ME428 / ME429 / ME430 Senior Design Project Reference Book and Success Guide

Department of Mechanical Engineering
California Polytechnic State University – San Luis Obispo
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Introduction

Welcome to your Senior Project Class. What is a Senior Project? According to the University's website:

"The senior project is a capstone experience required for all Cal Poly students receiving a baccalaureate degree. It integrates theory and application from across the student's undergraduate educational experiences."

This class fits exactly that description. You will integrate knowledge and skills you have gained throughout your education to *design*, *build*, and *test* hardware that solves an externally supplied problem for a customer. Design is what most engineers do most of the time and is practically synonymous with the verb "to engineer". It is a process you will learn best by doing! You will be proud of the things you create, but what is of more importance is the understanding you take away of the process that was necessary to do that creation. You will find this process useful throughout your life. This class will be very different from most others you have taken. First, the class lasts 30 weeks and you will be working on the same team and the same project for the entire time. Your team output (documentation, presentations, hardware, etc.) will be the result of a team effort. Your grade for the class will be primarily based on these team products; therefore, it is our experience that any project "failures" will be the result of a team failure.

The basic structure of the course is as follows. In the first quarter, you will attend a one-hour lecture on Monday each week. This will provide you with some overall structure and give you specific course content, including project management and specific design techniques that will help you along your way. Attendance in the lecture is mandatory. Additionally you will have two lab meetings each week. You will be required to attend these six hours. How those hours are organized will depend on the project advisor/lab instructor. During the first week's labs, you will be presented the projects and will inform the instructors of your project preferences at the end of the week. The specific lab section you will attend depends on which project you are working on. This will be determined at by the beginning of the second week. If your project ends up in a different lab section than one you register for, there is no need to change your registration. For the second quarter (ME 429) you will be scheduled for two 3-hr lab sections (there is no lecture). Your project advisor/lab instructor will give you details on how the time will be organized. For the third quarter (ME 430) there is neither any lecture nor lab section. Rather you meet with your advisor once a week as you do your testing and complete the project.

For 30 weeks, the teaching staff will be guiding you through the process of designing, building, and testing a solution to a design problem. This reference book and success guide is intended to assist you by providing background information and answers to questions that will come up during the next three quarters. The best way to use it will be to read it! Please let us know if when you find errors so we can promptly get them corrected. Thanks and good luck as you embark on a journey of learning, discovery, hard work, and hopefully great personal satisfaction for your completed project. The teaching staff is here to help and guide you through that process.

Course Objectives

1. Apply a formal engineering design process to solve an open-ended, externally supplied engineering design problem.
2. Work effectively on an engineering team.
3. Develop, analyze and maintain an engineering project schedule using a Gantt chart and appropriate software.
4. Use Quality Function Deployment (QFD) to evaluate customer requirements
5. Formally define an engineering problem
6. Generate an engineering specification document.
7. Apply creative techniques to generate conceptual design solutions.
8. Apply structured decision schemes to select appropriate engineering concepts in a team environment.
9. Design subsystems within constraints of strength, size, materials, performance, cyclic loading, etc.
10. Evaluate potential design solutions through the use of engineering and physical science analysis techniques and tools.

11. Apply current industrial design practice and techniques such as DFX, FMEA and/or TQM to engineering design problems.
12. Construct and test prototype designs.
13. Develop and implement a design verification plan and report.
14. Communicate and present engineering design project results orally, graphically and in writing
15. Students will improve their ability to discuss and take a stand on open-ended topics involving engineering ethics and product liability
16. Discuss engineering professionalism and its responsibility to society
17. Understand the codes of ethics and their implications in engineering practice

Course Syllabus

See the syllabus on Blackboard

Grading and Assessment

All students, regardless of lab advisor will be evaluated based on a common set of deliverables across all lab sections. See the Deliverables section of this document for details. These deliverables will be graded based on a common set of grading rubrics which will be published on Blackboard or on the web by the course organizer. Lecture and logbook work are individual assignments which will be graded accordingly. Reports, presentations, and hardware are the responsibility of the team and will be assigned a single grade shared by all team members. Other sources of assessment are provided by faculty members who may attend presentations, a peer review by fellow students, and input from the project sponsors. Please consult the course syllabus and your lab advisor for details. Late projects are unacceptable. Due to unforeseen circumstances in which students cannot complete the project on time, a binding contract will be drawn up for the delayed team indicating specific completion milestones and dates. Failure to fulfill this contract will result in a failing grade and the requirement that students enroll in the next section of ME 428 with a new project and a new team. This may delay graduation by a full year.

In addition to the assessment of student work, the Senior Design Project class is an essential component of a Cal Poly Mechanical Engineering student's education. This class fulfills many requirements necessary for the ME program at Cal Poly, accredited by ABET (Accreditation Board for Engineering and Technology). In order for the department to receive accreditation we must assess student learning and outcomes; therefore, we administer a Senior Exit Exam during the third quarter of this course. It is a required exam that accounts for 15% of the grade. Preparation for this exam can be accomplished in a similar fashion to preparation for the FE (Fundamentals of Engineering) licensing exam. Also as a part of accreditation, all senior project students must fill out a Senior Exit Survey at the end of ME 430. This is not graded, but completion of the survey is necessary to receive a grade for the course.

Student, Sponsor, and Faculty Roles

The student design team is responsible for completing all tasks required to produce a final product and report in a professional manner. This is **YOUR** project. The project sponsor, project advisor, and course organizer are available to provide technical and management assistance and to help you keep your project on schedule. The following is a list of responsibilities for each:

Student Design Team:

- Manage project (establish team roles, schedule, budget, etc.)
- Define project scope in a *Project Proposal*
- Use engineering skills to design a product
- Procure materials, fabricate, build, and/or supervise construction of a product
- Establish a test plan, procure diagnostic equipment, and perform testing
- Document design progress in a *Design Logbook* (recommended on a daily basis)
- Document entire process in a *Final Project Report*
- Present *Critical Design Review* to sponsor at beginning of 2nd quarter
- Present final project and poster at *Senior Design Expo*
- Meet additional intermediate course requirements outlined on syllabus
- Complete all required forms for purchasing and traveling
- Interact with faculty advisor (required on a biweekly basis)
- Interface regularly with sponsor (recommended on a weekly basis)
- Attend ME 428 lecture
- Take *Senior Exit Exam*
- Fill out *Senior Exit Survey*

Sponsor (Company Contact, Student Club, or Faculty):

- Provide initial project scope and present to students and faculty
- Be accessible to provide technical assistance and to provide data
- Identify proprietary information to ensure company protection
- Mentor team on customer issues
- Mentor team on resources for fabrication and testing
- Evaluate team progress at *Conceptual and at Critical Design Review*.
- Evaluate team product at *Senior Design Expo* and *Final Project Report*

Course Organizer (Lecture Faculty):

- Collect projects from sponsors and review initial project scope
- Facilitate and coordinate senior design experience
- Teach project management and design content
- Evaluate project management aspects of team's work
- Administrate *Senior Exit Exam* and *Exit Survey*

Project Advisor (Laboratory Faculty):

- Ensure valid project scope
- Demonstrate project management and design content introduced in lecture
- Mentor team on planning and scheduling
- Mentor team on roles, responsibilities, and handling conflicts within the team
- Mentor team on technical issues or refer to alternate source(s) if appropriate
- Mentor team and/or provide resources for fabrication and testing
- Provide a link to sponsor
- Evaluate team assignments, *Final Project Report*, and assign final grade

Travel Policy and Forms:

By its nature, Senior Design Project typically involves some travel to visit your sponsor. Teams will be given a travel budget that cannot be exceeded for the three quarters and are responsible for maintaining that budget. Students should arrange a meeting at your sponsor's site during the second or third week of the first quarter. It is essential for you to understand your customer's requirements and seeing first-hand their needs is the most efficient way to do this. At the beginning of the end of the first quarter you should plan on traveling to your sponsor's site for a Design Review. A second Design Review during ME429 can either be done via teleconference or in person depending on arrangements made with your sponsor. Expenses (gas receipts and food) for travel outside of San Luis Obispo County to your sponsor's site will be reimbursed by the class unless the sponsor reimburses you directly. In addition, you will need to fill out some paperwork as described below.

It is likely you will be taking a personal vehicle to travel to your sponsor's site. Please select one team member to be the "travel lead" for your team and plan on using their vehicle for all team travel to the sponsor's site. This person will also pay for all gas and meals for which they will be reimbursed.

The following paperwork needs to be completed and returned to your lab instructor at your first meeting:

1) A *Field Activities Notification and Release* form must be filled out by each student and returned to the lab advisor. (Only filled out once for the current fiscal year.)
2) A *Volunteer Identification Form* should be filled out by each student and returned to the lab advisor. (Only filled out once for the current fiscal year.)
3) Any team member with a car needs to fill out the *Authorization to Use Privately Owned Vehicles on State Business* form and return it to your lab advisor. (Only filled out once for the current fiscal year.)
4) Any team member with a car also needs to fill out a *Request to Operate Vehicles on University (STATE) Business* Form and **return it to building 80** along with a copy of their driver's license. (Only filled out once for the current fiscal year.)
5) Prior to any trip, the driver must fill out a *Travel Request 1A* form and a *List of Participants* form additionally filled out by accompanying team members. This needs to be signed by your lab advisor and is then turned in to Christine Haas in the ME office.
6) In order to be reimbursed for expenses, the travel leader must fill out a *Travel Claim 262* form within 10 days following the trip. The travel leader can claim food and gas and must supply original receipts. It should be turned in to Christine Haas in the ME office after it is signed by your lab advisor.

- All forms listed above in *red* are available on Blackboard.

Travel Reimbursement

This section contains directions on how to obtain reimbursement for approved travel to meet with your sponsor outside of San Luis Obispo County. We expect that you should travel once early in the quarter as you try and prepare your formal design specification and once at the end of the quarter for a preliminary design review. Please get specific approval from your lab instructor for other travel.

- Only your team travel leader (the driver) will be reimbursed for gas and food receipts.
- Only travel outside the County of San Luis Obispo will be considered for reimbursement.
- If travel must include overnight stays, then please get approval from your lab advisor first. In general, we hope that your project sponsor will pay for any overnight lodging.
- Alcohol cannot be purchased or consumed during travel on university business.

To be reimbursed, the travel leader (the driver) must:

1) Submit a *Travel Claim 262* form within 10 days upon return of your trip.
2) Tape any meal and gas receipts to a blank piece of 8 ½ x 11 paper and paperclip to the *Travel Claim 262* form. (Note this is the receipt that says what you ate and how much, not just a credit card receipt.)
3) Write the names of the team members who ate on the food receipt(s).
4) Obtain your lab advisor’s signature on the *Travel Claim 262* form.
5) Turn in the signed *Travel Claim 262* form to Christine Haas in the ME office.
6) In roughly 2-3 weeks a check will be sent to the ME Office. When the ME Office receives your check, you will be notified via email that your check is available for pick-up.

The *Travel Claim 262* form is available as an Excel file on Blackboard or on the web.

The following pages contain examples of filled out forms: Travel Request 1-A, List of Participants and Travel Claim 262.

Cal Poly State University Form 1A **TRAVEL REQUEST** **1/5/2011**

Name: Your Name Here **Empl ID:** Found in the Portal

Department: Mechanical Engineering **Phone:** Your Phone #

Departure/Return: **From:** **Date** 1/2/11 **Time:** 8am **To:** **Date** 1/3/11 **Time:** 10:00 PM

Destination: Long, Beach, CA

Purpose of Trip: To visit our senior project sponsor. Our sponsor is: Lockheed Martin
Team members include: John Doe and Jane Smith

[X] **I am driving a private vehicle** **Vehicle License #:** ABC1234CP
I have on file in my department a properly completed 261 Authorization to Use Privately Owned Vehicles form

STATE FINANCIAL INFORMATION

Account	Fund	DeptID	Program	Class	Project/Grant	Amount

Travel Advance Request: **Amount:** ______ **Date Needed:** ______

State Expenses not to exceed:

CAL POLY CORPORATION FINANCIAL INFORMATION

	OrgKey	ObjCode	Amount
Advance Request:			
Advance Request:			

CPC Expenses not to exceed:

OrgKey #:

Total Advance Request: $ - **Date Needed:** ______

CAL POLY FOUNDATION FINANCIAL INFORMATION

	OrgKey	ObjCode	Amount
Advance Request:			
Advance Request:			

CPF Expenses not to exceed:

OrgKey #:

Total Advance Request: $ - **Date Needed:** ______

Please read and sign below:

I certify that if I am driving a privately owned vehicle that I have liability insurance in force in at least the following amounts: $15,000 for personal injury to, or death of, one person, $30,000 for personal injury to two or more persons in one accident, $5,000 for property damage. I further certify that my vehicle is adequate for the work performed, equipped with seat belts and in safe mechanical condition; that a current Privately-Owned Vehicle Insurance Certification Form STD 261 is on file with my supervisor, and that any accident that may occur while the vehicle is being operated on State business will be reported within 48 hours on Form STD 270.

I agree to submit my TRAVEL EXPENSE CLAIM for this trip no later than 10 days after my return and to repay the balance, if any, of unexpended travel money advanced. I understand and agree that any amount due may be deducted in full from funds payable to me by the State, including any salary warrant(s) issued to be by the State Controller. **(NOTE: The State will not pay for expenses not incurred or related to trips not taken, such as non-refundable deposits/registration fees, airline ticket charg for trips that are canceled. The employee will be held personally responsible for such charges unless non-State funding can be identified.)**

Traveler's Signature: Your Signature Here **Date:** ______

Department Chair's Authorization: ______ **Date:** ______

Faculty Advisor's Authorization: ______ **Date:** ______

Cal Poly College of Engineering

FIELD TRIP LIST OF PARTICIPANTS

(Attach to 1A Form)

Trip Date(s): 1/2/11-1/3/11 Name of Responsible Party: Travel Lead (the driver)

Destination: Long Beach, CA

Purpose: to visit with senior project sponsor – Lockheed Martin

Name	Student ID	Signature	Check if Driving Private Vehicle	DRIVERS ONLY: Vehicle License #
The Driver	Found in Portal	Sign	X	ABCD123CP
John Doe	Found in Portal	Sign		
Jane Smith	Found in Portal	Sign		

EXAMPLE

FOR DRIVERS:
I certify that I am driving a privately-owned vehicle and I have liability insurance in force in at least the following amounts: $15,000 for personal injury to, or death of, one person; $30,000 for personal injury to two or more persons in one accident; $5,000 for property damage. I further certify that my vehicle is adequate for the work performed, equipped with seat belts and in safe mechanical condition; that a current Privately-Owned Vehicle Certification Form STD 261 is on file with my supervisor; and that any accident that may occur while the vehicle is being operated on State business will be reported within 48 hours on Form STD 270.

CAL POLY San Luis Obispo

TRAVEL EXPENSE CLAIM

Rev. 1-14-09

Claimant's Name	Residence Address	City	State	Zip Code
Your Name Here	**Your Address Here**			

EmpID *(not SS#)*	Department	Telephone Number	Vehicle License #	Mileage Rate Claimed
Found in the Portal	**Mechanical Engineering**	**Your telephone #**	**ABC1234CP**	**$ 0.51**

Destination (city and state)	Purpose of Trip
Long Beach, CA	**To visit senior project sponsor. Our sponsor is Lockheed Martin**

Date	Time	Location where expenses were incurred	Hotel	Meals B 10.00	Meals L 15.00	Meals D 25.00	Misc per day 5.00	Airfare	Transportation Private Car Use Miles	Transportation Private Car Use Amount	Misc.	Business Expense	Total
1/2/11	8:00 AM	SLO, CA to Long Beach, CA			32.50	68.00	/////////////			0.00	$45.00		145.50
1/3/11	10:00 PM	Long Beach, CA to SLO, CA	175.50	28.20	32.50					0.00	$45.00		281.20
										0.00			0.00
										0.00			0.00
										0.00			0.00
										0.00			0.00
	Note:	Claimant paid for self and team members' meals: John Doe and Jane Smith								0.00			0.00
		Transoportation Misc. expenses for 1/2/11 - Gas $45 and 1/3/11 - GAS $45								0.00			0.00
										0.00			0.00
										0.00			0.00
										0.00			0.00
										0.00			0.00
		Totals	175.50	28.20	65.00	68.00	0.00	0.00	0.00	0.00	90.00	0.00	426.70

STATE	Acct.	Fund	DeptID	Prog.	Class	Proj.	Amount	Less State Advance	
								STATE TOTAL	

CAL POLY CORPORATION (Acct #'s 30000-59999 Through 80000-99999)	Org Key	Object Code	Amount	Less CPC Advance	
				CPC TOTAL	

CAL POLY FOUNDATION (Acct #'s 60000-79999)	Org Key	Object Code	Amount	Less CPF Advance	
				CPF TOTAL	

I hereby certify that the above is a true statement of the travel expenses incurred by me in accordance with the applicable California State University procedures and that all items shown were for the official business of The California State University. If a privately owned vehicle was used, and if mileage rates exceed the minimum rate, I certify that the cost of operating the vehicle was equal to or greater than the rate claimed, and that I have met the requirements as prescribed by SAM Sections 0750. 0752, 0753 and 0754 pertaining to vehicle safety and seat belt usage.

