# Table of Contents

1. Introduction ............................................................................................................................... 5  
   Course Objectives ................................................................................................................... 6  
   Course Syllabus ....................................................................................................................... 6  
   Grading and Assessment ......................................................................................................... 6  
   Student, Sponsor, and Faculty Roles ....................................................................................... 7  
   Travel Policies and Required Forms: ...................................................................................... 8  
   Purchasing and Reimbursements ............................................................................................. 9  
   Project Materials & Travel Budget .......................................................................................... 9  
   Intellectual Property and Non-Disclosure Agreements .......................................................... 9  
   Senior Project Safety ............................................................................................................. 10  
      Design for Safety Guidelines: ............................................................................................ 11  
      Senior Project Safety Timeline: ....................................................................................... 13  

2. Deliverables ............................................................................................................................ 19  
   Surveys and Reflections ........................................................................................................... 20  
   Design Logbooks (1 per person) ............................................................................................. 20  
      Logbook Details ............................................................................................................... 21  
      Logbook Assessment ....................................................................................................... 21  
   Letter of Introduction to Sponsor (Week 2 of ME 428) ........................................................ 22  
   Reports .................................................................................................................................... 24  
      Project Proposal (Week 5 of ME 428) .............................................................................. 24  
      Preliminary Design Report (Near End of ME 428) ............................................................ 28  
      Final Design Report (Week 5 of ME 429) ................................................................ .......... 29  
      Project Update Report to Sponsor (Week 10 of ME 429) ................................................. 31  
      Final Project Report (Week 10 of ME 430) ....................................................................... 32  
   Presentations ............................................................................................................................ 40  
      Preliminary Design Review (Week 10 of ME 428) .......................................................... 40  
      Critical Design Review (Week 5 of ME 429) .................................................................... 40  
      Manufacturing and Test Review (Week 10 of ME 429) .................................................... 40  
      Senior Design Expo (Week 9 of ME 430) ........................................................................ 40  
   Senior Project Completion Checklist ...................................................................................... 42  

3. Content Reading ...................................................................................................................... 44  
   Design Process and Methodology .......................................................................................... 44  
   Working on a Team ............................................................................................................... 46  
   Background and Motivation .................................................................................................. 46
Team Development Stages .................................................................................................. 46
Establishing Team Norms/Effective Team Meetings......................................................... 48
Team Roles......................................................................................................................... 48
Team Decision Making...................................................................................................... 49
Managing Team Processes................................................................................................. 50
References......................................................................................................................... 52
Social Styles ....................................................................................................................... 54
Background and Motivation............................................................................................... 54
Social Styles ....................................................................................................................... 54
Managing your Team’s Diverse Social Style .................................................................... 56
References......................................................................................................................... 56
QFD: Quality Function Deployment .................................................................................. 57
Background ....................................................................................................................... 57
Steps for the Method ......................................................................................................... 57
Analyzing the Results ........................................................................................................ 61
References......................................................................................................................... 61
Design Thinking and Creative Techniques ....................................................................... 62
Background and Motivation............................................................................................... 62
Creativity in the Design Process ....................................................................................... 62
The Creative Person ......................................................................................................... 62
Creative Blocks ................................................................................................................ 63
The Creative Problem Solving Process ............................................................................. 65
Techniques to Improve Creativity .................................................................................... 65
Last Thoughts on Creativity: ............................................................................................ 68
References......................................................................................................................... 68
4. Manufacturing Resources ......................................................................................... 70
Student Projects Shop Facilities (Aero Hangar and Mustang 60 Shops)......................... 70
Shop Procedures and Safety Tests: .................................................................................. 70
Safety Reminders.............................................................................................................. 71
Helpful Tips So You Can Finish Your Project: ................................................................. 71
Using the Laser and Vinyl Cutters in Mustang 60 ............................................................ 72
Contact Information ........................................................................................................ 72
Student Projects Shop, Contract Fabrication ................................................................... 72
Bonderson Student Project Center ................................................................................... 72
24-hour Computer Lab .................................................................................................... 72
Design Studio: .................................................................................................................. 73
Rapid Prototyping (3-D Printing) ................................................................. 73
Manufacturing and Testing Consultants .................................................. 74
Audio Visual Equipment ......................................................................... 74
Material Resources ............................................................................... 75

5. Mechanical Testing and Inspection ....................................................... 76
Dimensional Inspection or Measurement .................................................. 76
Mechanical Testing .............................................................................. 77
  Hardness ............................................................................................. 77
  Load Frames ..................................................................................... 77
  Torsion .............................................................................................. 78
  Strong Floor .................................................................................... 79
  Electric Actuators ........................................................................... 80
Load, Pressure, Displacement and Strain Instrumentation ....................... 80
  Load ................................................................................................. 81
  Pressure ......................................................................................... 81
  Strain .............................................................................................. 82
Data Acquisition Systems ....................................................................... 82
Dynamic testing .................................................................................. 84
Typical Instron Tensile Test Procedure .................................................... 85
1. 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 exactly fits that description. You will integrate knowledge and skills you have gained throughout your undergraduate 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 will take away of the process. You will find this design process useful throughout your life.

This class will be very different from most others you have taken. First, the class lasts three quarters and you will be working with the same team on 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 each week. This will provide you with some overall structure and give you some course content, including project management and specific design techniques that will help you along your way. Attendance in the lecture is mandatory. In addition, you will have two lab meetings each week. You will be required to attend these labs for all six hours. How those hours are organized will depend on your project advisor (lab instructor).

During the first week’s labs, you will learn about all potential design challenges. At the end of the week, you will inform the instructors of your project preferences. The specific lab section you attend depends on which project you are working on. This will be determined by the beginning of the second week. If your project ends up in a different lab section than one you registered for, you may 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. The third quarter (ME 430) has no scheduled lecture or lab section. Rather, you meet with your advisor once a week as you finish construction, do testing and complete your project.

