To Specifications
- Project Feasibility and Risk Assessment
- Mechanical Design Elements
- Electrical Design Elements
- Software Design Elements
- Performance Analysis
- Integration Plan
- Preliminary Verification, Validation and Test Plan
- Project Management Plan including environmental health and operational safety
- Appendices
    - Requirements flowdown
    - Analysis Details
    - Build-to-Specification Data package
    - Product Data
    - Experimental Data

If the CDR was successful students will manufacture, test, verifiy and document the design of their system during the second semester (ASEN 4028). Students must now validate the original requirements levied on the system. Two Interim Readiness Reviews (IR1, IR2) are held where students inform the PAB about the current status of their project. They must know which parts are procured, which ones are fabricated and what will be tested. All sub-systems have to be individually tested, then integrated into a fully testable system. Troubleshooting, redesign and re-fabrication of components may be needed.

After testing is concluded students report their results in a Final Project Review (FPR) presentation to the PAB and customers followed by a 2-semester comprehensive Spring Final Report (SFR), which is the final deliverable for the two-semester course. The key components of the final project review and report are:

- Test data reduction
- Comparison with models or design predictions
- Understanding discrepancies
- Assessment of project success
- Evaluating prospects for continued development

A last course requirement is to present their project in poster format to the public at the Integrated Teaching & Learning Laboratiory (ITLL) exposition held every year at the end of the spring semester.

Conclusions

In the senior design course students learn how to systematically address a requirements-based project with analysis and testing of sub-systems and reintegration into a fully testable system. All systems satisfy customer requirements and all data are compiled, analyzed and transferred into a communicable form. Results are compared to initial design requirements to determine degree of success. Lessons learned are assessed and provide a benchmark of the learning experience which students carry on into professional life. In the course of the two semesters students deliver the following reports and presentations:

1) PDD Data Package
2) CDD Data Package
3) PDR Data Package
4) CDR Data Package
5) Semester I Fall Final Report FFR
6) Interim Review I
7) Interim Review II
8) FPR Data Package
9) ITLL Expo poster
10) Semester II Spring Final Report SFR

Students must defend their work in from of the Project Advisory Board (PAB) which is composed of 10 faculty members with differing backgrounds, the head of our departmental machine shop and the head of the departmental electronics shop.

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Appendix 1: Acronyms

PP	Project Proposal (form)	document
CPD2	Customer Project Definition Document	document
PDD	Project Definition Document	document
CDD	Conceptual Design Document	document
PDR	Preliminary Design Review	presentation
CDR	Critical Design Review	presentation
FFR	Fall Final Report	document
IR1	Interim Review #1	presentation
IR2	Interim Review #2	presentation
FPR	Final Project Review	presentation
SFR	Spring Final Report	document
ITLL	Integrated Teaching & Learning Laboratory http://itll.colorado.edu/ITLL/	

Appendix 2: History of Recent Projects

Project	Explanatory Title	Objectives
BIRDIE	Biologically-Inspired low Reynolds number Dynamic Imagery Experiment	To create an experimental apparatus that can trace out a given wing motion similar to a hummingbird in hovering flight
DIABLO	De-rotated Imager of the Aurora Borealis in Low-Earth Orbit	Provide a spinning satellite with a de-rotated imaging system
D-SUAVE	Deployable Small UAV Explorer	To design, fabricate, integrate and verify a RC controlled UAV capable of being remotely deployed from the ARES aircraft and flying a specific flight pattern
PRV	Peregrine Return Vehicle	To provide the Colorado Space Grant Consortium with a reusable vehicle that can return student built science payloads to a selected target
SOARS	Self Organizing Aerial Reconnaissance System	Design, build and test an autonomous aerial system (UAS) capable of imaging multiple targets within a 1 km circle as quickly as possible with 99% probability of object detection (according to Johnson criteria)
SWIFT	Supersonic Wind and Imaging Flow Tunnel	Supersonic wind tunnel (Mach number 1.5 – 2.5) and flow visualization system operable by undergraduate students
VITL	Vehicle for Icy Terrain Locomotion	Desiogn and build a prototype for locomotion system of a vehicle exploring a Europa-like surface capable of traversing 1 km of icy terrain in 7 days with characteristic obstacles
BREW	Bolt-on Racecar Enhancing Wing	Conceive, design, fabricate, integrate, test, and verify a device that allows the measurement of the downforce and drag of any rear wing for present and future CU FSAE cars
CALAMAR-E	Cavity Actuated Low-speed Actively Maneuverable Aquatic Rover Experiment	Conceptualize, design, fabricate, test, and verify synthetic jet actuators for a highly maneuverable, low speed under water vehicle
FARS	Flap and Aileron Replacement System	Produce a wing that demonstrates roll control without mechanical linkages by integration of smart materials as actuators
MaCH-SR1	Multi-disciplinary university of Colorado Hybrid Student Rocket	Conceive, design, fabricate, integrate, and verify a self-sufficient hybrid rocket engine
MARS	Meteorological Aerial Research Sonde	Conceive, design, fabricate, and test a deployable dual-mode sonde system that will provide multi-unit communications ability capable of sustained flight times and controlled flight
PHOENIX		Design a small, lightweight, hand-launched UAV marketed toward research and rescue missions
SPEC	Space Elevator Climber	Design a model space elevator system to compete in the *Spaceward Foundation* “Elevator 2010” competition.
STOW	Short TakeOff Wing	Design, fabricate , and characterize a FanWing device
HAVUC	Heavy-lift Aerial Vehicle for the University of Colorado	Conceive, design, fabricate, integrate, test, and verify an un-inhabitated aerial vehicle (UAV) with a heavy-lift capability that has an empty weight no greater than 10 lb; heavy-lift being defined as the payload contributing a minimum of 60% to the total takeoff weight

Appendix 2 cnt.: Projects in Academic Year 2007-2008

Project	Explanatory Title	Objectives
SHARC	Stable Handling Aerial Radio-controlled Cargo-testbed	Develop a low-cost, easy to operate, and reliable aerial vehicle for testing of sensor payloads
CUBDF	Colorado University Design-Build-Fly	Design, build, fly a high-volume payload competitive aircraft
HARRV	High Altitude Research Return Vehicle	Design, build, test a return vehicle for scientific payloads released from high altitude balloons to proximity of balloon launch site
APTERA	Aero-Braking Project To Effectively Reduce Altitude	Design, build, and test a deployable device which will increase aerodynamic drag with the intent of changing the orbit of the DANDE satellite from 600km to 350km within 300 days.
Mach-SR1	Multi-disciplinary University of Colorado Hybrid Student Rocket Project	design, build, test, integrate feed, injection and ignition subsystems into a flight configuration for a hybrid rocket to deliver a 0.5 kg payload to an altitude of 4,500 m.
KRAKEN	Kinematically Roving Autonomously controlled Electro-Nautic	Design, build, competitively test an unmanned underwater vehicle equipped with vortex ring thrusters
MARVLIS	Micro Air Reconnaissance Vehicle Launch and Imaging System	Design, fabricate, and test a micro air vehicle capable of capturing an image and transmitting it with a time and position stamp
ADAMSS	Aerially Deployed Autonomously Monitored Surface Sensors	Design and build a system that can remotely place low-cost disposable sensors, collect science data, and then retrieve this data all without on-site human interaction