CLAIMANT'S SIGNATURE	DATE	DEPARTMENT CHAIR'S APPROVAL	DATE
		FACULTY ADVISOR'S APPROVAL	DATE

Purchasing and Reimbursements

Toward the middle of ME429 you will probably need to begin purchasing items and have them delivered to Cal Poly. All purchases should be discussed and approved by your lab advisor. The preferable method of procurement is to have your sponsor purchase materials for your team and have them drop shipped to Cal Poly. For some projects, you will need to purchase materials yourself and be reimbursed. How you are reimbursed will depend upon the project. There are three basic methods of materials procurement:

1. **SPONSOR PURCHASES YOUR MATERIALS** (PREFERED) - Your project sponsor purchases the materials for your team and are shipped to the address below.
2. **YOU PURCHASE YOUR MATERIALS** - Pay for items yourself (with prior lab advisor approval) and submit original receipts for reimbursement.
3. **CAL POLY PURCHASES YOUR MATERIALS** - You purchase the material through the ME budget person, Christine Haas (appointments required with Christine and can be made via email at cehaas@calpoly.edu) OR through her budget student assistant. You will be guided through the process. Via this method you can use a Cal Poly credit card (the VISA ProCard) and order your materials on-line or over the phone. If you choose to use this method of purchasing, a VISA ProCard Preauthorization form will need to be filled out for each intended use (see example on page 14). Again, your lab advisor's signature authorization will be required.

For delivery of equipment and components, use this address:

To: Cal Poly Mustang '60 Machine Shop
Your name (first and last)
1 Grand Avenue
San Luis Obispo, CA 93407
Your phone #

Purchasing Restrictions:

- Any purchase from a single vendor over $3,500 (tax and shipping included) must be processed as a purchase order. A formal quote will be required from the vendor in order to initiate this.
- Any purchase from a single vendor that exceeds $5,000 (tax and shipping included) will require three formal bids or a *Sole Source Justification* to process a purchase order.

ATTENTION:

Assistance in purchasing, reimbursements and travel is now available to you in the Mustang '60 Machine Shop

As a convenience, Christine's budget student assistant will be made available in the Mustang '60 Machine Shop (197-117) for assistance with purchasing, reimbursements and travel. The student's hours of availability at Mustang '60 are emailed to you at the beginning of each quarter. Outside the student's hours, you may come to Christine for assistance with these transactions. Please email her to make an appointment at cehaas@calpoly.edu.

VISA ProCard Preauthorization

(Please provide this form to a VISA ProCard user)

Today's date: 1/3/11

Person requesting use of ProCard: John Doe

The ProCard can only be used for supplies. I will be using the VISA ProCard to purchase:

(You may attach a shopping list of supplies in lieu of filling out this section.)

Sheet metal, casters, nuts and bolts

→ **FOR SENIOR PROJECTS ONLY:**

Funding source for this project comes from account #: (will be filled out by budget person)

Senior Project Title: robot hand

Faculty Advisor: Jim Widmann

Faculty Advisor's Signature Authorization: (obtain advisor's signature)

FOR ALL OTHER PURCHASES:

Funding for this purchase comes from account#: ______

The Director/PI of this account is: ______

Signature Authorization from Director/PI: ______

Intellectual Property

External sponsors may ask you to sign a Non-Disclosure Agreement (NDA) and/or an Intellectual Property (IP) agreement before you begin work on a project. You should read through the agreement carefully before you sign and you are welcome to seek clarification or ask for changes to the agreement. Ultimately you must comply with their desire, or you will be placed on another project that does not involve these agreements. A standard, sample IP agreement for sponsors is given below. Usually sponsors will have their own internal agreements that you may be asked to sign. Again, if you are unwilling to sign a required agreement from a sponsor, you will be placed on a different project.

A student is expected NOT to try to take advantage of intellectual property acquired during the course of a project. This would be considered highly unprofessional and unethical. That is, a student should not take a sponsor's ideas and attempt to market or commercialize them or to use them in any way to compete commercially with the sponsor. Our sponsors have been generous enough to open their doors to us, to bring us projects, to support the projects and teams financially and attentively. The last thing we want to do is to have a student or a group of students use information learned in the course of complete a project to the disadvantage of the sponsor.

ME 428 AGREEMENT

This agreement is between **Name** ("STUDENT"), a student at Cal Poly State University, San Luis Obispo, California, who is enrolled in the course **ME428: Senior Design** ("COURSE") during the academic year 2010-2011, and **Company** ("COMPANY"), a private enterprise having its principal place of business in **city, state**.

As part of the COURSE'S educational experience, COMPANY has proposed a design problem entitled "**Title**" ("PROBLEM"), described in the exhibit attached hereto, as a subject for a design and development study ("STUDY"), and STUDENT has voluntarily decided to undertake that STUDY jointly with the COMPANY as part of his/her participation in the COURSE'S education experience. Now, therefore, STUDENT and COMPANY agree that the following provisions shall apply to their joint STUDY of the PROBLEM:

1. The COMPANY shall make certain relevant design information and ideas relating to the PROBLEM available to the STUDENT to facilitate his/her learning experience in performing the STUDY.

2. The COMPANY shall pay a fee which covers the construction of any models or prototypes designed by the STUDENT and any other direct costs associated with the STUDENT'S activities.

3. The STUDENT shall evaluate and advance designs directed toward a solution to the PROBLEM for the COMPANY and, in connection with the requirements of the COURSE, shall submit a final report describing the results of these activities.

4. The COMPANY and the STUDENT are free to discuss the information disclosed by the COMPANY and the designs advanced by the STUDENT among all participants in the COURSE as part of the COURSE'S educational experience. However, at the request of COMPANY, STUDENT will sign COMPANY's standard non-disclosure agreement Confidential information must be so identified in writing in advance by the COMPANY. The confidentiality obligation contained in any COMPANY non-disclosure agreement signed by STUDENT shall survive termination or expiration of this AGREEMENT.

5. The STUDENT shall disclose in writing to the COMPANY each invention, innovation, or improvement pertaining to the PROBLEM which the STUDENT conceives or reduces to practice prior to receiving a final grade for the COURSE. Ownership of this intellectual property shall go to COMPANY. To ensure this transfer of ownership, the STUDENT hereby agrees to irrevocably assign, convey and transfer to the COMPANY all right, title and interest to each such invention, innovation, or improvement. Furthermore, the STUDENT agrees to disclose all such inventions, innovations, or improvements to the COMPANY within thirty (30) days of their development and shall promptly execute such assignments and other documents as the COMPANY may request to perfect its title to such intellectual property (the "Assigned Intellectual Property").

6. The STUDENT agrees to fully and completely assist the COMPANY and any attorneys or agents designated by the COMPANY in the protection of the Assigned Intellectual Property and any patent applications pertaining to the Assigned Intellectual Property. The STUDENT shall execute any and all documents necessary to prosecute such patent applications and to perfect any assignments of patent rights therein to the COMPANY.

7. The COMPANY shall indemnify and hold the STUDENT harmless from and against all losses, liabilities, damages, or expenses that relate to the protection or enforcement of the Assigned Intellectual Property.

8. The terms of this agreement are effective upon the date of execution by both parties, and shall terminate on the date STUDENT receives a final grade for the COURSE except for terms 5, 6, and 7, which shall survive termination and will remain in effect during the useful life of any Assigned Intellectual Property.

Student:	Date	Company's representative:	Date
Faculty Advisor:	Date		

Deliverables

For your Senior Design Project there is a minimum set of deliverables required of all students. These have been designed to help you complete your project in a timely and professional manner. Your lab instructor will have **further** requirements and deliverables as he/she guides you through the process in the manner he/she sees fit. Note that any additional work is designed to assist you in completing the fixed set of deliverables in the most timely and professional manner and should not be considered “extra” work. This section describes the fixed set of deliverables in detail; please **see your project/lab advisor for additional requirements**. The common set of deliverables by quarter includes:

ME428 (First Quarter)
- Reflections and Surveys (Individual)
- Design Logbooks (1 per person)
- Letter of Introduction to Sponsor
- Project Proposal/Requirements Document
- Conceptual Design Report
- Conceptual Design Review (at Sponsor’s site)

ME429 (Second Quarter)
- Reflections and Surveys
- Design Logbooks (Continued)
- Final Design Report (with detailed drawings)
- Critical Design Review (Presentation)
- Ethics Memo
- Ethics Case Study Presentation
- Project Update Report

ME470 (Third Quarter)
- Design Logbooks (Continued)
- Manufacturing and Test Plan Review (Presentation)
- Hardware Demonstration
- Senior Exit Exam and Senior Exit Survey (Required for ABET)
- Design Expo
    - Poster Presentation
    - Final Hardware Review
- Final Project Report

Surveys and Reflections

The learning in the course as well as writing objectives will be reinforced through occasional reflective essays. These will be assigned in lecture for the entire class. Please consult the syllabus for details. You will also be requested to complete several surveys to provide feedback for your instructors.

Design Logbooks (1 per person)

Rationale: For any design project, the final drawings, models or prototypes are only a part of the value of the design. Much of the value also lies in the process used to generate it. For example if you contracted with somebody to design a new piece of inexpensive outdoor furniture and the final design calls for aluminum instead of plastic, you would want to know why. The answer might be that the price of plastic was too high or maybe the stiffness was too low. This is useful information and adds to the value of the design, because you will now be in a position to switch to plastic if an oil glut results in a decrease in the bulk price of plastics (not likely to happen soon!).

The purpose of the design notebook is to <u>document your design process</u>. You can’t begin to realize how important this information is until it is missing; then it is too late.

Parts of the design process that need to be documented include:

- Ideas, questions, and notes from group meetings.
- Notes on sponsor meetings, customer needs/requirements.
- Preliminary sketches, doodles, outlines, half-baked ideas and plans for different aspects of the design.
- A record of the analysis you performed. Do calculations directly in logbook.
- A record of the results from any tests that you conducted.
- Evaluation of data.
- References and notes on relevant literature and research findings– particularly your conclusions concerning articles that you read or discussions that you may have had with experts in the field.
- The choices you made at each step: what you chose, what you rejected, and why.
- Conversations with associates and vendors, pasted-in catalog or handbook pages, websites, etc…
- Personal thoughts and reflections concerning the project or process. Note that this is not normally included in an industrial setting, but it is important from an educational standpoint. One of the objectives of this class is for you to grow personally so that you understand your particular strengths and weaknesses in approaching a team-based design project. Keep in mind that your lab instructor will be reviewing your logbooks so only put notes and observations that you are willing to share.

Logbook Details: One logbook is required per person. Use an **unlined**, bound (spiral is ok) sketchbook of high quality paper (heavy) with at least 100 pages. You might want to consider having the pages be larger than 8 ½” x 11” so that you can glue/tape in printed pages without having to cut them (please don’t put folded pages in the logbooks). Examples of completed logbooks can be reviewed at the office of the course organizer/lecturer.

- Put your name, phone number, email, project name, group contact information, and other pertinent information on the inside cover or the first page. This is especially important should you misplace your logbook!
- Leave several pages at the beginning initially blank and fill them in as a table of contents as you make entries.
- Number each page sequentially and date all entries (note that multiple entries/dates on a page are fine).

- **Use ink!**, don't erase, simply put a line through any item you would like to delete.
- Do not remove pages, do not skip pages. Don't backfill. If you realize you forgot to put something in, simply note that as you continue forward in the book by chronological entry.
- Sign your work when making important entries (for a professional consulting engineer, the signed design logbook can become an important piece of legal evidence in patent disputes).
- Have important and novel ideas countersigned by someone who understands your design. This will usually be a teammate or your lab advisor. They should write something like "I have reviewed and understand the concept presented on these pages".
- You should be making entries in your logbook a minimum of **5 times each week!**
    - Planning, communication and team activities (10-20% of entries)
    - Research, sketching and engineering analysis (65-75% of entries)
    - Personal notes and review of team and/or product performance (10-15% of entries)

Logbook Assessment: Your logbooks will be collected midway and at the end of the quarter for grading. Note that your logbooks are not expected to be a polished, edited documents (that is what the formal reports are for) but I should be able to look at it and tell what you did and why. Your logbook is like your project journal or diary. It is an integral part of your project and its use as such should be reflected in its pages. It should be much more than a few scribbled notes and a repository for taped-in meeting agendas. To know what to aim for in your logbook, pose these questions to yourself: If my logbook was the only thing used to grade my work on this project, how would I fare? Is everything I did either written down or referenced in the logbook?

Logbooks will be graded based on tracking of project management information, product development, organization, and personal reflection. Be sure to follow the logbook format specifications given above. In the past we have found a pretty good correlation between good notebooks, good designs, good end of the quarter projects and grades, and functioning hardware that meets the design specifications.

Problems noted with logbooks previously:

The idea that the logbook is a dialogue about the project, written in a fashion that is understandable by a third party seems to escape many students. It is not just notes written for the writer. Annotate, annotate, annotate. Read the guidelines for the logbook (see above) occasionally to remind yourself what should be in the logbook.

Often the context of a calculation or a sketch is missing. Why the calculation or sketch was done and what was concluded from it is missing. Ask these questions upon making every entry: Is what I have written understandable by a third party not involved in the project? Is the context clear (what the entry concerns, why it is even in the logbook)? Is the reason I am making a calculation or sketch made clear in an annotation? Is what I have concluded from the sketch or calculation stated clearly?

Letter of Introduction to Sponsor Due first day of 2nd Week

As soon as your team is assigned a project, you need to write a letter of introduction to your sponsor. Before doing this, get together with your team and decide who will be the main point of contact with your sponsor. All future correspondence will go through this team member. For the Introduction letter, each team should compose an e-mail to your industrial contact (**copy to your lab advisor**), identifying the team working on the project (with names, phone numbers and e-mail addresses for correspondence with the group) and clearly stating who will be the main point of contact. You may also want to also give the FAX# in the design studio resource room 192-133 (805-756-5606) as another means of communication with the design team.

In the letter include a restatement (in your own words) of what the problem is that you are trying to solve. Also indicate that your initial goals are to study the project requirements and scope as well as perform necessary background research. State that you need to meet or have a teleconference by the end of the week to discuss the detailed scope of the project and specific requirements. Ideally you should travel to the sponsor's site during this week to assess first hand your sponsor's needs. You may also want to suggest a weekly meeting time (teleconference) with your sponsor. Note this may have to be worked out with other folks in your lab section as there is only one conference phone for us in 192-133.

Remember to correspond in a formal and professional manner when contacting your industry sponsor. Document all correspondence and copy your lab advisor as required. Do not send an email with only an attachment. If you do attach a formal letter, make sure you introduce and sign your email message. Think in terms of "friendly" letters. Dear Mr. Sponsor….Thank you for the opportunity….Sincerely, J. Student.

Reports (see syllabus for due dates!, see course website for grading rubrics)

Project Proposal/Requirements Document Due in Lab

The Project Proposal is one of the most important documents that an engineer has to prepare – whether he or she works in government, industry or academia and whether he or she is a designer, a researcher, or a production engineer. This proposal will also be the start of your formal documentation for your project. The Proposal will grow into an Interim Design Report, a Draft Design Report, a complete Final Design Report, and then eventually into a Final Project Report. The reports are intended to be cumulative in that information from previous reports is expanded and refined in subsequent reports in order to generate a complete and professionally written Final Project Report.

The Proposal is not written to a general technical audience, but to a specific person (e.g. a client) or to a small group (e.g. a board of directors or a review committee) which has a problem that you believe you can solve. The purpose of the document is to convince that person or group, in this case your sponsor, that:

1) You clearly understand what the problem is; this includes defining the extent of the problem.
2) You have studied the background, related literature and similar hardware, or problems
3) You have a process that you will follow to effectively solve the problem.
4) You have the necessary resources to complete the task and can do it in the time available.

The proposal must be professional. Statements must be supported; ideas must be defined clearly so that the reader can judge for himself or herself their merits. Above all, avoid self-praise, empty promises, and zero-information statements. The most important sections are the <u>Background</u> and <u>Objectives</u>. Once agreed upon by the sponsor, the specifications included in the <u>Objectives</u> section will become a contract that you are agreeing to fulfill.