For the three quarters, the teaching staff will guide 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 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.
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.
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 systems within constraints (strength, size, materials, performance, cyclic loads, 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.
14. Communicate and present engineering design project results orally, graphically, and in writing.
15. 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 PolyLearn

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 by your lab instructor. 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 Exam during the third quarter of this course. It is a required exam that accounts for 10-15% 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 all:

**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 twice each week)
- Interface regularly with sponsor (recommended weekly)
- Attend ME 428 lectures
- Complete Senior Exam
- Complete Senior 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 Preliminary and Critical Design Reviews.
- Evaluate team product at Senior Design Expo and in 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 Exam and Survey

Project Advisor (Laboratory Faculty):

- Ensure team defines a 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
- Assist with sponsor-team interactions
- Evaluate all team assignments and assign final grade

Travel Policies and Required Forms:

By its nature, Senior Design Project typically involves some travel to visit your sponsor or interact with end users. Teams will be given a travel budget that cannot be exceeded for the three quarters and are responsible for maintaining that budget. When possible, you 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 end of the first quarter you should plan on traveling to your sponsor’s site for a Preliminary Design Review. A second Critical Design Review during ME429 can either be done via teleconference or in person depending on arrangements made with your sponsor.

All information concerning traveling is available at a website maintained by Moncerratt Peralta & in the GENE office. All students must fill out Travel forms at the beginning of ME428 even if they don’t think they will be traveling. Over the course of a nine month project, plans can change so it is important to have these Travel forms filled out before any trips. The forms and instructions can be found at:

http://me.calpoly.edu/cpr/senior-project-student-info/

Special note: If International Travel is part of your senior project, please see the website and Moncerratt Peralta for instructions.
**Purchasing and Reimbursements**

During ME429 you or your sponsor will need to procure parts and materials for your prototype. **All purchases should be discussed and approved by your faculty advisor BEFORE any purchases are made.** 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.

---

**Important! All purchases must be shipped to Cal Poly – not to your home.**

More information about purchasing materials for your senior project can be found at the Senior Project Budget Information and Forms webpage at:

http://me.calpoly.edu/cpr/senior-project-student-info/

---

**Project Materials & Travel Budget Spreadsheet**

Whether or not you are purchasing materials for your prototype, your team must create and maintain a Materials & Travel Budget for your project. This document (a spreadsheet works well – see example on the Senior project Budget Information and Forms webpage) is your means of ensuring you have adequately planned for all project expenses and as you purchase you are not exceeding your planned amounts.

You should prepare your Budget file early in the first quarter, while you are developing your Project Proposal. At this point, it would consist of line items for any anticipated travel, and an overall budget limit (provided by your sponsor) for the prototype and testing. All budget details (prices and sources for all purchased components) should be included in this document as you are finalizing the design details during the second quarter. As you travel and begin purchasing, track the actual expenses for all items in a separate column from the planned expenses, so you can easily see how well you are keeping to your budget.

Intellectual Property and Non-Disclosure Agreements

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.

---

**Important! Do not sign ANY agreement before consulting your project advisor!**

For many projects the agreements will take a standard form proposed by Cal Poly. Some projects will have more complex agreements required by the sponsor. Ultimately you must sign the agreements or you will be placed on another project that does not involve these agreements. The standard Cal Poly Student Project Agreement will either call for shared IP or assign all IP to the sponsor. Some 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, let the course organizer know and you will be placed on a different project.

Upon signing an agreement a student is expected to comply fully. It would be considered highly unprofessional and unethical to violate the terms of the agreement. Our sponsors have been generous enough to open their doors to us, to bring us projects, to support the projects and teams financially and with their time. 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 in violation of a legal agreement.

**Senior Project Safety**

The ASME code of ethics' first Fundamental Canon is:

> "Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties."

In this class you are learning what it means to be a professional engineer, by acting as a professional engineer on your project. It is absolutely imperative that you place safety first in all your senior design project work. This means that you will:

- Design a safe product that does not impose any undue hazard to a user.
- Construct your prototype in a safe manner
- Test your prototype in a safe manner.

Preventing injuries or property loss during your time in this class and by the products you design is your first priority.

Preventing injuries or property damage involves a process of identifying hazards and quantifying risks. Hazards and risks can be defined as:

- A **hazard** is any unsafe condition where there is the potential for human, property, or environmental damage.
- The **risk** is the likelihood, probability, or frequency of a hazard materializing.

Products in the process of design and development require analysis to determine whether hazard potential and product safety features are being properly assessed and provided. The primary concern of product designer(s) should be to develop "reasonably safe" products that are reliable and maintainable. A product is considered “reasonably safe” if the potential risks are judged to be acceptable by society. In general U.S. society deems products as being not reasonably safe through litigation.

Liabilities stemming from the design and product development process are usually based on one or more of the following premises:

- A concealed danger has been created
- Safety devices have not been incorporated
- Materials are of inadequate strength
- Failure to comply with accepted standards
- Failure to consider possible misuses of the product which were legally foreseeable
- Warnings and instructions are inadequate
Designers should make every effort to minimize and control such hazards using:

- Established design safety criteria
- Applicable mandatory and voluntary (proprietary, industrial, and consensus) standards
- State of the art technologies
- Design safety reviews
- Documentation for the decision making process

Like all organizations, Cal Poly has established Safety procedures and guidelines. Since you will be working in different places on campus, it is important that you review the University’s safety guidelines. They are maintained by the Cal Poly Environmental Health and Safety: [http://afd.calpoly.edu/ehs/](http://afd.calpoly.edu/ehs/) and can be found at:

Cal Poly Injury and Prevention Program: [http://afd.calpoly.edu/ehs/docs/iipp2.pdf](http://afd.calpoly.edu/ehs/docs/iipp2.pdf)

Your first order of business in lab for senior project will be to review and sign the Mechanical Engineering Department’s General Laboratories Safe Practice Procedures Form. The purpose is to raise awareness of the importance of following safety procedures in all activities you engage in at Cal Poly.