The standard format for a technical proposal requires:

1) A <u>Title Page</u> showing the project title, sponsor name, and names and email addresses of the persons preparing the proposal.
2) An <u>Introduction</u> which tells the reader what the project is about, who the stakeholders are, and what the goals are.
3) A <u>Background</u> section should follow and include a discussion of what existing information (from literature, previous work, etc.) will have a bearing on the proposed work. Information should include a literature review, a discussion of applicable codes and standards, a look at existing products that solve similar problems, or any experimentation that helped develop the engineering specifications. Other background information should be included as appropriate for the project.
4) <u>Objectives:</u> This section should begin with a statement of your overall goals. This is what you will do for your client/sponsor. This should be followed by the most important part of this report, which is the engineering specification that was derived from the customer requirements. The success of your solution will be judged by how well it meets the specification. It will also be the basis of your testing plan. The section should include a discussion of how various specifications were developed from the various customer requirements with reference to the QFD method. A specification table using the format given below should be included in this section with reference to your house of quality, which can be put in an appendix.
5) A section on the <u>Method of Approach</u> will come next. This section tells the reader what process you expect to follow in solving their problem. You might reference the design process flow chart presented in lecture for a skeleton plan. Keep in mind that this flow chart is generic, and your project may require different steps. For example, do you plan on building conceptual prototypes (a quick mock-up) this quarter to figure out how something might work? Or do you plan on getting some test data on a particular material before you make a decision about using it? Note: you are

not expected in this report to present any solutions, only the plan you will follow to develop the "Best" solutions.

6) Management Plan. This section describes the responsibilities of the team members. For example, it identifies who will have primary responsibility for information gathering, documentation of project progress, manufacturing considerations, prototype fabrications, testing plans, etc. Where appropriate, also identify who is primarily responsible for particular subsystems of the design. The management plan at this point should include a timetable of milestones relevant to the sponsor. (In the next report we will include a software generated Gantt chart). Look at the syllabus and include the milestones that will require the sponsors participation (Design Reviews, Reports, prototype testing and Design Expo).

7) Appendices: These may include a breakdown of design requirements, technical specifications, etc. The appendix may also include details about sources of information, contacts, etc. if known. Be sure to reference any information in an appendix at the appropriate location in the body of the report. Unreferenced material should not be included and will be ignored by readers.

In a commercial proposal there are often other items, such as qualifications of proposer(s), a reporting schedule, a cost estimate, and various contractual conditions. Of these, only the time and work estimates and the reporting milestones are required in your proposal.

Objectives revisited: The objectives and specification part of this proposal is particularly important for senior design projects and really all projects. Lots of time and resources are often wasted designing the wrong system or component because it is poorly specified. It is also important to realize that any important specification must be verified. One possible way to do this is to define how you plan to show compliance as you set the important engineering targets.

A formal specification and compliance matrix can be developed and documented as follows.

- Use Quality Function Deployment (QFD) to identify all customer requirements and a complete engineering specification. Also this method will help you set engineering targets for your project. Explain the House of Quality to your sponsor, i.e. do not just dump the House on your sponsor and expect him or her to figure it out for him or herself. What are its important features? What information did you glean from the House of Quality?
- Then construct a table of requirements or formal engineering specification. Include reference figures as required for things like geometry or interface requirements.

The formal engineering specification should also include how each design requirement is to be met. This is known as a "compliance" method. Typically these methods are:

1. Analysis (A)
2. Test (T)
3. Similarity to Existing Designs (S)
4. Inspection (I)

Also assess the risk of meeting each the engineering targets or specifications you set. Assign High (H), Medium (M) or Low (L) to each. High-risk requirements should be thoroughly discussed in the report as they are typically hard to meet. Use the following basic format for the table as shown on the next page.

Project X Formal Engineering Requirements

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Weight	5000 lb	Max.	H	A, T, S
2	Size (see Figure 1.)	10 in	±0.005	L	I, A
3	Production Cost	$438	Max	M	A
4	Power	10 HP	Min	L	T
5	Etc..				

The figure below serves a checklist to see that all aspects of a design have been specified. The main headings can be used to organize a specification list into logical groupings.

Main headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension.
Kinematics	Type of motion, direction of motion, velocity, acceleration.
Forces	Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, interia forces, resonance.
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc).
Signals	Inputs and outputs, form, display, control equipment.
Safety	Direct protection systems, operational and environmental safety.
Ergonomics	Man-machine relationship, type of operation, operating height, clearness of layout, sitting comfort, lighting, shape compatibility.
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.
Quality control	Possibilities of testing and measuring, application of special regulations and standards.
Assembly	Special regulations, installation, siting, foundations.
Transport	Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch.
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions).
Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.
Costs	Maximum permissible manufacturing costs, cost of tools, investment and depreciation.
Schedules	End date of development, project planning and control, delivery date.

Figure 4.5. Checklist for drawing up a specification

Figure Taken From "Engineering Design" by Pahl and Beitz, Springer Verlag 1988

Conceptual Design Report Due in Lab

Like your design logbooks, the reports you generate in this class are cumulative. In other words the Final Design Report will include material (most likely revised) from the Project Proposal and this Conceptual Design Report. Also these reports will document your design and the process you used to generate the design. The main goal of this report is to document your chosen concept for your design and support that decision with appropriate evidence.

The Conceptual Design Report should contain revised material from your proposal including:

- An improved Introduction that includes the project definition, justification, and motivation
- An enhanced discussion of the Background information that is required to complete the design including competitor information, similar systems, standard testing and validation regimes, literature, etc…
- A more polished version and update of the Design Requirements and Specifications based on sponsor feedback. Note that once your sponsor has agreed to the set of specifications, you must get their approval for any changes.

This report as mentioned will build from the proposal. The important new information that should be included in the Interim Design Report is your progress or the documentation of the conceptual design phase. Note that some groups will have selected a top concept while others may not, which will change this report slightly. Regardless, the Interim Design Report should contain new information such as:

- A short description and layout drawings (sketches) of your top concepts.
- A description of the process you used to select your top concept.
- Discussion of how your concepts satisfy the specifications.
- Associated quantitative work (analysis) to justify your selected concept.
- A more complete description of your top concept including a Solid Model Layout. Include geometries, materials, manufacturing process, etc… if known. Be sure to indicate what parts of the concept are still incomplete.
- Preliminary plans for construction and testing (validation) of your design.

One suggested approach for developing your interim report is to build from your proposal. Replace Method of Approach with a section called Design Development, which discusses your concepts, selection, final concept, and any other pertinent information as described above. Note results of detailed analysis, if included, should be put in the body of the report, and the reader should be referred to an appendix which will contain the details. Finally, the Management Plan should be updated with the current Gantt chart and a description of outstanding tasks and how they will be completed.

This is really the template for your Final Design Report. It will simply grow from this and have a lot more detailed design content as presented in the next section.

Final Design Report Due in the second quarter

This report is an extension of your Interim Design Report with the addition of a section describing your final design in detail. This report should contain all the information a third party needs to build your design without any other help. Appendices should include part drawings and assemblies. If you do a good job on this report, you will have the majority of your Final Project Report complete! You will only need to add manufacturing, testing and conclusions to it.

The Design Report should contain revised material from your Interim Design Report as necessary and the following new material:

- A functional description of your final design including at least one layout drawing (a *labeled* 3D isometric is appropriate) that helps identify the main components and/or subassemblies. More complex projects will require layouts of subsystems.
- Supporting analysis which shows that the design will meet the design specifications. (Note: the body of the report should contain analysis results while details of the analysis should be contained in an appropriately labeled and referenced appendix.)
- Safety considerations
- Explanation and justification for material selection
- Any special fabrication and assembly instructions
- Maintenance and repair considerations
- Appendix containing a top-level assembly drawing with Bill of Materials (BOM) and detailed part drawings and schematics.
- A cost analysis (This will be important for externally sponsored projects as we need to get funding.)
- Any pertinent product literature for purchased items should go in an Appendix (labeled and referenced!).
- A Management Plan with a Gantt chart for the entire project

Be sure that your report flows both in reading and in style (fonts, headings, etc.). Be sure that any information you include (figures, tables, appendices) is referenced. If you do not reference one of these items in the text, it should not be in the report. You may change headings from the Interim Design Report and rearrange sections as you see fit. Since your documentation is growing, your Final Design Report will usually be better if you adopt a chapter format. A suggested report format:

Title Page – Clearly show that this is the Final Design Report, include date
Table of Contents
List of Figures
List of Tables
Abstract or Executive Summary – Can be read quickly by someone to determine whether or not to read further

Chapter 1 Introduction
Include:
1. Sponsor Background and Needs
2. Formal Problem Definition
3. Objective/Specification Development

Chapter 2 Background
Include:
1. Existing Products
2. Current State of the Art
3. Specific Technical Data
4. List of Applicable Standards (safety, testing, etc…)

Chapter 3 Design Development
Include:
1. Discussion of Conceptual Designs
2. Concept Selection
3. Supporting Preliminary Analysis
4. Any proof of concept analysis or testing

Chapter 4 Description of the Final Design

Include:
1. Overall Description/Layout with labeled solid model
2. Detailed Design Description
3. Analysis Results (Details in Appendix)
4. Cost Analysis (a Bill of Materials with costs, a cost analysis of product)
5. Material, Geometry, Component Selection
6. Flowcharts, Schematics, Pseudo Code, Wiring Diagrams
7. Refer to your manufacturing drawings in appendix!
8. Any special safety considerations
9. Any maintenance and repair considerations

Chapter 5 Design Verification Plan (Testing)

Include:
1. Test Descriptions with list of necessary equipment.
2. Specification Verification checklist or DVPR

Chapter 6 Project Management Plan

Chapter 7 Conclusions and Recommendations

References

Appendix A QFD, Decision Matrices etc. (As appropriate)
Appendix B Drawing Packet (Assemblies with Bill of Materials, detailed part drawings, Process and Instrumentation Drawings, Electrical Drawings, as appropriate)
Appendix C List of Vendors, Contact information and pricing
Appendix D Vendor supplied Component Specifications and Data Sheets
Appendix E Detailed Supporting Analysis
Appendix F Gantt Chart with summary of time spent so far, time planned, percentages complete of all sub-tasks, etc.
More appendices as appropriate

It is recommended that you stick to the above format, including the numbered chapters, unless it does not fit your project for some reason.

Project Update Report to Sponsor Due at end of second quarter

This is a report of several pages that simply reports the status of the project to the sponsor. This report is written well into the build phase of your project, so it reports primarily on your progress through the build phase. You should have taken a number of photos of your progress in constructing the product or system that you have designed, so the report can be written as a narrative accompanying these pictures. This status report is completely separate from the Final Design Report and the Final Project Report. To write this report, review your Final Design Report and then ask yourself, what's changed and what's been accomplished since then. The enumeration of these changes and accomplishments, accompanied by photos, constitutes this report. Be sure also to use this as an opportunity to update your Gantt chart and to report specifically on time spent on the project 1) since the beginning and 2) this quarter. The percentage complete of the project should be reported as well as a prognosis for whether or not the project will be completed on time next quarter. If your budget has changed because of unforeseen components that you need to buy, you need to report this too.

Final Project Report Due at the End of ME 430

The Final Project Report is intended to be an extension of your Final Design Report from the second quarter. In general you will need to update your description of the design and drawings to account for any changes you have made this quarter. You will then need to add chapters for manufacturing, testing, and conclusions. The organization of your report might vary from the recommendation below, but should include all the elements listed. Please use your best judgment in creating your outline. Some standardization on format is necessary as copies of all senior projects reports will be kept in the library. The format of your report should be similar to the following:

Title Page
Disclaimer Page
Table of Contents
List of Tables
List of Figures
List of Nomenclature
Executive Summary

Chapter 1 Introduction
Include:
1. Sponsor Background and Needs
2. Formal Problem Definition
3. Objective/Specification Development
4. Project Management

Chapter 2 Background
Include:
1. Existing Products
2. Current State of the Art
3. Specific Technical Data
4. List of Applicable Standards (safety, testing, etc…)

Chapter 3 Design Development
Include:
1. Discussion of Conceptual Designs
2. Concept Selection
3. Supporting Preliminary Analysis
4. Any proof of concept analysis or testing

Chapter 4 Description of the Final Design
Include:
1. Overall Description/Layout with labeled solid model
2. Detailed Design Description
3. Analysis Results (Details in Appendix)
4. Cost Breakdown (prototype, mass manufacturing)
5. Material, Geometry, Component Selection
6. Flowcharts, Schematics, Pseudo Code, Wiring Diagrams
7. Refer to any manufacturing drawings in appendix!
8. Any special safety considerations
9. Any maintenance and repair considerations

Chapter 5 Product Realization
Include:
1) Description of the various manufacturing processes employed (with photos).
2) Description of how your prototype might differ from your planned design.
3) Recommendations for future manufacturing of your design

Chapter 6 Design Verification (Testing)
Include:
1. Test Descriptions with photos

2. Detailed results
3. Specification Verification checklist or DVPR

Chapter 7 Conclusions and Recommendations

References

Appendix A QFD, Decision Matrices etc. (As appropriate)
Appendix B Final Drawings (Assemblies with Bill of Materials, detailed part drawings)
Appendix C List of Vendors, Contact information and pricing
Appendix D Vendor supplied Component Specifications and Data Sheets
Appendix E Detailed Supporting Analysis
Appendix F Gantt Chart
Appendix G More appendices as appropriate

You can review past Senior Project reports, which are kept in the library on campus.

What to Turn in:
1) One or more bound copies for lab advisor (check with advisor to see how many)
2) One bound copy for sponsor (delivered at the Senior Design Expo is preferred)
3) One electronic (pdf) file posted to the digital dropbox on the ME428-01 website.
4) One electronic (pdf) file which will be uploaded to the library's DigitalCommons Website.

1) The copies for your advisor should be spiral bound or 3-hole punched in a semi-rigid folder and starting with:

   a) Evaluation and Grade Page (typed by student)
   b) Body of Report, with the first two pages being the Title Page and Statement of Disclaimer.

2) Sponsor Copy: It is best if you can give this to the sponsor in person at the Senior Design Expo. If it is not ready or the sponsor cannot make it, mail the bound copy to the sponsor (a pdf file by email suffices only if the sponsor agrees). Since the sponsor will be giving feedback to the teaching staff, you must be sure the sponsor gets the report early in finals week or you may receive an incomplete for the course. The sponsor copy should **not** have the Evaluation and Grade Page.

3) Class PDF Copy: Do **not** include the Evaluation and Grade page. Please upload a pdf copy of the report to your ME428-01 Blackboard Digital Dropbox.

4) Library PDF Copy – Do **not** include the Evaluation and Grade page. This will be uploaded to the Library's Digital Commons website. If you have a proprietary project, please see below. All instructions for turning uploading the library copy can be found on the Library's website at:

   http://lib.calpoly.edu/seniorprojects/guidelines.html

Please follow the steps exactly they are lengthy.

Proprietary Work: If your project is proprietary and your sponsor does not want the report available in the library, then should submit everything above, with the following modifications:

1) Instructor Copy: The only change should be the addition of a Confidentiality Statement just before the Statement of Disclaimer.

2) Sponsor Copy: The only change should be the addition of a Confidentiality Statement just before the Statement of Disclaimer.

3) Library PDF Copy: For the body of the report, submit only the title page and Confidentiality Statement. Yes, you still have to fill out the other forms, and you still have to pay the fee.

4) Electronic File: The only change should be the addition of a "Confidentiality Statement" just before the Statement of Disclaimer.

Sample Pages:

The next five pages contain sample pages to help you with the format of your report. They contain the basic text and margins required. You are free to change the format of the title page.

The Evaluation and Grade Page
The Title Page
The Disclaimer Page
Confidentiality Statement
A formatted example for the Table of Contents

Each page is labeled in RED. Simply use this Word file, erase the red text, and edit.

EVALUATION AND GRADE PAGE (ERASE THIS LINE)

Steam Powered Lawn Mower

by

John Q. Student
Jesse Q. Student
Pat Q. Student

Project Advisor: Type Advisors Name Here

Instructor's Comments:

Instructor's Grade: _______________

Date: ___________________________

TITLE PAGE (ERASE THIS LINE)

Steam Powered Lawn Mower

by

John Q. Student
Jesse Q. Student
Pat Q. Student

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

2011

STATEMENT OF CONFIDENTIALITY ONLY IF NECESSARY
(ERASE, AND NOTE THAT TEXT BEGINS 1.5 INCHES FROM TOP OF PAGE)

Statement of Confidentiality

The complete senior project report was submitted to the project advisor and sponsor. The results of this project are of a confidential nature and will not be published at this time.

DISCLAIMER
(ERASE, AND NOTE THAT TEXT BEGINS 1.5 INCHES FROM TOP OF PAGE)

<u>Statement of Disclaimer</u>

Table of Contents (Example)

Presentations

Design Reviews First and second quarter at sponsor's site

At the first part of the second quarter (see syllabus) you will make a formal presentation to your project sponsor at his/her site. Your lab advisor will most likely want to see the presentation beforehand on campus. Consult with you lab advisor for details. Please reread the travel policies before making your plans for the Critical Design Review.