Your next task will be to “Design for Safety” whatever system you are developing for your project. Since Product Safety is not easily quantified, you should employ guidelines as you work on your design. A typical set of guidelines taken from Dieter and Schmidt follow.

**Design for Safety Guidelines:**

At a minimum you should use the following guidelines as you evaluate your design:

1. Recognize and identify the actual or potential hazards, and then design the product so they will not affect its functioning.
2. Thoroughly test prototypes of the product to reveal any hazards overlooked in the initial design.
3. Design the product so it is easier to use safely than unsafely.
4. If field experience turns up a safety problem, determine the root cause and redesign to eliminate the hazard.
5. Realize that humans do foolish things, and allow for it in your design. More product safety problems arise from improper product use than from product defects.
6. There is a close correspondence between good ergonomic design and safe design.
   - Arrange controls such that the operator does not have to move to manipulate them.
   - Make sure fingers cannot be pinched by levers.
   - Avoid sharp edges and corners.
   - Products that require heavy or prolonged use should be designed to avoid cumulative trauma disorders like carpal tunnel.
7. Minimize the use of flammable materials, including packaging.
8. Paint and other surface finishing materials should be chosen to comply with EPA and OSHA regulations. For toxicity to the user and when they are burned, recycled and discarded.

9. Think about the need for repair, service, or maintenance. Provide adequate access without pinch or puncture hazards to the repairer.

10. Electrical products should be properly grounded. Provide electrical interlocks so that high-voltage circuits will not be energized unless a guard is in place.

With these guidelines in mind, you will be developing concepts and finalizing the detail design of your solution. At the end of ME428 you will have a Preliminary Design Review. During that review you will present your best design concept generated during the first quarter. You will also complete a Preliminary Design Hazard Checklist. This checklist is intended to be a check of any potential hazards present in your concept and allow you to focus on mitigating the risks during the detail design phase. Any boxes checked will require special attention during the detail design phase. At the end of the detail design phase (middle of ME429) you will have a Critical Design Review. During that review and in the Critical Design report you will outline your risk assessment and mitigation for any potential hazard. You will also complete a second checklist which will determine whether your project should undergo a hazard assessment by an outside professional. Note that your advisor can decide outside assessment is necessary regardless of the checklist. This outside hazard assessment will occur prior to providing any power to your system (ie, before turning it on!!).

A special note on designs that include large batteries or electric potentials above 40 volts: These teams should attend a special session during the detail design phase with Ben Johnson of Facilities to learn more about safe electrical design. The project hardware will also be reviewed by Mr. Johnson prior to providing any power. The following timeline outlines the hazard assessment and safety training that will occur during your senior project.
Senior Project Safety Timeline:

ME428
- Week #2 – Review and sign the Senior Project Safe Practice Procedures (Error! Reference source not found.)
- ~Week #5 – Attend regular lecture on “Design for Safety”
- Week #10 – Preliminary Design Review and Report – Include Concept Design Hazard Identification Checklist (Error! Reference source not found.).

ME429
- Weeks #1-5 – Assess and mitigate identified risks while working on the details of your design. For any project involving large batteries or voltages above 40 volts, the team must attend a special session on the design of safe electrical systems
- Week #5 – Critical Design Review and Report – Include Critical Design Hazard Identification Checklist (Error! Reference source not found.). With your advisor, identify any project that requires outside hazard assessment and have the design reviewed by a safety professional.
- ~Week 7 – Develop a detailed Operators Manual that also captures all known safety hazards.
- Weeks #6-10 – Follow machine shop safe practices and procedure while manufacturing parts of your design.

Important: Do NOT work on your senior project hardware at home!

ME430
- Weeks #1-10 Follow machine shop safe practices and procedures while manufacturing, assembling and testing your design.
  - For any project with potential electrical hazards, your hardware MUST be inspected by a qualified electrician prior to providing any power.
  - Prior to the Design Expo, hardware with any known hazards must be reviewed by a safety professional who will determine whether it can run at the Expo.
  - Install safety placards/labels at all safety hazards on your prototype.

Remember that safety is everyone’s responsibility and as engineer your primary ethical duty. Injuries and property damage often occur when you are in a hurry. There is no reason that you should be in such hurry to design, manufacture, assembly or test your senior project that you increase the risk of injury. Your and others’ safety is more important than the deadlines. Keep in mind that you are not an expert in Product Safety and neither are the teaching staff. If you have any question about hazards and risk bring it your Advisor’s attention and they will help you find the appropriate resources to assess the hazard.

Other Campus Safety Resources:
Cal Poly Injury and Prevention Program: http://afd.calpoly.edu/ehs/docs/iipp2.pdf
Cal Poly Environmental Health and Safety: http://afd.calpoly.edu/ehs/
Online Materials Safety Data Sheets: https://m.msdsonline.com/msdsmanagement/ebinder/
Senior Project Safe Practice Procedures

1. Read the course Senior Project Safety Section of the Success Guide.

2. Do not do any Senior Project hardware development (i.e. manufacturing or testing) outside a Cal Poly facility without the authorization for your senior project advisor.

3. All hardware testing must follow written testing procedures reviewed by your advisor or the department safety coordinator.

4. When working on your senior project in a Cal Poly facility, you must follow all of those facilities Safety Procedures.

5. Use proper Personal Protective Equipment (safety glasses or goggles, ear plugs, gloves etc.) when operating laboratory equipment or experiments.

6. Wear appropriate attire when operating equipment. Secure long hair around rotating equipment or open heat source, proper shoes where drop hazards exist, etc.

7. No equipment shall be operated without the instructor’s permission.

8. No unsupervised use of laboratories without prior written authorization by the instructor.

9. No working alone in the laboratories.

10. Any accident or illness must be immediately reported to the instructor and/or the Mechanical Engineering Department office.

11. Any unsafe or hazardous condition in lab (liquid spills, electrical hazards etc.) must be immediately reported to the instructor.

12. In case of an emergency dial 911 and tell the dispatcher:
   - The nature of the emergency
   - Your name
   - The location of the emergency

13. To evacuate the building in an emergency follow routes posted near the exits of the building.
**SENIOR PROJECT CONCEPT DESIGN HAZARD IDENTIFICATION CHECKLIST**

Team: ___________________________  Advisor: ___________________________

<table>
<thead>
<tr>
<th>Y/N</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?</td>
</tr>
<tr>
<td>☐</td>
<td>Can any part of the design undergo high accelerations/decelerations?</td>
</tr>
<tr>
<td>☐</td>
<td>Will the system have any large moving masses or large forces?</td>
</tr>
<tr>
<td>☐</td>
<td>Will the system produce a projectile?</td>
</tr>
<tr>
<td>☐</td>
<td>Would it be possible for the system to fall under gravity creating injury?</td>
</tr>
<tr>
<td>☐</td>
<td>Will a user be exposed to overhanging weights as part of the design?</td>
</tr>
<tr>
<td>☐</td>
<td>Will the system have any sharp edges?</td>
</tr>
<tr>
<td>☐</td>
<td>Will any part of the electrical systems not be grounded?</td>
</tr>
<tr>
<td>☐</td>
<td>Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?</td>
</tr>
<tr>
<td>☐</td>
<td>Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
</tr>
<tr>
<td>☐</td>
<td>Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?</td>
</tr>
<tr>
<td>☐</td>
<td>Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
</tr>
<tr>
<td>☐</td>
<td>Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
</tr>
<tr>
<td>☐</td>
<td>Can the system generate high levels of noise?</td>
</tr>
<tr>
<td>☐</td>
<td>Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?</td>
</tr>
<tr>
<td>☐</td>
<td>Is it possible for the system to be used in an unsafe manner?</td>
</tr>
<tr>
<td>☐</td>
<td>Will there be any other potential hazards not listed above? If yes, please explain on reverse.</td>
</tr>
</tbody>
</table>

For any “Y” responses, add a complete description, list of corrective actions to be taken, and dates to be completed on the reverse side.
<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Corrective Actions to Be Taken</th>
<th>Actual Completion Date</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
<th>Planned Completion Date</th>
</tr>
</thead>
</table>
## SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

For any “Y” responses, add a complete description on the reverse side. DO NOT fill in the corrective actions or dates until you meet with the mechanical and electrical technicians.
<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Corrective Actions to Be Taken</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. 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 s/he guides you through the process in the manner s/he 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 common deliverables in detail; please see your project/lab advisor for additional requirements. The common set of deliverables by quarter includes:

ME428 (First Quarter)
- Design Logbooks (1 per person)
- Letter of Introduction to Sponsor
- Team Contract
- Quality Function Deployment - House of Quality
- Project Proposal/Requirements Document
- Conceptual Prototype / Test or Experiment
- Preliminary Design Report
- Preliminary Design Review (at Sponsor’s site)
- Preliminary Safety Checklist

ME429 (Second Quarter)
- Design Logbooks (Continued)
- Final Design Report (with detailed drawings)
- Critical Design Review (presentation)
- Critical Design Safety Review + Checklist
- Ethics Memo
- Ethics Case Study Presentation
- Manufacturing and Test Plan Review (Presentation)
- Project Update Report

ME430 (Third Quarter)
- Design Logbooks (Continued)
- Project Update Memo to Sponsor
- Hardware Demonstration and Safety Verification (You must bring your Design Safety Checklist)
- Senior Exit Exam and Senior Exit Survey (Required for ABET)
- Design Expo
  - Poster Presentation
  - Final Hardware Review
- Final Project Report
- Senior Project Completion Checklist
**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 document your design process. 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. Make sure to annotate these to explain them.
- 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. Consult your lab instructor as s/he may modify the suggested guidelines or details that follow.

Use an unlined, bound sketchbook of high quality (heavy) paper with at least 100 letter size sheets (200 sides). 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. Here are some additional logbook specifications:

- 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 five pages at the beginning initially blank and fill them in as a table of contents as you make entries.
- Create a time log for your project work starting at the LAST page of the logbook moving forward. Make an entry there every time you work on the project.
- 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 and do not skip pages. Do not 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 and product liability 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)

Note that in some cases, your lab instructor will allow you to have a Project Binder for printed pages so you don’t need to paste them all into your logbook. If so, you should consider the binder an addendum to your logbook. In other words, anything you add to the binder should be specifically referenced in your logbook.

Logbook Assessment
Your logbooks will be collected midway and at the end of each quarter for grading. Note that your logbook is NOT expected to be a polished, edited document (that is what the formal reports are for). But, another engineer should be able to look at your logbook 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 project work, 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.