Manufacturing and Test Review First of Quarter: ME 430

At the beginning of the third quarter you team makes a 15-minute presentation which gives a status report on the Manufacturing and Test plans. Items to include are:

Status of component manufacturing with hardware present
Updated test plan including location and hardware necessary for the testing
Results of any component or subsystem testing to date
Updated schedule focusing on the on-time completion of the project

This presentation will be scheduled through your lab advisor, and all students in a lab section are expected to attend.

Senior Design Expo Thursday of Dead Week: ME 430

This is the culminating presentation for the Mechanical Engineering Department's three-quarter Senior Design Project Course. Students will present their Senior Design Projects in a poster session with accompanying hardware whenever possible. If there is a compelling reason that hardware cannot be at the event, then photos and/or video should be on hand. The teaching staff, project sponsors, other faculty, and guests will attend this exposition. Students should feel free to invite their friends and family to the event as well. (In our experience, parents of graduating students love to come see their son's or daughter's magnus opus.) Teams must have their poster display set up prior to the public event. Please consult your lab advisor for the day's schedule. Prior to opening the show to the public, the teaching staff will be moving around the room and visiting each poster for grading purposes. Your poster should not be manned during this time. During the public portion, each team should plan on having its poster station manned for the entire event by at least one student from the team.

Attire: This is a formal session, and project sponsors will be traveling to see the event. Please dress appropriately and professionally. Business Casual is okay.

Poster Requirements: Posters should consist of one 34" x 44" (ANSI E) poster mounted on foam board in either portrait or landscape orientation. You will need to build a support on the back so that they will be free-standing on provided tables. The posters will be rated in three main categories.

1) **Visual Appeal**: The posters should be neat and professional and arranged so that they are easy to understand. All figures should be clearly labeled. Visual appeal is important.

2) **Technical Content:** Sound engineering principles with quantitative results as applied to your design should be presented as appropriate. These should support your solution as the best possible one. Use of creativity and the completeness of the project, including test results, is expected.

3) **Organization:** Poster should be logically organized and easy to follow without explanation. There should be a logical progression from the problem statement, to design objectives, to conceptual design, to final design with analysis, testing, conclusions and recommendations.

Laying Out and Printing the Poster

The posters must consist of a single plotted sheet glued to the foam board. Students have found that using PowerPoint is effective in creating the layout. You can also use Adobe software and others. Printing can be done using the color plotter in 13-107. Please read the important instruction near the plotter for important tips. When plotting out your final copy, we will provide glossy paper. A sign up sheet for printing times will be posted on the course instructor's office door. The times will be during the 10th week of classes when the photo quality roll will be in the printer for your use.

Note: More information on Poster Design can be found on Blackboard or the web. Note ignore any "pasting" suggestions since we have the resources to make a single sheet poster.

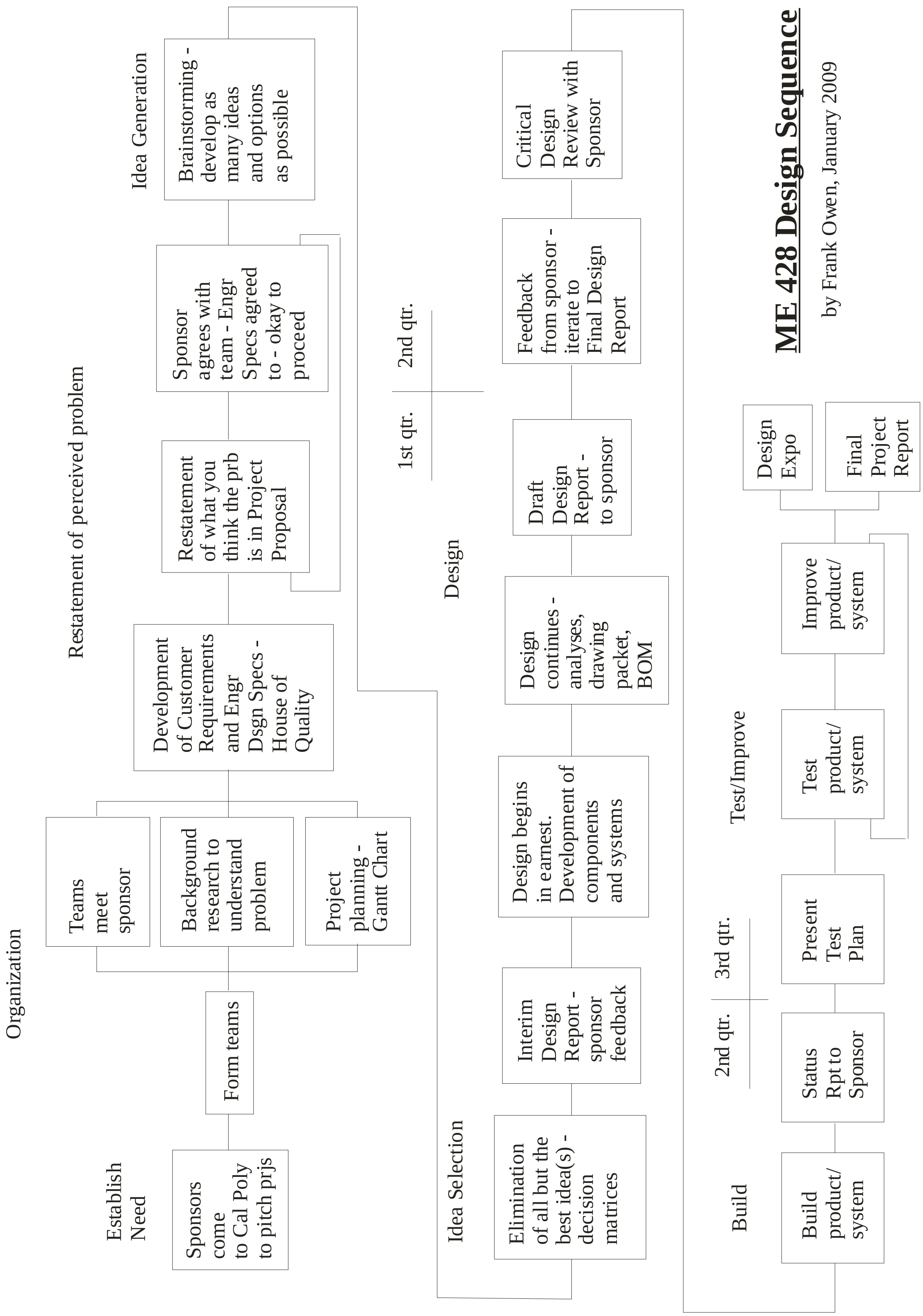
Content Reading

Design Process and Methodology

The engineering design process is a type of problem solving which can be summed up by five basic steps:

1) Establish a need
2) Explicitly state the problem
3) Generate possible solutions
4) Evaluate the solutions and pick the best one
5) Document the work

In reality the process of designing a mechanical, electrical, electro-mechanical, software or any other type of engineering system is more complicated and certainly not linear. In this class you will gain experience with the engineering design process by actually experiencing it as you solve an externally supplied engineering design problem. The problems are real and do not have a single “right” answer. Instead we will apply a formal (although nonlinear) process to find the “best” answer over a 30-week period. The flowchart shown below from “The Mechanical Design Process” by David Ullman gives a more complete picture of the steps of the engineering design process. Note the many arrows on the flowchart that point back towards the beginning of a project. This is an important and sometimes frustrating aspect of the design process which you will all experience in this class. Hopefully with guidance from your advisor you can appreciate the effectiveness of this process and not be bogged down in frustration.


ME 428 Design Sequence
by Frank Owen, January 2009
Establish Need
Sponsors come to Cal Poly to pitch prjs
Organization
Form teams
Teams meet sponsor
Background research to understand problem
Project planning - Gantt Chart
Restatement of perceived problem
Development of Customer Requirements and Engr Dsgn Specs - House of Quality
Restatement of what you think the prb is in Project Proposal
Sponsor agrees with team - Engr Specs agreed to - okay to proceed
Idea Generation
Brainstorming - develop as many ideas and options as possible
Idea Selection
Elimination of all but the best idea(s) - decision matrices
Design
Interim Design Report - sponsor feedback
Design begins in earnest. Development of components and systems
Design continues - analyses, drawing packet, BOM
Draft Design Report - to sponsor
1st qtr.
2nd qtr.
Feedback from sponsor - iterate to Final Design Report
Critical Design Review with Sponsor
Build
Build product/ system
2nd qtr.
3rd qtr.
Status Rpt to Sponsor
Present Test Plan
Test/Improve
Test product/ system
Improve product/ system
Design Expo
Final Project Report

Teaming

Background and Motivation

Although students have likely worked together on team-based projects prior to their Senior Design Project experience, it is just as unlikely that they have done so for 30 weeks. The success of the project is in large part determined by the success of the team. It is therefore important that all students in the Senior Design Project course have an understanding of teaming skills, knowledge and attitudes. Katzenbach defines a team as "… a small number of people with complementary skills who are committed to a common purpose, performance goals, and an approach for which they hold themselves mutually accountable." Teaming, especially in engineering, is necessary to complete any reasonably complicated task whether it is designing a new product, setting up a new production process or implementing a new management organization. In this class we are focusing on the design process and therefore we will focus on the design "team." Most of the deliverables for this class are "team" not individual items. Your ability to perform as part of a high performance team has a direct bearing on the success of your project. Most of the project failures and poor results in the past can be directly attributed to poor performance of the teams and most of the successes come from teams that perform at a high level. It is essential for you to have an understanding of teams and team processes and to develop your skills as a team member and practice them on your design team during this class. Once you develop these skills, you will be able to apply them for the remainder of your career. An excellent reference for engineering students is provided by Levi et. al. and much of what appears here comes from their manual on Student Team Work.

Team Development Stages

In the 1960's , Bruce Tuckman a Professor of Education at Rutgers (He is now at Ohio State University) published a paper about the development sequence of small groups which is now the most quoted and accepted model of the process of team development. He described four basic stages of team development as **Forming**, **Storming**, **Norming**, and **Performing**. Figure 1 shows these stages as a pyramid with the top representing those teams which have obtained a high-level of performance. The idea is that all teams must go through these four stages to achieve peak performance.

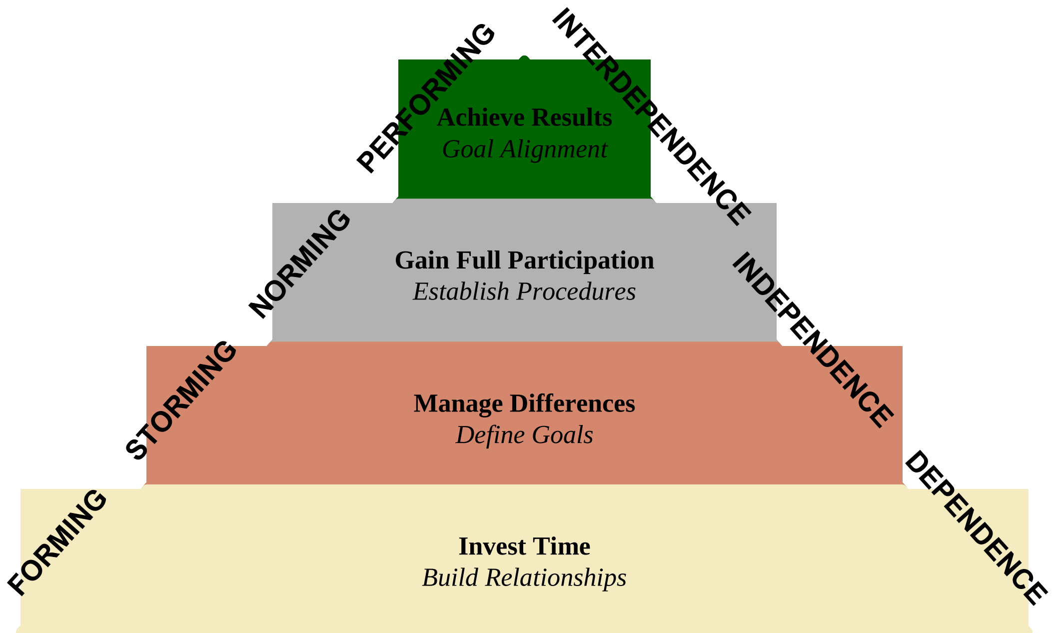


Figure 1: Stages of Team Development after Anne Virkus and Mark Steiner

Forming:
The forming stage begins when the team is first gets together. For you this was when you first met to discuss writing your Sponsor Introduction Letter. The length of time of this stage depends on many factors including the number of team members and the amount of time spent together. This is considered by the some the most critical phase as this is when you can build foundations of trust among your team members by learning about each other. This time also sets expectations among team members for success and behavior. The forming stage is usually an upbeat, happy time where team members are polite and responsive. Team members will usually have feelings of optimism for the outcome of the project. Also there is usually no real progress made towards completing the task. The real work is forming the team. This is the ideal time in a design project for working on the problem definition, the scope and developing the detailed engineering specification.

Storming:
This second phase of team development is the most difficult. It is characterized by conflicts among team members and confusion about team roles. Team members recognize that progress towards solving the problem at hand must be made, but there is not yet an established structure within the team to move forward, reach consensus and make decisions. There can be power struggles at this time if multiple people vie to be team leaders and are not willing to share responsibility. Often, individuals will blame the "concept" of having a team for their problems. Some feelings associated with this stage include defensiveness, competitiveness, tension and jealousy. Team members attitudes about the potential success of the project might swing wildly. Some typical behaviors at this stage include not completing tasks, excessive arguing about small points, choosing sides, establishing unrealistic goals and questioning the wisdom of having a team at all. Like the forming stage, little progress towards the completion of the design task is expected or possible at this stage. Real progress won't kick in until the Norming stage. Also real understanding of the diversity of your team members will begin.

Norming:
During the *Norming* stage, the team members begin to agree on the structure of the team. You decide who will take what roles and how you will conduct "business." The team will start making progress on their task, but will often bounce back and forth between "Storming" and *Norming*. This process does not happen all at once. Communication among team members will improve during this phase. Some feelings associated with this phase include an increasing optimism about the team's chance of success, a growing sense of team unity, acceptance of the team's individual diversity and a growing sense of harmony.

Performing:
This is the highest stage of team development and is characterized by a well-functioning team capable of completing the assigned task. At this point the team is primarily self-directed, needed little input from an outside manager. Roles are clearly defined and tasks are regularly completed on time as promised. This team will be able to tackle almost any similar problem assuming they have the correct technical background. Feelings associated with this phase include pride both in the task progress as well as the team process. Team members respond positively to constructive criticism from their teammates and personal growth can be achieved. This is when the bulk of high-quality work will get done.

Establishing Team Norms/Effective Team Meetings

At the early stages in team development, a team must establish the ground rules for meetings. These include what kind of behavior is acceptable and how the interaction will occur. Although many individuals prefer "loose" arrangements, some formal rules for meetings should be put in place if you want to become a high performing team. Some other hints that you need ground rules (suggested by Levi) include:

- Topics are avoided repeatedly.
- Irrelevant conversations keep reoccurring.
- Team members do not acknowledge or follow the norms.
- There is conflict over the meaning of norms.
- A meeting leader cannot get members to comply.

Scholtes suggest the following list of options for ground rules for team meetings.

Meetings – When do they occur? How often? How long?
Attendance – When is missing a meeting okay. How are missing members informed about decisions or task assignments? How will you handle excessive absence by team members.
Promptness – What do you mean by on time? How is it enforced?
Participation – How to ensure that everyone gets their say?
Conversational Courtesies – Raise hand to talk? Don't interrupt? Listen?, Respect?
Assignments – How do you make sure tasks are completed on time? How do you know who does what and when?
Roles – Who will fill various roles? How should they be selected? How can they change?
Agendas and Minutes – Who is responsible? What is the format?

Decisions - What represents consensus? How is it attained? Do you vote? Is there veto power?

Team Roles

The primary reason for engineers to be included on design teams is their technical expertise and experience. Beyond that, there are secondary roles that team members must take on for successful teams. The role(s) that each team member takes depends on their individual problem solving style. Based on work by R. M. Belbin, Ullman suggest eight secondary team roles that need to be filled on successful engineering design teams. Usually team members fill more than one role and often multiple team members can fill the same role; however, the roles are consistent with the team member problem solving style preference. The roles are:

- **Coordinator** – This team member is typically mature, confident and trusting. They are good at clarifying goals and promoting effective decision making. This can be a good chairperson for a team
- **Creator** – This person is imaginative and can solve difficult problems. They can also be impractical, have no regard for established team norms and don't necessarily like to work with facts.
- **Resource-Investigator** – This team member is usually an extrovert known for their resourcefulness. They excel at finding new opportunities and developing contacts. They can sometimes lose interest when the detail stage is reached.
- **Shaper** – This person may be dynamic, outgoing and assertive. They make things happen by finding a way around obstacles. They can also be impatient with vagueness, but like to make logical and objective decisions.
- **Monitor/Evaluator** – The team member is good at seeing the "big" picture and accurately judging possible outcomes. They may not be inspirational leaders, but they are intelligent and shrewd.
- **Team Worker** – This is a consensus building who is concerned about making the team function in harmony and avoiding conflict. They are typically subjective decision makers.
- **Implementer** – This team member turns ideas into action. They are usually disciplined, reliable and efficient. They can be sometimes construed as resistant to change.
- **Completer/Finisher** – This team member is conscientious and detail-oriented and usually delivers results on time. This people are often reluctant to delegate authority and they worry about progress.