Two common problems we’ve noticed with students’ logbooks:

- Many students think of the logbook as just notes written for the writer. It is not! The logbook is a dialogue about the project, written in a fashion that is understandable by a third party. Annotate, annotate, annotate. Explain, explain, explain. Read the guidelines for the logbook (see above) occasionally to remind yourself what should be in it.
- Often the context of a calculation or a sketch is missing. Why was the calculation or sketch done? What was concluded from it? 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 (Week 2 of ME 428)**

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 sponsor (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 the problem 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. For local sponsors 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, Skype, Google hangout, etc.) with your sponsor. Note this may have to be negotiated 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 always remember to copy your lab advisor. 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 Ms. Sponsor….Thank you for the opportunity….Sincerely, J. Student.
Reports
See syllabus for report due dates and course Polylearn for grading rubrics.

Project Proposal (Week 5 of ME 428)
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 a Preliminary 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 Background and Objectives. Once agreed upon by the sponsor, the specifications included in the Objectives section will become a contract that you are agreeing to fulfill.

The standard format for a technical proposal requires:

1) A Title Page showing the project title, sponsor name, and names and email addresses of the persons preparing the proposal.
2) An Introduction which tells the reader what the project is about, who the stakeholders are, and what the goals are.
3) A Background 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) Objectives: 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 Method of Approach 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 the 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.

More About the Objectives
The objectives and specification part of this proposal is particularly important for senior design
projects (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 (tested). One possible way to do this is to define how
you plan to show compliance AT THE SAME TIME 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. This method will also help you set engineering
targets for your project. In your report, be sure to explain the QFD 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 formal engineering specifications. Include reference figures as required for things like geometry or interface requirements.

The formal Engineering Specifications Table should also include how each design requirement is to be verified. This is known as a "compliance" method. Typically these methods are:

- Analysis (A)
- Test (T)
- Similarity to Existing Designs (S)
- Inspection (I)

The Specifications Table should also assess the risk of meeting each the engineering targets or specifications you set. Assign High (H), Medium (M) or Low (L) to each specification. High-risk requirements should be thoroughly discussed in the report as they are typically hard to meet. Use the basic format shown in Table 1.

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

To make sure you have considered all important aspects of the design, check the list of potential requirements in Figure 2. In your Project Proposal, you might use the main headings from this figure to organize your specification list into logical groupings.
<table>
<thead>
<tr>
<th>Main headings</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension.</td>
</tr>
<tr>
<td>Kinematics</td>
<td>Type of motion, direction of motion, velocity, acceleration.</td>
</tr>
<tr>
<td>Forces</td>
<td>Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, inertia forces, resonance.</td>
</tr>
<tr>
<td>Energy</td>
<td>Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.</td>
</tr>
<tr>
<td>Material</td>
<td>Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc).</td>
</tr>
<tr>
<td>Signals</td>
<td>Inputs and outputs, form, display, control equipment.</td>
</tr>
<tr>
<td>Safety</td>
<td>Direct protection systems, operational and environmental safety.</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>Man-machine relationship, type of operation, operating height, clearness of layout, sitting comfort, lighting, shape compatibility.</td>
</tr>
<tr>
<td>Production</td>
<td>Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.</td>
</tr>
<tr>
<td>Quality control</td>
<td>Possibilities of testing and measuring, application of special regulations and standards.</td>
</tr>
<tr>
<td>Assembly</td>
<td>Special regulations, installation, siting, foundations.</td>
</tr>
<tr>
<td>Transport</td>
<td>Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch.</td>
</tr>
<tr>
<td>Operation</td>
<td>Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions).</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.</td>
</tr>
<tr>
<td>Costs</td>
<td>Maximum permissible manufacturing costs, cost of tools, investment and depreciation.</td>
</tr>
<tr>
<td>Schedules</td>
<td>End date of development, project planning and control, delivery date.</td>
</tr>
</tbody>
</table>

Figure 4.5. Checklist for drawing up a specification

Figure 1: Potential Types of Requirements (from *Engineering Design* by Paul & Beitz, Springer-Verlag 1988)
Preliminary Design Report (Near End of ME 428)

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

The Preliminary Design Report should contain revised material from your Project 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 your sponsor feedback. Note that once your sponsor has agreed to the set of specifications, you must get their approval for any changes.

In addition to this material, a lot of important new information should be included in the Preliminary Design Report. This report details your progress through and results of the conceptual design phase. Note that most groups will have selected a top concept to present in this report, but a few might yet be deciding between a couple of alternatives. The Preliminary Design Report should contain:

- Short description and layout drawings (sketches) of your top 5-10 concepts.
- Description of the process you used to select your selected (lead) concept.
- Discussion of how your concepts satisfy the specifications.
- Basic quantitative work (analysis such as Statics) to justify your selected concept.
- A more complete description of your selected 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.
- Concept Design Hazard Identification Checklist

The suggested approach for developing your Preliminary Design 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 and when 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 (Week 5 of ME 429)

This report is an update to and extension of your Preliminary 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 detailed part drawings and assemblies. Provide sufficient information about purchased parts and materials so someone could purchase them. 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 Final Design Report should contain all material from your Preliminary Design Report (revised 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.). The purpose of this section is to convince your sponsor (and advisor) that your design will work!
- 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.
- Detailed cost analysis for your prototype
- 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
- Critical Design Hazard Identification Checklist

Ensure that your report is continuous in writing style, fonts, headings, verb tenses, etc. Any information you include (figures, tables, appendices) should be referenced in the text of the report (if it is not listed in the text, it should NOT be in the report at all). You may change headings from the Preliminary 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 is shown on the next page in Figure 3. It is recommended that you stick to the suggested format, including the numbered chapters, unless it does not fit your project for some reason.
<table>
<thead>
<tr>
<th>Title Page – Clearly show that this is the Final Design Report, including date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table of Contents</td>
</tr>
<tr>
<td>List of Figures</td>
</tr>
<tr>
<td>List of Tables</td>
</tr>
<tr>
<td>Abstract or Executive Summary – Read quickly by someone to determine whether or not to read further</td>
</tr>
</tbody>
</table>

## Chapter 1 Introduction
- Sponsor Background and Needs
- Formal Problem Definition
- Objective/Specification Development

## Chapter 2 Background
- Existing Products
- Current State of the Art
- Specific Technical Data
- List of Applicable Standards (safety, testing, etc…)

## Chapter 3 Design Development
- Discussion of Conceptual Designs
- Concept Selection
- Supporting Preliminary Analysis
- Any proof of concept analysis or testing

## Chapter 4 Description of the Final Design
- Overall Description/Layout with labeled solid model
- Detailed Design Description
- Analysis Results (Details in Appendix)
- Cost Analysis (a Bill of Materials with costs, a cost analysis of product)
- Material, Geometry, Component Selection
- Flowcharts, Schematics, Pseudo Code, Wiring Diagrams
- Refer to your manufacturing drawings in appendix!
- Any special safety considerations
- Any maintenance and repair considerations

## Chapter 5 Design Verification Plan (Testing)
- Test Descriptions with list of necessary equipment.
- 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, % complete of all sub-tasks
- **Appendix G** Any other supporting information

**Figure 2: Sample Final Design Report Format**
Project Update Report to Sponsor (Week 10 of ME 429)

At the end of ME 429, you will prepare a short (several pages) report that simply updates your sponsor on the status of the project. 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 is the one stand-alone report in senior design – it 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) during the current 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 (Week 10 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 during construction or after testing. 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 Digital Commons at the library. The format of your report should be similar to Figure 4. For format ideas, we recommend you review past Senior Project reports on Digital Commons through the library website at:

http://digitalcommons.calpoly.edu/mesp/

What to turn in (after approved by your advisor):

1. One or more bound copies for lab advisor (check with advisor to see how many). Please add these pages to the front:
   a) Evaluation and Grade Page (typed by student)
   b) Title Page
   c) Statement of Disclaimer.

2. One bound copy for sponsor (delivered at the Senior Design Expo is preferred). 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 before finals week or you may receive an incomplete for the course. The sponsor copy should not have the Evaluation and Grade Page.

3. One electronic (pdf) file which you will upload to the library’s DigitalCommons website. Do not include the Evaluation and Grade page. Before uploading you must get your advisor the receipt and library form where he or she signs to confirm the project meets the course requirements. 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/need-help/seniorprojects/#student-submit

Please follow the library steps, EXCEPT leave the library form with your project advisor.

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 Upload: For the body of the report, submit only the Title Page and Confidentiality Statement. You still have to fill out the other forms, and you still have to pay the fee. Make sure you check the box on the library from that this project is not for public release.
Figure 3: Example Final Project Report Format
Operators Manual with Safety Guidelines

Your design is not complete until you have fully documented the correct method of operation and identified any known safety concerns. If you have ever looked at the owner’s manual of your car or other piece of equipment, this is the type of information you should include in Appendix G of your Final Project Report. Ask your instructor for some examples to use as guidelines.

Sample Pages:

The next five pages contain samples 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 pages included are:

- 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.
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: _________________________
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

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.
Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.
# Table of Contents (Example)

## List of Tables
- ii

## List of Figures
- iii

## Nomenclature
- iv

## Abstract
- vi

## Chapters

1. **Introduction**
   - 1

2. **Background**
   - 5

3. **Design Development**
   - 10
     - 3.1 Concept Generation
     - 12
     - 3.2 Concept Selection
     - 15
     - 3.3 Preliminary Analysis
     - 17

4. **Description of the Final Design**
   - 22
     - 4.1 System Layout
     - 24
     - 4.2 Design Description
     - 26
     - 4.3 Supporting Analysis
     - 29
     - 4.4 Etc...
     - 34

5. **Product Realization**
   - 45

6. **Design Verification**
   - 51

7. **Conclusions and Recommendations**
   - 60

## References
- 61

## Appendixes
- **Appendix A Final Drawings and Parts Lists**
  - 63

- **Appendix B Component Specifications**
  - 65

- **Appendix C Supporting Analysis**
  - 67

- **Appendix D Etc**
  - 75
Presentations

Preliminary Design Review (Week 10 of ME 428)
At the end of the first quarter, you will make a formal presentation to your project sponsor. The goal of this presentation is to obtain your sponsor's approval to focus the rest of your design and analysis efforts on one or two specific concepts. Your presentation should describe your process, explain the most promising design concepts you developed, and go into detail about the final selected concept. Detailed plans for analysis of this concept should also be included. You should plan to make this presentation in lab before your deliver to your sponsor in order to get feedback. Consult with you lab advisor for details. If your sponsor requests that you make this presentation in person, please reread the travel policies before making your plans for the review.

Critical Design Review (Week 5 of ME 429)
After completing your detailed design in the middle of the second quarter, you will make a formal presentation to your project sponsor. The goal of this presentation is to obtain your sponsor's approval to begin constructing your prototype. Your presentation should provide sufficient evidence of your design and analysis to convince your sponsor that your solution will work. Complete prototype costs, manufacturing plans, and test plans/costs should also be included in this presentation. You should plan to make this presentation in lab before your deliver to your sponsor in order to get feedback. Consult with you lab advisor for details. If your sponsor requests that you make this presentation in person, please reread the travel policies before making your plans for the review.

Manufacturing and Test Review (Week 10 of ME 429)
At the end of the second quarter your team will make a short presentation in lab to give a status report on your Manufacturing and Test plans. Include:

- Status of component manufacturing with hardware present
- Updated test plan including location and necessary testing hardware
- Safety Check list to be signed by your instructor prior to any testing
- 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 (Week 9 of ME 430)
This is the culminating presentation of the Mechanical Engineering Department’s three-quarter Senior Design Project Course. Your team will present your 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 acceptable.