Team Decision Making

The decisions your team makes during the problem solving process will mostly decide the quality of your solution. The process that you use to make these decisions will have a great impact on how you feel about your team and the solution. According to Levi, there are generally four approaches to Team Decision Making. They are:

Consent: This is the approach to use when the decisions are fairly straightforward or have been effectively already made by the team member best suited to make the decision. The typical approach is to create a Consent List on a meeting agenda. During the meeting, the facilitator asks if anyone has a problem with these items. If there are no objections then the decision has been made. This is an excellent way to avoid wasting time discussing low importance decisions or items that have already been agreed upon by the relevant team members.

Consultative: In this method, one team member is given the authority to make the decision (usually due to a particular expertise). This person should elicit advice from team members, but they will make the final decision. It is usually obvious when a team member's qualifications give them the authority, but it should be stated and made clear to all team members that they will be making the decision.

Democratic: This seems like a good method (given the history of the U.S.) but it turns out to be the worst team decision making method. The popular vote always makes winners and losers (sometimes almost ½ of the team!). The losers may be quite unwilling to support and implement the decision after it is made. Although this is a quick and decisive method, it should be avoided except as a last resort.

Consensus: This is the best approach for any major team decision and it sometimes requires the most work. The key is to continue discussion until all agree on accepting a decision. This does not mean that it is every team member's favorite decision, but by acceptance all team member are stating that they are willing to support and implement the decision.

How to achieve Consensus*:*
Hackett and Martin having the following suggestion on how to reach consensus:

Team facilitators can help to achieve consensus by:

- Giving adequate time to discuss and work through issues.
- View conflict as inevitable and ultimately beneficial.
- Encourage negotiation and collaboration among team members.
- Recognize that giving in on a point is not losing and that gaining a point is not winning.
- Encourage team members not to give in just to avoid conflict.
- Don't allow coin flipping or voting when differences emerge.

Ways to get unstuck when trying to reach consensus include:

- Agree to not agree and then move on to the issue.
- Change topics, call a recess or decide to decide later.
- Work towards a compromise, knowing it might not be the best decision.
- Ask for outside help and input.
- Use voting only as a last resort.

If team members can say yes to the following statements, then consensus has been achieved.

1) Will you agree this is what the team should do next?
2) Can you go along with this position?
3) Can you support this alternative?

Managing Team Processes

Communication Skills
The ability to communicate is often agreed as the most important skill for effective teamwork. According to Levi, four important skills include how to ask questions, how to listen, how to give constructive feedback and how to manage feelings.

***How to ask questions*:**
In general open ended questions are useful for promoting team discussions while yes/no questions are not. It is often useful to follow up on answers with questions that ask for further explanation. Questions asked to the meeting facilitator should be echoed back to the team for discussion.

Hackett and Martin have proposed a set of rules for asking non-threatening questions:

1) Initially ask each question of the entire team.
2) Pause and allow the team members time to consider the questions.
3) If a team member responds, acknowledge the remark and explore the response further if possible or necessary.
4) If no one responds, either ask a particular person or consider reworking the questions.
5) Avoid biased questions
6) Avoid asking too many yes/no questions
7) Avoid questions that put team members on the defensive

***Active Listening*:**
The goal of active listening is to increase communication by giving the speaker feedback in order to clarify and promote further discourse. An active listener should communicate that you want to understand the speaker and their underlying feelings. In active listening, the receiver should paraphrase back to the speaker what they heard as a means of clarifying the message. They should also describe their perception of the speaker's feelings. In this way the speaker and listener can go back and forth and reach consensus on the meaning. This is a method of avoiding the evaluation of a speaker's communications which may make them defensive and thus decrease further discussion. Active Listening is also a very effective method for conflict resolution.

***Providing Constructive Feedback*:**
A hallmark of a high performing team is the ability of the team members to provide and receive constructive feedback. Receiving feedback can sometimes be difficult and providing it can be ineffective. The following guidelines by Scholtes can be helpful when providing this type of feedback:

Start With	Explanation
1) "When you…"	describes the behavior
2) "I feel.."	tells how you are affected
3) "Because I…"	Why you are affected that way
4) Pause for discussion	
5) "I would like…"	Describe the change you want
6) "Because…"	Why you think it will fix the problem
7) "What do you think?"	Listen and discuss

How to Manage Feelings

Emotions can run high during a long term project especially when important decisions are made. This can be especially true during the "Storming" stage of Team development. These emotions can be a source of great strength to the team's efforts, and it is absolutely critical that these emotions do not become destructive. All team members should learn how to handle emotional interactions between members. Kayser suggests the following:

1) Stay Neutral: Everyone has a right to their own feelings. The team should acknowledge the expression of those feelings
2) Understand rather than evaluate feelings: Be sensitive to verbal and non-verbal messages. When dealing with emotional issues, be sure to ask questions and seek information to better understand the feelings.
3) Avoid asking team members why they feel a certain way.
4) Process feelings in the group: When the team's operation is disrupted by emotions, stop and cool down. Then discuss the issues in the whole group.

Conflict Resolution

Conflicts occur for a variety of reasons that are desirable on a design team, especially as they work to solve difficult open-ended problems. Differences in opinions, ways of thinking and different methods of solving problems are some of the main reasons teams are more effective than individuals. Maddux points out that conflict become unhealthy when it is avoided or viewed as a competition. He points out five basic methods that are used to resolve conflict.

1) **Avoidance:** This is "the bury your head in the sand" approach hoping that the problem will go away. It never does.
2) **Accommodation:** Some team members give up their position just to be agreeable, but this costs the team their input.
3) **Confrontation:** By acting aggressively, some members may "win" a confrontation. This can become more important than making a good decision and leads to isolation and non-participation of the "loser"
4) **Compromise:** This way balances the goals of each team member by having each give a little. Unfortunately the optimal decision is most likely not made.
5) **Collaboration:** The team agrees to solutions to the conflict that satisfy all team members. This requires cooperation and respect and takes the most time, usually with the most satisfying outcome.

Of the above approaches, collaboration usually leads to the best and most creative decisions and should be the preferred method of conflict resolution.

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Social Styles

Background and Motivation

One of the most important skills that a team can develop is the ability to manage the diversity inherent among its members. This diversity is one of the strengths of using teams to solve complex problems like your design project. Managed properly, the team's diversity can be leveraged to provide high performance for many of the tasks that need to be completed during the project. Managed improperly, misunderstanding of team diversity can lead to prolonged conflict, team member isolation and poor team performance. The types of diversity that design team members' exhibit include basic knowledge, skills, attitudes, ability, culture, behaviors, and problem solving and working styles. This document provides a framework for addressing team member's behaviors and how they are affected by Social Styles.

Social Styles

The social style model was originally developed by Dr. James Taylor who was a staff Psychologist at Martin (later Martin-Marietta) Corporation. It was based on earlier work by Dr. David Merrill and Roger Reed who were trying to understand how to predict individual success in business careers based on personality. The Social Style Model™ is now trademarked and owned by the TRACOM group which is a business consulting firm that helps companies get the most from their organizations. For our purposes, we are going to use the model to provide a framework for understanding team members behaviors based on their perceived social style.

The social style model is based on three main measures of human behavior: **Assertiveness**, **Responsiveness and Versatility**. **Assertiveness** is the degree to which one tends to *Ask* or the opposite, *Tell* during interactions with teammates. For example would you ask, "Should we sit down and do the analysis of this system?" or would you pronounce, "Let's draw the Free Body Diagram now!" Obviously this is a gray area and you probably might fall in between the two opposite. You may even switch between on or the other depending on the situation. Assertiveness can also be thought of as the degree to which others see you as trying to influence their ideas. **Responsiveness** is the tendency that you emote or control your feelings. In social situations it is a measure of how you openly display or hide feelings or emotions. An *Expressive* behavior is marked by open displays or feelings while *Controlled* behavior is marked by mild or no open displays of emotion. These two measures, Assertiveness and Responsiveness can be plotted on orthogonal axes which divide a plane into four quadrants. Each quadrant as depicted on the next page represents a Social Style. They are:

Driving (Telling and Controlled): A team member with this social style is perceived as independent, practical, decisive, and one who values actions and results.
Analytical (Asking and Controlled): A team member with this social style is perceived as serious, orderly, and logical and one who values facts and accuracy.
Amiable (Asking and Expressive): A team member with this social style is perceived as dependable, open and supportive and one who values security and relationships.
Expressive (Telling and Expressive): A team member with this social style is perceived as ambitious, enthusiastic and stimulating and one who values approval and spontaneity.

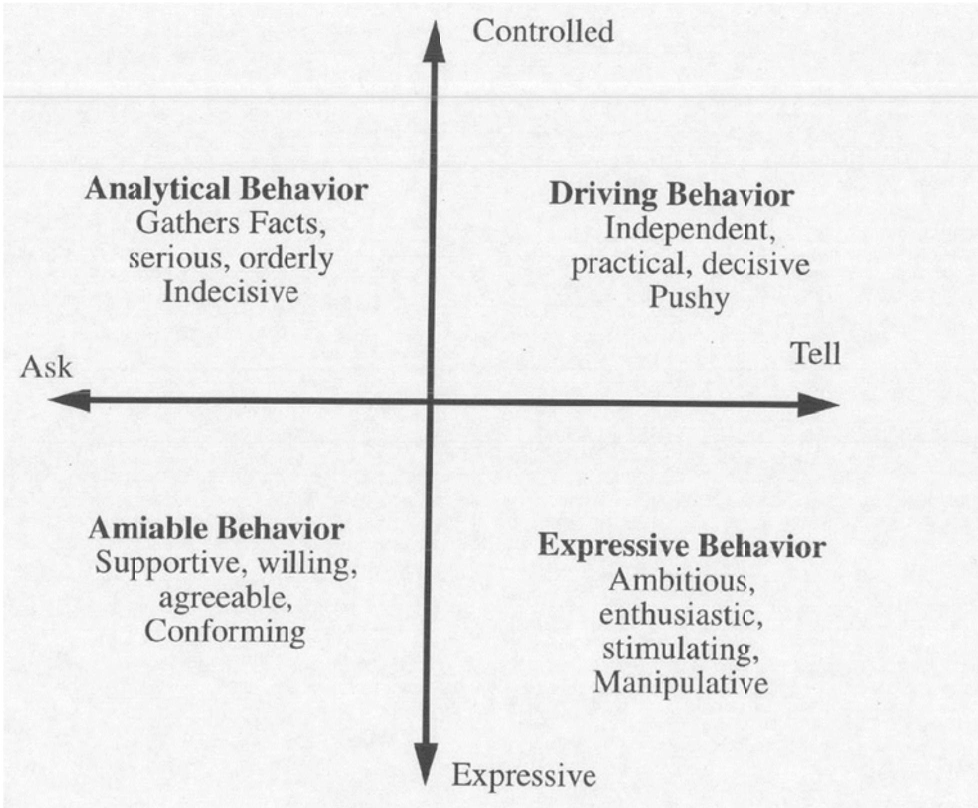

Figure 1: Social Styles with both positive and negative attributes

Versatility, the third measure, is the ability to adjust individual behavior in a given situation to maximize team productivity. For example your dominant social style might be Driving Behavior. If you have high Versatility, you may behave in an Amiable manner if it most benefits your team performance. Being versatile is not "changing" who you are; rather it is adjusting your behavior to meet the team's needs to maximize performance. It is important to note that there is nothing inherently good or bad about your social style. Also note that it is how you are perceived, not how you are or think you are. It turns out that individuals who measure themselves are usually wrong 50% of the time, yet when assessed by others their social style is consistently identified. Keep in mind that these are not absolute measures.

Managing your Team's Diverse Social Style

The most important aspect of managing your team's social style diversity is basic understanding of your teammate's behaviors and how your own behaviors are perceived. Then you can use your own versatility to adjust your behavior in certain situations in order to maximize team performance. Your adjustments based on understanding the social styles of your teammates can improve communication, trust, reduce conflict and ultimately increase your team's performance.

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QFD: Quality Function Deployment

Background

One of the first and most critical tasks in developing a product is understanding the problem. Individuals and companies large and small have been known to spend incredible amounts of time and money, solving the wrong problem and developing products or devices that do not satisfy the original need. This usually results in product development delays once functioning prototypes are built and it becomes obvious that they do not solve the intended problem. These types of delays are very costly to companies and often result in a huge competitive disadvantage. The best way to avoid solving the "wrong" problem is to work hard at defining the "right" problem. For an engineer, the problem is best defined in terms of a specification where actual measures can be used to determine whether a design has met an intended need. This is no easy task and probably you are starting to appreciate the difficultly in defining in engineering terms such ambiguous ideas of "looks good," "is safe" or "the best." One method to translate these ambiguous customer requirements into effective, measurable engineering specifications is Quality Function Deployment (QFD).

QFD was developed in the 1970s in Japan as part of a nationwide effort to improve the countries industrial competitiveness. It was so successful that companies in the U.S. started adopting the method in the 1980s. The American Supplier Institute in Michigan has been a strong proponent of its use in the U.S. auto industry. It has now been established as a proven design technique to assist in specification development and is taught formally to about 2/3 of graduating undergraduate engineers. By adopting this method Toyota Motor Company was able to lower the costs of bringing a new car to market by 60% and to decrease the time required by 1/3. Surveys of mid to large U.S. companies show that about 70-80% use the method and 83% of those feel that the method increases customer satisfaction with their products.

The QFD method is time intensive. It is reported that Ford Motor Company will spend 3-12 months developing its QFD of a new feature. The basic output of the QFD method is a "House of Quality". This is a diagram which contains all the information relating customer requirements to engineering specifications along with analysis of how competitors satisfy the customers. The best way to understand the value is to go through the process. You should develop a House of Quality (or QFD Table) for your design project and revisit it several times before you make a final conceptual decision for your design project.

Steps for the Method

Figure 1 shows a blank House of Quality worksheet (note this excel file is available on Blackboard for your use). There are seven basic steps to filling this table and capturing what is referred to as the "Voice of the Customer" in appropriate engineering requirements (a.k.a. specifications)

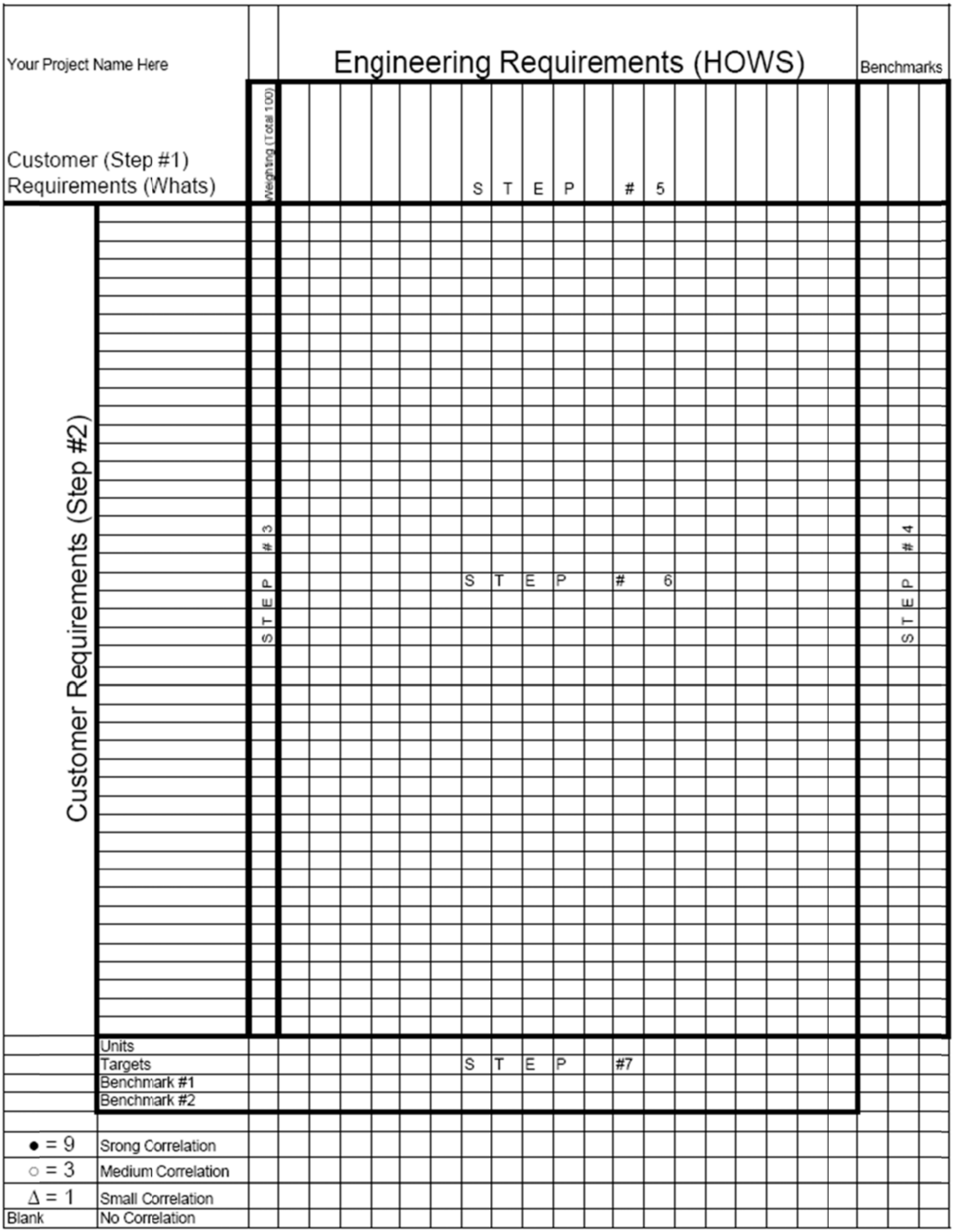

Figure 2: Blank House of Quality

Step 1 – Identify the Customers (Who)

In consumer product development, it is easy to see that the end-user of a product is a customer; however, they are not the only customer that a designer must consider while developing a product. Manufacturing, Marketing and Sales, and Service may also be important "customers" of a design. If the artifact that is going to be created is a device to increase manufacturing productivity, than the workers who will interface with the device directly might be considered the customers. For your project you must consider all the customers who need to be satisfied by your project, but you can focus on your sponsor. Often times QFD tables will have multiple columns input in Step #3 indicating the relative importance of a requirement for the different customers.