**Poster Requirements**
Posters should consist of one 34” x 44” (ANSI E) poster mounted on foam board in 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. You will need to sign up for a specific time slot in which to print your poster on the glossy paper. The sign up sheet will be posted on Google drive and announced around week 7.

Note: More information on Poster Design can be found on PolyLearn or the web. Note ignore any “pasting” suggestions since we have the resources to make a single sheet poster. Ask your lab advisor for examples of highly rated posters from past Expos.

**At the End of the Expo**
In addition to being present to show off your work to Expo attendees, we strongly recommend you take advantage of your sponsors’ presence to deliver these to them at the conclusion of the Expo, so you don’t have to arrange shipment:

- Final Prototype (but, your tests must be done!)
- Final Report (but, it must be approved by your advisor first!)

Senior Project Completion Checklist

After the Senior Design Expo, all that remains are to clean up your project work areas, deliver all parts and components, and turn in any remaining reports. A checklist of the required project wrap-up activities is shown on the next page. Your project advisor may not issue you a grade for the class until all of these activities have been completed and signed off. Please make sure to do this in a timely fashion.
# Senior Project Completion Checklist

Before a final grade can be issued by your advisor, your team must obtain signatures verifying ALL of the items on this checklist have been completed.

**Project/Team:** ________________________________________________________________

<table>
<thead>
<tr>
<th>Task</th>
<th>Advisor or Tech Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype tested to verification plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review copy of Final Report delivered to Advisor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabrication area cleaned up &amp; tools returned to shop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test equipment returned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revised Final report delivered to Sponsor (pdf via email, CC Instructor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Report and Expo Poster uploaded to ME 428 PolyLearn site.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Ledger or Spreadsheet of Project Costs to Advisor and CC'ed to Christine Haas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prototype delivered to sponsor/customer or recycled appropriately. Discuss any use or safety issues with your advisor before delivery. Any hazard should be described in an Operator’s Manual.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poster Delivered to Sponsor or Advisor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Library Senior Project Submission Process: <a href="http://lib.calpoly.edu/seniorprojects/submit.html">http://lib.calpoly.edu/seniorprojects/submit.html</a> (Signed form and receipt to Advisor NOT dept. office)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IP or NDA Project Restrict Report Access on Library form? (Check with your Advisor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Report pdf file uploaded to the digital commons.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. 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.
Figure 4: ME Senior Design Process
Working on a Team

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 (and later 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 5: Stages of Team Development (after Anne Virkus and Mark Steiner)](image-url)
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 some as the most critical phase. 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:

<table>
<thead>
<tr>
<th>Start With</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>“When you…”</td>
<td>Describes the behavior</td>
</tr>
<tr>
<td>“I feel..”</td>
<td>Tells how you are affected</td>
</tr>
<tr>
<td>“Because I…”</td>
<td>Why you are affected that way</td>
</tr>
</tbody>
</table>

Pause for discussion

| “I would like…”  | Describe the change you want                     |
| “Because…”      | Why you think it will fix the problem            |
| “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.

References
- Hackett, D. and Martin, C., Facilitation Skills for Team Leaders.
- Kayser, T., Mining Group Gold
- Maddux, R., Team Building: An Exercise in Leadership
- Scholtes, P., The Team Handbook for Educators.
- Tuckman, Bruce W. (1965) 'Developmental sequence in small groups', Psychological Bulletin, 63, 384-399. The article was reprinted in Group Facilitation: A Research and Applications Journal - Number 3, Spring 2001 and is available as a Word document:

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 6: 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.

References

- Sullivan, J., Personal Correspondence, ASEE Annual Conference, Honolulu, HI, June 2007
**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 difficulty 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 8 shows a blank House of Quality worksheet (note this excel file is available on PolyLearn 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 7: QFD House of Quality (blank)
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 your 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.

References

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:

- **Preparation**: 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 is 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, etc.

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.

![Figure 8: Example Morphological Cube](image)

**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:**
• Roth, B., *Notes on Creativity*, ME112 Stanford University, 1994
4. Manufacturing Resources

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

These are the main fabrication facilities available to you for manufacturing tasks that you can undertake on your own to complete your project. The shop is open to all, regardless of abilities, but for safety reasons, shop access requires completion of the Red Tag tour & Test. Your senior project will likely require access to more machines, so you are required to obtain your Yellow Tag before the end of ME 428. This will give you access to the milling machines & lathes for the rest of your time at Cal Poly.

**Important: Do NOT work on your senior project hardware at home!**

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.

If there is a more complicated component that either requires high precision or is safety-related and you do not feel you are qualified to build it, there are three options:

1) Discuss the manufacturing with the Techs. They may be able to find a more efficient, effective way of manufacturing it that you can perform yourself.

2) If the Techs cannot help you to do the manufacturing yourself, your project can "hire" a Tech to build it for you. This will require transferring a portion of your senior project budget to the machine shop, so requires approval by your sponsor and your project advisor. See Contract Fabrication, below.

3) In some cases, your sponsor will have access to more advanced manufacturing facilities and will build some of the components for you. This is acceptable, but be sure to discuss it with your project advisor.

For current shop times, forms, and reading for shop tests visit [https://studentprojectscenters.calpoly.edu/](https://studentprojectscenters.calpoly.edu/)

**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 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.

**Using the Laser and Vinyl Cutters in Mustang 60**
Instructions for using the rapid prototyping tools can be found in the Mustang 60 shop.