Step 2 – Determine the Customer Requirements (Whats)

Different customers want different things in a design. A customer requirement is a statement of "what" the customer wants, usually in their own words. For example, a consumer might want a product that works well, looks good, lasts a long time and is inexpensive. A manufacturing customer might want something easy to make out of easy to obtain materials and standard parts. A Marketing and Sales person might want something attractive, reasonably priced and easy to display. There are many techniques to get these requirements, but the basic idea is to listen to your customers. It is best to get them in the same room. Surveys are also a great tool. For your projects you will be asking questions of your sponsors and you may add some customer requirements of your own as you will in some respects act as the manufacturing customer of your project. Once you have made a list of customer requirements you will probably want to sort them into like categories. Categories that usually come up include:

- Functional Performance
- Human Interaction
- Physical Requirements
- Reliability
- Life Cycle Concerns
- Resource Concerns
- Manufacturing Concerns

Once the customer requirements are determined they can be filled into the House of Quality and grouped by Category

Step 3 – Weighting the Customer Requirements (Who vs. Whats)

Not all customer requirements are created equal. Some are more important to customers than others. Some are absolutely essential. In this step of the QFD process we will mark any must-have customer requirement with an *. One could use surveys and historical data to weight the customer requirements. Another method that we will use is to do pair wise comparison of each customer requirements asking which is more important, adding up how many times each requirement is more important than the others. Once these sums are made, they are scaled so that the sum total equals 100. Often times QFD users make separate weighting columns for each customer so that it becomes clear which requirements are most important to which customer.

Step 4 – Benchmarking the Competition

In the columns of step 4, include the nearest competitors to your project. In many cases there is no competitor, but it is still important to compare against alternatives. The current state of affairs (no new product) might be considered as an alternative. Next mark in the column how well each competitor device satisfies the customer requirements using the following scale:

1 = Design does not meet the requirement at all
2 = Design slightly meets the requirement
3 = Design somewhat meets the requirement
4 = Design mostly meets the requirement
5 = Design Fully meets the requirement

This step will indicate possibilities for competitive advantage and product improvement. It also will show what requirements the competition meets well. You should investigate how your competitor is doing that. Remember that most “design” is redesign of existing concepts. The best way to get this data is to use “focus groups of users” who can rate the competition. We don’t have this luxury although in some cases we can consult with our sponsor or other users of the benchmarked products.

Step 5 – Filling in the Engineering Requirements (Specifications, Hows)

Hopefully you have already generated a list of specifications. It probably is not yet complete. Remember from last week that these specifications must be measurable and verifiable. A way to get further specifications is to look down your Customer Requirements list and determine how you can measure some aspect of each requirement. It is very common to have multiple specifications for each customer requirement.

Step 6 – Relating Customer Requirements to Engineering Specifications (Hows vs. Whats)

This step involves determining the relationship between each customer requirement and each specification. The intersecting cell in the house of quality is filled in depending on the strength of that relationship. You can either use symbols or numbers, although the symbols make for a better visual correlation of the strength of relationship. The symbols (or values) to use are:

● = 9 Strong Relation
○ = 3 Medium Relation
∆ = 1 Weak Relation
Blank – no Relation

This process should be done as a team and will likely lead to many detailed discussions since there is an element of uncertainty here. For a complicated system, filling out this portion of the House can take months!

Step 7 – Setting Engineering Targets (How Much)

This gets at answering the question of how good is good enough. These are the numbers and units of the Engineering Specifications. They must be derived using input from the customer, basic engineering knowledge and by comparing to any competition. There is also space in the section of the table to include any known specifications of your benchmarked competition.

Analyzing the Results

There is huge value in setting up a QFD table due to the discussion by your team about the problem. Note that there is nothing in the table about solving the problem, only defining it. You should always make sure that customer requirements are strongly addressed by one or more engineering specifications. If not (a blank row or a row with only triangles), then you are missing specifications and have not yet fully defined the problem. If you have specifications with no related customer requirements (blank columns or columns with only triangles) then you may be over specifying your problem or you don't know what your customer wants. You should always be concerned whether your target values are different from your competition, especially if customers are satisfied with you competition. It might mean you are solving the wrong problem! Lastly this is considered a working document and will need to be updated as you learn more about your customer and the problem you are trying to solve. There should be discussion in the specification development portion of your Project Proposal about what you learned from employing the QFD process.

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Design Thinking and Creative Techniques

Background and Motivation

Engineers are often called upon to develop innovative solutions to unique technical problems. Engineering is an applied science and combines elements of both Art and Science. One of the skill sets of successful engineers is their ability to solve problems not only with applied technology but with their creativity. With the current "Global" economy, U.S. businesses have been pushing innovation in attempt to have a competitive advantage over lower production cost competition. The idea is that new technology and new innovation are the hallmarks of future successful enterprises in the U.S. This document is a summary of the most well-known and generally useful creative techniques for the design process that have been proven effective for engineers in both industry and in applied research. This document closely follows notes developed by Dr. Bernard Roth of Stanford University. He describes creativity as "… a mental process that can aid in the recognition of a problem, and can motivate the person to formulate an imaginative solutions, which are both valuable and innovative."

Creativity in the Design Process

Phase 2 of Ullman's general design process is titled "Conceptual Design." At this stage the goal is to generate concepts that will solve the fully defined design problem. Note it is generally not useful to begin an earnest effort of generating concepts until the problem is fully defined. This may lead to wasted effort or worse yet, development of solutions that do not meet customer needs. The conceptual design phase is the prime time to apply formal creative techniques to generate as many concepts as possible to solve a design problem. That stated, the techniques described here are applicable to all stages of the design process and anytime problems that need solutions arise.

The Creative Person

Often "creativity" is associated with "genius." For example it seems to be universally agreed that Albert Einstein was a creative genius. Many associate creativity with some type of high level of intellectual or artistic functioning. In practice, however, this seems not to be the case. According to Dr. Roth, "All persons of normal intelligence possess some ability to think creatively and to engage themselves in imaginative and innovative efforts." Not only that, but it is possible to improve one's ability to think creatively. Furthermore, creativity is not necessarily associated with high levels of intellectual ability. Studies have shown that over 70% of the most creative students do not rank in the upper 20% of their class in traditional IQ measures. Given that all college engineering students are of normal intelligence and know how to learn, it is proper to assume that they can all become more creative through study and practice. This is indeed the case if they are motivated. Motivation to use creativity can take many forms including the most basic to human existence. These might include the need for food and preservation, faith, love, aspirations for fame, fortune or freedom, competition, pride and loyalty. Personal feelings derived for the creative process include pleasure, frustration, exhilaration, fear and satisfaction and pride when a creative task is complete.
The following is a list of attributes that are associated with a creative person. Your further development of any and all of these characteristics will improve your ability for better and more creative problem solving.

- Intellectual Curiosity
- Sensitivity to existing problems

- Acute powers of observation
- Directed imagination
- Initiative
- Ability to think in analogies and images
- Originality
- Intuition
- Memory
- Good verbal articulation
- Ability to analyze
- Ability to synthesize
- Patience
- Determination
- Persistence
- Intellectual integrity
- Good understanding of the creative process

The above list describes human attributes that stimulate creativity. There are many conditions that do the opposite and depress creativity. These will be described next.

Creative Blocks
Adams in his seminal work, "Conceptual Blockbusting" identified major blocks or obstacles to creative thinking and provides methods for overcoming them. The blocks are mental processes that act as a wall to prevent us from correctly understanding a problem or conceiving a solution. Others have identified further blocks so our list is not exhaustive. You can note as you read the list that the "peak" of creative energy for most humans occurs during their childhood where imagination can rule our experience. As we get older, our creative ability is usually eroded due to social pressures and lack of use. It is easy to see how these blocks may have been put in place to allow us to function in our everyday lives. It is equally important to know how to overcome these obstacles when solving design problems. The following gives a general overview of the most common conceptual blocks.

Perceptual Blocks: These are blocks that occur when first encountering a problem that prevents the engineer from correctly perceiving the problem. They include:

- Difficulty in isolating the problem
- Tendency to look at the problem to closely or narrowly
- The inability to view the problem from various viewpoints
- Stereotyped Seeing, "seeing what you expect to see" and premature labeling
- Saturation: The inability to process all problem information.
- Failure to use all sensory inputs.

Emotional Blocks: These blocks tend to color, shade or limit how we see a problem and we think about it. They include

- A lack of challenge or the problem fails to interest
- Excessive zeal or over motivation to succeed quickly which usually results in going in one direction from the outset
- Fear of making a mistake, of failing, or of taking a risk
- The inability to tolerate ambiguity, or an overriding desire for security

- Preference to judge ideas rather than generate them
- The inability to relax and incubate, i.e. no patience for the creative process to work.

Cultural Blocks: These blocks are acquired by your exposure to a given set of cultural patterns in which you were raised and live. They include:

- The idea that fantasy and reflection are a waste of time and form of laziness. They may even be though of as a sign of mental instability!
- The idea that playfulness is only for children
- Reason, logic, numbers, utility and practicality are good and that intuition, qualitative judgments, and pleasure are bad.
- Traditional is preferable to change
- Any problem can be solved by science and money
- Taboos: Things that are considered forbidden or profane.

***Environmental Blocks*:** These blocks are imposed your immediate social and physical surroundings. They might include:

- Lack of cooperation and trust on your team
- Presence of an autocratic boss
- Job insecurity, unwilling to risk
- Distractions, i.e. cell phones, room mates, etc..
- Lack of support to bring ideas into action

Imagination Blocks: These are blocks that interfere with the freedom with which we explore and manipulate ideas. Other than the first in the list below, most college students do not experience these blocks. They include:

- Fear of the unconscious
- Lack of access to imagination
- Lack of control of imagination
- The inability to distinguish reality from fantasy.

Intellectual Blocks: These blocks usually occur when information is collected or interpreted incorrectly. Much of your undergraduate engineering education has been focused on preventing these blocks from occurring. Some examples are:

- Incorrect information
- Missing information
- Inflexible or inadequate use of the intellectual problem-solving strategies
- Formulation of problems in the incorrect format or "language" (i.e. verbal, math or visual)

Expressive Blocks: These restrict conceptualization at the final stage of idea-expression and communication.

- Inadequate or imprecise language skills to express an idea (language includes verbal, visual, mathematical, musical, etc..).
- Slowness in expression that results in the inability to record ideas quickly enough
- In mechanical engineering, often time the inability to draw out ideas on paper can limit your expression.

The Creative Problem Solving Process

Like the overall design process, there is a generally agreed upon process that most individuals use (some consciously, but most unconsciously). This process involves five major steps:

- **Preparatio**n: This is the problem formulation phase and involves gathering information and skills needed to work on a creative solution. Note the strong parallel to what is required in your project proposal document.
- **Concentrated Effort** ("Perspiration"): As Tomas Edison says, Creative "Genius is 1% inspiration and 99% perspiration." This is a period of intense hard work and can be characterized by lots of frustration. There are many techniques that can be learned to increase the productivity of this phase which are outline in the next section
- **Withdrawal** ("Incubation"): This is a period where the conscious mind stops working on a problem and the subconscious takes over.
- **Insight** ("Illumination"): This can be that magic "ah ha" moment when the light bulb goes on as the solution appears to the conscious mind. Make sure you are ready to document it!
- **Follow-Through**: The creative process is complete and accomplishes nothing if the there is no follow through on the idea including implementation.

Although in the best of all worlds, this would be a linear process with a fixed amount of time dedicated to each step with guaranteed results; none is true. Like the design process, it is not linear and iteration is again an important characteristic. Also the withdrawal ("incubation") phase may take some time. There are many documented magical moments of insight during times of idle thought. These famous situations were always preceded by preparation and concentrated effort!

Techniques to Improve Creativity

The following described techniques are well-documented and recommended to improve the Concentrated Effort phase of the creative problem solving process. They are named separately, but combining them is often desirable. They include:

- Set-Breaking
- Brainstorming
- Inversion
- Analogy
- Empathy
- Fantasy
- Check Lists
- Attribute Listings
- Morphological Analysis

Set-Breaking**:** A "Set" is a word used by psychologists to mean a predisposition to or a particular method or way of thought in solving a problem. It is also sometimes referred to as a "schemata." A person who is "in a rut" connotes set. Being aware of a set is not easy and being aware that a set might be limiting your problem solving creativity is even harder. To become aware of a set, one can use a "set-breaking" experience. This means forcing yourself to let go of your conventional ways of thinking. One technique is to imagine that you are trying to solve the same problem in a whole new environment. For example your user is in the Arctic, not California or maybe they live on another planet where gravity is reversed and the inhabitants are handless and have no vision. In this imaginary world, your set will not work, forcing you outside it to look for solutions. When you return from this imaginary environment you may have lost some of your set.

Brainstorming**:** This is clearly the most used and trusted idea generating technique. It can help remove obstacles of creativity that are caused by fear of criticism or fear of appearing foolish. The basic idea is to generate as many ideas as possible by avoiding all judgment during the process. There are basic rules that should be followed:

- Someone must keep a record of all ideas for all to see
- No Criticism or Judgment (good or bad) is allowed.
- Go for quantity and always say the first thing that comes to your head.
- Think as wild as possible and use humor.

A brainstorming session is over when you will have a long list of ideas that have spawned new ideas. If done correctly, you will be exhausted at the end of the session and should wait until a later date for evaluation and further elaboration.

Inversion**:** This is set-breaking technique which calls for looking at problems from new vantage points. Osborn suggests a checklist to consciously set-break by asking the following questions to ask of your problem.

- Could a solution be put to other uses? Are there other ways to use it or new ways if it was modified?
- Can you adapt another idea? Do similar things exits. What ideas do similar things suggest? Are there parallels?
- Can something be modified? Is there a new twist, color, motion, sound, odor, form, shape or any other change?
- Can ideas be magnified? What can you add, more time, more frequency, stronger, higher, longer, more value?
- Can an idea be minified? What can be subtracted, made smaller, condensed, miniaturize, lower, shorter or lighter?
- What can be substituted? Who else instead? What else instead? Other ingredients, other materials, other part, other power, other place, other approach, other process?
- What can be rearranged? Can components be interchanged? Other patterns, other layouts, other order, switch cause and effect, difference speed, different schedule?
- What can be reversed? Can positive and negative be switched? Can it be turned around,
- What can be combined? Can there be a blend? Alloys? Assortments, Combine purposes? Combine ideas? Combine appeal?

Analogy**:** This method uses similar situations in other problems to stimulate new ideas. Analogies may come from other engineering solutions, or from nature, or even from literature non-technical areas. This can be done by individuals and is also useful for groups.

Examples: Could you design airplanes that fly like birds?

Can you make tunnel digging machines that dig like worms?
Can you make landing gear for an airplane that stows like birds feet?
The original cars were built like horse-drawn carriages.