**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.

**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**
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, visit the ME Department in 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
- 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 available in 13-124B (See ME dept. to schedule).
- Smart board

**Important: Do not use dry erase markers on the smart board!**

Telephone Rules are as follows:

- The FAX number is **805-756-5606**
- If you need to use the phone then:
  - Have the sponsor call you
  - Call only toll free numbers
  - Make collect calls
- Don’t talk more than necessary (i.e. plan the call, don’t waste time)
- 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 has three rapid prototype machines available for use on your project. The capabilities of these machines are listed in the table below. Prices apply to industrially sponsored senior projects. Consult you lab advisor for details.
### 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/](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

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/
5. 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**
  - large blue digital floor scale that has a capacity of 1000lb
  - two small precision scales or balances
- **13-124**
  - 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.

**Small Intron Tensile Test machine**

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.

![Figure 9: Intron Servo-Hydraulic Test Machine](image-url)
Servo-hydraulic Load Frame
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 an 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.

![Figure 10: Servo-hydraulic Load Frame](image)

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.

MTS 100kip Tensile Tester
For very large loads the Civil Eng. dept. has a 100kip load frame. If you need to use this machine, please contact Dr. Dan Jensen in Civil Engineering.

Torsion
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.

![Figure 11: Tinius-Olsen torsion tester](image)

**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.

![Figure 12: Composites Lab Strong Floor](image)
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.
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.

![Figure 16: Load Cell Hardware](image)

**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 shown in Table 2.

**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.

**Desktop Cart Data Acquisition System**

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.


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

**Portable Data Acquisition System**

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.
### Table 2: Specifications for Instrumentation

#### LOAD

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Full Scale Capacity (LB)</th>
<th>S/N</th>
<th>Full Scale Output (mV/V)</th>
<th>Zero (mV/V)</th>
<th>Max Excite (V)</th>
<th>Excitation (V)</th>
<th>Voltage Range (mV)</th>
<th>Scale Factor (LB/mv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Cell, Muse M2400-100</td>
<td>100</td>
<td>186244</td>
<td>1.8247</td>
<td>-0.006</td>
<td>15</td>
<td>10</td>
<td>18.247</td>
<td>5.48035293</td>
</tr>
<tr>
<td>Load Cell, Omega LCH-1k</td>
<td>1000</td>
<td>352053</td>
<td>3.0031</td>
<td></td>
<td>15</td>
<td>10</td>
<td></td>
<td>looks damaged</td>
</tr>
<tr>
<td>Load Cell, Omega LCH-100</td>
<td>1000</td>
<td>207113</td>
<td>?</td>
<td></td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Cell, Omega LC101-500</td>
<td>500</td>
<td>219878</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 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

<table>
<thead>
<tr>
<th>Description</th>
<th>Design</th>
<th>S/N</th>
<th>Nominal Voltage</th>
<th>Max Excitation</th>
<th>Tension (Lb)</th>
<th>Full Travel (Lb)</th>
<th>Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Trans. Space Age</td>
<td>13.5</td>
<td>23818</td>
<td>10</td>
<td>10</td>
<td>35</td>
<td>1.02</td>
<td>1.78</td>
</tr>
<tr>
<td>pn 160-1085</td>
<td>13.5</td>
<td>23819</td>
<td>10</td>
<td>10</td>
<td>35</td>
<td>0.98</td>
<td>1.9</td>
</tr>
<tr>
<td>Shulemburger DCR/15mm/s</td>
<td>2</td>
<td>847624</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>24.88 mV/V/mm</td>
</tr>
</tbody>
</table>

#### PRESSURE

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

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

#### Strain Measurement

<table>
<thead>
<tr>
<th>Description</th>
<th>Full Scale Capacity (PSI)</th>
<th>S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG p-3500 strain indicator</td>
<td>60270</td>
<td></td>
</tr>
<tr>
<td>MG p-3500 strain indicator</td>
<td>98703</td>
<td></td>
</tr>
<tr>
<td>Strainsert HW T-D</td>
<td>814</td>
<td></td>
</tr>
</tbody>
</table>

#### Instron Strain Measurement

<table>
<thead>
<tr>
<th>Description</th>
<th>Travel (inch +/-)</th>
<th>S/N</th>
<th>Gauge Length (in/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain gauge extensometer</td>
<td>0.1</td>
<td>69280</td>
<td>5/2.0</td>
</tr>
<tr>
<td>Strain gauge extensometer</td>
<td>0.05</td>
<td>69280</td>
<td>5/2.0</td>
</tr>
</tbody>
</table>
Dynamic testing

The vibrations lab can be used by permission form the lab coordinating instructor Dr. Jim Meagher. The equipment available are:

- Accelerometers
- Shake Tables
- Drop Tester
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).

Important: 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.

![Figure 18: Example Tensile Specimen Setup for Instron](image)

**Instron Set-up**

| Important: 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:
   a) Load is going out channel A.
b) Position is going out B.

c) 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.

5. 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.

6. 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.)

7. Install on the grips the specimen alignment blocks. These control the alignment off the specimen.

8. 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.

9. 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**

10. Double-Click the LabVIEW VI file 2g-ext.vi. This file acquires load, extensometer, and longitudinal and transverse strain gages.

11. Check that the voltage relationships correspond with the Instron outputs.

12. Manually balance the strain bridges if input voltages are excessive.

13. 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.

14. Note the ASCII data file name and folder or location. This file should be saved after each test.

**Run Test**

15. 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.

16. 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.

17. Start the data acquisition process by clicking the start arrow on the labview VI.

18. Press START on the Instron controller to start the test, the lower grip will move down.
19. 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.

20. Press START to resume the test waveform.

21. After failure of the specimen press HOLD.

22. The lower portion of the fractured specimen may be removed by opening the lower grip.

23. End the test by pressing RESET which will move the actuator to its position at the start of the test.

24. Remove the upper portion of the specimen from the upper grip.

**System Shut Down**

25. 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.