Empathy: This method involves identifying personally with the thing, part of process being devised. The object is to become the part that is the solution to a problem and see the problem from that position. A famous example is provided by an engineer who was tasked to remove walnut meat (whole) from a shell. By imagining himself as the meat, trying to get out of the shell by pushing, the engineer realized that internal pressure could remove the shell. He then devised a system of drilling a hole in the shell and pressurizing the shell to remove it, thus leaving the meat intact. This is an extremely useful method which requires the willingness to play act. This may require overcoming some inhibitions.

Fantasy: Closely related to empathy, this technique requires directed daydreaming. Forget about the rules of nature and let your mind go in any direction your imagination takes you. Easy to do as individual, but can also be done in groups.

Check Lists: General listings are useful during early idea development to avoid the omission of important features or customer requirements. They can also suggest possible improvements. The type of list is dependent on the particular product being developed. New ideas should be added as they occur for later use. When making lists you should keep an open mind for new ideas inspired by associations. Check lists should contain the following information

Physical Conditions including: size, weight, shapes, taste, color, finish, pressure, temperature, vibration, shock acceleration, noise, radiation, etc.

Functional Aspects including materials, production processes applications, packaging, etc.

Attributes and unusual characteristics of shape, finish details, package, energy sources, appearance, feel, fashions, maintenance features, assembly methods, etc.

Social Aspects including timing, human compatibility, degree of complexity, serviceability, cost, production potential, effect on living conditions, et..

Look for Possible rearrangements, recombination, modifications and elimination excessive details, features or waste.

Attribute Listings: this technique involves the list of attributes of various objects, or the specifications or limitations of certain need areas. After completing the list attributes or specifications can be modified allowing originally unrelated objects to be brought together to form new combinations that might better satisfy needs. For example an old fashioned wooden-handled screw driver has attributes such as:

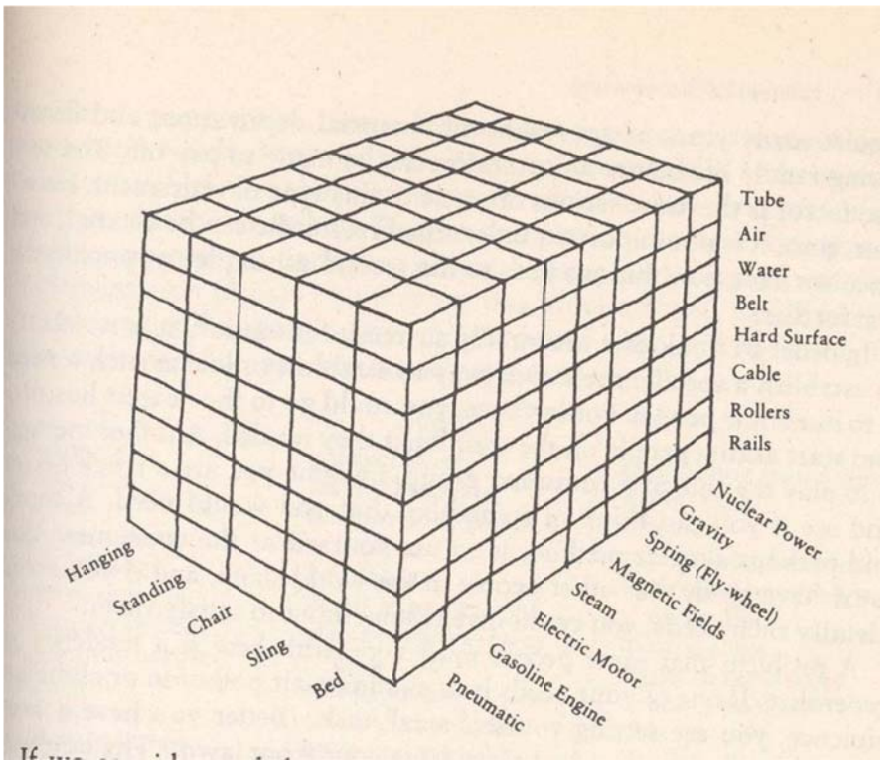
1) Round, steel shank
2) Wooden handle attached by a rivet
3) Wedge-shaped end for engaging a slot in a screw
4) Manually operated
5) Torque provided by twisting action

All of these attributes have been changed to improve the screw driver:

Round shank – hex shank (can add a wrench for increased torque)

Wooden handles – molded plastic handle (less expensive, more durable)
Wedge shape – various interchangeable shapes for different screw heads
Manual Power – Electric battery or pneumatic available
Twisting action – "Yankee" type with pushing action

Morphological Analysis: This is a programmable method of using the attribute listing to make new combinations. The method involves breaking the problem into two or more dimensions, attributes or subsystems based on the functional requirements. Each attribute is brainstormed to generate a long list of possible ways of meeting the requirement. This list is then placed in an orthogonal matrix and then a new idea is generated by forming every possible combination and evaluation the feasibility of the combination. An example from Adams book is shown below for a new personal transportation device where the three dimensions are power, seating and operational media. Each cube represents a possible combination of the three dimensions for consideration.



Last Thoughts on Creativity:

When working at being creative there are two major points to keep in mind:

1) Everyone can be creative
2) Everyone has some blocks that limit them

By working at the skills and being aware of the cause of your own blocks you can begin to fully tap your creative potential and improve it for the remainder of your life!

References:

Adams, J., *Conceptual Blockbusting*, 3rd Edition, Addison Wesly, 1986

McKim, Robert, *Experiences in Visual Thinking*, PWS Publishers, 1980

Roth, B., *Notes on Creativity*, ME112 Stanford University, 1994

Ullman, D., The Mechanical Design Process, McGraw Hill, 1992

Manufacturing Resources:

Student Projects Shop Facilities (Aero Hangar and Mustang 60 Shops)

These are the main fabrication facility available to you for manufacturing tasks that you can undertake on your own to complete your project.

All students who wish to use the Shop must take and pass the Shop Safety Tour and Test.

Our Student Technicians ("Techs") can provide help and guidance in the manufacture of your project. You will build it yourself and possibly learn new skills, techniques and "tricks" through Cal Poly's "Learn by Doing" philosophy.

Our shop is open to all, regardless of abilities.

Contract machining is available for parts or processes beyond your capability. See Section 0 for more information on this service.

For current shop times, forms, and reading for shop tests visit http://me.calpoly.edu/machineshop/

Shop Procedures and Safety Tests:

In order to take a tour and test to use the Shop you must:

- Wear appropriate clothing for the Tour. If you wear shorts, open-toed shoes or excessively loose clothing or loose jewelry, you WILL NOT be allowed to take the Tour and Test for safety reasons.
- The Shop Safety Tour and Test takes approximately one and a half hours and is limited to the first TEN (10) people who arrive promptly. See the times listed below:
- YOU MUST READ the following documents prior to arriving for a tour:
  Shop Rules and Regulations AND Red Tag Tour and Test Manual (Available at: http://me.calpoly.edu/facilities/spms/)

The Red Tag Tour and Test is the REQUIRED standard introduction to the Hangar Shop and has no prerequisites. You MUST read the Red Tag Tour and Test Manual prior to your tour and safety test. You will most likely fail the test if you do not take the time to read the Red Tag Tour and Test Manual. This Tour and Test introduces you to many stationary and hand tools that allow you to fabricate a wide variety of materials in many ways. It DOES NOT include machining or welding tools.

The Yellow Tag Tour and Test allows you to expand your fabrication skills into machining and welding. You MUST read the Yellow Tag Tour and Test Manual (Available at: http://me.calpoly.edu/facilities/spms/) prior to your tour and safety test. You must have a REQUIRED minimum of 10 hours of Red Tag shop use on record to qualify for this tour and test. Red Tag qualified students who have demonstrated competence on hand and stationary power tools using in the shop may take the Yellow

Tag Tour and Test. Yellow tags allow students to use any machine in the shop if they are properly supervised.

Safety Reminders

- Wear appropriate clothing. If you wear shorts, open-toed shoes or excessively loose clothing or loose jewelry, you WILL NOT be allowed to use the shop or take the Tour and Test for safety reasons.
- You must have your set-ups checked by a technician before beginning an operation.
- ***You are expected to ask questions if in doubt about safety or operations or when you are unfamiliar with a tool.***

NOTICE: Limited Access to CNC Machines :

- CNC machinery is restricted to skilled machinists, you should be able to do BOTH CAD and CAM programs without a lot of assistance before using CNC machines.
- Start on your project as early in the quarter as you can!
- Submit your project design as a CAD file for consideration at least 2 weeks in advance of your need, NOT your due date.
- We will take your CAD file or an accurate drawing into consideration, depending on your experience in OUR shop, the complexity of the process, Tech availability, time considerations for other CNC projects and other factors.
- All decisions are FINAL, there is no appeals process.
- Have a contingency plan in place to manufacture your project using available manual machines and tools. Start on your project as early in the quarter as you can.
- Your CNC project must be approved by the Staff ShopTechnician, George Leone or Eric Pulse.

Helpful Tips: So You Can Finish Your Project :

- Begin your project well in advance, as tool and machine time can be limited.
- Feel free to discuss with us how you plan to build your project, most likely we may know a “trick” or tool that would save you lots of time.
- Design your project for tools that you know how to use. It's O.K. to learn to use 1 or 2 new tools in your project, but don't design the majority of the project to be built by processes or machines that you don't know how to use. We don't build stuff for you!
- We want you to succeed. We will help you, but we won’t “bail you out”. As they say, “Bad Planning on your part does not necessarily constitute an emergency on our part.”
- As a rule of thumb, if you’ve never done a process before, it will take 4 TIMES as long as you think! If you have done it before it will take only 3 TIMES as long as you think! This is not an attempt at humor, this is a reality! We see it every quarter.

- Work on your project as early in the quarter as you can, it gets harder to check out the tools that you need as the shop gets busier near the end of the quarter.

Contact Information:

For Information Regarding shop authorization, or with any questions call the Student Projects lab office at (805) 756-2266 during shop hours. Or contact George Leone (805) 756-6350.

Shop Hours and dates and times for Red and Yellow tag tours are posted on the machine shop website.

http://me.calpoly.edu/machineshop/

Student Projects Shop, Contract Fabrication

The Student Projects Shop does offer some contract fabrication services for senior projects. This service is provided for parts that are beyond the capability of your team including CNC, complex welding, and precision machining. **This service is not supposed to replace the "learn by doing" nature of these projects**. These services must be paid for by the project sponsor. To utilize this service follow the guidelines below.

- Consult with a Student Shop Machinist (SSM) early on in the process to determine if you in fact do require this service, or if there is a simpler way to manufacture your part that you may be able to accomplish on your own.
- Get a quote from the SSM on the cost of producing your part and an estimate for the turn around time.
- Produce complete shop drawings and/or datasets as required by the SSM.
- Have your sponsor make a donation to the M.E. department Senior Design Account to cover the quoted cost.
- Schedule the job with the SSM.

Bonderson Student Project Center

The Bonderson Student Project Center is available to you to complete your senior design project.

Access:

Ask your faculty advisor to contact the head of the student shop in the Bonderson Building to get access to the building.

Resources:

The center offers storage lockers where raw materials and equipment can be stored for the duration of the project. The center has fabrication space.

24-hour Computer Lab Access:

All ME students have access to the following labs 24/7 with their poly card id: 13-107, 192-120, 192-131, 192-132 and 192-134. Contact Larry Coolidge in Bldg 13-103 to sign up for your hour of clean up each quarter.

Software:

CAD:	Solidworks, CATIA, ProE…
FEA:	ABAQUS…
Analysis:	MATLAB…

Design Studio:

Room 192-133, to Schedule room and have your Polycard programmed contact ME Dept. 13-254.

The facilities in this room include:

- Speaker Phone (on table) with cell phone connector.
- Fax for long distance communication
- 8-person Conference table with built in AC and Ethernet for your notebook
- Smart board

  Do not use dry erase markers on the smart board!
- A computer with design software
- Computer (color printing, scanning …)
- Digital camera connection and software (Digital cameras available for checkout from media services 2-9)
- Video conference capability also avail in 13-124B (See ME dept. to schedule 13-254).

Telephone Rules are as follows:

- FAX rather than phone **805-756-5606**
- If phone then use, if available
    - Toll free numbers
    - Have sponsor call you
    - Collect calls
- Don’t talk more than necessary (i.e. plan the call)
- Log all calls, including FAX

If you have a weekly teleconference scheduled with your project sponsor, please write it on the white board so other teams know not to schedule theirs at the same time.

Rapid Prototyping (3-D Printing)

The ME Department now has four rapid prototype machines available for use on your project. The capabilities of these machines are listed in the table below.

	FDM 768	FDM 1200	FDM 2000	Eden 250
Capacity (Size) (in.)	8x8x12	10x10x12	9x9x9	9.8x9.8x7.8
Resolution (in.)	0.010	0.010	0.010	0.004-0.008 (direction dependent)
Material Type	ABS	ABS	ABS	Photosensitive Resin
Material Cost	$5/in^3	$5/in^3	$5/in^3	$.225g

Procedure for scheduling a rapid prototype part:

1) Take a drawing of your part signed by your project advisor to Larry Coolidge in 13-103 (756-1260) along with a high resolution .STL file (ask project advisor if you are not familiar with this).
2) Good part size is around 4"
3) If part costs are excessive the sponsor will be requied to reimburse the dept. In which case they would supply a check made out to the ME Department Senior Design.
4) To schedule machine with Larry use Zimbra Calendar:

Login to my.calpoly.edu portal
Select Zimbra
Calendar
New appt
Schedule
Enter Larry Coolidge in Attendees
Pick a time when Larry is available
Save

Using the Laser and Vinyl Cutters in Mustang 60

Instructions for using the rapid prototyping tools can be found in the Mustang 60 shop and on the class Blackboard site.

Manufacturing and Testing Consultants

The mechanical engineering department employs consultants that can help you with questions on manufacturing and testing of your project. Testing is a critical phase of these projects and you must start preparing your test plan parallel to your design activity. Often you will find that you require specialized equipment that the ME Department can provide to help you verify your design. These resources include strain gages, accelerometers, thermocouples…

All of the resources of the ME Department are available to you. The testing consultant can help you plan and perform your design verification.

Ask your project advisor for contact information.

Audio Visual Equipment

If you require any A.V. equipment including digital cameras, video recorders…these are available through media distribution services. Information available at http://www.mds.calpoly.edu/.

Material Resources

I. Senior Project Scrap Bin
There are scrap bins (location to be determined) that have metal and other scrap materials that are free for the taking **for use on your Senior Design project**.

II. Heilman's Salvage and Metals
6450 Rocky Canyon Road, Atascadero
466-4893

III. McCarthy Steel
313 South Street, San Luis Obispo
543-1760

IV. Web Resources
A few websites that have been used by the ME department and student clubs are listed below. This is by no means a comprehensive list but it is a good starting point.

a) McMaster Carr
Almost anything you could imagine. Freakishly fast delivery times.
http://www.mcmaster.com/

b) Online Metals
Good for small orders of aluminum and steel structural shapes and tubes.
http://www.onlinemetals.com/

c) Fiberglass Hawaii
Fiberglass, carbon, Kevlar, resins, molding materials…
http://www.fiberglasshawaii.com/

Mechanical Testing and Inspection

Designs are verified by some combination of analysis, similarity to existing hardware, inspection, and testing. The following briefly describes mechanical inspection and testing resources available to senior project teams in the mechanical engineering department at Cal Poly.

Dimensional Inspection or Measurement

Engineering parts and systems are built to print or drawing with dimensions and tolerances. Parts and systems are inspected to verify they meet drawing requirements and thus will function as the designer intended. The mechanical engineering department has measurement or inspection equipment available for student teams. This equipment is in the hangar or shop facilities and is described briefly below.

Scales and Tape Measures

The student shop has a variety of scales, squares and measuring tapes. These can be used to things like basic lengths, spacing, clearances, bores and hole patterns. Dimensional inspection to interface requirements is usually the first thing after completion of hardware prior to assembly any other mechanical testing.

Calipers and Micrometers

More accurate dimensional measurements of parts are made with calipers and micrometers which are also available in the hangar.

Granite Surface Plate

The hangar also has a small granite surface plate which serves as a flat reference or zero datum for measuring parts. This dimensionally stable flat part is used in conjunction with measuring instruments.

Height gage and Dial Indicators

The height gage is similar to a caliper but has a flat base and thus is most often used in conjunction with a surface plate or “ways” of machines tools. Dial indicators are used similarly and have a variety of bases (including magnetic) to attach to your hardware directly to make measurements of heights and run-out. These come in a variety of travel and accuracies. These could be used to measure the deflection of a loaded structure at critical locations.

Weight and Mass

Part weight and mass are critical design information for many mechanical engineering components and systems. There are a variety of scales in the ME department.

Engines Lab

There is a large blue digital floor scale that has a capacity of 1000lb

There are also two small precision scales or balances in the engines lab as well.

13-124

There is a mechanical Toledo scale that has a capacity of about 500lb.

Mechanical Testing

There are a variety of resources in the mechanical engineering department for materials characterization and structural proof testing. Most of the structural testing equipment and associated instrumentation are housed in the composite and structures lab 192-135 of Engineering IV.

Hardness

Recall that hardness and tensile strength are related for materials like steel. Also remember wear and contact stresses are functions of hardness as well. The hangar has a hardness tester that can be used to measure the hardness of material samples.

Load Frames

The composites and structures lab has a variety of large equipment that can be used to test both material coupons and structural components.

<u>Small Instron Tensile Test machine</u>
A 2000lb mechanical load frame is available for tensile testing. This machine is pictured below. It has wedge action grips which can used to pull on small specimens or structural components in tension only. Note the grips can be removed and purpose built tooling installed for testing of small structural components Load can be recorded along with cross-head displacement. This machine is best suited for quasi-static tests. This machine has upgraded controls and a front panel which is user-friendly. Note the new "on switch" is at the back of the black box on resting on the table top.

This machine is lead-screw based and can produce forces that can cause injury. Do not use this machine without permission and a safety briefing from an instructor.

<u>Instron Servo-Hydraulic Test Machine</u>
A servo-hydraulic load frame is available for higher loads up to 22,000 lb. This machine has sophisticated controls and can be used for fatigue and other static and dynamic tests. This machine has hydraulic grips that grasp coupons or tooling stubs that are am

maximum of .25in thick by 1.0in wide with a grip length of 1.-1.5inches. Dedicated flex test tooling is also available for performing small three point bending tests such as ASTM 790 for characterizing polymer materials.

This machine is instrumented to measure load, cross head displacement and strain via clip on extensometers. Strain can also be measured using strain gages. A dedicated PC equipped with a NI/LabView hardware and software has virtual instruments or VIs which can be used to record values from strain and load instrumentation. Operating procedures are documented and available but use must be coordinated with faculty, technicians or trained student technicians as this machine is capable of generating tremendous loads and strain energy.

See the included attachment which has detailed instructions for performing a tensile test using the hydraulic test machine with load, extensometer and two strain gages as instrumentation.

<u>MTS 100kip Tensile Tester</u>
For very large loads the Civil Eng. dept. has a 100kip load frame. Use of this Machine must be coordinated through Dr. Dan Jensen.

<u>Torsion</u>
The composites and structures lab has a small Tinius-Olsen torsion tester. This mechanical machine can be instrumented to record load and twist. The machine can be fitted with a 500lb load cell to measure torque with its given lever arm. The gear reduction unit allows the user to many times simply twist the handles to provide the necessary torque to the hardware.

Strong Floor

The composites and structures lab has an 8 foot square load floor for bolting structures down for testing. The interface is ½ inch T-nuts which go in metal slots in the floor. Load application can be performed using hanging weights and electric actuators or things like hydraulic “bottle” jacks. The floor has insert fastener maximum loads of about 2000lbs in any direction. All test set-ups again must meet faculty approval for safety considerations. The photo below shows a purpose built pendulum tester bolted to the strong floor.

Electric Actuators

Two electric actuators are available for testing. These have a 2000N capability and a 300mm stroke. These are picture below. They are lead screw based and the user pushes the buttons to raise and lower the actuator. These could be bolted between a structure and the load floor for proof testing.

Load, Pressure, Displacement and Strain Instrumentation

Spring Gages

Spring gages, useful for measuring small pull forces are available for check out at the Mustang 60 shop tool crib. They have a variety of capacities.

Displacement Transducers

There are several displacement transducers available to measure structure or machine displacement. These have different displacement ranges and experimental set-ups. Some of these are pictured below and brief descriptions follow.

Large Displacement String Potentiometers
The blue devices are capable of measuring displacements up to about 12inches with pretty good accuracy. These particular devices are made by Space Age Control.

http://www.spaceagecontrol.com/S021h

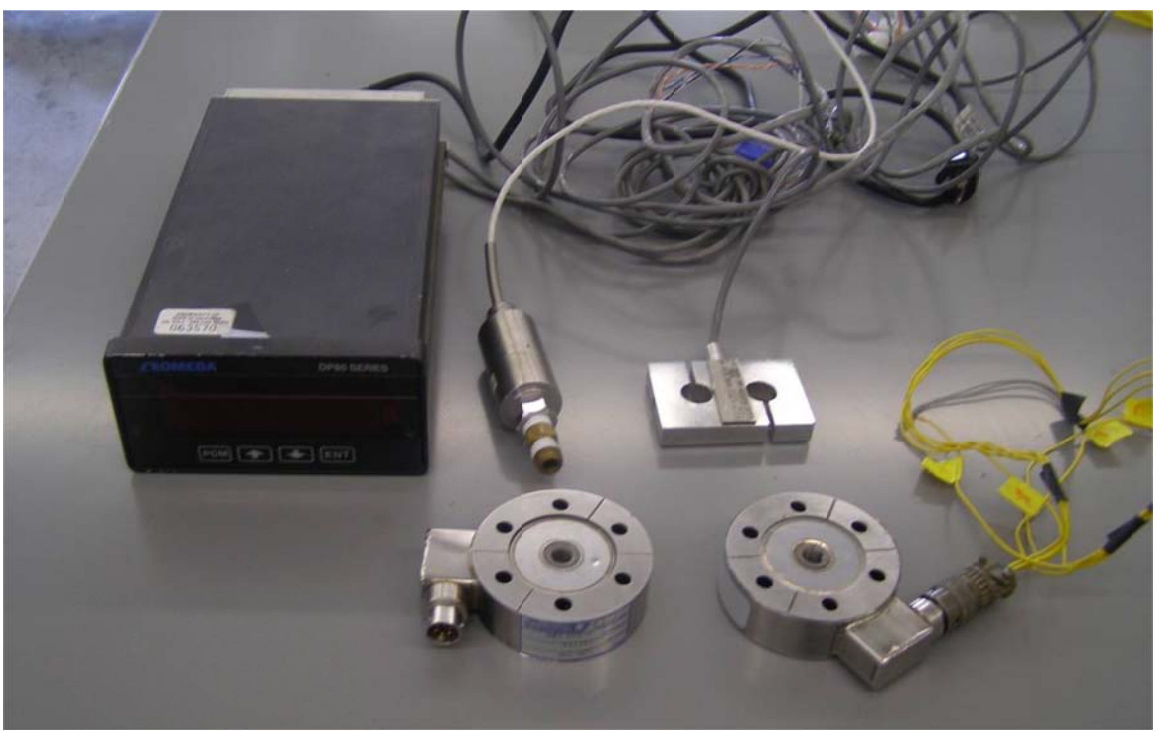
They are mounted to a plate and the string or wire in this case has fishing tackle type hooks which attach to the structure in the place you want to measure displacement. These are voltage divider potentiometers. You simply excite them with ten volts and then measure the output voltage which is proportional to the displacement. A data acquisition system and VI is already set up to read these devices.

Two-inch LVDT
The silver barreled plunger device is a linear variable differential transformer or LVDT.

http://www.macrosensors.com/lvdt_macro_sensors/lvdt_tutorial/index.html

This device offers more accuracy but less travel. It again needs an excitation voltage and output voltage is measure which is proportional to displacement.

Load
A variety of load cells are available to proof load hardware. These come in a variety of capacities and are described below. Note that your test set-up must have the free body diagrams “designed” such that these devices only see axial load. There must be rod ends or spherical bearings to ensure that these are two-force members.



Pressure

Two pressure transducers are available in the structures lab as well. These are again strain gage type devices which require excitation voltage and output voltage measurement. Dedicated DP80 boxes like the one shown can be used for this task. These boxes have calibration routines and can output analog signals to a data acquisition system.

Strain

Strain can be measured using strain gages and Micro-Measurements strain indicator boxes and switch and balance units. Two of these are available in the composites and structures lab. The Vishay Micro-Measurements website has a wealth of product and technical data. The links below are just a few places to start looking for information on things like strain gages and installation procedures.

http://www.vishay.com/strain-gages/

http://www.vishay.com/strain-gages/knowledge-base-list/

Detailed information on the load, displacement, pressure and strain instrumentation described above is tabulated below.

LOAD
load cells are Wheatstone bridge type instrument
excitation to two wires, change in voltage out

Description	Full Scale Capacity (LB)	S/N	Full Scale Output (mV/V)	Zero Bal (mV/V)	Max Excite (V)	Excitation (V)	Voltage Range (mV)	Scale Factor (Lb/mv)
Load Cell, Muse M2400-100	100	186244	1.8247	-0.006	15	10	18.247	5.48035293
Load Cell, Muse M2400-100	100	186244	1.8247	-0.006	15	10	18.247	5.48035293
Load Cell, Omega LCH-1k	1000	352053	3.0031		15	10		looks damaged
Load Cell, Omega LCH-1k	1000	407565	3.0109		15	10		
Load Cell, Omega LCH-100	1000	297113	?		15	10		
Load Cell, Omega LC101-500	500	215878						

Load Cell Ecxitation, Calibration and Reading		
Power Supply, Omega DP 80		712507
Power Supply, Omega DP 81		90101573

DISPLACEMENT
Cable Spring Potentiometers are a voltage divider device
zero travel gives near Zero Voltage, full travel is nearly the full excitation voltage
For Low loads TARE off tension

Description	Design Travel (in)	S/N	Nominal Excitation	Voltage Range (V)	Max Excitation (V)	Tension (Lb) Zero Travel	Tension (Lb) Full Travel	Scale Factor (in/mv)
Position Trans. Space Age	13.5	23818	10	10	35	1.02	1.78	1.35
pn 160-1085	13.5	23819	10	10	35	0.98	1.9	1.35
Shulemburger DCR/15mm/s	2	847624		10				24.88 mV/V/mm

Excitation Box
Power Supply, Omega pst-4130

PRESSURE
Pressure transducer is Wheatstone Bridge type instrument
excitation to two wires, change in voltage out

Description	Full Scale Capacity (PSI)	S/N	Nominal Excitation (V)	Voltage Range (mV)	Max Excitation (V)	Full Scale Output (mV/V)	Zero Balance (mV/V)	Scale Factor (psi/mv)
Omegadyne PX906-300GV	300	186244	10	30.636	15	3.0636	0.0124	9.7924011

Strain Measurement

Description	Full Scale Capacity (PSI)	S/N
MG p-3500 strain indicator		60270
MG p-3500 strain indicator		98703
Strainsert HW 1-D		814

Instron Strain Measurement

Description	Travel (inch +/-)	S/N	Gauge Length (in/in)
Strain gauge extensometer	0.1		.5in/2.0in
Strain gauge extensometer	0.05		.5in/2.0in

Data Acquisition Systems

The load displacement and pressure instruments are typically analog voltage signals. The composites and structures lab has a couple of data acquisition systems to log and manipulate your test data in this case analog inputs.

<u>Desktop Cart Data Acquisition System</u>
The system shown below is PC based. A National Instruments PCI board and associated hardware and software NI6033PCI board with analog inputs as well as digital inputs and outputs.

http://sine.ni.com/nips/cds/view/p/lang/en/nid/1057

This system is wired currently to read two load cells, two displacement transducers and a pressure transducer.

<u>Portable Data Acquisition System</u>

A notebook computer with equipped with a National Instruments data acquisition system and software is available for testing outside the lab. Please see Larry Coolidge to check out this machine.

Dynamic testing

The vibrations lab can be used by permission form the lab coordinating instructor Dr. Jim Meagher. To check out this equipment you must do the following.

Recall the equipment available are:

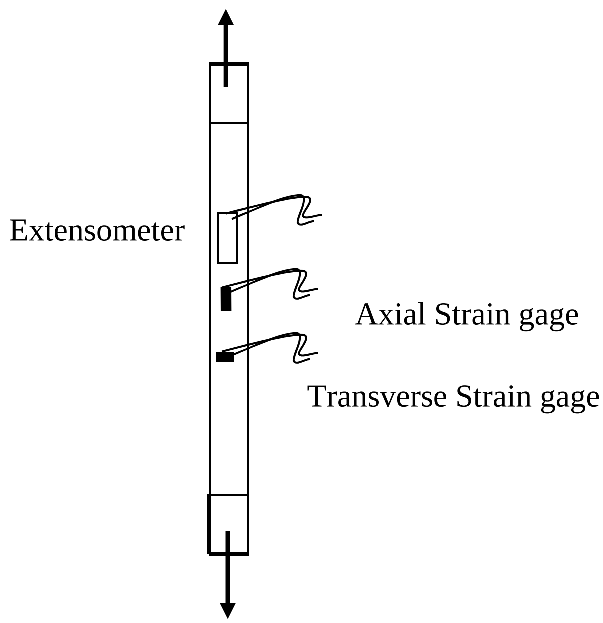
Accelerometers
Shake Tables
Drop Tester

Attachment 1. - Typical Instron Tensile Test Procedure

This procedure outlines the steps for testing materials and small structures using the Instron servo-hydraulic load frame and associated NI/LabView data acquisition system (DAS)**. Note: DO NOT do any testing on this machine without an instructor or teaching assistant. This machine is capable of generating loads which can cause significant injury. All set-ups must be reviewed to ensure safety.**

Note: Instron Manual should be consulted with questions to the load frame and 8500 controllers. The 8500 front panel controls all the test parameters. DAS and labview questions can be answered via the on-line help menus associated with the software.

This procedure is based on a set-up that includes and extensometer and two strain gages in addition to reading the load. This could be a tensile specimen as shown below.



<u>Instron Set-up</u>
Safety Note: One person should load the specimens and operate the tests. This will preclude starting a test while hands are in the test area.

1. Make sure that the water line to the hydraulic pump is open.
2. Connect the extensometer to the controller at the Strain 1 port.
3. Turn on the Instron Controller. (May have to “unlatch” the oil light safety)
4. Using the OUTPUTS button on the front panel make sure the following:
   Load is going out channel A.
   Position is going out B.
   Strain1 is going out X.

Then select each (load, position, and extensometer) and note the data/voltage relationship, e.g. load channel may output 2.0kips/volt. The DAS must have corresponding relationships to convert the voltage into appropriate units. Make sure each channel is in the track mode as well. Make sure extensometer gage length set-up corresponds to the current configuration.

4. Calibrate the load cell. The set-up light is flashing. Press this then CAL, CAL, AUTO, GO. The cell is calibrated when the light stops flashing.
5. Turn on the hydraulic pump. (Note sometimes the circuit breaker may need to be reset. Get a technician or Instructor to help in this case.)
6. Install on the grips the specimen alignment blocks. These control the alignment off the specimen.
7. Install the specimen by clamping it in the upper grips only by holding it against the alignment tooling. Keep away from the hydraulic jaws during this procedure.
8. Install the extensometer via elastic bands or o-rings. Remove the safety pin and calibrate the extensometer in the same fashion as the load cell.

LabVIEW DAS Setup

9. Double-Click the LabVIEW VI file ***2g-ext.vi***. This file acquires load, extensometer, and longitudinal and transverse strain gages.
10. Check that the voltage relationships correspond with the Instron outputs.
11. Manually balance the strain bridges if input voltages are excessive.
12. Set the strain gage factors and shunt calibrate the gage circuits. You must run the vi by clicking the start arrow to perform this operation. Verify that the extensometer and load values correspond with Instron front panel displays. You may need to press display buttons on front panel to view strain rather than displacement.
13. Note the ASCII data file name and folder or location. This file should be saved after each test.

Run Test

14. Press WAVEFORM corresponding to position control on the Instron front panel. Lower display entries should be: “ramps”, “S RAMP”, .5in, .0025in/sec (i.e. the actuator will move down 0.5 in at a rate of 0.0025 in/sec; this waveform works well for composite tests but may be modified as desired.
15. Close the Lower grip. Note the jaw action may result in load on the specimen at this point. The operator can manually, carefully fine adjust the crosshead manually to remove jaw induced tensile or compressive loads.
16. Start the data acquisition process by clicking the start arrow on the labview VI.
17. Press START on the Instron controller to start the test, the lower grip will move down.
18. It is necessary to remove the extensometer prior to specimen failure to avoid possible damage to the extensometer: Press HOLD on the controller at an appropriate strain level to stop the actuator; cut the lower rubber band on the extensometer, reinstall the pin to fix the lower knife edge, and then cut the upper rubber band on the extensometer.
19. Press START to resume the test waveform.
20. After failure of the specimen press HOLD.
21. The lower portion of the fractured specimen may be removed by opening the lower grip.
22. End the test by pressing RESET which will move the actuator to its position at the start of the test.
23. Remove the upper portion of the specimen from the upper grip.

System Shut Down

24. The system may be shut down as follows: A) turn off actuator by pressing LOW, then OFF, B) turn off hydraulics, C) turn off controller, D) Exit VI and shutdown the DAS computer.